Early Modern Philosophy of Technology: Bacon and Descartes

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Abstract

The contemporary understanding of technology is indebted to Bacon and Descartes, who challenged the pre-modern conceptions regarding useful material production. Although the production of artefacts has been a constant activity of humans since the dawn of history, the Ancient world tended to disvalue it, considering it a lower endeavour that aims to satisfy ignoble material needs. Technology, according to Ancient Greek thinkers, cannot surpass nature but can only bring small improvements to it; moreover, there is a difference in kind between natural things and technological artefacts; the activity of inventing and producing useful objects is unsuited for the nobility and for free men; there is an irreducible gap between proper knowledge and the production of artefacts. This approach toward technology is completely reversed in Bacon's and Descartes' works: material utility comes to be considered a genuine value; nature can be completely transformed through technological inventions, and even the human body can be improved by prostheses; natural things and technological artefacts are identical in their constitution and function; the invention of new artefacts becomes a proper endeavour of the natural philosopher; thinking about artefacts, or machines, is raised to the status of proper knowledge, while mechanical arts and mechanics become the core of natural philosophy. These ideas regarding technology became the familiar background of the contemporary approach toward material production; accordingly, to understand the magnitude of Bacon's and Descartes' paradigm shift it was necessary to analyse it against the pre-modern view. Moreover, in order to emphasize their powerful influence I approach their works from the technological perspective, since an epistemological analysis fails to rend justice to and to clarify some of the core ideas of their philosophy: utility, the centrality of mechanical arts and mechanics, the scope and scientific character of technology, the similarity between nature and technology.

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List of Abreviations

AT *René Descartes – Oeuvres de Descartes*. Edited by Charles Adam and Paul Tannery. New revised edition, Paris: Vrin-CNRS. 1964–1974. 11 volumes.

CSM/CSMK *The Philosophical Writings of Descartes*. Translated and edited by Cottingham, J., Stoothoff, R., Murdoch, D. and (for the third volume) Kenny A. Cambridge University Press. 1984-1991. 3 volumes.

JB *René Descartes – Conversation with Burman*. Translated by Jonathan Bennet, 2010, pdf document retrieved at http://www.earlymoderntexts.com/pdf/descburm.pdf .

PO *René Descartes – Discourse on Method, Optics, Geometry, and Meteorology*. Translated and edited by Paul J. Oldscamp. Hackett Publishing. 2001.

RA *René Descartes – Philosophical Essays and Correspondence*. Translated and edited by Roger Ariew. 2000.

SV *René Descartes – The Passions of the Soul*. Translated and edited by Stephen Voss, Hackett Publishing Company, 1989.

Works *The Works of Francis Bacon*. Edited by J. Spedding, R. L. Ellis, and D. D. Heath. London: Longman, 1857-1874. 14 volumes.

Introduction

In the second half on the twentieth century technology became an object of philosophical study. A great amount of research has been dedicated to the philosophy and history of technology. Nevertheless, an analysis focusing on technology of the major philosophical systems that set the stage for its modern understanding, i.e. Bacon's and Descartes', is still missing. In the present thesis, I analyse the paradigm shift that Bacon and Descartes produced in conceptualizing technology. As an example of the central place that the thinking about machines plays in the developments of their philosophies it is sufficient, I think, to quote the successful formulation of Descartes' position, that appear in his conversation with Burman, that almost all errors in philosophy come from an insufficient philosophical consideration of machines:

> We don't think in terms of machines as much as we should, and this has been the source of nearly all error in philosophy. (*Conversation with Burman*, JB 22, AT V 174)

Reading Bacon's and Descartes' works, one cannot fail to observe the emphasis they lay on the useful character of knowledge, on the need of creating artefacts, on the importance of mechanics and mechanical arts, and on the scientific approach toward material production. Nevertheless, an epistemological approach toward Bacon's and Descartes' works fails to rend justice to their conceptions of technology and I chose to focus precisely on these aspects. It is what I have done in the second and third chapter, but because their ideas concerning technology are not just an instance among others but represent a paradigm shift with a legacy unshaken until the twentieth century, I presented in the first chapter the Ancient paradigm which they manage to change and the Renaissance transformations that questions Ancient assumptions, and, in the fourth chapter, the content of their legacy.

1. The term 'technology' and its precursors

'Technology' is a contemporary coined term that refers collectively to the system of human-made artefacts, their making and using, and the associated theoretical and practical knowledge. Although the meaning of the term 'technology' is similar to its historical predecessors, the ancient Greek terms *techne* and *banausias* and the medieval and modern *artes mechanicae*, Carl Mitcham, the historian and philosopher of technology, argues against a facile identification of "Greek *techne* with the English technology ... A study of the historical origins of the word 'technology' ... can however suggest the questionable character of this identification." (Mitcham, 1994, 117) Therefore, in this part of the Introduction, I shall give a succinct presentation of the conceptual evolution of the various terms that signify, more or less accurately, what we understand by 'technology'. This conceptual evolution matches, to a certain extent, the evolution of the philosophical conceptions of technology.

In her book, *Paradise restored: the mechanical arts from antiquity through the thirteenth century* (1990), Elspeth Whitney exposes the principal characteristics of *techne* and *artes mechanicae* until the Renaissance and follows the conceptual evolutions of these terms. The main actors involved in this evolution are Plato and Aristotle, for the Ancient Greek world, and Hugh of St. Victor, for the medieval period. In Plato an Aristotle, technology is referred by the term *techne*, but this broad term also refer to rhetoric or poetry. In fact, when the Ancient Greeks have in mind specifically the useful material production they prefer to use a pejorative term, *banausias*. *Banauson* can be render in English as 'vulgar' and this term for technology is still used by late Renaissance writers like Solomon de Caus.[1] But even the term *banausias*, which better renders the idea of lower *techne*, is not an appropriate translation of

1 "Banauson ... serves to raise, pull, and carry from one place to another all sorts of loads, and likewise as a force to do a number of things difficult for us without this help, like mills ..., pumps, clocks." (De Caus, 1615, Epistre au bening lecteur)

‘technology’, because these terminological distinctions are made on moral and epistemological grounds and not as a description of technological objects and practices.

> The inferiority of banausic arts is derived neither from their technological character nor their physicality alone but from the idea that these particular arts do not involve the soul in either its intellectual or its moral capacities but are practised *merely* to satisfy physical needs or pleasures. (Whitney, 1990, 30)

As a consequence of using external ground in considering various types of technology, “no single ancient classification of the arts subsumed all the arts or activities now called technology under one heading.” (Whitney, 1990, 51) The most prominent examples are medicine, agriculture and navigation which are rarely defined as productive arts. Notwithstanding this lack of unity in dealing with what nowadays we call technology, there is a common Ancient conception regarding the useful material production that can be specified.

Whatever term is employed for material production, technology is considered, throughout Antiquity, an ignoble endeavour. One of the legacies of Plato an Aristotle for the conceptual evolution of technology is their respective classifications. In *Statesman* 289b Plato offers a classification of material production into seven classes: “we put the [1] first-born’ class of things at the beginning and after this [2] ‘tool’, [3] ‘vessel’, [4] ‘vehicle’, [5] ‘defense’, [6] ‘plaything’, [7] ‘nourishment’” (289b). In the beginning of *Metaphysics* (980a-981b), Aristotle classifies *techne* as the lowest form of human activity, just a little above mere experience. In the *Nicomachean Ethics* (1139b), Aristotle divides human activity into knowing, doing and making, with making as the lowest form. And even in the domain of making there is a further division between the productive arts that aim to bring pleasure and those that aim only at utility. The contempt of Aristotle toward mere utility extends to material production. Therefore technology is primarily viewed as *banausias*, a pejorative term that proves the perceived ignoble character of productive arts. The views of Plato and Aristotle are the most elaborated approaches to technology and remain the standard interpretation until the Middle Age:[2]

> Although classification of the arts and sciences became increasingly detailed and elaborate over the course of time, basic attitudes toward craft had already been formulated in the time of Plato and Aristotle. A view of knowledge as hierarchically ordered from the lowest arts to those closest to the divine and an emphasis on the moral value of knowledge was primarily associated with Plato and thinkers influenced by him, who often defined crafts as banausic or illiberal arts. (Whitney 1990, 50-51)

A major change in the conception of technology comes in the Middle Age with Hugh of St. Victor who, in his treatise *Didascalicon* (from the late 1130s), unifies the useful material production, i.e. crafts, under a single term, that of *artes mechanicae*,[3] and divides it into seven classes in analogy with the seven liberal arts: fabric-making, armament and building, commerce, agriculture, hunting and food preparation, medicine and theatrics. Another important idea of Hugh of St. Victor is that these *artes mechanicae* are a way to remedy the losses of the Fall, which can be said to represent the first true positive evaluation of technology (Mitcham, 2009, 1150). This idea, which will appear later in Francis Bacon, views technology not only as "merely" useful for the ignoble human needs but as genuinely good.

Despite Hugh of St. Victor's positive evaluation, technology continues to be considered ignoble. The term *artes mechanicae* is used interchangeably with terms like *artes illiberales*, *artes vulgares*, *artes sordidae*, as a Latin rendering of Greek *banausias*. This terminological usage maintains the contempt towards useful material production. The only

2 It is worthwhile to mention here the opinions of Seneca and Saint Augustine, who expressed the same contempt towards technology as did Plato and Aristotle: "Seneca reports Posidonius as asserting that it was a philosopher and wise man who first invented buildings, tools and weaving and to this Seneca answers that philosophy has nothing to do with tools and anything else which involves a bent body and a mind gazing upon the ground." (Whitney 1990, 26) While Augustine, in Book 22.24 of *City of God*, after praising the human genius for various arts invented, states that these are not only irrelevant to human salvation but are even dangerous and immoral.

3 "The earliest known use of the term *artes mechanicae* in the plural and referring to a category or group of arts occurs in John the Scot's commentary on Marcianus Capella's *Marriage of Philology and Mercury*" (Whitney, 1990, 70)

thing that medieval and Renaissance period retains from Hugh of St. Victor is that all useful material production falls under a single category, whose characteristics will have to be specified.

During the Renaissance, technological inventions flourished and, even though they were disregarded by the academic establishment, they began to elicit theoretical, i.e. both scientific and philosophical, approaches. The term *artes mechanicae* referred in this context primarily to mechanical contrivances but also to material changes brought about by natural magic and alchemy. Especially toward the end of Renaissance, around 1600, discussions of technology were concentrated around magic as the practical part of natural philosophy (Henninger-Voss, 2004, 10), and mechanical arts were in some cases considered to cheat nature by bringing about anti-natural effects[4].

Artes mechanicae and mechanics are, in the beginning of the seventeenth century, redefined by Descartes and Bacon, who rank them at the core of natural philosophy. This reshaping of technology comes along with a paradigm shift in which mechanics and mechanical arts have different relations to man, knowledge, and nature.

During the entire modern age, until the beginning of twentieth century, the term that applied to whatever we call 'technology' today was 'mechanical arts', with the meaning it acquired through the works of Bacon and Descartes. Although the term 'technology' appeared in English in the seventeenth century, it referred to that part of science that studies the mechanical arts or *techne*, as the etymological root of the term shows.

> As for *technology* in the now familiar sense of the word — the mechanic arts collectively — it did not catch on in America until around 1900, when a few influential writers, notably Thorstein Veblen and Charles Beard, responding to German usage in the social sciences, accorded technology a pivotal role in shaping modern industrial society. But even then, the use of the word remained largely confined to

4 The accusation of cheating is made for the first time by Galileo who said that some artisans pretend to "cheat nature": he criticised the belief of the "Mechanici," that they "can move and raise the heaviest weights with little effort, intending thereby, with their machines, to cheat nature, to some degree." (Galileo, *Schriften. Briefe, Dokumente*. 2 vols. Ed. Anna Mudry. Munich: Beck, 1987, p. 209)

> academic and intellectual circles; it did not gain truly popular currency until the 1930s. (Marx, 2010, 562)

Only during the last century did the term[5] acquired its extended meaning and come to be widely used. It eliminated from public discourse terms like mechanic arts, industrial arts, practical arts, or machinery because of their specificity and their specific reference to mechanical things. What came to be realized was that there is a certain reality that has to be named and that it is more than the collection of mechanical arts and their products. The term 'technology' is nowadays extremely widely used[6] "to represent things, actions, processes, methods, and systems" (Kline, 2003, 210) and also is used symbolically to represent progress.

2. The Place of Technology in Early Modern Studies

While the term "mechanical arts" is used for all useful material production from the thirteenth until the beginning of the twentieth century, I show in my thesis that its meaning is changed through the works of Bacon and Descartes from the practice of ignoble production of useful material things to a scientific-based creation of devices that would "procure, as much as is in our power, the common good of all men" (AT VI 61, RA 74).

The majority of studies on the Early Modern period shows that in natural philosophy there is a shift toward a practical approach.

> The choice, in the first instance, was between the active or practical life and the contemplative life, where philosophers had traditionally fallen in the latter category. The explicit shift to the defence of the active or practical life placed new requirements

5 Leo Marx (2010) affirms that the introduction of the term 'technology' filled a semantic void for which the concept 'mechanical arts' was no longer appropriate because it lacked the extended meaning of the new term.
6 In Google NGram, a software that analyses the recurrence of terms in all books archived by Google, the term 'technology' had in the nineties a statistical weigh of nearly 0.01 % while 'philosophy' (for comparison) had a statistical weight of about 0.006 %.

> on philosophy, for philosophers now had to show that they were able to live up to the aims of the active or practical life. (Gaukroger, 2006, 199)

Early modern philosophers, as Galileo, Bacon, Beeckman, Descartes, stand for an active/practical life. This shift does not concern the classical dichotomy between contemplative and practical, where practical means doing moral actions, because practical is understood by early modern philosophers as a material involvement with the world, mainly through experiments. Consequently, Gaukroger (2006) offers an epistemological interpretation, focusing on cognitive values such as justification, impartiality, objectivity etc. In my thesis I argue that Bacon and Descartes situate themselves at the extremity of the spectrum of practical philosophy that presupposes not only the creation and manipulation of experiments in order to find natural-philosophical truths, but the creation of new works for the material well-being of humanity. As a consequence of positioning myself on a technological approach I was able to show that utility gains a tremendous importance in the works of Bacon and Descartes to the point that it becomes as important, if not even more important, than truth: "you may always conclude that the Axiom which discovereth new instances be true, but contrariwise you may safely conclude that if it discover not any new instance it is in vain and untrue." (Bacon, Works, III, 242) Such an interpretation is usually rejected by epistemological approaches (Gaukroger, 2006, 166).

Together with practicality and utility, another important feature of Early Modern philosophy is its approach to mechanisms and the consequences of this approach for the understanding of the human body (Des Chene, 2001) and for the scientific endeavour (Hattab, 2009). My thesis aims to fill the gap between these philosophical approaches toward mechanisms and machines, on the one hand, and the studies that show the importance of technology in the Early Modern period (Sawday, 2007; McClellan & Dorn, 2006; Wolfgang, 2004), on the other hand. Another gap that my thesis aims to fulfil is that between philosophical studies of Early Modern period, which give technology only a secondary place in their analysis, and the contemporary philosophy of technology (Mitcham, 1994; Achterhuis, 2001), which although it emphasizes the importance of Bacon's and Descartes' works, does not offer an analysis of their approach to technology.

I approach Bacon and Descartes from a technological perspective because both of them explicitly affirm that their aim is the “works” and the “fruits” of natural philosophy, which cannot be brought about without a complete scientific understanding of nature. The studies that emphasized the importance of technology for Bacon and Descartes, like Lampert, 1993 and Catton, 1982, focus on the technological aims of their philosophy but do not provide the necessary links to their ontological commitments.

4. Thesis outline

In the first chapter I analyse the pre-modern approaches to technology, focusing on the Aristotelian corpus and on the Renaissance approaches to technology. In the beginning of the seventeenth century the philosophical view that permeated all intellectual approaches was that of Aristotle, as amended by Thomist philosophy. As the Ancient and the medieval approaches toward technology are shaped by Aristotle’s various remarks, I expose first his conception, trying to establish the place of technology is his system, the relation between technology and nature, knowledge, human flourishing. An important legacy of Aristotelian conception is the ignoble social an intellectual status of technology. His legacy is not going to be dismissed until Bacon and Descartes but the Renaissance thinkers begin to challenge important points of the Aristotelian approach. The Renaissance artisans create new artefacts and write books to promote them while the humanists bring arguments for a higher social and intellectual status of technology. The main technological domains involved in this change are mechanics, alchemy, mining and metallurgy, and natural magic.

The second chapter is dedicated to the presentation of Bacon's conception of technology. He is the first philosopher to make mechanics and mechanical arts a focus of philosophical endeavour. Technology is for Bacon the model for philosophy, an inestimable source of knowledge and the rightful outcome of natural philosophy. His approach toward technology is based on his ontological view regarding the ultimate constituents of matter, the active atoms. He argues for the identity between what is natural and what is artefactual and present a project of arriving at the perfect technology, which will eliminate the burdens of human life, restore health and prolong life.

The third chapter explores Descartes' his approach to technology. The core idea of Descartes' approach is that every material thing is a machine constituted of rigid particles, even the universe and the human body. Based on that identification, he emphasizes the centrality of mathematics and mechanics for the knowledge of nature and for the creation of useful artefacts. The prospects of a complete mathematisation of nature determine him to conceive the design of new machines, new artefacts, as a purely a priori endeavour based only on a complete knowledge of mechanics. By this and by the emphases on utility and on the infinite possibilities of technology, he manage to raise the status of technology from that of an ignoble endeavour to that of one of the most respectable human activities.

Finally, the fourth chapter focuses on the paradigm shift that Bacon and Descartes, despite their differences, bring about in conceiving technology. The first part of this chapter documents the direct influence of Bacon on Descartes and the content of their common approach toward material production. Based on that, I shall show the importance of their conceptualization of technology for the modern philosophy, emphasizing their approach toward machine, medicine, utility, progress, and the scientific character of technology.

Chapter I

Autonomization of Technology

The first comprehensive philosophical approaches to technology are those of Bacon and Descartes, yet their philosophical considerations are deeply indebted to Scholastic and Renaissance thought. Although technology is not at all a Renaissance invention, the philosophical approach to technology is. Before the Renaissance, with the exception of Plato and Aristotle, any account of technology comprised descriptions of technological devices and processes but the authors did not address the technology critically. The Renaissance philosophical considerations pertaining to mechanics, mining and metallurgy, alchemy, and natural magic set the stage for a proper philosophy of technology.

In this chapter we start by presenting Plato's and Aristotle's considerations on technology. Aristotelian conception will be extensively analysed since his views regarding mechanics and motion, the relation between technology, nature, and knowledge, the classification and the social status of technology, form the basis of Scholastic understanding and to a large extent remain unchallenged until late Renaissance. Next, the Renaissance arguments pertaining to technology are discussed. These arguments concern mainly the status of technology and the relationships between technology, nature and science. Particular attention will be paid to the social interactions that made possible the conceptual changes regarding technology. The Renaissance raises arguments against the Aristotelian mainstream that prepare the way for the mechanical philosophy and for a coherent philosophical approach to technology.

1. Plato and Aristotle

1.1. Plato's Approach to Technology

In the *Statesman*, Plato gives both a definition and a classification of his contemporary technology. The importance of this text comes from the fact that his purpose is not to define and classify technology but to show how one can analyse the art of the statesman. Therefore, he gives just a didactic example which means that the conception presented here is a piece of common knowledge. Thus, Plato only clarifies what is commonly thought of technology. He refers to craftsmanship, carpentry and manufacture as the "practical actions ... [that] complete those material objects they [the artisans] cause to come into being from not having been before." (*Statesman* 258e) Thus, for Plato the technology is understood as the practice of creating and perfecting material objects that do not exist naturally. This practice is linked to a practical knowledge, a "knowledge... naturally bound up with practical actions." (*Statesman* 258e) Knowledge, especially mathematical knowledge, is an important part of technological endeavour:

> If someone is to take away all *counting, measuring, and weighing* from the arts and crafts (τεχνων), the rest might be said to be worthless... All we would have left would be conjecture and the training of our senses through experience and routine. We would have to rely on our ability to make the lucky guesses that many people call art, once it has acquired some proficiency through practice and hard work. (*Philebus* 55e, my emphasis)

If one is to eliminate mathematical knowledge from crafts, these will become worthless because all that is left is lucky guess and conjecture. However, for Plato, technology is a systematic endeavour that uses principles in making things. The principles, the knowledge that the artisan uses is mainly mathematics. Therefore, technology is mathematically embedded. Plato criticizes the (probably) popular view of technology as based only on routine, experience and lucky guesses, in which no real knowledge is involved. Although knowledge is involved in craftsmanship and Plato stresses that, in the *Republic* Plato shows that the type of knowledge that the artisan, the practical man, possess is impure and corrupt:

> No one with even a little experience of geometry will dispute that this science is entirely the opposite of what is said about it in the accounts of its practitioners... They give ridiculous accounts of it, though they can't help it, for *they speak like practical men*, and all *their accounts refer to doing things*. They talk of 'squaring', 'applying', 'adding', and the like, whereas the entire subject is pursued for the sake of knowledge. (*Republic* 527a, my emphasis)

The geometry of the artisan is an ignoble form of the real science and the craftsman does not possess the proper language and the principles of science. The practical geometry of the artisan is even the opposite of the real science because it is a geometry of the things that become, that come into being, while geometry as such is a science of being *qua* being, of the incorruptible: "If geometry compels the soul to study being, it's appropriate, but if it compels the soul to study becoming it's inappropriate." (*Republic* 526e) This distinction will be further used to argue for the low status of the artisan in the city. Moreover, Plato and all subsequent tradition single out technology, the material production of useful things, from the greater domain of τέχνη by calling it τάς βαναυσίας[7]:

> In the *Republic* (495e) when Socrates casually remarks that manual crafts debase the human mind and body, the word he uses for crafts is not the neutral *τέχνη* but τάς βαναυσίας ... Both before and after Plato the term banausic for crafts was strongly pejorative and was associated with philosophical and social attitudes which labelled certain occupations and activities, primarily but not exclusively those requiring physical, rather than mental, labor, as inferior and base. (Whitney, 1990, 27-28)

7 Handicrafts. Other meanings specified by dictionaries: the habits of a mere artisan, the practice of a mere mechanical art, vulgarity, bad taste, quackery, charlatanism.

In the *Statesman*, Plato discovers by analysis seven great technological classes[8] based on the intended use of the things made: "it would be most appropriate if we put the [1] 'first-born' class of things at the beginning and after this [2] 'tool', [3] 'vessel', [4] 'vehicle', [5] 'defense', [6] 'plaything', [7] 'nourishment'" (*Statesman* 289b) These seven classes comprise all that can be called 'craftsmanship' or, in contemporary terminology, technology. Of these classes, Plato distinguished tool-making as a special class because the production of tools is the basis of technology. Tool-making is called "contributory causes of production" (*Statesman* 281e) because tools are used in all other classes. Without tools, no other technological class would be possible. Consequently, no civilization would be possible: "we must put down as being contributory causes all the sorts of expertise that produce any tool in the city whether small or large. Without these would never come to be a city, nor statesmanship." (*Statesman* 287d) However, in the end of his analysis of technology, at 289b, he changes the order of classes, considering that obtaining the raw materials is the most fundamental technological class. Nevertheless, this contradiction amounts to the view that technology necessarily proceeds from tools and raw materials in order to pursue further. The other important ingredient for making things is, as stated at 258e and 55e, the practical knowledge of the artisan.

Plato consequently classifies technology in seven domains based on the teleology of artefacts, on what they are good for. 'Tools' are the things made for "the purpose of causing the coming into being" (*Statesman* 287e), all instruments used by craftsmen; the 'vessel' class comprises the things made "for the sake of preserving what craftsmen have produced" (*Statesman* 287e), like amphora and barns; the 'vehicle' class comprises products of carpentry, pottery and bronze-working, which "it is all for the sake of some supporting or other, always being a seat for something" (*Statesman* 288a); the 'defense' class comprises

8 "Pierre-Maxime Schuhl has claimed that Plato's classifications of technological arts were not superseded in complexity and detail until Francis Bacon; although this judgement fails to take into account the Middle Ages, it carries some weight with respect to antiquity." (Whitney, 1990, 34)

things made “for the purpose of defending”, “all clothing, most armor, and walls, all those encirclements made out of earth, or out of stone, and tens of thousands of other things” (*Statesman* 288b); the ‘playthings’ class is “a fifth class of things to do with decoration, painting, and those imitations that are completed by the use of painting, and of music, which have been executed solely to give us pleasures”, “not one of them is for the sake of a serious purpose, but all are done for amusement” (*Statesman* 288c);[9] the ‘first-born’ class consists of “gold and silver and everything that is mined”, “art of tree-felling”, “the art of stripping off the outer covering of plants”, “the art of the skinner”, and all the arts that “make possible the working up of classes of composite things from classes of things that are not put together” (*Statesman* 288e), i.e. the obtaining of raw materials; and finally, the ‘nurture’ class comprises “the arts of the farmer, the hunter, the trainer in the gymnasium, the doctor and the cook” (*Statesman* 289a), i.e. all technologies of obtaining and preparing food, medicines and good health.[10] Technology comprises all human made products and the associated practices, whatever the mode of production, which are somehow necessary to human life.

To this classification of technology, that receives over time many variations (Whitney, 1990, 50-51), a new technological class will be added during Renaissance, that of scientific instruments, the class of things created to study nature.

> Although in the Middle Ages there had been specialized craftsmen who made astrolabes and, later, clocks, the emergence of a specialized craft for the production of a line of scientific instruments with distinct functions first emerged (in England, at least) in the 1540s, in response to the need for more accurate measurement in navigation, surveying, and astronomy. (Glick, 2004, 333)

An important part of Plato’s approach to technology is the stress he puts on the lower social and ontological status of artisan. This is a recurrent theme that lasts until Renaissance

9 Here Plato introduces among crafts what usually pertains to fine arts. But his explanation shows that this is not about the works of art made by artists but about the common decorations executed by lower artisans.
10 Based on this classification, one can add, beside tools, raw materials and knowledge, a fourth important element of technology: the purpose of the thing made. But, this would amount to the Aristotelian analysis of the four causes, the efficient cause, the material cause, the formal cause and the final cause, which is not an explicit feature of the Platonic text.

and even beyond. As we already mentioned, one Platonic reason for this contempt is the fact that artisans deal only with 'becoming' while the highest purpose of life is 'being' and the incorruptible Ideas. The knowledge involved in craftsmanship is of a lower form because it deals with becoming and not with being. Another argument against the artisans is that they are not the real experts in their own domain: "a user of each thing has most experience of it and ... he tells a maker which of his products performs well or badly in actual use." (*Republic* 601d) In other words, the artisans are inferior to the users of technology and they should follow the users' prescriptions.

Finally, in the *Laws*, Plato explicitly regards craftsmanship as a disgrace for a citizen and argues for the ignobleness of such endeavour: "As for craftsmen in general, our policy should be this. First, no citizen of our land nor any of his servants should enter the ranks of the workers whose vocation lies in the arts or crafts." (*Laws* 846d) He specifies punishments for the citizens that would become artisans: "If a citizen born and bred turns his attention to some craft instead of to the cultivation of virtue, the City-Wardens must punish him with marks of disgrace and dishonour until they've got him back on the right lines." (*Laws* 847a) Plato's mythical reason in the *Republic* for banning citizenship to artisans is that they are made out of different base materials and that that diminishes their civil capabilities:

> 'All of you in the city are brothers' we'll say to them in telling our story, 'but the god who made you mixed some gold in those who are adequately equipped to rule, because they are most valuable. He put silver in those who are auxiliaries and *iron and bronze in the farmers and other craftsmen*'. (*Republic* 415a, my emphasis)

1.2. Nature and τέχνη

Aristotle presents basically the same conception of technology as Plato, except for the latter's emphasis on mathematics. Nevertheless, Aristotle does not simply repeat Plato but he has a more comprehensive treatment of technology. Aristotle establishes in his *Physics* that there are four causes for every thing that exist, either naturally or by art: the material cause, the formal cause, the efficient cause, and the final cause. For example, a bronze statue is made out of bronze (material cause), having its particular form (formal cause), it is made by artist's actions with the help of tools (efficient cause), and it serves for religious worship (final cause). (Ross, 2005, 45-47) An important distinction that Aristotle draws is between the cause being in the thing itself and its being external to the thing, i.e. the thing is caused by something else. Technological things are the things that have their causes (the formal, the efficient and the final causes) in the craftsmen that produced them, i.e. the things that are made by the work of men who imprint in matter a form that pre-exists in man's soul for some human purpose.

The craftsman imprints on matter a certain form that pre-exists in his soul. Aristotle tries to explain where this form comes from. Is it a human invention or is it an imitation of nature? He takes the example of a house and shows that the form of a house comes neither from pure imitation nor from pure invention. In fact, the form of the house is an innovation, a completion of nature's purposes.

> Thus if a house, e.g., had been a thing made by nature, it would have been made in the same way as it is now by art; and if things made by nature were made not only by nature but also by art, they would come to be in the same way as by nature. The one, then, is for the sake of the other; and generally art in some cases completes [*epiteleitai*] what nature cannot bring to a finish, and in others imitates [*mimeitai*] nature. (*Physics*, 199a)

The form of the house is a natural end; it is a final stage of a natural development. The only problem is that nature cannot accomplish by itself its purposes partly because of accident (health is damaged by illness), partly because of complexity (building houses requires too complex operations). Consequently, human technology is a natural way to complete what nature cannot finish.

> The question might be raised, why some things are produced spontaneously as well as by art, e.g. health, while others are not, e.g. a house. The reason is that in some cases the matter which determines the production in the making and producing of any work of art, and in which a part of the product is present, is such as to be set in motion by itself and in some cases is not of this nature, and of the former kind some can move itself in the particular way required, while other matter is incapable of this; for many things can be set in motion by themselves but not in some particular way ... Therefore some things cannot exist apart from some one who has the art of making them, while others can exist without such a person. (*Metaphysics*, 1034a)

This feature, of completing natural purposes, is not particular to human technology, because nature creates nests, spider-webs and other things through the work of animals (birds, spiders, etc.) that do not have rational souls:

> This is most obvious in the animals other than man: they make things neither by art nor after inquiry or deliberation. That is why people wonder whether it is by intelligence or by some other faculty that these creatures work, - spiders, ants, and the like. (*Physics*, 199a)[11]

Thus, in cases in which the product of technology does not exist naturally, it is made by following the natural path of development. If the thing exists naturally, the craftsman should faithfully imitate nature. Therefore, technology is a matter of imitating natural things or completing the natural evolution of things without inventing new forms. Technology's end is nature or the aim of technology is to produce things exactly as nature would have produced them. Moreover, to complete nature is more or less the same thing with imitation. If imitation

11 A similar passage is found in *Fragments*: "art exists to aid nature and to fill up what nature leaves undone. For some things nature seems able to complete by itself without aid, but others it does with difficulty or cannot do at all; ... similarly, some animals too attain their full nature by themselves, but man needs many arts for his preservation, both at birth and in the matter of nutrition later" (I Dialogues, Iamblichus, Protrepticus 49.3-51.6 Pistelli, B13)

means to do things in the same way they are in nature, to complete nature is to do things in the same way they naturally should be. The technician should always consider the intent of nature. The passage quoted earlier from *Physics* should be read both as descriptive and as normative. It describes that technology is an imitation, but it also prescribes that technology should be so, and this is indeed how the scholastics understood it. The normative element of the passage rejects the possibility and the desirability of invention. One should not try to modify the technology, except by imitating nature; otherwise one might come to be in conflict with nature. Aristotle rejects technological inventions that are totally new and do not complete the existing potentialities of nature, either because that would impair natural perfection or because it is impossible to create things that do not exist potentially in nature.

Technology needs to imitate nature not only in its final products but also in its ways of proceeding. Tools used in technology are best suited for an operation if they are copies of natural objects: "in the ordinary crafts the best tools were discovered from nature." (Fragments, Dialogues, Iamblichus, Protrepticus 54.10-56.12 Pistelli, B47) The purposive character of technology is an imitation of the purposive character of nature. "If, then, art imitates nature, it is from nature that the arts have derived the characteristic that all their products come into being for the sake of something." (Fragments, Dialogues, Iamblichus, Protrepticus 54.10-56.12 Pistelli, B14) Similarly, the order of technological operations should follow the sequence of natural processes.

1.3. Automata and Motion

A very important theme that distinguishes Antiquity from Modernity is the consideration of automata and the principles of motion. The imitation and the completion of nature do not amount to identity between natural products and technological products. It is true that a house made by art is similar to a house that would have been made by nature. The similarity holds as far as the actual function of a house is concerned. However, a certain property of natural objects, that of self-reproduction, that of internal principle of motion, is an absolute limit for technology. From the point of view of the natural order, technology has the character of the accident and, like monsters, artefacts are not self-reproducible:

> If you planted a bed and the rotting wood acquired the power of sending up a shoot, it would not be a bed that would come up, but wood; which shows that the arrangement in accordance with the rules of the art is merely an accidental attribute, whereas the substance is the other, which, further, persists continuously through the process. (*Physics*, 193a)

Technology is external to its products while nature is not. The efficient, final and formal causes of technology lie in the technician that imprints them on matter. This imprinting is only accidental to the imprinted substance and it does not change the real nature of things. Only the material cause (what the thing is made of) is wholly present in the technological product and it retains its own principles of change.

The principles of change are external to technological products and thus they cannot change by themselves: "a bed and a coat and anything else of that sort, qua receiving these designations – i.e. in so far as they are products of art – have no innate impulse to change." (*Physics*, 192b) Technological products cannot move by themselves. The cause of movement is external to the thing. Movement is either internal or external. If it is external, some mover must exist that have to be, in general, in permanent contact with the thing moved. Thus, artificial autonomous movement requires explanation. In the case of an arrow or of an automaton, the mover does not cause the movement continuously:

> In addition to the naturally occurring up or down motion of bodies composed of earth, water, fire, and air, non-spontaneous motion observed in the world around us, such as the flight of an arrow, requires explanation. Aristotle envisioned all such motion as forced or violent (as against natural) motion. He proclaimed that such motion always requires an external mover, someone or something to apply an outside force of some

> sort to cause the motion in question. Moreover, the mover must be in constant contact with the object. In the vast majority of instances Aristotelian movers can be easily identified and the principle apparently confirmed: the horse pulls the cart, the wind blows the sail, and the hand guides the pen. But paradoxical counterexamples exist: the arrow or the javelin in flight after it has lost contact with its mover. Where is the mover in those cases? (Aristotle himself said the medium somehow does the pushing.) (McClellan & Dorn, 2006, 75)

Aristotle explains that a movement can sometimes be so violent that it can continue to act for some time without any contact between the mover and the moved thing:

> Pushing off occurs when the mover does not follow up the thing that it has moved; throwing when the mover causes a motion away from itself more violent than the natural locomotion of the thing moved, which continues its course so long as it is controlled by the motion imparted to it. (*Physics*, 243a)

If this argument explains the flight of an arrow, the movements of automata remain still unexplained, for they tend to move autonomously for a too long period of time without the help of any external mover.

Aristotle considers the movement of automata and explains their capacity to move quasi-autonomously. Discussing animal movements, Aristotle compares animals with automata in *Movement of Animals* and *Generation of Animals*. Automata present a kind of self-movement by the fact that they, on the basis of design, can transform one kind of locomotion into another kind of locomotion. They are set in motion by a mover through a causal chain. This causal chain that affects only local motion is their substantial form and this is similar with the animal motion caused mechanically by the environment. The motion is potentially contained in the automata, i.e. the potential motion of automata was imprinted in them by the artisan.

> It is possible, then, that A should move B, and B move C; that, in fact, the case should be the same as with the automatic puppets. For the parts of such puppets while at rest have a sort of potentiality of motion in them, and when any external force puts the first of them in motion, immediately the next is moved in actuality. As, then, in these automatic puppets the external force moves the parts in a certain sense (not by

touching any part at the moment, but by having touched one previously) *(Generation of Animals*, 734b)

Aristotle accepts a limited[12] similitude between animals and automata but maintains the clear categorical distinction between them: "However, *in the puppets* [...] *there is no change of quality*." (*Movement of Animals*, 701b, my emphasis) Automata lack qualitative change, a concept that disappeared from modern science, and also an internal principles of change. They can only transform the motion they receive without adding a surplus of motion. An automaton's causal chain can affect only local motion. For Aristotle, local motion is just one type of motion alongside change in quality, change in quantity, and generation-destruction. The four changes (change in quality, change in quantity, change of place and the generation-destruction) cannot be reduced just to one: "Aristotle ... never tries to reduce one kind of change to another; the difference of category stands as a barrier against any such attempt." (Ross, 1995, 51) Although a change of place, locomotion, is involved in every change, this one is not fundamental and cannot explain the process of change as such. What is peculiar to automata is that based on their design they can transform the received motion. Automata cannot initiate movement and they cannot change into something else or evolve. The limit of the comparison is the local motion set by an external agent. Moreover, animals can continue to move by themselves while automata will stop when the imprinted artificial movement is consumed.

12 "Animals – unlike stones or artifacts – can instigate local motion when there are changes in their environment, but nothing pushing or pulling them. The automata he describes do not precisely do this, but they share with self-movers the capacity to transform one kind of input into motion of a different kind. In the puppets Aristotle uses as analogues, the unwinding of twisted cords is transformed into the motion of the limbs. The sequence of motion continues without an agent operating it, and unlike a projectile – which simply continues the motion it is given – it is the constitution of an automaton that determines the resultant motion." (Berryman, 2003: 358)

1.4. Knowledge and τέχνη

In the beginning of the *Metaphysics* (980a-981b), Aristotle presents a historical evolution of knowledge from perception, which is common to man and animals, to philosophical contemplation. In this text Aristotle reaffirms the Platonic low status of technology as being an ignoble kind of knowledge. For Aristotle, knowledge begins with perception, the possibility of every animal to distinguish differences. The faculty of perception gives rise to memory as the trace of perception in the soul. The next step is the experience that represents the creation of a certain universal based on multiple memories over the same thing. Experience is the origin, on the one hand, of science, *έπιστήμη*, if the concern is being as such, and, on the other hand, of art, *τέχνη*, if the concern is becoming: "science and art come to men through experience" (*Metaphysics*, 981a). Art, τέχνη, that comprises all Platonic technological classes, is inferior to knowledge because it is "limited in its interest by having some ulterior practical end" (Ross, 1995, 99): "when all such inventions were already established, the sciences which do not aim at giving pleasure or at the necessities of life were discovered" (*Metaphysics*, 981b). Utility is not a noble purpose for Aristotle. The real knowledge is the knowledge of universals and causes, not a description of how particulars are. Thus, in the first paragraphs of *Metaphysics*, Aristotle rejects τέχνη as a lower activity, which obviously is not recommended for a citizen. At the end of his discussion on the origins of knowledge, Aristotle gives a hierarchy of knowledge with arts (τέχνη) at the bottom and wisdom (σοφία) at the top: "the man of experience is thought to be wiser than the possessors of any perception whatever, the artist (τεχνίτης) wiser than the men of experience (έμπείρων), the master-worker (αρχιτέκτων) than the mechanic (χειροτέχνου), and the theoretical kinds of knowledge to be more of the nature of wisdom than the productive." (Metaphysics, 981b)

Beside art (τέχνη, the domain of making or material production) and science (έπιστήμη, "the disposition by virtue of which we demonstrate" (*Nicomachean Ethics*, 1139b)), Aristotle admits other three ways of knowing: a practical wisdom (φρόνησις, the domain of doing or acting) dealing with living a good life, political or military actions, and taking good decisions; an intuitive reason (νους), the faculty that grasps the first principles, the universal truths; and finally the theoretical wisdom (σοφία) that is the union of science and intuitive reason directed at the loftiest objects as heavenly bodies or God.[13] Nevertheless, the faculties of knowledge can be reduced to three given that έπιστήμη, νους and σοφία have the common domain of studying the necessary and the immutable. We therefore have, in order of importance, proper knowledge, dealing with the necessary; practical wisdom, dealing with praxis; and art,[14] dealing with the making of artificial things.

Knowledge		
Of the necessary	Of the contingent	
Science + Intuitive reason + Theoretical wisdom	Practical wisdom	τέχνη

Fig. 1. The division of Knowledge. After Ross, 1995, 137.

Technology posses a certain degree of knowledge, however ignoble. Aristotle affirms that mechanical knowledge is the practical subset of geometry. In fact, mechanics and music seem to be the only arts that possess a specific kind of knowledge: “But demonstration does not apply to another genus – except, as has been said, *geometrical demonstrations apply to mechanical* or optical demonstrations, and *arithmetical to harmonical*” (*Posterior Analytics*, 76a, my emphasis). On this account, mechanics and music seem to be, out of all other forms of τέχνη, the most knowledgeable arts because they are most reducible to simple mathematical relations. Mechanics abstracts from real motions and it deals with geometrical

13 “Let it be assumed that the states by virtue of which the soul possesses truth by way of affirmation or denial are five in number, i.e. art, knowledge, practical wisdom, philosophic wisdom, comprehension; for belief and opinion may be mistaken.” (Nichomachean Ethics, 1139b)

14 The fact that τέχνη does not possess real knowledge is made very clear in the *Magna Moralia*, where Aristotle or his follower – the authenticity of the book is still disputed – considers mechanics as being a bad branch of knowledge: “pleasure was held ... not to be good ... because some pleasures are bad. But this sort of objection and this kind of judgement is not peculiar to pleasure, but applies also to nature and knowledge. For there is such a thing as a bad nature, for example that of worms and beetles and of ignoble creatures generally ... In the same way there are bad branches of knowledge, for instance the mechanical” (*Magna Moralia*, 1205a)

figures and thus it has the characteristics of a science. Mechanics does not deal with objects *qua* objects but qua instantiating geometrical entities, lines and figures:

> A science is most precise if it *abstracts from movement*, but if it takes account of movement, it is most precise if it *deals with the primary movement*, for this is the simplest; and of this again uniform movement is the simplest form. The same account may be given of harmonics and optics; for neither considers its objects qua light-ray or qua voice, but qua lines and numbers; but the latter are attributes proper to the former. And *mechanics too proceeds in the same way*. (*Metaphysics*, 1078a, my emphasis)

Although mechanics is linked to geometry, the exchange between them is only in one direction: geometric principles can be applied in mechanics but geometry remains totally unchanged. Science is immutable while art only imitates some of its features. Science has nothing to gain from technical endeavours.

1.5. Classification of τέχνη

There are lower and higher forms of τέχνη, based on the utility of technological products: higher utility of technological products corresponds to lower status of that technology. Artists belong to a higher level of human development than master artisans and artisans, although all of them deal only with particulars that do not qualify for real knowledge. Thus, if the products of artisans aim at satisfying the necessities of life, the associated τέχνη has a lower status: "as more arts were invented, and some were directed to the necessities of life, others to its recreation, the inventors of the latter were always regarded as wiser than the inventors of the former, because their branches of knowledge did not aim at utility." (*Metaphysics*, 981b) This distinction classifies τέχνη in two great domains, that of art – the playthings class in Platonic terminology – and technology as such, the so called τάς βαναυσίας.

Aristotle gives three criteria for classifying arts: the materiality involved in that art, the abilities that that specific art develops in men, and the contingency of that art. Thus, if an art requires an important involvement with material things, that art is more ignoble. Also, if an art requires more physical abilities at the expense of theoretical and practical ones, that art has a lower status.[15]

> Those occupations are most truly arts in which there is the least *element of chance*; they are the meanest in which the body is most maltreated, the most servile in which there is the greatest *use of the body*, and the most illiberal in which there is the least *need of excellence*. (*Politics*, 1258b, my emphasis)

Although in mechanics more geometrical principles are involved, this art is condemned by Aristotle because it requires a lot of physical work and its products are made for others to use them, transforming the technician into some kind of slave:

> The artisan ... attains excellence in proportion as he becomes a slave. The meaner sort of mechanic has a special and separate slavery; and whereas the slave exists by nature, not so the shoemaker or other artisan. (*Politics*, 1260b)

An art is nobler if it is closer to practical life, the exercise of citizenship. The practical life is attained only if one develops practical wisdom. Practical wisdom deals, like technology, with contingent beings. “The class of things that admit of variation includes both things made and actions done. But making is different from doing.” (*Nicomachean Ethics*, 1140b) In the case of praxis there is on the one hand the nobility of purpose, the development of human personality, and on the other hand the fact that practical actions are ends in themselves. “Making aims at an end distinct from the act of making, whereas in doing the end cannot be other than the act itself.” (*Nicomachean Ethics*, 1140b) The separation between praxis and τέχνη seems quite straightforward but in fact it is not so, at least for the modern mind, because if sculpture, architecture, mining, and carpentry belong to technology as expected, agriculture is on the borderline because it elevates the people who practice it:

15 “parents who devote their children to gymnastics while they neglect their necessary education, in reality make them mechanics” (1338b)

> Now in the course of nature *the art of agriculture is prior*, and next come those arts which extract the products of the earth, mining and the like. Agriculture ranks first because of its justice; for it does not take anything away from men, either with their consent, as do retail trading and the mercenary arts, or against their will, as do the warlike arts. Further, agriculture is natural; for by nature all derive their sustenance from their mother, and so men derive it from the earth. In addition to this it also conduces greatly to bravery; for it does not make men's bodies unserviceable, as do the illiberal arts, but it renders them able to lead an open-air life and work hard; furthermore it makes them adventurous against the foe, for husbandmen are the only citizens whose property lies outside the fortifications. (*Economics*, 1343a-b)

Here Aristotle redesigns the Platonic classification of *techne*. Firstly, he divides τέχνη into liberal and illiberal arts. Liberal arts, like music, are noble arts because they do not involve utility and develop human superior abilities. Secondly, Aristotle classifies the illiberal arts on the basis of their closeness to practical life. Thus, agriculture is the first of illiberal arts because it develops liberal character traits.

> The ancients certainly used technologies and techniques in the actual practice of agriculture, but they considered it to be conducive to the development of good character traits in the landholder that would prepare him for political and military action. They believed that agriculture inculcated virtue, training elite males to be good leaders. It was a discipline appropriate to the praxis of political and military leadership, quite separate from lower-status occupations involving the technical arts. (Long, 2001, 16)

After agriculture comes what Plato called 'first-born' class, obtaining the raw materials. The last position is occupied by mechanics, which is closest to slavery, the opposite of citizenship. Aristotle shows that science and practice are superior to technical endeavours and beside that, he prohibits the mixing of these domains. The borders are clear and distinct and cannot be trespassed. It will be the task of the Renaissance to show the important links between science and technology.

1.6. The Social Status of Technology

As already mentioned, technology is classified between slavery and practical life with different degrees of excellence. Aristotle wrote many passages in which he denies citizenship to artisans and limits the involvement of citizens with arts, especially illiberal arts. Even music and gymnastics can become illiberal if pursued immoderately:

> Nor is there any difficulty in meeting the objection of those who say that the study of music is mechanical. ... It is quite possible that certain methods of teaching and learning music do really have a degrading effect. It is evident then that the learning of music ought not to impede the business of riper years, or to degrade the body. (*Politics*, 1340b-1341a)

From the above quotes one can see that to become a craftsman is shameful. Artisans do not deserve to be citizens:

> There still remains one more question about the citizen: Is he only a true citizen who has a share of office, or is the mechanic to be included? ... In ancient times, and among some nations, the artisan class were slaves or foreigners, and therefore the majority of them are so now. The best form of state will not admit them to citizenship; but if they are admitted, then our definition of the excellence of a citizen will not apply to every citizen, nor to every free man as such, but only to those who are freed from necessary services. The necessary people are either slaves who minister to the wants of individuals, or mechanics and labourers who are the servants of the community. ... so that under some governments the mechanic and the labourer will be citizens, but not in others, as, for example, in so-called aristocracies, if there are any, in which honours are given according to excellence and merit; for no man can practise excellence who is living the life of a mechanic or labourer. In oligarchies the qualification for office is high, and therefore no labourer can ever be a citizen; but a mechanic may, for an actual majority of them are rich. At Thebes there was a law that no man could hold office who had not retired from business for ten years. (*Politics*, 1277b-1278a)

The mechanic, because he works for others and is paid for that, is just a different kind of slave. In conclusion, it is dishonourable for citizens to involve in such activities:

> Certainly the good man and the statesman and the good citizen ought not to learn the crafts of inferiors except for their own occasional use; if they habitually practice them, there will cease to be a distinction between master and slave ... There is, indeed, the rule of a master, which is concerned with menial offices – the master need not know

> how to perform these, but may employ others in the execution of them: the other would be degrading; and by the other I mean the power actually to do menial duties, which vary much in character and are executed by various classes of slaves, such, for example, as handicraftsmen, who, as their name signifies, live by the labour of their hands – under these the mechanic is included. (*Politics*, 1277b)

Aristotle uses the Platonic argument that the technician does not even know the standards of what he is doing. His products are subject to users' opinions who best evaluate them.

> Moreover, there are some arts whose products are not judged of solely, or best, by the artists themselves, namely those arts whose products are recognized even by those who do not possess the art; for example, the knowledge of the house is not limited to the builder only; the user, or, in other words, the master, of the house will actually be a better judge than the builder, just as the pilot will judge better of a rudder than the carpenter, and the guest will judge better of a feast than the cook. (*Politics*, 1282a)

An important Ancient work on technology is pseudo-Aristotle's *Mechanics*, which, in the introduction, critically analyses the relation between technology and nature, a book that tremendously influenced the Renaissance. This book is consistent with the Aristotelian corpus and during the Renaissance it was considered an original work of Aristotle. All contemporary literature, however, agrees that the *Mechanics* was not written by Aristotle. The work will be discussed when dealing with its Renaissance reception.

Other important Ancient writers on technology are Hero of Alexandria, Vitruvius and Archimedes,[16] who design and describe complex mechanisms; but their intentions are neither philosophical nor scientific. The closest we get to a view on the role of technology in those authors is Hero's comment on the aim of his work, that of bringing "much advantage ... to those who shall hereafter devote themselves to the study of mathematics." (Hero of Alexandria, 1851, 1) But after a short introduction on the problem of vacuum and on the elements, he proceeds to describe diverse mechanisms.

16 However Archimedes who deals a lot with mechanisms "refuses to write about his inventions, regarding 'the work of an engineer and every art that ministers to the needs of life as ignoble or vulgar' [Plutarch, *Life of Marcellus* (trans. Perrin) 17.4.]" (Long, 2001, 115).

After Plato and Aristotle, who create the framework of thinking about technology until the Renaissance, there is only one important author who has a philosophical approach to technology, Hugh of St. Victor (c. 1096 – 1141).[17] His main contributions are, first, the use for the first time of the term *artes mechanicae* as encompassing all arts that deal with useful material production and are opposed to liberal arts; secondly, he gives a classification of these mechanical arts into seven classes (fabric-making, armament, commerce, agriculture, hunting, medicine and theatrics); and thirdly, he considers the mechanical arts as a way to restore, through technology, the prelapsarian condition, to relief our physical deficiencies. This last idea, similar to Bacon's, was the least influential of the three, as the subsequent tradition until Early Modernity continued to view technology as ignoble. (Whitney, 1990, 110-111)

2. The Renaissance

The Renaissance is usually considered to be the period roughly between 1450 and 1620, although its origins are traced back to Petrarch around 1350 in Italy. This is a very tumultuous period with various preoccupations and solutions to old and new problems. The scientific and philosophical starting point of the Renaissance, officially held and most outspread, are the works of three Ancient authors, Aristotle, Galen and Ptolemy, completed by Arabic and Middle Age commentaries on these authors. (Grendler, 2004, 177-185) Dealing with the Renaissance approach to technology, this chapter will focus, on the one hand, on those domains that combine theoretical and practical skills in order to create artefacts or to transform materials, and, on the other hand, on authors who debate the status of technological practices and knowledge. Thus, we will briefly look at the developments and arguments

17 See the comprehensive analysis of Elspeth Whitney in her book, *Paradise restored: the mechanical arts from antiquity through the thirteenth century* (1990).

regarding mechanics, alchemy, natural magic, mining and metallurgy in the works of Georgius Agricola, Paracelsus, Marsilio Ficino, Nicholas of Cusa and Galileo Galilei. The aim is to reconstruct the arguments regarding technology that challenged the established framework and made possible the Baconian and Cartesian approaches.[18] The thesis to be defended here is that Bacon and Descartes, in their different ways, integrate and systematize the Renaissance developments in ways that enable them to give a comprehensive philosophy of technology.

In the twelfth century in Latin Europe began an important translation movement from Arab and Greek into Latin. The main purpose was to translate scientific and philosophical books. In mid-twelfth century James of Venice translated the entire logical corpus of Aristotle. At the same time, Gerard of Cremona translated into Latin Aristotle's *Posterior Analytics*, *Physics*, *On the Heavens*, *On the Universe,*[19] *On Generation and Corruption*, and *Meteorology*. Along with these works, the translators of the twelfth century translated also the Arabic commentaries on Aristotle. In mid-thirteenth century, William of Moerbeke translated the entire Aristotelian Corpus and his edition was to become the standard translation for many years. Having such a great number of manuscripts as well as a coherent system, Aristotle became the official philosopher of the Catholic Church. In addition, the conciliation between Aristotle's philosophy and Christianity undertook by Thomas Aquinas (1225-1274) helped Aristotle a lot in becoming the supreme authority in all domains of human knowledge. His doctrine is the doctrine taught in Schools all over Europe during the entire Renaissance.[20] Nevertheless, his teachings are critically approached and not followed blindly. After the condemnation in 1277 of 219 propositions, many of them Aristotelian, deemed 'errors' by the

18 Sawday (2007, xvii) claims that not only Early Modern philosophy but even "many of our complex and contradictory attitudes towards our own technologies were ... first shaped in the period of the European Renaissance."
19 Not an original work of Aristotle.
20 "All teachers, whether Catholic or Protestant, Northern or Southern European, could agree with the Jesuit *Ratio studiorum* (Plan of Studies) of 1586, their manual of instruction, in holding that, at least in the classroom, 'in logic, natural philosophy, morals and metaphysics, the doctrine of Aristotle is to be followed'." (Garber, 2008, 26).

Church, the works of Aristotle are more freely interpreted and other scientific options are investigated.

Renaissance thinkers will bring arguments against the limitations of technology set up by Scholastic doctrine and Aristotelian tradition. During the Renaissance the Aristotelian term *techne* is translated as *ars* and a clear-cut distinction between liberal arts and mechanical arts, *artes mechanicae* (a phrase I will use as synonymous with 'technology') is imposed. The term 'mechanical arts' does not refer only to mechanics but to every technological class. During the Renaissance, there is no systematic approach to technology, but the various arguments pertaining to the value of various mechanical arts prepare the seventeenth century philosophical approach to technology. "We have no corroborating evidence of anything resembling a theory or science of machines before the mid–sixteenth century." (Mahoney, 2004, 281)

As I try to show that during the Renaissance the conceptions of technology begin to change I should give an overview of the actors involved in this change. Their mutual debates and mixing of disciplines prepare the field for the inauguration of mechanical philosophy and a proper theoretical evaluation of technology. Edgar Zilsel in his 1942 article "The Sociological Roots of Science" proposed the idea, which is fundamental for this chapter, that the interaction of artisans and scholars in the Renaissance is the starting point for modern science and for the modern conception of technology:

> In the period from 1300 to 1600 three strata of intellectual activity must be distinguished: university scholars, humanists, and artisans. Both university scholars and humanists were rationally trained. Their methods, however, were determined by their professional conditions and differed substantially from the methods of science. Both professors and humanistic literati distinguished liberal from mechanical arts and despised manual labor, experimentation, and dissection. Craftsmen were the pioneers of causal thinking in this period. Certain groups of superior manual laborers (artist-engineers, surgeons, the makers of nautical and musical instruments, surveyors, navigators, gunners) experimented, dissected, and used quantitative methods. The measuring instruments of the navigators, surveyors, and gunners were the forerunners of the later physical instruments. The craftsmen, however, lacked methodical

> intellectual training. Thus the two components of the scientific method were separated by the social barrier: logical training was reserved for upper-class scholars; experimentation, causal interest, and quantitative method were left to more or less plebeian artisans. Science was born when, with the progress of technology, the experimental method eventually overcame the social prejudice against manual labor and was adopted by rationally trained scholars. This was accomplished about 1600 (Gilbert, Galileo, Bacon) At the same time the scholastic method of disputation and the humanistic ideal of individual glory were superseded by the ideals of control of nature and advancement of learning through scientific co-operation. (Zilsel, 2000, 935)

The university scholars were trained for the first six years of their studies in the faculty of arts where they would learn mainly logic and philosophy based on Aristotle's works and their commentaries. The arts referred to in the name of the faculty comprise the seven liberal arts (*trivium*: logic, grammar, and rhetoric; and *quadrivium*: arithmetic, geometry, astronomy, and music theory) which had to be known by the student to obtain a Bachelor Degree. Being a Bachelor of Arts, the student could pursue his studies in law, medicine or theology. Theology studies were the mix between Christian theology and Aristotelian metaphysics and natural philosophy. The theologians of the universities were the principal adversaries of humanists and learned artisans. They represented the Knowledge. Their writings were strictly textual, arranged in the scholastic form either as commentary or as debates of metaphysical questions.

The humanists were mainly scholars and writers that opposed the scholastic methods, scholastic Latin, and the scholastic ideal of man. They tried to revive the ancient traditions and to create a moral citizen taking as model classical antiquity. They rediscovered ancient texts, alternative philosophies to mainstream Aristotelianism, applied philological methods to texts, dealt with alchemy, mystical and hermetic philosophy. They emphasized practical wisdom. Their writings, again strictly textual, emphasized eloquence, beautiful style and the moral and practical development of individuals.

Finally, there were the learned artisans who were hired by the nobility to work in mechanical and fine arts and who began to write books in order to disseminate their know-how. The men in power at that time patronize all arts, either out of necessity, such as mining for gold or gunnery for power, or out of the need to show off their power, such as architecture or water-mechanisms. Their patronage leads to inventions, development and dissemination of technical knowledge. The books of artisans were rich with accurate drawings of mechanisms, accompanied by little text, which in fact consisted of recipes and descriptions of the construction and working of those mechanisms. "According to some experts' estimation, for the period 1400–1700 alone, one has to reckon with five to ten thousand drawings of machines and machine parts." (Lefevre, 2004, 13) The world of artisans was very different from that of scholars and humanists. While the latter were studying Latin and philosophy for many years, "workshop apprenticeships usually began at an early age (8–14 years), often after an elementary education involving vernacular reading, writing, and arithmetic." (Long, 2001, 104)

2.1. Mechanics

One of the main domains that promote the development of the early modern philosophy of technology, especially the Cartesian one, is mechanics. The creation of mechanisms, a widespread activity during Renaissance, became a field of interest for scholars and the subject of various books in the period. At the beginning of the Renaissance, some important ancient works dealing with mechanisms are translated into Latin, and Renaissance authors begin to write their own treatises on the subject. The most influential ancient work is *Mechanics* (*Mhkanixe*), a book wrongly attributed to Aristotle. The fact that it was attributed to Aristotle raised its value in the eyes of a Renaissance man. As for the real author, David Ross and

G.E.R. Lloyd think that it is somebody from the Peripatetic School while Thomas Winter tries to show by elimination of possible authors that the book was written by a Pythagorean contemporary of Plato, namely Archytas of Terentum, the inventor of mathematical mechanics. (Winter, 2007, iii-ix)

The book was considered unique amongst Aristotle's work because it focuses on simple machines, describing pulleys, gears, levers, and other devices that produce mechanical advantage and also because it mixes physics and mathematics in treating mechanical problems. *Mechanics* is copied in 1457 for cardinal Bessarion but at the time of its discovery there is little interest in its content.

> For nearly a hundred years thereafter, its main readers were humanist scribes and scholars who had little interest in its contents, but at the turn of the sixteenth century, around the time of its first Greek printing in the Aldine edition of Aristotle (1495-8), researchers began to look at the *Mechanics* more closely, creating demand for improved editions, Latin translations, vernacular versions, and commentaries that made the work more widely available. (Copenhaver, 1992, 66)

The initial lack of interest shows the traditional contempt of both scholars and humanists for technology.

Mechanics begins by establishing the categorical difference between art and nature. Mechanics is not a part of physics because mechanics is *para physin*. This can be interpreted either as "contrary to nature" or as "beyond nature" in the sense of completion of nature. Anyway, nature and mechanics are separated. What is important and non-Aristotelian about the conception of technology in this book is the fact that mechanics use both physics and mathematics and mix them in creating artefacts.

> They [mechanical problems] are not quite identical nor yet entirely unconnected with Natural Problems. They have something in common both with Mathematical and with Natural Speculations; for while Mathematics demonstrates how phenomena come to pass, Natural Science demonstrates in what medium they occur. (*Mechanics*, 847a)

The marvels of mechanics are all explained by the marvellous status of circular motion because the circle is a combination of opposites and the authors of *Mechanics* tried to demonstrate that any mechanism is reducible to circles:

> There is nothing strange in the circle being the origin of any and every marvel. The phenomena observed in the balance can be referred to the circle, and those observed in the lever to the balance; while practically all the other phenomena of mechanical motion are connected with the lever. (Mechanics, 848a)

The oppositions contained in the circle are the existence of concavity and convexity in the same circumference, the backward and forward movement in the same time,[21] the possibility of movement in circumference while the centre is at rest and the fact that a point farther from the centre moves faster than a point closer to the centre. Therefore, the author will try to explain all the problems by reducing them to circular motion. After the introduction, the *Mechanics* continues with thirty-five problems or mechanical phenomena, some taken from everyday experience and others of more theoretical nature. It is important to notice that in the Aristotelian corpus there is no mention of mechanisms that use fire, water or wind. These limitations are overcome by Hellenistic authors, who made extensive use of these phenomena in constructing their mechanisms: for example, both Hero and Vitruvius describe the aeolipile, the first recorded steam engine in history.

Other authors who have written about mechanical devices and whose texts were discovered during the Renaissance and deeply influenced it were Vitruvius, Hero of Alexandria, Archimedes and Pappus. The combined works of Aristotle and Hellenistic authors form the basis for the Renaissance development of both technology and a philosophical conception of technology.[22] Vitruvius' *De architectura* was rediscovered in 1414 by the Florentine humanist Poggio Bracciolini. The next major book on architecture is the

21 The upper point on the circumference of a wheel moves in one direction relative to the centre while the opposite point moves in the opposite direction relative to the centre.

22 Other ancient sources, like Plato or Scepticism, are not taught in schools, but are highly valued by humanists and, toward the end of the Renaissance, their influence increases tremendously and they play an essential role in the new conceptualization of technology.

Renaissance reformulation of *De architectura* by Leone Battista Alberti in 1452. His book popularized Vitruvius' work with scarce improvements. *De architectura* contained the state of art of Roman technology and represented an inestimable model for humanists and Renaissance architects and technicians. The book contained descriptions of various machines such as pulleys, cranes, hoists, catapults, siege engines, as well as architectural designs and technologies.

Georgio Valla published the first fragments of Hero of Alexandria in 1501. But the real renaissance of Hero was through the translation of his *Pneumatics*, which was received with great interest. It was translated and published for the first time by Giovanni Battista Aleotti in 1589 under the title *Gli Artifitiosi et Curiosi Moti Spiritali di Herrone*. The best-known editions are by Alessandro Giorgi da Urbino of 1592 and 1595. His book contains many mechanisms that work with air, steam or water pressure, most of them being marvellous artefacts. Another important book of Hero was *On the Measurement of the Circle* translated into Latin by Gerard of Cremona in the twelfth century. In 1544, Johann Herwagen published in Basel the standard edition of the extant works of Archimedes in both Greek and Latin. In 1588, Commandinus published the books of Pappus in Latin which influenced seventeenth century geometry, including Descartes'.

The Renaissance artisans begin to write their own books on various mechanisms, such as mining and military mechanisms, waterworks and mechanical marvels.[23] They improve on ancient mechanisms and help disseminate technological know-how across Europe. Few of

23 In 1335 Guido of Vigevano, physician and engineer, writes what is thought to be the first such book, *Texaurus Regis Francie Aquisitionis Terre Sancte de ultra Mare*, a "crusade book" meant to help King Philip IV of France to conquer the Holy Land. This kind of book became familiar during the Renaissance: *Bellifortis* from 1405, by Conrad Kyeser; *Bellicorum instrumentorum liber* from 1430, by Giovanni Fontana; *Liber tertius* from 1430, by Mariano Taccola; *Trattato di Architettura* from 1462, by Antonio Averlino known as Filarete; *De re militari* from 1466, by Roberto Valturio; the *Büchsenmeisterbuch* from 1475, by Johannes Formschneider; *Trattati di architettura ingegneria* from 1484, by Francesco di Giorgio Martini; *Zeughausinventar* from 1489, by Ulrich Bessnitzer; *De la pirotechnia* from 1540, by Vannoccio Biringuccio; *De Subtilitate* from 1554, by Geronimo Cardano; *Tre discorsi* from 1567, by Giuseppe Ceredi; *Theatrum Instrumentorum et Machinarum* from 1578, by Jacobus Bessonus; *Instruments mathematiques mechaniques* from 1584, by Jean Errard de Bar-le-Duc; *Le diverse et artificiose machine* from 1588, by Agostino Ramelli; *Novo Teatro Di Machine* from 1607, by Vittorio Zorca; and *Les Raisons des Forces Mouvantes* from 1615, by Salomon de Caus.

those books, the most renowned exception being the *Büchsenmeisterbuch*, an "armourer-guide-book", are really intended for practitioners. They were too expensive, too lengthy, and in fact, the designs are hard if not impossible to be reproduced at scale.

> A variety of practitioners in the Renaissance drew machines for a variety of apparent reasons: to advertise their craft, to impress their patrons, to communicate with one another, to gain social and intellectual standing for their practice, to analyze existing machines and design new ones, and perhaps to explore the underlying principles by which machines worked, both in particular and in general. (Mahoney, 2004, 281)

The principal impetus for writing such books seems to be the need of the artisan to obtain the patronage of the ruling class who hired technicians to legitimate their own power by grandiose and clever constructions. Every such book is dedicated to a wealthy man, the actual or potential patron. "Authorship in the mechanical arts expanded because of a changing political culture in which the legitimacy of rulership was increasingly supported by the constructive arts." (Long, 2001, 102) This represents a mixture of categories that departs from the Aristotelian classification of knowledge as science, practice and *techne* because the technological construction of marvellous artefacts became part of a political practice of legitimising power. The books on mechanisms have also the goal of systematizing the complex knowledge involved. Mechanics becomes more than just a craft, and the artisan has to manipulate and construct complex machinery.

One of the important issues for the Early Modern philosophy of technology is the relation between mechanics and nature. This relation is formulated as the answers to two main questions, one regarding the autonomy of mechanics and the other regarding the workings of nature. First question: Is mechanics an autonomous domain or is it just an imitation and perfection of nature? Second question: To what extent are the mechanisms present in natural phenomena? The traditional view is that mechanics cannot create new things and that the power of nature, even if natural objects exhibit some similitude with mechanical devices, belong to a different category.

The relation between technology and nature is complicated by the fact that during the Renaissance the modern dichotomy natural–unnatural is differently conceived. Events and objects are divided in five big categories (natural, supernatural, preternatural, artificial and unnatural), nature being what *usually* and *normally* happens without man and God's intervention.

> The early modern period […] utilized a variety of categories defined vis-à-vis the natural. The *supernatural* was a category largely created by Thomas Aquinas (1225–1274) in the thirteenth century. He viewed miracles – supernatural events – as God's intervention in the natural order and therefore above that order. A second category, '*preternatural*', described events that were highly unusual, ''beyond nature,'' but not supernatural. Examples include monstrous births, bizarre weather, the occult powers of plants and minerals, and other deviations from ordinary natural events. A third category, the *artificial*, comprised objects fabricated by humans that could imitate nature but could never become part of the natural world. Finally, the *unnatural* was a moral category used to describe acts, such as patricide and bestiality that transgressed the natural order ordained by God. (Long, 2004, 255, my emphasis)

Therefore, nature is limited to what is normally ordered without man or God's intervention, and strange natural phenomena are excluded from the realm of nature. If the artificial is to imitate nature but not the preternatural, then mechanics cannot attempt to satisfy natural standards based only on similar structural features. A basic ingredient, that only the natural things have, is missing and it cannot be created by man.

The artisan can only imitate and at best can bring improvements to natural things. i.e. to what is *usually* and *normally* present in nature. The highest perfection to be attained in mechanical arts is innovation, improving tools in accord with nature, but never invention. This in not only the Aristotelian view but also a Neo-Platonic author like Plotinus holds the same ideas:

> Even more tellingly, Plotinus attacks the sufficiency of construction techniques to explain the natural world, and tells us more about the perceived limitations of this approach. He rejects the idea that levering – *to mochleuein* – can account for the production of the natural world, because it will not be able to produce the variety of shapes and colours found. In contrast to those who claim that the craftsmanship of nature is like that of wax-modelers, Plotinus objects that craftsmen can only make use of existing colors and cannot produce new ones. Apparently, then, the comparison to mechanical techniques was taken to restrict explanation to structural features and to rule out qualitative transformation. The techniques of craftsmen are limited to reshaping and structuring material: they cannot turn straw into gold. (Berryman, 2003, 363)

One argument for the inventiveness involved in technology, and therefore its autonomy from nature comes from Nicholas of Cusa. He writes in 1450 three dialogues known as *Idiota* after the main character, a layman in the market-place. Nicholas of Cusa wanted to show that the knowledge extracted from experience by the layman is superior to the mediated knowledge of scholars. This is a recurrent humanistic idea especially in later literal text as those of Rabelais and Moliere that ridicules the unintelligible Latin and the much too complicated explanations of Scholasticism. For Aristotle, the forms of nature have a different, higher status and the artefacts are only copies or improvements. Therefore, there is no proper domain of mechanical arts. However, the autonomy of mechanical arts is fundamental for the possibility to use them as a foundation of philosophy. Nicholas of Cusa tries to extract a certain subdomain of art from the realm of imitation, a conception that perpetuates from Plato and Aristotle on. His argument was that there are products of human artistry that have no eternal archetypes and they transcend created nature. These products cannot therefore be products of imitation but human inventions.

> Having taken a spoon in hand, the Layman said: “A spoon has no other exemplar except our mind’s idea [of the spoon]. For although a sculptor or a painter borrows exemplars from the things that he is attempting to depict, nevertheless I (who bring forth spoons from wood and bring forth dishes and jars from clay) do not [do so]. For in my [work] I do not imitate the visible form of any natural object, for such forms of spoons, dishes, and jars are perfected by human artistry alone.” (Nicholas of Cusa, Idiota de Mente, II, 538)

There is a paradigmatic difference between Aristotle and Nicholas of Cusa. Aristotle in *Physics* (199a) also accepts the idea that there are some artefacts, creations of human technology that do not resemble any natural object, for example houses. Nevertheless, for Aristotle houses are a kind of imitation either because nature, if it were perfect, would have created houses or because it is in the human nature like an instinct to create our own shelters in the same way that birds create nests. In the case of Nicholas of Cusa the story is totally different. The forms of human artefacts do not pre-exist in any potentiality of nature. The artisan creates *ex nihilo* forms and shapes that serve human needs. Nicholas of Cusa defends both human inventiveness and the positive value of utility against Aristotle's claim.

The autonomy goes even further in the late Renaissance, and mechanics is thought to create a different realm altogether, a realm that competes and even surpasses nature. Mechanics is even thought to be so powerful that it can cheat nature.

> Early-modern people, similarly, tended to think of machines as devices for overcoming the resistance of animated nature. Machines were 'ingenious devices for cheating Nature, for getting something for nothing'. Thus mechanics, in the words of Guido Ubaldo, whose *Mechanicorum liber* was published in 1577, were to be understood as a means of working 'against nature or rather in rivalry with the laws of nature'. (Sawday, 2007, 54)

Such a view on technology should grant that mechanics is a totally autonomous domain that is not reduced to imitation, and that different rules apply to mechanisms that overcome the laws of nature so that the latter can be 'cheated'.A different perspective on the relation between mechanics and nature is taken by the professors of mathematics in Padua. Professors of mathematics, such as Galileo, used mechanics and pseudo-Aristotle's *Mechanics* in their teachings aiming at discovering the natural laws by manipulating mechanisms.

> At the University of Padua from 1548 to 1610, professors of mathematics lectured on the *Mechanics*. The last in this line was Galileo Galilei, who taught at Padua from

> 1592 to 1610. His commentary on the *Mechanics* has been lost, but the imprint of this ancient treatise is visible in the great scientist's work during one of his most productive periods. (Copenhaver, 1992, 67)

Galileo Galilei shows in his writings that mechanical laws apply in nature and that nature is to a great extent mechanical. This was the greatest impediment for technology and a point of metaphysical disputations and arguments. The matter could not be solved empirically. For the Scholastics, there is a set of laws that works in nature and another that works in experiments and artefacts of mechanical arts. This argument, valid in the Aristotelian philosophy, is rejected more than once during the sixteenth century on the grounds that "certain man-made artifacts like mechanical clocks and birds had (even as Nature's own productions) that inner principle of motion which presumably acted as an identifying mark of the natural." (Antonio Perez Ramos, commenting on Petrus Ramus, 2006, 113) Experiments, artefacts and nature obey one and the same law; therefore what one find in experiment or by observing artefacts is the way everything, including nature, behaves.

Giuseppe Moletti, Galileo's predecessor as professor of mathematics at Padua, discusses the idea that the possibility of mechanics to imitate nature comes from the fact that in nature itself mechanics is at work.

> The lectures are organized around particular topics, and several pages are dedicated to the question "whether the art of mechanics is found in the works of nature" (*An in operibus naturae ars mechanica reperiatur*) (fol. 22). The problem with which Moletti deals is a familiar one by now: how to reconcile the notion that art imitates nature with the ability of art to bring about effects that nature cannot, and with the ability of some arts (especially mechanics) to conquer nature. Moletti's strategy is to argue that mechanics conquers nature by applying principles that it has learned from nature itself. (Schiefsky, 2007, 95)

The response of Molleti is that the nature obeys mechanical laws and that mechanics is perfectly natural. "In general the art of mechanics is found everywhere in nature, meaning that mechanics operates on fully natural principles." (Schiefsky, 2007, 95)

Galileo Galilei promotes the idea that mechanics can bring us knowledge about nature and that technology is an important field for philosophy to research. In the beginning of the *Two New Sciences* Salviati, the character who presents Galileo's positions, says: "The constant activity which you Venetians display in your famous arsenal suggests to the studious mind a large field of investigation, especially that part of the work which involve mechanics; for in this department all types of instruments and machines are being constructed by many artisans." (Galileo, 1914 [1638], 1) The importance of this acknowledgement that mechanics is a proper subject of philosophy is that it inaugurates a completely new ideology of knowledge. This passage represents the end of Aristotelian classification of knowledge.

> That the everyday practice of mechanics should be the subject of philosophy is perhaps the most revolutionary statement in Galileo's famous work. Clearly, something had to have raised the intellectual standing of mechanics for Galileo to feel that the philosophical audience to whom he was addressing the *Two New Sciences* would continue reading past those first lines. (Mahoney, 2004, 284-285)

Galileo does not identify the laws of nature with the laws of mechanics but he maintains that the two domains have similar limits and that nature, whatever it does, can not ignore the laws which mechanics also obeys.

> Finally, we may say that, for every machine and structure, whether artificial or natural, there is set a necessary limit beyond which neither art nor nature can pass; it is here understood, of course, that the material is the same and the proportion preserved. ... I am certain you both know that an oak two hundred cubits [braccia] high would not be able to sustain its own branches if they were distributed as in a tree of ordinary size; and that nature cannot produce a horse as large as twenty ordinary horses or a giant ten times taller than an ordinary man unless by miracle (Galileo, 1914 [1638], 4)

The natural world, even the human organism, must obey some mechanical laws of construction similar to those that apply to mechanisms. Also, these limitations work both ways so that mechanics cannot 'cheat' nature. From the mechanical point of view, there is no more a separation between natural and artificial, and nature can be known by observing the construction and working of mechanisms. Scientists as Galileo

> challenged traditional Aristotelian categories by bringing together *techne* (manipulation of machines and instruments) and *episteme* (theoretical knowledge) Seventeenth-century Aristotelians countered the experimentalists with the argument that this combination was a category mistake involving the improper fusion of separate conceptual entities. (Long, 2001, 2)

Another important aspect of the relation between mechanics and nature is the status of mathematics. Mechanics was always considered a form of mixed mathematics because mathematical theorems apply to mechanical devices. But mathematics cannot be used, in Aristotelian framework, for studying nature.

> Whereas metaphysics deals with objects that are "both independent and immovable" and the natural sciences deal with objects that are "neither independent nor immovable," mathematics deals with objects that are "immovable, [but] are for the most part not independent of material reference" (1026a14–16) It is for this reason that Aristotle believed that mathematics is inherently inadequate for explaining natural phenomena: mathematics ignored what is most important about physical objects: that they are the kind of objects that change, and moreover, that they are the kind of objects that have within them their source of change. (Biener, 2008, 26)

Moreover, mathematics is not a science; it does not represent scientific knowledge in the Aristotelian and Scholastic meaning of έπιστήμη or *scientia*. The classical place where Aristotle defines science is *Nichomachean Ethics* 1139b4. *Scientia* (έπιστήμη) is defined as "the quality whereby we demonstrate" through syllogistic deductions from the first principles. In the sixteenth century, philosophers denied that pure mathematics should be regarded as *scientia*, that is, scientific knowledge in the Aristotelian sense. Piccolomini in *Commentarium de certitudine mathematicarum disciplinarum*, 1547, argues that mathematics is not a scientific discipline because it does not demonstrate by syllogism. The middle term is none of the causes in Aristotelian sense. His treatise "contains a bitter attack on mathematics as science and ends up denying the basis of any plan for the mathematization of the natural sciences." (Ferraro, 2010, 216)[24] Mathematics itself was not usually taught in a university. Cristopher Clavius introduced mathematics to the Jesuit curriculum at the end of the sixteenth century as an autonomous discipline and argued for its general utility for other disciplines.

The university mathematicians and the writers on natural magic shared a special interest in mathematics and established a link between natural philosophy, mathematics and technology. Natural philosophy is the Renaissance name for what later will become the science of nature. In the Aristotelian-Scholastic framework, natural philosophy has almost nothing to do with technology. Moreover, mathematics in universities is not particularly linked to the study of nature or to technology. Mathematics, physics and technology are methodologically different domains although in practice during the Renaissance humanists and scholars mixed these domains in various ways such that at the end of the period Galileo equates the study of natural motion with the study of mechanics and thinks of the universe as mathematically designed. The Magi and alchemists argue for the use of mathematics in natural magic and use quantitative methods in alchemical experiments. The extensive use of mathematics both in natural philosophy and in technology broadly conceived is due to the Platonic tradition that represents an alternative to the mainstream Aristotelian teaching. "Some university mathematicians were more pleased by Plato's praise of mathematics than by Aristotle's hasty denial of that subject's efficacy in natural philosophy." (Copenhaver, 1992, 187)

24 "contiene un duro attacco alla matematica come scienza e finisce con il negare alla radice ogni eventuale progetto di matematizzazione delle scienze della natura."

2.2. Alchemy

Beside mechanics, another source of developments and arguments pertaining to technology are the experimental parts of occult sciences and various theoretical works on Renaissance crafts. This tradition is the main source for the Baconian approach to technology.

Alchemy is a mystical and experimental endeavour, the precursor of chemistry. A lot of natural philosophers during Renaissance deal with alchemy,[25] and this section deals only with the experimental part of this 'art'. The aim of alchemy is to create 'medicines' that 'heal' metals, bodies and souls, i.e. to create substances that transform ordinary metals into noble metals, that heal body illnesses and that perfect the soul.[26] Alchemy is developed out of two sources: the recipe literature of Middle Age monasteries, that provide recipes on metalwork and how to make glass, pigments, panels, etc.; and the Arabic texts on alchemy, in which a coherent theory of metals, as composed of two basic components (sulphur and mercury), was developed.[27] The most important synthesis and the most influential alchemical text is *Summa perfectionis magisterii* written probably by Paul of Taranto around 1280 and attributed to Gerber, Jābir ibn Hayyān, an Arab polymath from the eighth century. The Arabic theory of mercury-sulphur is combined in this book with the *minima naturalia* theory of Aristotle,[28] the result being a working theory which can explain the properties of minerals and their transformations in laboratory. Marsilio Ficino and other humanists such as Cornelius Agrippa,

25 "In a work called *De Natura Rerum* (*On the nature of things*) he [Paracelsus] notes, 'transmutation is when a thing loses its form or shape and is transformed so that it no longer displays at all its initial form and substance. . . . When a metal becomes glass or stone . . . when wood becomes charcoal . . . [or] . . . when cloth becomes paper . . . all of that is the transmutation of natural things.' By this definition almost everyone in the early modern period was engaged in alchemy." (Moran, 2004, 34)

26 "A variety of laboratory procedures, including the separation of metals, sublimations, and distillations, were generally described in alchemical terms, and alchemy had already for a long time been associated with making medicines." (Moran, 2004: 32)

27 The most important Latin texts are *Liber de compositione alchimiae*, translated from Arab in 1144 by Robert of Chester, and *De diversis artibus* written around 1100-1120 by Theophilus Presbyter.

28 *Minima naturalia* theory is based on Aristotle's claim that there is a minimum amount of prime matter that can hold a form. "it is obvious that neither flesh, bone, nor any such thing can be of indefinite size in the direction either of the greater or of the less. … even though the quantity separated out will continually decrease, still it will not fall below a certain magnitude. … it is clear that from the minimum quantity of flesh no body can be separated out." (*Physics*, 187b-188a)

Paracelsus and Giordano Bruno favoured alchemy in its most scientific form based on Arab books and their own chemical experiments and even thought to promote alchemy as a university discipline.

> Alchemy failed to find acceptance within the curricula of the medieval universities, and it came under increasing attack with a backlash that had set in by the end of the thirteenth century. The discipline was not incorporated into university curricula in part because it included operational, workshop processes with connections to craft traditions such as dyeing and metallurgy, which were incompatible with the logical orientation of university scholasticism. (Long, 2001, 146)

Also, because the claim that the alchemists can create gold, a practice that would destabilize a gold-based economy, Pope John XXII issued a bull against alchemical counterfeiting (*Spondent pariter*, 1317). In fact, it was this rejection from the university and the Church that transformed alchemy from an honourable proto-science into the late abracadabraic movement. Because of the papal bull as well as for preserving the secrecy of their recipes alchemy authors begin to use cover names (*Decknamen*) for substances:

> It is true that the Latin alchemists acquired the Arabic (and ultimately Greek) practice of substituting the planetary names for the metals, so that gold became sol, silver luna, copper venus, iron mars, tin jupiter, lead saturn, and quicksilver mercury. Yet this simple substitution code was only one element in a complex and variant set of Decknamen or "cover names" alchemists used. In the rich alchemical glossaries of the Middle Ages, quicksilver's planetary designation had to compete with such names as "the fleeting," "the runaway," "the fugitive slave," "the cloud," "the lightning," "the heavy water," "the spirit," "the fluid," and "water of life," to name but a few. The same was true of the other metals. (Newman & Grafton, 2001, 18)

Behind these very colourful metaphors the practitioners of alchemy were making real chemical experiments in their laboratories. There are three important aspects of their work that contribute to a philosophical conception of technology: the use of experiments reproduced over and over again, the creation of new substances that do not exist naturally and the use of scientific instruments.

One of the alchemists' main purposes is to create gold. In fact they try to obtain the right soil in which gold could vegetate and germinate. The metals are, for Renaissance and Early Modern non-mechanical thinkers, natural elements that, in the same way as plants, grow in the soil.[29] Therefore, gold should be obtained out of gold seeds (which are probably the gold itself) implanted in the proper soil. Lawrence Principe reproduced the experiments described in alchemy books and obtained such a gold germination:

> After a fairly lengthy process involving various materials and numerous distillations, I obtained an 'animated' Mercury, which was supposedly the necessary 'mineral water' that mercurialists required for the 'moistening of the seed of gold'. … I used this material along with gold to prepare a mixture that was sealed in a 'glass egg' and heated. The mixture soon swelled and bubbled, rising like leavened dough, recalling (perhaps not unwarrantably) the numerous references to fermentation and leavening in mercurialist literature. Then it became more pasty and liquid and covered with warty excrescences, again perhaps accurately recalling the 'moorish low bog' that 'Toads keep'. After several days of heating, the metallic lump took on a completely new appearance [that] some today might call this a dendritic fractal but I think that most onlookers would refer to it first as a tree. (Principe, 2000, 69-70)

The gold as well as the various 'medicines' obtained by alchemists is thought to be even better than the natural one, this showing the power of technology:

> Alchemical writers, unlike those in the mainstream of the Scholastic tradition, were willing to argue that human art, even if it learned by imitating natural processes, could successfully reproduce natural products or even surpass them. In so doing the alchemists of the Middle Ages developed a clearly articulated philosophy of technology, in which human art is raised to a level of appreciation difficult to find in other writings until the Renaissance. (Newman, 1989, 424)

This trust in the powers of technology comes from the belief that alchemy artfully combines the basic natural elements. The quality of artefacts is not a consequence of some supernatural powers that the alchemist obtained through mysticism but of practical and theoretical knowledge about the basic elements of nature. Roger Bacon claims that "alchemy

29 "Don Juan Manuel (1282–1348) in the *Libro del caballero et el escudero* (*Book of the Knight and the Squire*) suggests a metallogenesis inherited from both the early medieval alchemists and the Arabs, concluding that metals (the eight he knew: gold, silver, mercury, brass, copper, iron, lead, and tin) grow inside Earth just as plants grow on the surface, influenced by the planets which ruled them." (Melero, 2009, 52).

is the science of the elements *per se*, while natural philosophy and medicine concern things made out of the four elements" and "he wants to make it the wellspring of all medical and natural knowledge." (Newman, 1989, 432)

The alchemical books also contain a lot of recipes for analysing metals and for purifying them. Most of them refer to methods of discerning through physical and chemical experiments between fake and real gold but at the same time they provide analytical methods for discovering the qualities of matter:

> They include dissolution in 'salts', which is a sign of artificial gold; use of the touchstone; weight (gold that is heavier or lighter in specie than normal gold is a fake); loss of its color when fired; ability to sublime; glowing or boiling on fusion; and taste. In all of these, the goal is to discern natural gold from its artificial imitations, so as to measure the success of the alchemist. (Newman, 2000, 45)

2.3. Mining and Metallurgy

The theoretical and practical knowledge of the alchemist, dismissed by the Schools and the Church, became a significant part of mining and metallurgy literature.

> Although it is certainly true that the sixteenth century witnessed the birth of an autonomous literature about mining and metallurgy, as evinced by the works of Vannoccio Biringuccio, Georg Agricola, Lazarus Ercker, and others, it does not follow that alchemists were unconcerned with the purification, testing, and exact measurement of their own materials. Indeed, I show here that two of the most important analytical tools of the early chemist, the blowpipe and the precision balance, were associated with alchemy long before the early modern development of the mining and metallurgy genre. (Newman, 2000, 35)

The mining and metallurgy literature does not use any more the alchemical *Decknamen*. Out of all alchemical processes and aims, the metallurgy literature kept only those that deal with purification and testing of metals. These alchemical processes for refining metals come to be used by practitioners in mine-working. As a consequence a rich literature appears that describes in detail the complex recipes that have to be followed.[30] Because of the flourishing of the practical mining literature, the humanists also come to be interested in mining technology, so that scholarly treatises that appear, not only describe, but also systematize and bring arguments in favour of this technology:

> Beginning in the mid-1520s, and emanating from Germany, and particularly the mining centre of Augsburg, whose water-powered devices would so fascinate Montaigne in the 1580s, small treatises, known (by their titles) as *Probierbüchlein* (assaying booklets) had begun to appear. From these collections of chemical 'recipes' for refining metals, constructing assay furnaces and crucibles, or separating (for example) silver from iron or lead, grew, in turn, the two most important works on technology in the mid-sixteenth century: the *Pirotechnia* of Vannoccio Biringuccio, first published at Venice in 1540, and the *De Re Metallica* of Georg Bauer, better known as Georgius Agricola, published at Basle in 1556. (Sawday, 2007, 87)

The most influential humanist in the domain of technology is Georgius Agricola (1494-1555). Agricola worked initially as a translator of Galen and Hippocrates and was interested in philology. He obtained his doctoral degree in Italy. His name was 'Bauer', meaning *farmer*, and he Latinized it into 'Agricola'. He writes the first scholarly book on mining, *De re metallica* published in 1556, whose main importance is the creation of a Latin vocabulary for mining, and by doing that he elevated the art of mining to the level of a learned subject. His book remains the authoritative text on mining for many years. Agricola used logic and scholastic distinctions as well as quotes from Greek and Latin classics, the book being a real scholarly work written for other scholars and not for actual miners. Even if he did visit mines as a physician, he did not have a practical knowledge about mining. If one examines the book's drawings of mining mechanisms, one will observe that a lot of them are not going to work. The book contains descriptions of how to find, how to open and how to work mines, the various machines that are needed and various metallurgical processes. It also

30 The author of *Feuerwerkbuch*, a treatise from 1420 "claims to have written the book because the technical details of gunpowder manufacture are too complex to remember without the help of writing: 'And thereupon since the subjects belonging to it [gunnery] are so many, which every good gunner should know, and which a master without writing cannot remember in his mind', all the necessary details are provided." (Long, 2001, 119).

contains many drawings, and in this respect it is similar to the books written by the actual artisans. Georgius Agricola begins his *De re metallica* with a rationale that explains the importance of mining for acquisition of knowledge and how much knowledge is involved in mining. He defends the art of mining on the model of the Roman author Columbella's defence of agriculture. His first book out of twelve consists of examining the arguments against the art of mining, including general arguments against technology as such, which Agricola rejects and brings his own counterarguments.

> Many persons hold the opinion that the metal industries are fortuitous and that the occupation is one of sordid toil, and altogether a kind of business requiring not so much skill as labour. But as for myself, when I reflect carefully upon its special points one by one, it appears to be far otherwise. For a miner must have the greatest skill in his work, that he may know first of all what mountain or hill, what valley or plain, can be prospected most profitably, or what he should leave alone; moreover, he must understand the veins, stringers and seams in the rocks. Then he must be thoroughly familiar with the many and varied species of earths, juices, gems, stones, marbles, rocks, metals, and compounds. He must also have a complete knowledge of the method of making all underground works. Lastly, there are the various systems of assaying substances and of preparing them for smelting. ... Furthermore, there are many arts and sciences of which a miner should not be ignorant. First, there is Philosophy, that he may discern the origin, cause and nature of subterranean things. (Agricola, De Re Metallica, Book I)

The miner has to know many learned subjects in order to be able to pursue his goals. He has to know philosophy, medicine, astronomy, surveying, arithmetic, architecture, drawing, law and practical alchemy. Agricola argues for the profitability of mining and against the critics that affirm that "gems, metals, and other mineral products are worthless in themselves" and gold and silver are morally undesirable. He states that "If we remove metals from the service of man, all methods of protecting and sustaining health and more carefully preserving the course of life are done away with." (Agricola, Book I) He considers arguments regarding the danger of mining, the devastation of mining fields and the purpose of God to place metals underground. In the end of the first book Agricola shows that metals are necessary for physicians, painters, architects and merchants, and argues that mining is an honourable occupation and that it "is objectionable to nobody." (Agricola, Book I) As one sees, Agricola rejects Aristotelian arguments regarding the knowledge associated with technology, the value of utility and the honourability of a technological occupation. As the alchemists before him, he argues that technology is not just an art for doing things but also a source of knowledge.

An important idea that is developed along Agricola's book is that technology, in this case mining and metallurgy, is a systematic endeavour that involves various craftsmen and various devices. Technology is not any more a craft that a single man can perform but it is a fine-tuned interdependent collective activity.

> The sheer numbers of human figures in Agricola's illustrations suggest a variety of occupations. Specialists people Agricola's landscape: machine builders (using different simple tools), shovellers, sievers (five different methods of sieving are illustrated in the case of the ore crushing machine), wheelbarrow pushers, rakers, and so on. Each task is allotted its careful description, as though none were more or less important than the next. We also know that these are not representations of the same individual performing different tasks since Agricola's illustrators took considerable care to deploy artistic devices to suggest the individuality of the workers: their clothes are different, some are bearded, some clean shaven, some are old while others are young, and while men are in the majority, women also are shown in these scenes. The images, in other words, work synchronically as well as diachronically, showing some of the tasks that must be performed at the same time by different people, working to a pace which has become regulated by machinery. (Sawday, 2007, 92)

Agricola's book shows a new approach to work that requires skilled specialists working together in a technological context. What Agricola did is to invent the technical handbook for a systematic technological endeavour.

3.4. Natural Magic

The philosophy of technology is created by bringing together various arguments and purposes of these practical domains of natural philosophy such as mechanics, alchemy, mining and metallurgy. But during the Renaissance, the closest domain to what is now referred to as technology was natural magic.

> 'Natural magic' pointed to the operative power inherent in technology, and offered a framework outside that of Aristotelian causality. By the turn of the seventeenth century, discussions of technology often adopted the name 'magic' as 'the practical part of natural philosophy'. (Henninger-Voss, 2004, 11)

Natural magic aims at discovering and using the natural forces and elements for obtaining useful and marvellous effects through human industry. Natural magic is a Renaissance creation based on Neo-Platonism and hermetic traditions.

The humanists promoted the use of utilitarian magic aimed at changing the material world. In addition, they advocated the introduction into schools, alongside the normal Aristotelian curricula, of liberal and mechanical arts. One such proposal comes from Antonio Averlino, known as Filarete (c. 1400 – c. 1469), who envisaged a school in which

> 'some manual arts should be taught here' by craftsmen; these would include 'a master of painting, a silversmith, a master of carving in marble and one for wood, a turner, an iron smith, a master of embroidery, a tailor, a pharmacist, a glassmaker and a master of clay. ... The other crafts are also necessary and noble' (Long, 2001, 132)

In the same way, Giacomo Lanteri in his *Due dialoghi ... del modo di disegnare le piante delle fortezze secondo Euclide* ("Two dialogues ... on the way to design the plans of fortresses according to Euclid", 1557) recommends that all virtuous men should have some knowledge of mechanical arts.

Marsilio Ficino, the discoverer of Plato and the hermetic tradition, was highly interested in natural magic, the ways of using plants, stones and other natural object as modes of acting on nature without the use of demoniacal or angelical powers. He uses Neo-Platonist sources, Chaldean oracles and Aristotelian metaphysics in sustaining this mode of command over nature by using the sympathies that exist between natural objects. This natural magic can be seen as a form of occult technology that uses pre-existing "levers" in nature, hidden by the Creator at the moment of creation, in order to obtain the desired effects. Another point to be made about natural magic is that it focuses on the utility of knowing the natural laws. Ficino's Magus is not a detached observer of nature that pursues knowledge for its own sake but the knowledge should be useful, the Magus should be able to apply the knowledge. The books on natural magic not only deal with the similitude between natural objects that can be used by the Magus but also employ mechanics, mathematics, alchemy and every practical knowledge available at that time.[31] Cornelius Agrippa's *De Occulta Philosophia* (1533) discusses astrology, mathematics, mechanical marvels, numerology, universal harmony, the power of music and incantations, images for talismans, and the occult virtues in natural things.

> A magician, expert in natural philosophy, and mathematics, and knowing the middle sciences consisting of both these, arithmetic, music, geometry, optics, astronomy, and such sciences that are of weights, measures, proportions, articles, and joints, knowing also mechanical arts resulting from these, may without any wonder, if he excel other men in art, and wit, do many wonderful things which the most prudent, and wise men may much admire. (Agrippa, 2004, 233)

Giambattista Della Porta's *Magia Naturalis* (1588) describes procedures for such diverse things as transmuting metals, producing exotic plants and animals through grafting and crossbreeding, cutting, conserving, and cooking meat, staving off baldness, eliminating wrinkles, and engendering beautiful children. Other important authors in the natural magic tradition that are also viewed as experimental scientists are Paracelsus (1493–1541), Girolamo Cardano (1501–1576), John Dee (1527–1608), and Jean Baptiste van Helmont (1579–1644).

31 "For the occult writer, Henry Cornelius Agrippa, drawing on this well of mystical lore, mechanism and magic were inseparable from one another" (Sawday, 2007: 186).

3.5. Artificial Revelation: Scientific Instruments

Along with the extensive praise of mathematics, another important characteristic of Renaissance books pertaining to technology is the invention of a new technological field, that of scientific instruments. An important feature of Galileo's works is the extensive use of experiments as well as the construction of scientific instruments. In the *Dialogue Concerning Two New Sciences* a lot of experiments that support his theoretical claims are used, and Galileo designs mechanical devices that have no other purpose than that of demonstrating physical laws. Although experiments and mechanical devices are important they are not, at least methodologically, a primary source of knowledge. In many places in his work he states that, although he performs the experiments, his claims have to be deduced theoretically from the principles. Therefore, experiments are only didactic aids.

> Even without further experiment, it is possible to prove clearly, by means of a short and conclusive argument, that a heavier body does not move more rapidly than a lighter one (62) … Without depending upon the above experiment, which is doubtless very conclusive, it seems to me that it ought not to be difficult to establish such a fact by reasoning alone. (135) … From accounts given by gunners, I was already aware of the fact that in the use of cannon and mortars, the maximum range, that is the one in which the shot goes farthest, is obtained when the elevation is 45° … but to understand why this happens far outweighs the mere information obtained by the testimony of others or even by repeated experiment. (Galileo, 1914, 276)

Despite these declarations that belittle the use of experiments and scientific instruments, Galileo gives detailed descriptions of experimental settings and on how to construct scientific instruments, and he is well aware of the importance of observations and the knowledge he obtained through experiments. Derek de Solla Price called Galileo's use of telescope 'the principle of *artificial revelation*' that tremendously expanded the world, creating new domains of inquiry.

> The magnitude of this discovery cannot be overemphasized. That the Moon had mountains was an important discovery, but faded to relative triviality when compared with the nature of the experience itself. Galileo realized that he had manufactured for himself a revelatory knowledge of the universe that made his poor brain mightier than Plato's or Aristotle's and all the Church Fathers put together. (de Solla Price, 1984, 108)

A concern regarding the instruments that Galileo and his contemporaries have is to assure their readers that the observations are not artefacts.[32]

> Because of the features of early telescopes (narrow field of vision, double images, color fringes, and blurred images especially toward the periphery), people who looked through a telescope for only a few minutes could legitimately believe that Galileo's claims were artifactual, as numerous spurious objects could be seen through a telescope's eyepiece at any given time. (Biagioli, 2006, 102)

A contemporary of Galileo, the Jesuit astronomer Christoph Scheiner, who makes similar observations at the same time as Galileo, is more concerned to demonstrate the reality of his observations and to distinguish them from the inevitable errors of early telescopes:

> The images Scheiner was studying on walls or sheets of paper were not of sunspots but of flaws in the lenses. … He used the projection system not to make pictures of sunspots, but to map out how the optical artifacts produced by the telescope looked, and then to demonstrate that sunspots were clearly distinct from those artifacts. … Scheiner seemed much more concerned than Galileo with responding to possible philosophical objections to his use of the telescope, and described the painstaking procedures he followed to prove that the spots were not optical artifacts. (Bagioli, 2006, 200)

The use of scientific instruments raises philosophical problems also because experimental settings cannot be identical with natural phenomena.

> The use of instruments to investigate nature had important methodological implications because it challenged the notion of Aristotelian common experience. For Aristotelians common experience was valid because all reasonable people without

32 Biagioli (2006, 156, note 37) claims that even Galileo uses the argument of the artefactual nature of telescopic observations against its Jesuit enemies: "In the dispute on comets of 1619–23, Galileo argued that the comets observed by the Roman Jesuits may have been not real physical objects but optical artifacts. Galileo's claim emerged in a context in which the Jesuits had been first to publish observations of the comets while Galileo had been sick and unable to produce a comparable body of observations."

> question agreed that a particular claim was true. In contrast, truth derived from experimentation, and instrumentation depended on the manipulation of a device that was only available to particular individuals. Such individuals had to have access to the device itself and had to possess particular skills to use it. (Long, 2004, 340)

All data obtained through experiments are to a certain extent 'fabricated' in the sense that they do not naturally appear in everyday experience and they require special practical skills to operate the instruments and perceptual skills to extract the relevant data. Also, the data obtained require further interpretation. For example, Scheiner interpreted the sunspots as being planets revolving around the Sun as the available data were indecisive. And given the available instruments, all the experimental results were highly erroneous.

> Galileo turns to his celebrated inclined plane experiment. He first describes his experimental equipment: a wooden beam 24 feet long, three inches thick, with a channel chiselled in one edge, smoothed, and lined with parchment. One end of the beam is raised two to four feet, and a rounded bronze ball allowed to roll down the channel. Two paragraphs later he describes his timing method: he collected water running from a container and measured its weight to determine a time interval. It hardly needs to be pointed out that a not-perfectly-spherical or uniform bronze ball rolling and rattling down and over a vellum-lined channel no matter how smooth could not exactly produce the predicted results. (McClellan & Dorn, 2006, 239-240)

The books of alchemy also contain full descriptions of instruments as well as the methods of using and producing them:

> For example, in the fifteenth-century *Ordinall of Alchimy*, Thomas Norton devoted one of his verse chapters to 'concords' necessary for the Great Work. The third of these concords is that the 'Werke accordeth with Instruments' or, less poetically, that apparatus be accommodated to its purpose. Norton, like a man accustomed 'to ordeyne Instruments according to the Werke', recites the differing lengths and shapes of vessels for circulation, precipitation, sublimation, and so forth. He then details the differences in types of clay for earthenware vessels and the types of ashes and frits for making differing qualities of glass; he also describes various contrivances for furnaces, of which he provides illustrations. (Principe, 2000, 59)

The instruments are not only tools employed for obtaining various substances but they also serve as scientific instruments, i.e. tools for obtain theoretical knowledge. The techniques of mineral testing and analysis were not employed by medieval alchemists merely as empirical means for attaining precious metals. By the late Middle Ages, these techniques had already evolved into tools for the experimental investigation of nature. (Newman, 2000, 35)

3. Conclusion

This chapter presented the framework against which Bacon and Descartes would introduce a radically new conception of mechanics and mechanical arts. Plato's and Aristotle's contempt with τάς βαναυσίας remained the dominant attitude among the learned until the beginning of seventeenth century, despite some Renaissance attempts to raise the status of *artes mechanicae*. The singular positive theological evaluation of technology made by Hugh of St. Victor in the twelfth century was to a certain extent disregarded. Thus, one of the most powerful arguments against Descartes' project, voiced by a Scholastic professor of philosophy and theology, Fromondus, was that it used ignoble mechanical principles. He characterises Descartes' philosophy as crass, unsubtle, brutish, and gross[33] because of its extensive use of mechanics:

> I believe that without knowing, he falls too often into Epicurus' physics, which is *brutish* and *gross* (AT I 402) ... Such noble actions do not seem possible to be produced by such *ignoble* and *brutish causes* (AT I 403) ... The composition of those bodies out of parts of various shapes ... seems too *crass* and *mechanical* (AT I 406) ... He hopes to explain too much only by place, or local motion ... (Fromondus to Plempius, 13 September 1637, AT I 408, my emphasis)

This Scholastic attitude towards technology was not the only one available in the time when Bacon and Descartes wrote their works. Nonetheless it was the dominant one and various Renaissance attempts to create a scientific and philosophical approach toward

33 *rudem et pinguiusculam* (AT I 402), *ignobili et bruta* (AT I 403).

technology, although very important, were only marginal and, as shown, restricted to various technological domains.

In this chapter I presented the Renaissance developments that created a favourable environment for the philosophically positive approach toward technology. In this context, during the first half of the seventeenth century, between 1605, when Bacon publishes his *The Advancement of Learning*, the first work in which he gives a central place to mechanics and mechanical arts, and 1649, when Descartes publishes his *The Passions of the Soul*, the situation radically changes. Bacon and Descartes, in the works that I will analyse in the next two chapters, place a great emphasis on mechanics and the mechanical arts and set the human mastery of nature through technology as the aim of their philosophies. They create a new framework, in which technology occupies a major role, a framework that managed to replace the Aristotelian conception of technology as an ignoble art with its modern conception as a useful application of mathematical and experimental science.

Chapter II

Bacon's Philosophy of Technology

The first comprehensive philosophical approach to mechanical arts and the first works that promote the modern idea of technology as applied experimental science is the philosophy of Francis Bacon (1561-1626).[34] Francis Bacon, the Lord Chancellor of England during the reign of James I, wished to reform philosophy so that it would bring about material change of the world through technological invention. Bacon is generally considered and analysed as a reformer of science and the creator of experimental science, but his ideas about technology and progress in mechanical arts and medicine are the principal aims of his system and in need of a more attentive analysis. The overemphasised Baconian science is only instrumental for his goal of creating a scientific technology. In this chapter I shall provide a survey of Bacon's conception of technology, which I shall later use to document the Baconian and Cartesian paradigm shift and to emphasize the characteristics of modern technology.

The chapter is divided into three parts. The first part presents Bacon's considerations on his contemporary technology, which were intended both to show its promises and to criticise its state. The second part begins by exploring Bacon's ideas on the contingency of nature and the continuity between nature and technology. This metaphysical basis is used to clarify the status and the methods of technological development in Bacon's system. Finally,

34 The most important works of Bacon concerning technology are: *The Advancement and Proficience of Learning Divine and Human* (1605, hereafter Advancement), *Cogitata et Visa de Interpetatione Naturae ('Thoughts and Conclusions on the Interpretation of Nature'*, 1607), *Descriptio Globi Intellectualis ('A Description of the Intellectual Globe'*, 1612), *Instauratio Magna ('Great Instauration'*, 1620), Novum Organum Scientiarum (1620, hereafter NO), *Historia Naturalis ('Natural History'*, 1622), *Abcedarium Naturae* (1622), *De Augmentis Scientiarum* (1623), New Atlantis (1627) and *Sylva Sylvarum, or Natural History* (1627).

the third part discusses Bacon's three instances of technology, namely scientific instruments, enlightening technology and fruitful technology.

1. Examples and Metaphors

1.1. Printing Press, Gunpowder and Compass

Bacon classifies natural philosophy into theoretical philosophy, which comprises physics and metaphysics, and operative philosophy, which comprises mechanics and magic. I will use the term 'technology' to designate the operative part of natural philosophy, i.e. mechanics and magic. An inquiry into Bacon's conception of technology should start with his use of particular technological instances that were available in his lifetime. Bacon's approach to the available technology is twofold. On the one hand, Bacon is very optimistic regarding the possibilities of technological development and he presents a series of examples of actual technologies that clarifies his conception of technology, i.e. the relation between nature and technology, man's place in the technological endeavour, the main characteristics of technology and the directions that technological development should take. Moreover, he considers the practical approach that craftsmen took as the model for his reform of natural philosophy. On the other hand, he is deeply discontent with the status of mechanical arts and magic and he formulates an extensive criticism of it throughout his entire philosophical work.

Bacon's most celebrated instances of technological discoveries are the printing press, the gunpowder and the compass:

> It is well to observe the force and virtue and consequences of discoveries; and these are to be seen nowhere more conspicuously than in those three which were unknown

> to the ancients, and of which the origin, though recent, is obscure and inglorious; namely, printing, gunpowder, and the magnet. For these three have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes; insomuch that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries. (NO, Works IV 114)

These three instances of marvellous work show many of the characteristics that Bacon considers essential for technology. The most curious but also the most enlightening example is the compass because, properly speaking, it is not an artificial object. It expresses in the highest form the basis and the necessary condition of every technology, the "commerce between the mind of man and the nature of things" (NO, Works IV 7). The compass is a piece of a natural substance that can be used only because the navigators have certain knowledge of its nature: they know that the magnetic needle points to a certain spatial direction through which they can establish their own position and reach the desired destination. Therefore, compass technology implies both the knowledge of the very nature of things and man's inventiveness.

In addition, technology is not always required to produce immediate results but represents particular steps in a greater technological endeavour. The mariner's needle is useful only if it is inserted in an entire technological configuration, which comprises ship building, navigation, food storage for travels, and so on. Only in this way can its use "*change the whole face and state of things throughout the world.*"

The printing press exhibits another important characteristic of technology, its autonomous character. The printing press neither imitates some natural process nor perfects such a process. The printing press is a piece of technology that depends less on material properties, being mostly an instantiation of a plan designed by man's wits.

> For however the discovery of gunpowder, of silk, of the magnet, of sugar, of paper, or the like, may seem to depend on certain properties of things themselves and nature,

> there is at any rate nothing in the art of printing which is not plain and obvious. (NO, Works IV 91)

The workings of a printing press being so clear and obvious it rests only on human intelligence to bring it about. Therefore, it is very curious, but also deplorable for mechanical arts, that the ancients did not invent the printing press.

Along with this independence from the 'nature of things', the autonomy of the printing press also comes from the fact that it serves specific human needs, i.e. cultural needs. The technology is not just a means for the elimination of the burdens of natural man but a way to enrich man's life in all its aspects. An important part of Bacon's instauration is precisely the research into the direction of developing technologies, the research into the actual needs that should be fulfilled, out of innumerable possibilities of technology.

> Mere Power and mere Knowledge exalt human nature, but do not bless it. We must therefore gather from the whole store of things such as make most for the uses of life. … Besides in the work itself of Interpretation in each particular subject, I always assign a place to the Human Chart, or Chart of things to be wished for. For to form judicious wishes is as much a part of knowledge as to ask judicious questions. (NO, Works IV 232-233)

The last example, the gunpowder, points to what Bacon calls natural magic, "wherein a small mass of matter overcomes and regulates a far larger mass; I mean the contriving that of two motions one shall by its superior velocity get the start and take effect before the other has time to act." (NO, Works IV 212) In this sort of instances, the natural properties are used in an intelligent way, through knowledge of different forms, axioms, motions, and forces involved, to bring about the most marvellous works. Besides the mere knowledge of the nature of different things, technology qua magic requires also the knowledge of the possibilities of combining different natures such that a minimal change can produce a complete transformation.[35]

35 For Bacon, magic is purely natural and represents only the application of a more insightful knowledge of the

These three examples along with their characteristics point to the fact that technology is not a monolithic thing, which can be described by a set of necessary and sufficient conditions, but a bundle of different arts, without a common nature. For this reason it is more appropriate to speak, in Bacon's case, of technologies in the plural,[36] of the operative parts of natural philosophy, these comprising both mechanical arts and magic.

1.2. Mechanical Arts as a Model for Philosophical Research

Another important point made by Bacon in using these examples is the poor state of his contemporary technology. All these three inventions are "obscure and inglorious" if one considers their initial discovery or invention, being obtained through chance and not through systematic inquiry. As simple as they are, especially the mariner's needle, they would have been created long before if men had used their wits in combination with experiments to discover the nature of things and to use this knowledge for practical results.

These examples represent models or standards against which we should measure future technological discoveries. Alongside examples, Bacon used metaphors taken from the natural realm and from mechanical arts to point to the proper method needed for the advancement of knowledge and technology. One of his powerful metaphors is that of the natural philosopher as a bee that gathers matter and transforms it through its capacities.

> Those who have handled sciences have been either men of experiment or men of dogmas. The men of experiment are like the ant; they only collect and use: the reasoners resemble spiders, who make cobwebs out of their own substance. But the bee takes a middle course; it gathers its material from the flowers of the garden and of the field, but transforms and digests it by a power of its own. Not unlike this is the true

natural world.

36 This plurality of technology is rediscovered by philosophers of technology at the end of twentieth century. See Achterhuis (2001).

business of philosophy; for it neither relies solely or chiefly on the powers of the mind, nor does it take the matter which it gathers from natural history and mechanical experiments and lay it up in the memory whole, as it finds it; but lays it up in the understanding altered and digested. Therefore from a closer and purer league between these two faculties, the experimental and the rational, (such as has never yet been made) much may be hoped. (NO, Works IV 92-93)

Again, Bacon uses this metaphor in two directions: as a criticism against philosophers and as a proposal of a new method. This metaphor deals more with the production of knowledge than with technology proper, but it highlights the necessity of a link between experiments and human reason for the production of knowledge. The gathering of empirical facts is not enough but it is the essential first step for knowledge. Similarly, human reason cannot create knowledge, and certainly not technology, on its own. It has to apply its natural capacities to the empirical facts discovered. Only thus can one obtain new insights into the nature of things, which are essential for technological applications.

In addition, Bacon argues for mechanical arts as the model for advancement into natural philosophy. He rejects the ancient methods of doing natural philosophy, where each great master creates his own system of thought and each one starts anew without continuity and without using systematic experiments. He contrasts natural philosophy with mechanical arts in their respective methodologies and shows how it is possible to progress. For Bacon, an advance in science and philosophy is possible only if two conditions are met: first, any idea must meet the tribunal of experience, and second, different ideas of different authors have to corroborate each other.

In the mechanical arts, which are founded on nature and the light of experience, we see the contrary happen, for these (as long as they are popular) are continually thriving and growing, as having in them a breath of life; at first rude, then convenient, afterwards adorned, and at all times advancing. (NO, Works IV 74-75)

In the mechanical arts "many wits and industries have contributed in one", in the liberal arts and natural philosophy "many wits and industries have been spent about the wit of some one." (Advancement, Works VI 128) The difference between mechanical arts and natural philosophy in Bacon's time is that while in the latter the object of study is the work of some particular author, in the former the object of study is the empirical domain. Bacon's criticism is not directed at the work of the initiator of a school. These initial works are usually considered important for the advancement of knowledge, but the subsequent schools and commentators do not improve these works but remain trapped in the "cobweb" of the school's founder. In contrast, the craftsmen are focused on their specific technology, developing it in a collective endeavour.

This model for natural philosophy requires the creation of a scientific community, of dialogue and cooperation, as opposed to the schools of thought that only develop and polish the same ideas, being reluctant to alternative possibilities.

> Several typical categories of technical knowledge – collaboration, progressiveness, perfectibility, and invention – became categories to which Bacon attributed a universal value. Taking the mechanical arts as a model for culture, it is then possible to bring to birth a type of learning which, unlike the ancient kind, is capable of progress. (Rossi, 2006, 37)

The Aristotelian type of the investigation of nature lies in contemplation and in the search for instances that confirm one theory and refute others. By contrast, Bacon proposes to extract knowledge from experiments and artefacts and to use that knowledge in perfecting those artefacts or creating some new ones. In this manner, the value of knowledge lies in its outputs, in the works that instantiate the knowledge.

1.3. Bacon's Criticism of Mechanics and Magic

Although a model for his philosophy, Bacon heavily criticizes the technology of his time for being a blind endeavour that does not use knowledge, being driven only by chance: "the works already known are due to chance and experiment rather than to sciences." (Bacon IV, NO, 48) This criticism is similar to the Aristotelian view that the arts should proceed methodically and not by chance: "Those occupations are most truly arts in which there is the least element of chance." (*Politics*, 1258b)

Bacon does not reject entirely past theoretical works on mechanics. He admires some of the past thinkers that dealt with technology but considers their work as insufficient. The reason for his admiration is the fact that they analysed technology theoretically, systematizing it.

> The mechanic of which I now treat is that which has been handled by Aristotle promiscuously, by Hero in spirituals, by Georgius Agricola, a modern writer, very diligently in minerals, and by many other writers in particular subjects (Advancement, Works IV 366)

The most admired work is *De re metallica* by Georgius Agricola who systemized the arts concerning minerals exhaustively, taking into account not only mining and metallurgy but also the associated arts: philosophy, medicine, astronomy, surveying, arithmetic, architecture, drawing, law and practical alchemy. Another often-cited work is *De Magnete* by William Gilbert, because it is based on meticulous experiments on magnets. These works are important for the advancement of learning and technology but they did not inquire into the most important ingredient for the development of technology, the art of invention: "the sciences we now possess are merely systems for the nice ordering and setting forth of things already invented; not *methods of invention* or directions for new works." (NO, Works IV 48, my emphasis)

The method of invention requires as a first step a well-founded science that is still missing. The sciences possessed by men are either logical construction without empirical data or collections of empirical data without method and rational insight. Consequently, technologies are even in a state that is more deplorable because none of them uses science and systematic experiment but advances only by chance, sagacity and ingenuity.

> All inventions of works which are known to men have either come by chance and so been handed down from one to another, or they have been purposely sought for. But those which have been found by intentional experiment have been either worked out by the light of causes and axioms, or detected by extending or transferring or putting together former inventions; which is a matter of ingenuity and sagacity rather than philosophy. (Advancement, Works IV 366)

Bacon is reluctant in accepting chance, sagacity and ingenuity as the way of technological development. His aims are systematic and methodological inventions and not just fortuitous ones, which are rare and isolated. He examines most of the technologies and finds that all are in need of reform because none is able to invent. He lists the main domains that study nature and should be responsible for technological advancement, i.e. inventions, and he is highly disappointed because none of them is a respectable, mature science:

> The study of nature with a view to works is engaged in by the mechanic, the mathematician, the physician, the alchemist, and the magician; but by all (as things now are) with slight endeavour and scanty success. (NO, Works IV 47)

His main criticism to those who are closer to a scientific technology, i.e. those who use experiments in mechanical arts, is that their experiments are unsystematic and, in fact, they do not make enough experiments. Consequently, they did not find the real nature of things examined and cannot proceed to invention:

> There is none who has dwelt upon experience and the facts of nature as long as is

> necessary. Some there are indeed who have committed themselves to the waves of experience, and almost turned mechanics; yet these again have in their very experiments pursued a kind of wandering inquiry, without any regular system of operations. (NO, Works IV 17)

The experiments envisioned by Bacon should exhaust the entire domain under scrutiny and the adjacent instances. All facts of the matter should be laid down before beginning to construct a sound philosophy. In this respect, the work of Agricola is closest to Bacon's understanding of the way to proceed in philosophy: by writing the entire natural and experimental history of a specific domain, taking account of all associated phenomena.

Bacon praises those that combine experiment with rational insights, but he argues that all those experimentalists jump too quickly to unfounded conclusions. The research done until Bacon, whether it starts with good method and experiment, as in chemistry or in magnetism, draws too far-reaching and unreliable conclusions. Chemists[37] and William Gilbert are the preferred examples when it comes to the advancements in mechanical arts of his contemporaries. Nevertheless, regarding their respective contributions to science and technology, there is more to be blamed than to be praised.

> The race of chemists again out of a few experiments of the furnace have built up a fantastic philosophy ... and Gilbert also, after he had employed himself most laboriously in the study and observation of the loadstone, proceeded at once to construct an entire system in accordance with his favourite subject. (NO, Works IV 59)

Alongside with this intemperance and hastiness to reach philosophical conclusions, another reason for their failure to produce sound science and fruitful technology is their desire for immediate practical results. In fact, their endeavour aims entirely at the production of a single result. Consequently, they eliminate from their research most of the necessary experiments.

37 Or alchemists, as the difference was not fully established until the end of seventeenth century.

> And even if they apply themselves to experiments more seriously and earnestly and laboriously, still they spend their labour in working out some one experiment, as Gilbert with the magnet, and the chemists with gold; ... the inquiry must be enlarged, so as to become more general. ... They nevertheless almost always turn aside with overhasty and unseasonable eagerness to practice. (NO, Works IV 71)

The results of their approach are partial experimental data from which they can obtain neither sound philosophical conclusions nor the expected practical result. From this analysis of the most important works in experimental philosophy Bacon draws the conclusion that what is needed in the reform of natural philosophy is a more attentive and extensive use of experiments together with a sound method. The other necessary ingredient for the production of knowledge is the refraining from any theoretical generalisation in the first experimental stage because theory will disturb the record of facts as they are, "for the theory which they have devised rather confuses the experiments than aids them." (NO, Works IV 74) In exposing his method of inquiry Bacon will present further suggestions regarding experimental work, such as the use of instruments to constraint nature and to surpass the weakness of the senses.

In summary, while Bacon is convinced that technology can become a very successful endeavour, he dismisses the actual practice because "astronomy, optics, music, a number of mechanical arts, medicine itself ... altogether lack profoundness, and merely glide along the surface and variety of things" (NO, Works IV 79), and "natural magic, as they call it, [has] but few discoveries to show, and those trilling and imposture-like." (NO, Works IV 74) Consequently, he proposes to reform the entire edifice of science and technology with solid bases, meticulous advancement and great hopes.

2. Nature's Contingency and Technological Possibilities

Bacon's conception of technology is deeply influenced by the ideas pertaining to the status of natural objects, although he promotes an unconditional refraining from the formulation of any theory before doing and systemizing experiments. The aim of technology according to Bacon is to conquer nature by following its rules, "to command nature in action." (Bacon IV, NO, 24) In doing so, one has first to discover what these rules are. Consequently, a first step in analysing Bacon's philosophy of technology is to explain his conception of nature.

2.1. The Synchronous Image of Nature's Contingency

The first Baconian descriptive image regarding nature is that nature is just one of possible configurations of matter. Bacon accepts the Aristotelian theory of four causes (material, efficient, final, and formal) with little modifications. Not all four causes now pertain to the domain of physics, but they are redistributed between physics and metaphysics so that the material and efficient causes belong to physics while the formal and final causes belong to metaphysics: "Whereof Physic inquires of the Efficient Cause and the Material; Metaphysic of the Final Cause and the Form." (Advancement, Works IV 344) Physics becomes a new science, what we understand by classical physics, because it does not have to enquire anymore into the formal and final causes. Physics becomes the science of matter and efficient causes. Besides matter and causes, physics has to enquire into the internal structure of things that is nothing else than the ordinary and manifest configurations of common things and the ordinary and manifest processes that take place in nature:

> Let the investigation of the Efficient Cause, and of Matter, and of the Latent Process, and the Latent Configuration (all of which have reference to the common and ordinary

course of nature, not to her eternal and fundamental laws) constitute Physics. (NO, Works IV 126)

Concrete bodies present four main characteristics that are to be studied by physics: matter, efficient cause, latent process and latent configuration. The last two characteristics of bodies point to the internal structure of bodies, these being not necessary and eternal structures but the contingent ones of ordinary nature. The latent process is a continuous and constant motion inside bodies that remains unobservable for the most part, while latent configuration comprises the static relations between a body's components. "Latent Process [is] a process perfectly continuous, which for the most part escapes the sense." (NO, Works IV 123-124) "*Latent configuration* [concerns] bodies at rest and not in motion." (NO, Works IV 119)

The study of nature in physics, the discovery of matter, efficient cause, latent process and latent configuration is the prerequisite for discovering the forms and axioms, i.e. eternal and immutable laws that constitute the domain of metaphysics.

> To discover the form, or true specific difference, or nature-engendering nature, or source of emanation ... is the work and aim of Human Knowledge. [That means] the discovery, in every case of generation and motion, of the *latent process* carried on from the manifest efficient and the manifest material to the form which is engendered. (NO, Works IV 119)

The difference between physics and metaphysics is that the former studies the bodies of nature in their "common and ordinary course", while the latter studies the "eternal and fundamental laws." Physics and metaphysics form a continuum and as such they are fully compatible although different: "both causes [physical and metaphysical] being perfectly compatible, except that one declares an intention, the other a consequence only." (Advancement, Works IV 364) Physical causes are material and efficient, inquiring into the causal chain only from the point of view of the initial conditions, the beginning of the process, without searching for the end of this causal chain. Metaphysical causes inquire into the final configuration and into the purpose of any process or object, although following the same processes with the same methods as physics. The forms pertain to metaphysics as they present the ultimate necessary structure of all that there is. The forms are not essences of particular bodies but the fundamental laws of nature. The essences of particular bodies consist in the latent processes and latent configurations of those bodies. The forms are simple and fundamental natures that build up particular essences, particular processes and configurations. The forms are the 'letters' out of which the particular 'words', i.e. particular natural bodies, are constituted.

> The Forms of Substances …. (as they are now by compounding and transplanting multiplied) are so perplexed, as they are not to be enquired; no more than it were either possible or to purpose to seek in gross the forms of those sounds which make words, which by composition and transposition of letters are infinite. But on the other hand, to enquire the form of those sounds or voices which make simple letters is easily comprehensible, and being known, induceth and manifesteth the forms of all words, which consist and are compounded of them. In the same manner to enquire the Form of a lion, of an oak, of gold, nay of water, of air, is a vain pursuit: but to enquire the Forms of sense, of voluntary motion, of vegetation, of colours, of gravity and levity, of density, of tenuity, of heat, of cold, and all other natures and qualities, which like an alphabet are not many, and of which the essences (upheld by matter) of all creatures do consist; to enquire . . . the true forms of these is that part of Metaphysic which we now define of. (Advancement, Works III 355)

Bacon in fact admits two types of forms: the properly called form, which is simple, eternal, and necessary, i.e. the metaphysical form; and the so-called forms of natural bodies, which are contingent combinations of fundamental forms. The 'forms' of natural bodies are those latent processes and configurations that, contrary to metaphysical forms, are not eternal and necessary. A recurrent example of this way of conceiving nature is gold. Gold is a particular substance that has internal latent configurations and undergoes latent processes. Theses configuration and processes are built up from simple natures, fundamental qualities. Physics can study the particular processes and configurations that constitute gold but the knowledge of fundamental, simple and eternal laws that govern these processes and configurations are in the domain of metaphysics. Physics is the knowledge of particular configurations of metaphysical forms.

> In gold ... the following properties meet. It is yellow in colour; heavy up to a certain weight; malleable or ductile to a certain degree of extension; it is not volatile, and loses none of its substance by the action of fire; it turns into a liquid with a certain degree of fluidity; it is separated and dissolved by particular means; and so on for the other natures which meet in gold. (NO, Works IV 122)

All natural bodies, with their particular configurations and processes, are particular combinations of such forms. The forms are limited in number but their possible combinations are indefinite. This reinterpretation of the Aristotelian concept of form implies that particular natural bodies do not have eternal forms. These forms, being eternal laws, do not pertain to natural bodies, which are contingent bundles of essential qualities. Bacon proposes thus an *abecedarium Naturae* that links the fundamental laws of the universe to the manifest natural bodies:

> This metaphysical presupposition conveys the idea of, in Bacon's own phrase, an *abecedarium Naturae*, that is, a list or canon of fundamental physical properties which, by combining and recombining themselves in various modes, give rise to the manifold of sense experience. Such privileged set, however, does not depend on any empirical information, but appears to be posited a priori. Nature, as a collection of individuals conceptually ordered into classes, may be infinite; the number of its minimal components is not (Perez-Ramos, 2006, 103)

The main point I wish to stress and which is extremely important for the ontological foundation of technology is that the essences, latent processes and configurations of natural bodies are not eternal forms. They are, as Weeks puts it, only *habits* of nature. "Bacon maintains that nature limits its operations so that its manifestations arrange themselves in customary or habitual modes of action, leaving other pathways unused." (Weeks, 2007, 118)

Natural bodies are particular bundles of basic eternal forms. Bacon draws a strong division between "eternal and fundamental laws", forms, and the "common and ordinary course of nature", the actual natural bodies we encounter. The essences of natural bodies are just particular configurations and many other different configurations are possible. The fundamental forms could combine in different configurations than those presently existing in nature: "by the help and ministry of man a new face of bodies, another universe or theatre of things, comes into view." (Preparative, Works IV 253) Such different configurations of forms exist in praeter-nature and in technology. This conception has important consequences for the way of obtaining knowledge and for the powers of technology. Nature consists of certain combinations of matter and forms, but other combinations are possible. Nature is thus only one of the many technological possibilities.

Nevertheless, this is just one description of the contingency of nature, which I shall call the *synchronous* image. It establishes the contingency of nature as the consequence of the fact that possible configurations of forms exceed the actual types of natural bodies. It appears in theoretical works of Bacon, mainly in *Novum Organon* and in *De Augmentis Scientiarum*. However, there is yet another image, a *diachronic* one, which presents the evolution of nature as a particular unfolding of primordial matter.

2.2. The Diachronic Image of Nature's Contingency

This image appears in *De Sapientia Veterum* and *De principiis atque originibus*, where Bacon interprets the myth of Cupid, along with other ancient myths. Cupid is, for Bacon, the representation of the atom, of primordial matter. Sophie Weeks shows in "Francis Bacon and the Art-Nature Distinction" (Weeks, 2007) and in „The Role of Mechanics in Francis Bacon's Great Instauration" (Weeks, 2008) that Bacon's conception of the contingency of nature is a consequence of his account of primary matter (*materia prima*). While the synchronous image can be proved experimentally, according to Bacon, by showing that the same laws apply to nature, praeter-nature and technology, the diachronic argument, concerning the evolution of the universe, has no empirical confirmation. It is more a heuristic description that presents nature as a contingent unfolding of primary matter that could have developed otherwise. Actual natural evolution is just one of the possible paths that nature could have followed.

In the essay "Cupid; or the atom" from *De sapientia veterum*, Bacon affirms that this myth deals with "the cradle and infancy of nature." (De sapientia, Works VI 729) He then presents an atomic theory of nature and of natural evolution. Bacon's cosmology begins with chaotic matter, the primordial chaos, out of which Cupid "begot all things." Cupid, or Love, is "the appetite or instinct of primal matter; or to speak more plainly, the natural motion of the atom; which is indeed the original and unique force that constitutes and fashions all things out of matter." (De sapientia, Works VI 729) Cupid has four main characteristics which, in Bacon's interpretation, express the actual characteristics of atoms. "The attributes which are assigned to him are in number four: he is always an infant; he is blind; he is naked; he is an archer." (De sapientia, Works VI 729) As Bacon explains these metaphors, the atom never matures, it remains always a sum of potentialities; its movements have no pre-established directions, they are chaotic as the atom is blind; the nakedness suggests its simplicity and lack of characteristics; the atom is compared with an archer because it always heads to some direction. Also, the atom is eternal, coeval with chaos. Not being created, it cannot perish. The most important characteristic of the atom is its agency. The Baconian atom is not inert, it is active, and its main characteristic is motion. This motion is internal to the atom, not external, and it produces the entire complexity of the world. "For the summary law of nature, that impulse of desire impressed by God upon the primary particles of matter ... makes them come together, and ... by repetition and multiplication produces all the variety of nature." (De sapientia, Works VI 730) This motion is the origin of all things. The "natural", i.e. free and chaotic, unfolding of atoms creates the nature that we know.

Bacon's cosmogonical account moves from a state of unbridled chaos to the relatively stable system for which the term "nature" is normally used. The fundamental principle lying at the heart of Baconian cosmogony is an enriched and appetitive matter: eternal, unchanging, and the plenipotentiary source of all things. Successive limitations of matter's absolute power produced a lazy and habitual nature, which Bacon labelled "nature free." (Weeks, 2007, 101)

The main conclusion of Bacon's description of the evolution of this atomic nature is that nature is contingent. The essences of present natural bodies are produced by blind, "lazy and habitual", unfolding of atoms. Therefore, an alternative universe, namely a universe with alternative configurations, is possible. Such new and alternative configurations can be created by human technology.

> Nature exists in three states … Either she is free and develops herself in her own ordinary course; or she is forced out of her proper state by the perverseness and insubordination of matter and the violence of impediments; or she is constrained and moulded by art and human ministry. …For in things artificial nature takes orders from man and works under his authority: without man such things would never have been made. But by the help and ministry of man a new face of bodies, another universe or theatre of things, comes into view. (Preparative, Works VIII 357)

The next step in the analysis of Bacon's philosophy of technology is to clarify the relations between nature, praeter-nature and technology. Praeter-nature is the realm of monsters and all deviations from the common and ordinary course of nature. In the Aristotelian framework, where natural bodies have eternal forms and essences, praeter-nature is just an accident of nature that usually is overlooked in natural philosophy. By contrast, Bacon considers praeter-nature as an important field of research because it represents one stage of the continuum that comprises nature, praeter-nature and technology.

2.3. The Continuity between Nature and Technology

Nature is properly speaking "nature free", praeter-nature is nature bound by natural constraints, while technology is nature bound by human arts. Nevertheless, the difference between nature and praeter-nature is an artificial one, a difference created through contemplation of common nature and unfounded generalisations. If conditions would have been different, the praeter-natural bodies could have been the most common, i.e. natural, bodies because both nature and praeter-nature developed out of the same matter through natural constraints.

> When man contemplates nature working freely, he meets with different species of things, of animals, of plants, of minerals; whence he readily passes into the opinion that there are in nature certain primary forms which nature intends to educe, and that the remaining variety proceeds from hindrances and aberrations of nature in the fulfilment of her work, or from the collision of different species and the transplanting of one into another. ... they introduce with the greatest negligence a distinction between motion natural and violent, a distinction which is itself drawn entirely from a vulgar notion, since all violent motion is also in fact natural; the external efficient simply setting nature working otherwise than it was before. (NO, Works IV 66-68)

On the same grounds, Bacon strongly protests against a real division between natural and artificial. He rejects the traditional received conception that arts can only imitate and perfect nature and the corollary of that, that artificial objects miss some of the essential characteristics of natural objects. This is one of the greatest impediments to technology: to consider nature ontologically prior and technology only as an *ancilla naturae*. Technology and nature are, for Bacon, ontologically equal. They are so indistinct in their features, except for the fact that nature, in relation to man, is purposeless while technology is not. The natural unfolding can be thus seen, as Weeks argues, as a technological process in which forms configure matter while the technological process can be seen as evolutionary, a process in which forms are 'superinduced' over matter. "What is less well known is Bacon's appropriation of the term 'magic' to signify a recapitulation of the very processes that gave rise to our current nature." (Weeks, 2007, 105) Magic is the practical application of metaphysics through which the man 'superinduces' the desired forms in matter. Similarly, the process that led to the current state of the universe is also such a superindution, therefore a magical process that happened blindly. "One termination of the unfolding of matter manifests as the current world, haphazardly arrived at and sustained by habit." (Weeks, 2007, 114) The current world is just one of the possibilities at which nature can arrive. There are other possible stable worlds as shown by praeter-nature. From the human point of view the best possible stable world will be that 'superinduced' by purposeful technology because it takes human needs as its aims.

The fact that these three domains constitute a continuum and that the differences between them are quite unimportant is proved by their joint consideration in the "Natural History." While of different origin and brought about by different chains of efficient causes, the laws that apply to nature, praeter-nature and technology, as well as their way of functioning are identical, and their latent processes and latent configurations are similar.

> I do not make it a rule that these three should be kept apart and separately treated. For why should not the history of the monsters in the several species be joined with the history of the species themselves? And things artificial again may sometimes be rightly joined with the species, though sometimes they will be better kept separate. It will be best therefore to consider these things as the case arises. (Preparative, Works IV 253)

The specific difference that separates the three domains is the efficient cause. While nature proceeds by its own potentialities, i.e. internal motions of the atoms and latent processes, praeter-nature and technology are constrained to move in unusual ways: praeter-nature by excessive internal force ("perverseness and insubordination of matter") and external natural constraints ("the collision of different species" and "the violence of impediments"); technology by "art and human ministry." The efficient cause that creates praeter-natural bodies and technological objects only changes the old habits of nature without performing an ontological change. Ontologically, nature, praeter-nature and technology are similar, nature in technology "working otherwise than it was before." (NO, Works IV 68) That means that technology is nature "working otherwise" and all characteristics of natural objects can be maintained into technological objects with the condition of the proper knowledge and manipulation of forms. This conception undermines the ancient strict separation between nature and technology where "the arrangement in accordance with the rules of the art is merely an accidental attribute." (Aristotle, *Physics*, 193a)

The efficient cause consists only in simple procedures of uniting and separating matter, and technology is nothing more than a different configuration by which the natural motion is constrained in order to obtain the desired effects:

> The artificial does not differ from the natural in form or essence, but only in the efficient; in that man has no power over nature except that of motion; he can put natural bodies together, and he can separate them; and therefore that wherever the case admits of the uniting or disuniting of natural bodies, by joining (as they say) actives with passives, man can do everything; where the case does not admit this, he can do nothing. Nor matters it, provided things are put in the way to produce an effect, whether it be done by human means or otherwise. (Advancement, Works IV 294)

These extremely simple procedures, if properly known and applied, give man the power to radically change nature, to create a new nature according to his needs. Even Magic consists in nothing more than combining and separating natural bodies that by their natural interactions will produce marvellous effects. Nature and matter being active, technology will have only to create the favourable conditions for nature to evolve into desired outcomes: "Towards the effecting of works, all that man can do is to put together or put asunder natural bodies. The rest is done by nature working within." (NO, Works IV 47) Unlike Aristotle, for Bacon the technological products do not lose their internal qualities, the internal movement, because atoms remain active and, through real knowledge, this activity could be preserved and enhanced.

Bacon further argues not only that technology is nature too, but also that some technologies are already present in the natural realm. The most obvious example for Bacon is the production of honey by bees: "Sometimes again the ministering office is by the law of the universe deputed to other animals; for honey, which is made by the industry of the bee, is no less artificial than sugar, which is made by man" (Descriptio, Works V 507) It is true that even Aristotle recognized that there are products of animals that resemble technology, like nests, but for him those are perfectly natural, while Bacon considers honey as an artificial product. Like Cusanus before him, Bacon, by using examples similar to Aristotle's, draws different conclusions than the latter's.

Not only do the objects produced by animals exemplify technological processes and products, but nature itself is similar to a technological process:

> Gold is sometimes refined in the fire and sometimes found pure in the sands, nature having done the work for herself. So also the rainbow is made in the sky out of a dripping cloud; it is also made here below with a jet of water. Still therefore it is nature which governs everything; but under nature are included these three; the course of nature, the wanderings of nature, and art, or nature with man to help; which three must therefore all be included in Natural History. (Advancement, Works IV 295)

For this reason, the study of nature and of the artificial should be a single domain. For Bacon the artificial is a particular configuration of the universe, of nature broadly understood: "I am the more induced to set down the History of the Arts as a species of Natural History" (Advancement, Works IV 294) The knowledge obtained from the study of technology helps us to better understand nature and to find the fundamental laws, i.e. the forms, because technology offers different configurations of the same substances that obey the same laws. Nature and technology are different actualisations of the same domain of natural possibilities.

2.4. The Place of Technology in Bacon's System

Having described the way nature developed, according to Bacon, from an initial chaos of active atoms, as well as the possibility of developing technology in a similar fashion, we shall next inquire into the place that Bacon assigns to technology in his system and into the method of pursuing it. The operative philosophy constitutes for Bacon the most important aim of human endeavour. His philosophy is directed towards the creation of works by establishing a proper domain of technology with rules for invention, discovery and production of new things. The finality of Bacon's project is "The New Philosophy; or Active Science" (NO, Works IV 22) that would create "a new face of bodies, another universe or theatre of things" (Preparative, Works IV 253) by combining human knowledge with human power: "And so those twin objects, human Knowledge and human Power, do really meet in one; and it is from ignorance of causes that operation fails." (NO, Works IV 32)

Technology is the aim of Bacon's reform of knowledge. This purpose is stated in the designed plan of his work, a plan that presents the way natural philosophy should develop.

> The work is in six Parts:
> 1. The Divisions of the Sciences.
> 2. The New Organon; or Directions concerning the Interpretation of Nature.
> 3. The Phenomena of the Universe; or a Natural and Experimental History for the foundation of Philosophy.
> 4. The Ladder of the Intellect.
> 5. The Forerunners; or Anticipations of the New Philosophy.
> 6. The New Philosophy; or Active Science." (The Great Instauration, Works IV 22)

The first two parts discuss the method of the new philosophy, where a new scientific methodology is introduced. The third part consists in a comprehensive record of all empirical data concerning both nature and artificial things, data obtained by meticulous experiments.

These "histories" together with the methods of invention and discovery discussed in the fourth part will be the foundation of the "New Philosophy." The fifth part, as Bacon affirms, is "for temporary use only, pending the completion of the rest; like interest payable from time to time until the principal be forthcoming." (NO, Works IV 31) Only the sixth part will complete the active science or the operative philosophy, i.e. a scientific technology. Bacon mentions repeatedly that his aim is to institute a new philosophy, a new science that would produce new things and marvellous works: "I am principally in pursuit of works and the active department of the sciences." (NO, Works IV 29)

Bacon combines in his "New Philosophy" what Aristotle struggled to keep completely separate, that is "the categories of *techne* (material production and reasoning about that production) and *episteme* (certain knowledge of unchanging truths)." (Long, 2004, 341) This combination offers also a new definition of technology that displace it from the domain of art to that of applied science. Technology is first and foremost a science. However, it is not mere science but applied science, an active and operative science, a material production. In addition, it is a philosophy, a kind of reasoning on science and material production that sets goals for technology and organizes and manages the production of knowledge and artefacts.

Nevertheless, Bacon considers this endeavour too great to be completed in a single generation and he leaves the sixth part to be completed by his followers.

> The sixth part of my work (to which the rest is subservient and ministrant) discloses and sets forth that philosophy which by the legitimate, chaste, and severe course of inquiry which I have explained and provided is at length developed and established. The completion however of this last part is a thing both above my strength and beyond my hopes. (The Great Instauration, Works IV 32)

This may be the reason why his philosophy was mainly considered a philosophy of knowledge, despite the fact that his main interest lies in the development of technology and the establishment of an active and operative philosophy. However, the substantial part of his philosophy of technology is not explicitly stated because it is a consequence of his reform of knowledge. The proper formulation of the new philosophy has to wait until the reform of knowledge is completed. Only after the fundamentals of knowledge are laid down a new "entire or universal theory" can be proposed.

> I have no entire or universal theory to propound. For it does not seem that the time is come for such an attempt. Neither can I hope to live to complete the sixth part of the Instauration (which is destined for the philosophy discovered by the legitimate interpretation of nature), but hold it enough if in the intermediate business I bear myself soberly and profitably, sowing in the meantime for future ages the seeds of a purer truth, and performing my part towards the commencement of the great undertaking. (NO, Works IV 104)

Bacon sets as the goal of philosophy the realisation of "new works." Consequently, against the entire philosophical tradition, he considers knowledge only in its role of helping technology: "For it is works we are in pursuit of, not speculations." (Preparative, Works IV 259) Therefore, science, the advancement of learning, is a necessary but only an intermediate step towards technology. For Bacon, science is only an instrument in attaining his ultimate goal. "For information commences with the senses. But the whole business terminates in Works." (NO, Works IV 205) Natural philosophy should be an applicable and applied knowledge that consists in "methods of invention or directions for new works." (NO, Works IV 48) Bacon's system of natural philosophy is totally immersed into technology, into the operative realm, because knowledge is to be extracted from works and experiments and the knowledge thus obtained should serve to design new works and experiments:

> Not to extract works from works or experiments from experiments (as an empiric), but from works and experiments to extract causes and axioms, and again from those causes and axioms, new works and experiments, as a legitimate interpreter of nature. (NO, Works IV 104)

As Sawday puts it, the aim of philosophy is not merely the knowledge of the universe but the recreation of this universe according to human needs.

> The task of the natural philosophers was to create an alternative, mechanical, world of artefacts and systems conforming to human designs. In forging this world, a work which might be compared to that idea of the 'Second Creation' by which humankind partially recovers, by its own efforts, from the primal Edenic disaster, the philosophers first had to recreate the natural world around them according to mechanical principles. (Sawday, 2007, 216)

This shift from a contemplative philosophy, which aims at knowing the universe, to an active philosophy, which aims at recreating the universe, requires a very different methodology, a new kind of philosophy, a natural philosophy that finally becomes identical with technology.

In sustaining his technologically-oriented approach to philosophy, Bacon uses the theological argument of the Fall. The world in which we live and which is analysed by traditional philosophy is a world of vicissitudes for humankind. This universe is the consequence of the fall from Paradise. Nevertheless, with the help of technology the burdens of life can be eliminated or at least reduced.

> For Bacon these conceptions had a utopian touch as one can see in his *Nova Atlantis*. He aligned human thought towards the construction of machines as tools by the help of which man can compensate the negative consequences of the Fall: 'In the presence of thy sweat thou shalt eat your bread'. (Klein, 2008, 46)

Technology is one of the ways, the other being faith, by which humankind restores a paradisical life and counteracts the consequences of Adam's sin. Technology will restore, at least partly, man's "dominion over creation", the domination that existed in the Garden of Eden where Adam commanded over the entire nature.

Whence there cannot but follow an improvement in man's estate, and an enlargement

> of his power over nature. For man by the fall fell at the same time from his state of innocency and from his dominion over creation. Both of these losses however can even in this life be in some part repaired; the former by religion and faith the latter by arts and sciences. (NO, Works IV 247-248)

Moreover, the pursuit of technology is not only a possibility of redeem but a necessity, a divine commandment because technology is a divine gift. The theme of technology as a way of redemption is a recurrent one in the *Theatres of Machines*[38] that were common in Bacon's time.

> The majority of the authors of theatres of machines harbored strong religious beliefs that deeply shaped their lives and works. One of the most interesting aspects of the prefaces to the Theatres is the stress they almost always lay on theological justifications for technology. The mechanical arts are God's gift to mankind and offer some compensation for the losses suffered at the time of the Fall. (Dolza, 2008, 18)

The most important feature of Bacon's analysis of technology is the relation that he established between science and technology. It is true that prior to Bacon's reform mechanical arts were not entirely disjointed from knowledge. In order to be able to make artificial objects, the artisan had to possess some theoretical knowledge, but technology did not depended on theory. In this sense, technology was properly speaking an art, a set of rules to be applied in order to reach the desired outcomes. The scientific approach was not a main feature of technology. Moreover, if technology makes use of some theoretical results, theoretical knowledge was meant to be totally indifferent to its practical applications. The aim of knowing was knowledge itself, while the application of some theoretical results in mechanical arts was merely an accident, an inessential by-product of knowledge. By contrast, for Bacon, the essential feature of knowledge is its technological applications. Bacon asserts that the philosophy of knowledge developed in the first five parts of his work that it is just a helping ladder for technology: "the rest [the first five parts] is subservient and ministrant" (The Great

38 The "theatres of machines" were a new type of very popular books that began to appear in the second half of the sixteenth century. They consisted in descriptions and drawings of various machines and mechanisms.

Instauration, Works IV 32) That is the reason for Bacon's knowledge reform: science should be pursued in such a manner that it can be used to create artificial things. In addition, artificial things themselves become a proper object of knowledge, as mere knowledge of nature is not able to show how technology can affect natural processes and create new things: "Therefore I set down at length all experiments of the mechanical arts, of the operative part of the liberal arts, of the many crafts which have not yet grown into arts properly so called." (NO, Works IV 29)

The paradigm shift by which science and technology became interrelated, technology being the reservoir of new empirical facts to be generalized into physics and metaphysics and science being the knowledge that has as its only purpose to be technologically applied, is based on the Renaissance pursuit of practical knowledge visible in mechanics, alchemy, natural magic, mining and metallurgy. Nevertheless, as James E. McClellan III and Harold Dorn show, the instantiation of this relationship in the real practice of science and technology had to wait for the nineteenth century, although there were isolated instances in which scientific discoveries contributed even earlier to improvements of mass-produced artefacts (like lenses and clocks):

> Despite the ideology of the useful application of knowledge espoused by Francis Bacon and Rene Descartes in the seventeenth century, theoretical science did not immediately find applications in industry. ... In fact, in the eighteenth century and most of the nineteenth century theoretical science and technology (the crafts) continued to go their traditional, separate ways. And when they began to merge in the nineteenth century it was as much institutional factors, along with intellectual and technical developments, that shaped the partnership. (McClellan & Dorn, 2006, 295)

2.5. Technological Method

Bacon is most famous for establishing the scientific method. He sets the basis of the experimental method which had the aim of producing knowledge of nature. Nevertheless, Bacon's aim is the development of technology while the production of knowledge, science, is the required intermediate step. The development of technology requires a method of its own, different from the experimental method of science. This is what Bacon calls "methods of invention or directions for new works." (NO, Works IV 48) If the aim is to produce fruitful technologies then the way to proceed is the invention of technological devices, which is an autonomous endeavour with a proper place in Bacon's project. In Salomon's House there is a special division that deals with the invention of new works. Its purpose is different from the production of knowledge because the Benefactors, as Bacon calls them, have to find ways of applying the knowledge produced by the rest of Salomon's House.

> We have three that bend themselves, looking into the experiments of their fellows, and ask about *how to draw out of them things of use and practice* for man's life, and knowledge as well for works as for plain demonstration of causes, means of natural divinations, and the easy and clear discovery of the virtues and parts of bodies. These we call Dowry-men or Benefactors. (New Atlantis, Works III 165, my emphasis)

This very important part of philosophy, the invention of new works, is the part that, Bacon affirms, does not yet exist. His aim is to create the method of inventing and discovering technological applications of science.

> Division of the Art of Discovery into discovery of Arts and discovery of Arguments: and that the former of these (which is the most important) is wanting. Division of the Art of Discovery of Arts into Learned Experience and the New Organon. (Advancement, Works IV 407)

Bacon constantly affirms that there are always two directions that must be followed: a scientific direction that comprises the formulation of axioms, the complete knowledge of nature, and a technological direction that comprises the invention and production of new works and experiments, the latter being the true goal of philosophy while the former is instrumental. These two directions are to be considered separately because they deal with different domains, have different goals and different methods.

> All true and fruitful Natural Philosophy has a double scale or ladder, ascendent and descendent, ascending from experiments to axioms, and descending from axioms to the invention of new experiments; therefore I judge it most requisite that these two parts, the Speculative and the Operative, be considered separately. (Advancement, Works IV 343)

The main question for the Operative part of Philosophy is "how to draw out of [axioms] things of use and practice", i.e. the problem of designing new technological devices. This part of philosophy is intimately linked to the production of knowledge because only the knowledge of axioms, of forms, allows the consistent production of technological devices. The two parts of philosophy are complementary. Knowledge of axioms helps in creating new works and experiments, while works and experiments produce new knowledge.

> But from the new light of axioms, which having been educed from those particulars by a certain method and rule, shall in their turn point out the way again to new particulars, greater things may be looked for. For our road does not lie on a level, but ascends and descends; first ascending to axioms, then descending to works. (NO, Works IV 96)

For Bacon this constant movement between axioms and experiments does not seem to stop by reaching an ultimate level of knowledge and technology. The technological development is limitless because technology always creates a new nature that has to be studied. In turn, this will bring new knowledge which will direct to new works and experiments.

Technological method consists in creating new natures. It is a matter of combining simple essences into new and marvellous things. It is a matter of human creativity and not of blind application of knowledge. The application of knowledge is not a linear process by which one piece of knowledge is materialized in technological devices but a complex process of inventing and designing unusual combinations of simple natures into marvellous works. To bring about new works, the active philosopher should transfer, compare and apply knowledge from different domains.

> There is a great mass of inventions still remaining, which not only by means of operations that are yet to be discovered, but also through the transferring, comparing, and applying of those already known, by the help of that Learned Experience of which I spoke, may be deduced and brought to light. (NO, Works IV 92)

In order to create new works, the different sciences must be brought together and knowledge must be transferred from one domain to another. This recombination of knowledge from different particular sciences is to be made by the active natural philosophy.

> Meanwhile let no man look for much progress in the sciences, especially in the practical part of them, unless natural philosophy be carried on and applied to particular sciences, and particular sciences be carried back again to natural philosophy. For want of this, astronomy, optics, music, a number of mechanical arts, medicine itself ... altogether lack profoundness, and merely glide along the surface and variety of things; because after these particular sciences have been once distributed and established, they are no more nourished by natural philosophy (NO, Works IV 79)

The function of active philosophy is to bring together the knowledge obtained by different sciences and through inventions and combinations of simple natures to bring about new works. Bacon calls this part of philosophy "Applications to Practice." It inquires into what is useful to man and how this usefulness can be acquired. The application of science is a purposeful endeavour and this characteristic distinguishes technology from nature, which is a blind unfolding of the same potentialities. Active philosophy brings inventiveness and purpose into the realm of knowledge.

> Among Prerogative Instances I will put in the twenty-fifth place Intimating Instances; those I mean, which intimate or *point out what is useful to man*. For mere Power and mere Knowledge exalt human nature, but do not bless it. We must therefore gather from the whole store of things such as make most for the uses of life. But a more proper place for speaking of these will be when I come to treat of Applications to Practice. Besides in the work itself of Interpretation in each particular subject, I always assign a place to the Human Chart, or Chart of things to be wished for. For to form judicious wishes is as much a part of knowledge as to ask judicious questions. (NO, Works IV 232-233)

This application to practice, while most important, must be delayed as much as possible because it rests upon a comprehensive knowledge of axioms and upon a collective endeavour of scientists that takes time to complete. The invention of new experiments, as well as the formulation of axioms, is the last step in Bacon's project, the one to be completed by the real interpreters of nature.

> For the light itself, which was the third way, is to be sought from the Interpretation of Nature, or the New Organon ... For all transition from experiments to axioms, or from axioms to experiments, belongs to that other part, relating to the New Organon. (Advancement, Works IV 413)

Before beginning to design new technologies, Bacon proposes the accomplishment of experimental science, of Learned Experience, i.e. the gathering of all possible information from natural and mechanical experiments. In *New Atlantis*, Bacon presents the prerequisite steps before passing to the legitimate interpretation of nature.

> We have three that collect the experiments which are in all books. These we call Depredators.
> We have three that collect the experiments of all mechanical arts; and also of liberal sciences; and also of practices which are not brought into arts. These we call Mystery-men.

> We have three that try new experiments, such as themselves think good. These we call Pioners or Miners.
> We have three that draw the experiments of the former four into titles and tables, to give the better light for the drawing of observations and axioms out of them. These we call Compilers. (New Atlantis, Works III 164)

By recording and listing all knowledge gathered through experiments men will come to understand the hidden forces of nature that can be put to work. One of the reasons technology is in such a deplorable state is the fact that the production of works is limited by the ignorance regarding the possibilities extant in nature. Men think that "free nature" cannot be surpassed and as such they do not aim to transform nature. However, for Bacon the transformation of nature is the legitimate and necessary purpose of humankind.

> But there is likewise another and more subtle error which has crept into the human mind; namely, that of considering art as merely an assistant to nature, having the power indeed to finish what nature has begun, to correct her when lapsing into error, or to set her free when in bondage, but by no means to change, transmute, or fundamentally alter nature. And this has bred a premature despair in human enterprises. (Advancement, Works IV 294)

Although Bacon is convinced of the rightfulness of his approach, he affirms the he cannot provide logical arguments for his reform of knowledge. His pedagogical theory is one of persuasion. Bacon is aware that what he proposes is, in Kuhn's terms, a paradigm shift. The paradigm cannot be demonstrated because it concerns the first principles, the first notions and the forms of demonstration; the new paradigm will "enter quietly" in the prepared minds.

> I ... would have my doctrine enter quietly into the minds that are fit and capable of receiving it; for confutations cannot be employed, when the difference is upon first principles and very notions and even upon forms of demonstration. (NO, Works IV 53)

As for his technological method, Bacon, unlike Descartes, sets only a marginal role for mechanics and mathematics. Mathematics, although important for measuring and weighting natural phenomena, is just an appendix to science. Mathematics has the same place as logic for Bacon, and he rejects the centrality of mathematics for technological endeavour.

> I have thought it better to designate Mathematics, seeing that they are of so much importance both in Physics and Metaphysics and Mechanics and Magic, as appendices and auxiliaries to them all. Which indeed I am in a manner compelled to do, by reason of the daintiness and pride of mathematicians, who will needs have this science almost domineer over Physic. For it has come to pass, I know not how, that Mathematic and Logic, which ought to be but the handmaids of Physic, nevertheless presume on the strength of the certainty which they possess to exercise dominion over it. But the place and dignity of this science is of less importance. (Advancement, Works IV 370)

The same treatment is applied to mechanics, seeing it as a low form of technology that only combine extant matter without transformations and alterations, without inquiring into the true nature of things. As shown in the list of marvellous technologies of Salomon's House, the most cherished inventions are those of chemistry, biology, medicine, metallurgy, meteorology and so on, with little mention of mechanical and hydraulic engines. Those, by contrast, occupy the central place in Descartes' approach to technology.

3. Types of Technology

In Bacon's works, one can distinguish three main kinds of technology: scientific instruments, enlightening technology and fruitful technology. Scientific instruments are technologically designed devices that help the investigator of nature to surpass the fallibility of the senses and force nature to reveal its hidden features. Enlightening technology consists in technological devices designed not for their practical results but for being studied. Enlightening technology is meant to show how technology works and to find out the fundamental laws of various configurations and processes of the universe. Finally, there is fruitful technology which consists of useful devices, the “marvellous works” that bring about “a new face of bodies, another universe or theatre of things” (Parasceve, Works IV 253). This fruitful technology is the real goal of Bacon’s philosophy.

3.1. Scientific Instruments

Bacon states that knowledge was obtained traditionally by contemplating “nature free” with unaided senses. Certainly, there is a certain amount of knowledge that can be obtained through this method, but the senses can deceive us and “nature free” gives us information only about some common habits of nature that hide the true universal laws.

Both these inconveniences, the errors of the senses and the opacity of nature, can be surpassed by the use of assistant technologies, of scientific instruments. The immediate experience of nature by the senses can result either in error or in overlooking important features of nature. For this reason, Bacon proposes an instrumental mediation. The pursuit of knowledge should be technologically mediated from the beginning. This mediation by technology, the use of instruments in discovering natural laws, is one specific difference that distinguishes Bacon’s philosophy from that of the ancients. The ancients lacked experiments and instrumentation in their scientific endeavour, and it is for this reason that they have not done more than they did. If ancient authors were to use modern instruments and experiments, it is certain for Bacon that they would have arrived at marvellous results:

> The honour of the ancient authors, and indeed of all, remains untouched; since the comparison I challenge is not of wits or faculties, but of ways and methods. (74) ... For the microscope, the instrument I am speaking of, is only available for minute objects; so that if Democritus had seen one, he would perhaps have leaped for joy, thinking a way was now discovered of discerning the atom, which he had declared to be altogether invisible. ... Great advantages might doubtless be derived from the discovery. (NO, Works IV 193)

Similarly, Galileo in his *Two New Sciences* remarked that Aristotle was not doing the experiments that would sustain his affirmations.

> I greatly doubt that Aristotle ever tested by experiment whether it be true that two stones, one weighing ten times as much as the other, if allowed to fall [...] would so differ in speed. (62) ... it is clear that Aristotle could not have made the experiment; yet he wishes to give us the impression of his having performed it when he speaks of such an effect as one which we see. (Galileo, 1914 [1638], 66)

Contrary to Galileo, Bacon is aware that Aristotle was never trying to demonstrate his theories by experiments. It is precisely the importance of experiments, emphasized equally by Galileo and Bacon that distinguishes between ancient and modern approaches to science.[39] While Aristotle saw knowledge as emerging from immediate experience of free nature, Bacon requires both the enhancement of sensory experience and the use of constraints for nature in order to obtain knowledge.

> I have sought on all sides diligently and faithfully to provide helps for the senses; substitutes to supply its failures, rectifications to correct its errors; and this I endeavour to accomplish not so much by instruments as by experiments. For the subtlety of experiments is far greater than that of the sense itself, even when assisted by exquisite instruments; such experiments, I mean, as are skilfully and artificially devised for the express purpose of determining the point in question. (NO, Works IV 26)

For Bacon, all knowledge comes from experience, i.e. from the sensory contact with reality,[40] but the sensory experience can be erroneous. Therefore, the entire edifice of knowledge will be in error if the senses are not properly prepared and aided by instruments to apprehend the essential features of reality.

39 "The use of instruments to investigate nature had important methodological implications because it challenged the notion of Aristotelian common experience. For Aristotelians common experience was valid because all reasonable people without question agreed that a particular claim was true. In contrast, truth derived from experimentation, and instrumentation depended on the manipulation of a device that was only available to particular individuals. Such individuals had to have access to the device itself and had to possess particular skills to use it." (Long, 2004, 341)
40 "For information commences with the senses." (NO, Works VIII 205)

> In the first place, the impressions of the sense itself are faulty; for the sense both fails us and deceives us. But its shortcomings are to be supplied, and its deceptions to be corrected. (NO, Works IV 58)

Bacon, like Descartes, is sceptical about the information we obtain through the senses. However, unlike Descartes, he does not reject sensible qualities as mere by-products of the real nature. On the contrary, the sensible qualities obtained through the senses represent the basis of all knowledge so much so that a proper scientific endeavour, as pursued by those in Solomon's House, is to be organised around the domains of sensory experience.

> Sensory experience, indeed, appears to be, at first, the organizing principle of Salomon's House, with each portion of the study of nature particularized into various 'houses', based upon the human senses: 'Perspective-Houses' (for the investigation of light); 'Sound-Houses' (for the exploration of sound and harmony); 'Perfume-Houses' (where Bacon conjoined smell and taste). (Sawday, 2007, 214)

His solution is to technologically supplement the senses so that to obtain a sharper, clearer, picture of nature. The senses are fallible but they represent the only source of human knowledge. Therefore, Bacon rejects immediate human sensory experience and replaces it with technologically enhanced sensory experience.

Bacon mentions optical instruments—microscopes, telescopes and astrolabes—for he considers sight as the most important sense for the acquisition of information and thus the one most in need of help.

> Now of all the senses it is manifest that sight has the chief office in giving information. This is the sense therefore for which we must chiefly endeavour to procure aid. Now the aids to sight are of three kinds; it may be enabled to perceive objects that are not visible; to perceive them further off; and to perceive them more exactly and distinctly. (NO, Works IV 58)

The instruments should magnify or bring closer the objects of perception or make the perception as accurate as possible. These instruments should make the visible more visible than it naturally is. In that sense, scientific instruments recreate or redesign human sensory apparatus, enhancing human natural capabilities.

However, Bacon takes a step further than the mere enhancement of the senses. He proposes instruments and experiments that would render the invisible visible, which would translate the hidden properties and processes of nature into sensory data.

There are many ways in which natural objects and processes can be overlooked by the experimenter, while technologically enhanced perception, through instruments and experiments, should make manifest these hidden objects and processes.

> An object escapes the senses, either on account of its distance; or on account of the interposition of intermediate bodies; or because it is not fitted for making an impression on the sense; or because it is not sufficient in quantity to strike the sense; or because there is not time enough for it to act on the sense; or because the impression of the object is such as the sense cannot bear; or because the sense has been previously filled and occupied by another object, so that there is not room for a new motion. (NO, Works IV 194)

To surpass the fallibility of human sensory apparatus, Bacon envisions new domains of sensory experiences that are available only by the use of technologies. These instruments and experiments "summon objects to appear which have not appeared ... They are those which *reduce the non-sensible to the sensible*; that is, make manifest things not directly perceptible by means of others which are." (NO, Works IV 194, my emphasis) Bacon offers the example of temperature which is usually felt but which becomes visible with the use of a thermometer.

> Again, let the nature in question be heat or cold, in a degree too weak to be preceptible to the sense. These are made manifest to the sense be a calendar glass such as I have described above. For the heat and cold are not themselves perceptible to the touch, but the heat expands the air, and the cold contracts it. Nor again is this expansion and contraction of the air perceptible to the sight; but the expansion of the air depresses the water, the contraction raises it; and so at last is made manifest to the sight; not before, nor otherwise. (NO, Works IV 199)

Bacon also thinks of instruments and experiments that would translate for the senses things that are altogether outside the spectrum of human sensibility as the internal movements inside a body.

Another important domain of scientific instruments is represented by devices that will force nature to reveal its hidden laws. These instruments do not modify human senses or natural objects but only limit the free movement of natural objects so that some latent processes become apparent. Bacon stresses in many places the importance of constraining nature because nature manifests itself better when vexed by art.

> The nature of things betrays itself more readily under the vexations of art than in its natural freedom. (29) … a man's disposition and the secret workings of his mind and affections are better discovered when he is in trouble than at other times; so likewise the secrets of nature reveal themselves more readily under the vexations of art than when they go their own way. (NO, Works IV 95)

The experiments that constrain nature eliminate the manifest habits of nature that are not the real essences of natural objects but only emergent phenomena. The habitual manifestations of nature are like a veil or vestments that cover the actual workings that take place in nature.

> It takes off the mask and veil from natural objects, which are commonly concealed and obscured under the variety of shapes and external appearance. Finally, the vexations of art are certainly as the bonds and handcuffs of Proteus, which betray the ultimate struggles and efforts of matter. (Preparative, Works IV 257)

The use of scientific instruments must be freed of any possible theoretical bias; it serves only to record particular data, the naked nature, without proceeding to axiom formulation. Bacon compares experiments to torture ("bonds and handcuffs") and scientific instruments to instruments of torture, by which nature is forced to confess the truth.

By enhancing the senses and by constraining nature to reveal itself, Bacon fulfils his desideratum of revealing *some* of the fundamental processes that take place in the universe. Nevertheless, the information acquired through enhanced senses and constraining experiments is only one part of the knowledge needed for the realisation of an Active Philosophy. This knowledge is still indebted to the habitual course of nature. Bacon further requires experiments that not only set limits to nature but also change it through technological devices. He names this new type of scientific experiments '*experimenta lucifera*', experiments of light, by which technological devices and experiments are created with the sole purpose of extracting knowledge. Thus, by redesigning nature, Bacon wants to study the alternative possibilities of nature that were never before instantiated.

3.2. Enlightening Technology

The difference between scientific instruments and enlightening technology consists in the fact that, while the use scientific instruments focuses on nature, the use of enlightening technology focuses on technological devices that recreate nature and design new configurations. Enlightening technology is the proper object of study for Mechanical or Experimental History. Enlightening technology creates either artificial things that reveal processes observed in nature, or artificial things that reveal processes that are altogether different from habitual nature. "Among things artificial those are to be preferred which either come nearest to an imitation of nature, or on the contrary overrule and turn her back." (NO, Works IV 172) Enlightening technology consists in created objects. It leaves nature apart in order to study nature by making it anew, sometimes even differently. While scientific instruments are universal instruments that are used to uncover the workings of natural objects, enlightening technologies are specific to different arts and they are already the application of some knowledge gathered by using scientific instruments.

One important part of enlightening mechanics is gathering information from extant "mechanical arts", because they embody what Perez-Ramos calls "maker's knowledge." There is a certain form of theoretical but also practical knowledge that the craftsmen possess, which should be made explicit in Mechanical and Experimental History.

> The history of Arts is of most use, because it exhibits things in motion, and leads more directly to practice…. among the particular arts those are to be preferred which exhibit, alter, and prepare natural bodies and materials of things; such as agriculture, cookery, chemistry, dyeing; the manufacture of glass, enamel, sugar, gunpowder, artificial fires, paper, and the like. Those which consist principally in the subtle motion of the hands or instruments are of less use; such as weaving, carpentry, architecture, manufacture of mills, clocks, and the like; although these too are by no means to be neglected, both because many things occur in them which relate to the alterations of natural bodies, and because they give accurate information concerning local motion, which is a thing of great importance in very many respects. (NO, Works IV 257-258)

Bacon prefers technologies that not just rearrange the parts of matter but those that "alter" matter and natural bodies. His focus rests on redesigning nature and on making it differently. For this reason, the most important source of information is not nature *per se* but altered nature, technology.

For Bacon all real knowledge must come not from immediate contemplation of nature but from experiments. However, he considers as experiments not just the use of instruments for studying nature, but the workings of every technological device. As Weeks states, "The centrally important polysemous term 'experiment' (*experimentum*) refers in a general sense to intervention in nature" (2007, 135) as it is shown by his use of the notion of 'experiments of Fruit', which represent useful and working technological devices. Consequently, the foundation of his philosophy, as well as its aim, is not merely experiment in the modern sense, but technology at large. And among various technologies the 'experiments of Light' are very important as they serve both for the advancement of learning and for the production of new works. “And it must ever be kept in mind (as I am continually urging) that experiments of Light are even more to be sought after than experiments of Fruit.” (Advancement, Works IV 421) The marvellous works or the ‘experiments of Fruit’ are made possible only by the knowledge of Forms. In addition, the knowledge of forms is to be arrived at by the use of scientific instruments and by making experiments.

> From works and experiments to extract causes and axioms, and again from those causes and axioms new works and experiments, as a legitimate interpreter of nature. (NO, Works IV 104)

Bacon proposes, for the construction of enlightening technology, a constant movement from experiments to theoretical results and from these theoretical results to new, more enlightening experiments:

> Now my directions for the interpretation of nature embrace two generic divisions; the one how to educe and form axioms from experience; the other how to deduce and derive new experiments from axioms. (NO, Works IV 127)

Fruitful technologies must be delayed as much as possible because they represent a dead-end for development; they become a new kind of habitual nature, while enlightening technology is the foundation for the knowledge of nature and its constant redesigning.

> So must we likewise from experience of every kind first endeavour to discover true causes and axioms; and seek for experiments of Light, not for experiments of Fruit. (NO, Works IV 71)

Given the status of science and technology in his time, the most important endeavour is neither the study of ‘nature free’ nor the creation of fruitful technologies but the creation of new ‘experiments of Light’ and the gathering of all possible information from technological settings. The enlightening experiments are to be gathered from extant mechanical and liberal arts and from practices that are altogether marginal to the mainstream mechanical endeavour.

> History of Arts, and of Nature as changed and altered by Man, or Experimental History, I divide into three. For it is drawn either from mechanical arts, or from the operative part of the liberal arts; or from a number of crafts and experiments which have not yet grown into an art properly so called, and which sometimes indeed turn up in the course of most ordinary experience, and do not stand at all in need of art. (Parasceve, Works IV 257)

Bacon does not limit himself to mechanical arts. On the contrary, he considers as being of greater importance new experiments that are not included in the usual categories of practical arts. Moreover, the aim of enlightening technology is to invent experiments more than to gather information from the existent ones.

> But not only is a greater abundance of experiments to be sought for and procured, and that too of a different kind from those hitherto tried; an entirely different method, order, and process for carrying on and advancing experience must also be introduced. (NO, Works IV 172)

Even practices that were entirely rejected by the subsequent scientific endeavour, like magic and astrology, are to be examined because these practices are based on natural operations and could be helpful in inventing new experiments and in discovering certain hidden laws of nature.

> Matters of superstition and magic (in the common acceptation of the word) must not be entirely omitted. ... For it may be that in some of them some natural operation lies at the bottom (NO, Works IV 172)

An example of enlightening technology that Bacon uses is grafting, which shows not only the broad scope of technological endeavour but also the fact that enlightening technology should take account of all possible redesigns of nature. Bacon shows that, although his aim is useful technology, it is necessary to invent and try even *prima facie* unfruitful experiments that probably would give a more accurate picture of nature. Enlightening technology is precisely about the broadest domain of redesigning the natural realm because is it necessary to gather as much knowledge as possible before returning to useful technology.

> Grafting again is common in fruit trees, but has been seldom tried on wild trees; though it is said that the elm when grafted on the elm [*sic*] produces a wonderful foliage. Grafting in flowers is likewise very rare, though now it is sometimes done in muskroses, which are successfully inoculated with the common roses. (Advancement, Works IV 413)

Bacon's commitment to enquiry is manifest in the status of erroneous experiments. He sustains the realisation of experiments that are prone to failure because they show the limits of technology and the errors in the lesser axioms already discovered. His approach is closer to a Popperian theory of falsification than to a theory of confirmation, because he is aware that errors can appear in the formulation of axioms and that these errors should be experimentally refuted. As a consequence, enlightening technology should take the form of trials and errors rather than that of a certain production of successful experiments.

> For though a successful experiment be more agreeable, yet an unsuccessful one is oftentimes no less instructive. And it must ever be kept in mind (as I am continually urging) that experiments of Light are even more to be sought after than experiments of Fruit. And so much for Learned Experience, which (as I have already said) is rather a sagacity and a kind of hunting by scent, than a science. (Advancement, Works IV 421)

Contrary to enlightening technology, the experiments of Fruit are applications of indubitable science. These are stable working devices whose main characteristic is their usefulness for life.

3.3. Fruitful Technology

The final aim of philosophy for Bacon is the creation of “marvellous works”, “experiments of Fruit” or fruitful technology. His ideal is best expressed in his fictional work *New Atlantis* and the list of useful technologies known as *Magmalia Naturalia*. His scientific method and all scientific endeavour that comprise Experiments of Light and Natural and Experimental Histories have only one goal: the technology that would eradicate human burdens. “The true and lawful goal of the sciences is none other than this: that human life be endowed with new discoveries and powers.” (NO, Works IV 79)

Bacon considers the everlasting desires of humanity attainable by technology. Two of these goals, that are mentioned more than once by Bacon, are the making of gold and the prolongation of life. Not only that these are attainable goals, however improbable it may seem, but the way to attain them is similar. In order to be able to make experiments of Fruit, like making gold and prolonging life, all the axioms pertaining to the simple natures involved are to be known as well as the procedures to recombine those simple natures in order to obtain the desired effect. Bacon rejects all kind of supernatural magic and alchemy that promise to fulfil those goals by the use of ‘elixirs’ and ‘essences’. For Bacon technology is a rational and complex process that acts on the simple natures by standard procedures. Eventually, technology will redesign nature according to human needs.

> The conversion of silver, quicksilver, or any other metal into gold, is a thing difficult to believe; yet it is far more probable that a man who knows clearly the natures of weight, of the colour of yellow, of malleability and extension, of volatility and fixedness, and who has also made diligent search into the first seeds and menstruums of minerals, may at last by much and sagacious endeavour produce gold; than that a few grains of an elixir should in a few moments of time be able to turn other metals into gold by the agency of that elixir, as having power to perfect nature and free it from all impediments. ... So again the retarding of old age or the restoration of some degree of youth, are things hardly credible; yet it is far more probable that a man who knows well the nature of rarefaction and the depredations of the spirits upon the solid parts of the body, and clearly understands the nature of assimilation and of

alimentation, whether more or less perfect, and has likewise observed the nature of the spirits, and the flame as it were of the body, whose office is sometimes to consume and sometimes to restore, shall by diets, bathings, anointings, proper medicines, suitable exercises, and the like, prolong life, or in some degree renew the vigour of youth; than that it can be done by a few drops or scruples of a precious liquor or essence. (Advancement, Works IV 367-368)

Technology presupposes "much and sagacious endeavour", that, through experiments of light, would be able to create anointings and proper medicines, and to derive the proper diets, bathings, and exercises for the prolongation of life. It is a difficult process that requires the science previously acquired and the following of numerous and meticulous procedures that apply that knowledge. The results are to be acquired through Mechanical Arts, the operative part of Physics, and through Magic, the operative part of Metaphysics.

From these two sciences and their operative counterparts, Bacon expects the total transformation of nature according to human needs. The outcomes of such a technology surpass the wildest promises of magic and alchemy. Bacon suggests that the results of the technology that he proposes are as unbelievable as the inventions of his time (mariner's needle, printing press and gun-powder) would have been before they were made.

If, for instance, before the invention of ordnance, a man had described the thing by its effects, and said that there was a new invention, by means of which the strongest towers and walls could be shaken and thrown down at a great distance; men would doubtless have begun to think over all the ways of multiplying the force of catapults and mechanical engines by weights and wheels and such machinery for ramming and projecting ; but the notion of a fiery blast suddenly and violently expanding and exploding would hardly have entered into any man's imagination or fancy; being a thing to which nothing immediately analogous had been seen, except perhaps in an earthquake or in lightning, which as magnolia or marvels of nature, and by man not imitable, would have been immediately rejected. (NO, Works IV 90)

The list of these technological inventions is impressive, ranging from restoration of youth to creation of new species. In *New Atlantis*, he presents the ideal society in which these technological inventions were already acquired:

> Coagulations, indurations, refrigerations, and conservations of bodies. … imitation of natural mines; and the producing also of new artificial metals … curing of some diseases, and for prolongation of life … great variety of composts, and soils, for the making of the earth fruitful. … engines for multiplying and enforcing of winds, to set also on going divers motions. … artificial wells and fountains, made in imitation of the natural sources and baths … we imitate and demonstrate meteors; as snow, hail, rain, some artificial rains of bodies and not of water, thunders, lightnings; also generations of bodies in air; as frogs, flies, and divers others, … all conclusions of grafting and inoculating, as well of wild-trees as fruit-trees, which produceth many effects. And we make (by art) in the same orchards and gardens, trees and flowers to come earlier or later than their seasons; and to come up and bear more speedily than by their natural course they do. We make them also by art greater much than their nature; and their fruit greater and sweeter and of differing taste, smell, colour, and figure, from their nature. And many of them we so order, as they become of medicinal use. … We have also means to make divers plants rise by mixtures of earths without seeds; and likewise to make divers new plants, differing from the vulgar; and to make one tree or plant torn into another. … We make a number of kinds of serpents, worms, flies, fishes, of putrefaction; whereof some are advanced (in effect) to be perfect creatures, like beasts or birds; and have sexes, and do propagate. … We have also divers mechanical arts, which you have not (New Atlantis, Works III 156-161)

The technology of *New Atlantis* recreates nature in all its aspects, sometimes by imitating "nature free", sometimes by totally new designs. The examples of Bensalem's technology are not just trials but they represent well-established technologies based on science. The fruitful technology is a newly created stable nature, an applied science that produces a new universe of things in accord with human needs. These technologies are not arrived at by chance and all their effects are known in advance. "Neither do we this by chance, but we know beforehand of what matter and commixture what kind of those creatures will arise." (New Atlantis, Works III 159) Also, in these fruitful technologies, truth and usefulness become identical. On the one hand, these technologies are useful because they are based on genuine knowledge of both nature and human needs and they have no unforeseen and undesired effects. On the other hand, these technologies represent the instantiation of true knowledge; they are the materialisation of philosophy. Fruitful technologies are the most cherished things in Bensalem Island. Bacon presents in his fictional work a technological utopia because the basis of Bensalem's happiness is the technological development. Bensalem society is centred on development of knowledge and technology.

> I will give thee the greatest jewel I have. ... The End of our Foundation is the knowledge of Causes, and secret motions of things; and the enlarging of the bounds of Human Empire, to the effecting of all things possible. (New Atlantis, Works III 156)

Bacon is aware though that technology can have undesired effects and that the utopia he presents is possible only if there is a control of available technologies. While for enlightening technologies he recommended the realization of all possible experiments as a means of attaining knowledge, he limits the use of fruitful technologies to those approved by Salomon's House. The undesired technologies are to be kept secret, and those in charge with diffusion of technologies should exercise a strict control on available technologies.

> We have consultations, which of the inventions and experiences which we have discovered shall be published, and which not: and take all an oath of secrecy, for the concealing of those which we think fit to keep secret: though some of those we do reveal sometimes to the state, and some not. (New Atlantis, Works III 165)

By this, Bacon implies that the community of scientists and technologists is a closed community that evaluates and censures the use of technologies.

4. Conclusion

The Baconian conception of technology is the first formulation of a modern approach to material production. Bacon aims that natural philosophy, whose final stage is named 'the new philosophy or active science', the proper result of the 'true interpretation of nature', will develop and incorporate an all-pervading technology. Investigating his unfinished project, I tried to show that the way technology develops, according to Bacon, is dependent on his ontological view of a contingent nature that unfolds the potentialities of active atoms. As a consequence, the first stage in technological development is experimental science, which unveils these potentialities. The theoretical science, physics and metaphysics, will arrive at the true forms and axioms according to which function both the actual nature and any other possible variation of it. The theoretical science creates thus the background on which technology, the applied science—the most cherished examples of which being the mechanical arts, magic and medicine—will develop, fulfilling everlasting human needs and desires and changing the whole face of the Earth. By focusing on technology, Bacon effects a paradigm change in which human endeavours should focus on technological reconfigurations of the material world. He emphasizes the usefulness of technology as a way of overcoming the consequences of the Fall and shows the way in which technology is similar to nature such that completely new things can be created on the basis of natural principles. The same themes, although adopting different ontological premises, arguing for different means and following a different method, will be analysed in the next chapter in the works of René Descartes.

Chapter III

Descartes' Philosophy of Technology

René Descartes (1596-1650) is the philosopher who established the central place of mechanics and mathematics for the scientific endeavour.[41] The science that Descartes promotes must have practical results; it has to be useful to human life. He advocates the necessity of creating useful devices designed in accordance with the true principles of physics. Technology becomes the applied part of science and Descartes establishes in his writings the aims, the scope and the means of technology. The Cartesian conception of technology, such as the fact that technology is an applied mathematical science, that material utility is important and worth pursuing, and that technology can reproduce every natural object and even redesign human body, constitutes the core of the modern understanding of technology.

In this chapter I analyse the Cartesian conception of technology. It is divided into three parts. The first part describes the central place that mechanics, both as science and as practice, comes to occupy in Descartes' writings. Mechanics is almost coextensive with Cartesian science both in its methodology and in its content. The second part analyses the Cartesian ontology of the material world, which constitutes the background against which he constructs his understanding of technology. The third part presents the main characteristics of technology as described by Descartes. I first show the way in which Descartes establishes utility, the main characteristic of technology, as a genuine value. I then analyse the relationships between

41 The major works of Descartes published during his lifetime: *Discours de la méthode* (1637), *Meditationes de prima philosophia* (1641), *Principia philosophiae* (1644), *Les passions de l'âme* (1649).

metaphysics, science and technology, and the imposition of design as the central feature of technology, and their consequences.

1. Examples and Metaphors

1.1. The Mechanical Man

In the medieval great chain of being, man is the most complex visible creature that exists. By presenting as ontologically possible the creation, by human craftsmanship, of a completely mechanical man, Descartes sets up a very high standard for technology. Of course, this completely mechanical man will lack the properties conferred on man by his rational soul, i.e. reason and language, but he/it will be able to exhibit animal behaviour; he/it will be a man without a mind.

> [I]f there were such machines having the organs and the shape of a monkey or of some other animal that lacked reason, we would have no way of recognizing that they were not entirely of the same nature as these animals; whereas, if there were any such machines that bore a resemblance to our bodies and imitated our actions as far as this is practically feasible [*que moralement il seroit possible*], we would always have two very certain means of recognizing that they were not at all, for that reason, true men. The first is that they could never use words or other signs, or put them together as we do in order to declare our thoughts to others. … The second means is that, although they might perform many tasks very well or perhaps better than any of us, such machines would inevitably fail in other tasks; by this means one would discover that they were acting, not through knowledge, but only through the disposition of their organs. … [I]t is for all practical purposes impossible [*il est moralement impossible*] for there to be enough different organs in a machine to make it act in all the contingencies of life in the same way as our reason makes us act. (*Discourse*, RA 72; AT VI 56-57)

Descartes reduces all mechanical arts, all technology, to mechanics. The paradigmatic instances of technology that Descartes considers are hydraulic devices, as those constructed in royal gardens, and different automata, such as clocks, mills and even little man-like automata. All devices that he considers are systems composed of rigid parts that are moved by springs, counterweights, water or heat.

> We see clocks, artificial fountains, mills, and other similar machines, which, although they are made only by men, are not without the power of moving themselves in many different ways. (*World*, RA 42; AT XI, 120)

As a consequence the man made by craftsmen will be nothing but a mechanical machine. The only difference between a mechanical man and other moving machines made by human craftsmanship consists in the complexity of the former. There is no essential difference, no difference in nature, between a mechanical man devoid of a mind and a simple machine. It is only a matter of degree of complexity.

> This will in no way seem strange to those who are cognizant of how many different automata or moving machines the ingenuity of men can make, without using, in doing so, but a very small number of parts, in comparison with the great multitude of bones, muscles, nerves, arteries, veins, and all the other parts which are in the body of each animal. For they will regard this body as a machine which, having been made by the hands of God, is incomparably better ordered and has within itself movements far more wondrous than any of those that can be invented by men. (*Discourse*, RA 71; AT VI, 55-56)

Despite his examples of man-like and animal-like automata, Descartes presents them as practically impossible. However, Cottingham (1992) and Wheeler (2008) show that this does not mean that it is ontologically impossible to construct such automata but only that "it is morally impossible" ("*il est moralement impossible*" – AT VI 57). There are some limits to the power of the technological reproduction of men and animals and those limits are established by "what is morally possible" ("*que moralement il seroit possible*" – AT VI 56). The English translations render the moral impossibility as "for all practical purposes impossible" and the moral possibility as "practically feasible." Descartes constructs this moral impossibility as the physical limits of human intervention into the smallest mechanisms of nature.

> It is possible to make a machine that supports itself in the air like a bird, *metaphysice loquendo* [metaphysically speaking], for the birds themselves, at least in my opinion, are such machines; but not *physice* or *moraliter loquendo* [physically or morally speaking], because it would require springs so subtle and so strongly assembled that they could not be produced by men. (To Mersenne, 30 August 1640, AT III 163-164)

The limits of an actual construction of an animal-like automaton concern only the magnitude of material parts that can be manipulated by men. The "machine of the body", a phrase frequently used by Descartes, consists of minute parts that escape our senses and thus escape our manipulation. The machines men can construct should be big enough such that their parts are perceivable and capable of being assembled. Therefore, every part of the human body can be reproduced technologically but at a different scale, such that the unperceivable "<tubes, springs, or other> instruments" that exist in animal bodies become perceivable. Being made by man, the machines must be "proportional to the hands of those who made them" (*Principles* IV 203, AT IX 321) such that they "are so large that their figures and movements can be seen." (*Ibid*.) Except for these differences of scale, there is no other difference between natural organisms and artificial organisms, so that Descartes adds in the French edition of his *Principles* that "all that is artificial is also natural." (*Ibid*., AT IX 321-322)

> [T]he example of certain artefacts was of use to me, for I can see no difference between these and natural bodies, except that the effects of machines depend for the most part on the operation of certain <tubes, springs, or other> instruments, which, since men necessarily make them, must always be large enough to be capable of being easily perceived by the senses. The effects of natural causes, on the other hand, almost always depend on certain organs minute enough to escape our senses. (*Principles* IV 203, RA 270-271; AT VIII 326)

The consequence of this disproportion between human senses and instruments and the minute parts of natural organisms render the creation of an artificial living being morally impossible. However, equally impossible should have been a magnified view of the moon before Galileo. Such kind of analogy entitles Michael Wheeler to sustain that Descartes should be committed to the idea that the domain of what is morally possible rests on technological advances:

> As far as he [Descartes] can judge, it is practically impossible to construct a machine that contains enough different special-purpose mechanisms. However, he is, as far as this argument is concerned, committed to the view that the upper limits of what a mere machine might do must, in the end, be determined by rigorous scientific investigation and not by philosophical speculation. (Wheeler, 2008, 317)

The extension of the power of human senses, if not the power of human intervention, is dealt with in *Dioptrics*, where Descartes presents the method of creating artificial means that would serve to expand the power of vision probably to the point in which every minute organic mechanism could be viewed.

Descartes' argument for the ontological possibility of a mechanical man without a mind gives technology a new status because, at least theoretically, from now on, the complete reproduction of every material thing, without the flaws implied by Platonic mimesis, became possible.

1.2. Mechanics as Method

While ruling out the actual construction of a mechanical man, Descartes nevertheless retains the idea of the similarity between machines and organisms. He confesses in his *Principles* that in the construction of his system he was inspired by the contemplation of artefacts: "In this matter I was greatly helped by considering artefacts." (*Principles* IV 203, CSM I 288; AT VIII

326) He uses this idea in analysing men and nature as machines constructed by an artisan, machines composed by minute mechanisms that can be fully explained by mechanical rules.

> I assume that the body is nothing other than a statue or earthen machine, which God forms expressly to make it as much as possible like us, so that not only does he give it externally the colour and shape of all our members, but also he puts within it all the parts necessary to make it walk, eat, breathe, and ultimately imitate all those of our functions that may be imagined to proceed from matter and to depend only on the arrangement of organs. We see clocks, artificial fountains, mills, and other similar machines, which, although they are made only by men, are not without the power of moving themselves in many different ways. And it seems to me that I could imagine many different kinds of motions in the machine I am assuming to be made by the hands of God, and I could not attribute it so much artistry that you would have no reason to think there could not be more. (*Man*, RA 41-42; AT XI 120)

From the likeness he established between man and machine, Descartes not only deduces the idea of the identity between machines and nature, but he also employs the methods of artisans in constructing his system. There are three features of craftsmanship that he considers valuable for his reform of philosophy: simplicity and evidence of the first principles, the use of suitable instruments and the confirmation by experiments.

> Indeed, this method resembles those of the mechanical arts [*mechanicis artibus*] which need no outside help, and which themselves teach us how to construct their instruments. Thus if one wished to practice one of them, the art of the blacksmith, for example, one would be forced at first to use as an anvil a hard stone or a rough lump of iron, to take a piece of rock in place of a hammer, to shape pieces of wood into tongs, and to collect other materials of this sort according to need. Thus equipped, one would not then at once try to forge swords or helmets or any object of iron for the use of others; but one would first of all manufacture hammers, an anvil, tongs, and the other things useful to oneself. This example teaches us that, if we have been able at the outset to find only some rough principles, which seem to be innate in our minds rather than prepared by art, we must not use them to try to settle immediately the controversies of the philosophers or to solve the puzzles of the mathematicians. We must rather use them first for seeking with the greatest care all that is more necessary for the examination of truth; since there is surely no reason why this should seem more difficult to discover than any of the questions usually propounded in geometry or physics or other disciplines. (*Rules* VIII, RA 19; AT X 397)

As in mechanical arts, the construction of a philosophical system requires the construction of proper instruments that would help us in searching the truth. Philosophy should get rid of all preconceived ideas and find the first principles and its proper method before proceeding to actual results. Descartes admires the fact that the instruments are internal to art, are themselves products of that art. This gives the artisan the complete knowledge not just of the products of that art but of the principles and instruments he uses.

Another important characteristic that Descartes borrows from mechanical arts is the simplicity of the procedures employed; these procedures create infinitely varied patterns. The basic procedures of mechanical arts exhibit order and discipline and "give the mind excellent practice." They also show how the combination of simple and regular procedures creates innumerable arrangements that, although they seem extremely different in nature, are only regular combinations of the same simple natures.

> [We] should first discuss those disciplines which are easiest and simplest, and those above all in which order most prevails. Such are the arts of the craftsmen who make cloth and tapestries, those of women who embroider or make lace [in an infinitely varied pattern – CSM I 35], as well as all the games with numbers, and all that relates to arithmetic, and the like. All these arts give the mind excellent practice, provided we do not learn them from others, but discover them ourselves. For since nothing in them remains hidden, and they are entirely adjusted to the capacity of human knowledge, they show us very distinctly innumerable arrangements, all different from one another and yet regular, in the scrupulous observation of which the whole of human sagacity consists. (*Rules* X, RA 22; AT X 404)

Descartes proposes an unusual approach to these mechanical arts which are usually learnt through a period of apprenticeship. He proposes to his readers to rediscover for themselves the rules of specific arts thus acquiring not just the rules of the art but also the methods of invention and development. At the same time, dealing with mechanical arts makes one aware of the importance of experience because only the following of true principles would bring about desirable effects. Moreover, through practice, mechanical arts reach perfection only by following the rules confirmed by experience. Once the true principles and the proper method are found, the consequences cannot be but true conclusions.

> In all the arts that, although they are rude and imperfect at first, yet because they contain something true whose effect is revealed by experience, they come little by little to perfection through practice. So, when we have true principles in philosophy, we cannot fail by following them to meet occasionally with other truths. (*Principles*, Preface; RA 229-230, AT IX 18)

Moreover, not only does Descartes employ the methods of the mechanical arts, but he is also proud that his philosophy is similar to a mechanical endeavour. The reason of his high esteem for mechanics as a model for philosophy is that it contains as fundamentals simple materials and instruments and all its conclusions are in accord with experience. Likewise, philosophy should employ clear and distinct principles (shapes and magnitudes and motions) arranged in proper order and its results should be confirmed by experiments.

> For if my philosophy seems too "crass" to him because, like mechanics, it considers only shapes and magnitudes and motions, he is condemning what I believe is to be most praiseworthy. That is what I myself prefer about my philosophy and what I am proudest of, namely, that I use the kind of philosophizing in which there is no argument that is not mathematical and evident, and whose conclusions are confirmed by true experiments. ... so that if he condemns my style of philosophizing for its similarity to mechanics, this seems to me the same thing as if he were to condemn it because it is true. (To Plempius for Fromondus, October 3, 1637, RA 85-86; AT I 420-421)

What others, namely Fromondus, see as an important flaw of Cartesian philosophy, namely the similarity with and the frequent use of mechanics, is for Descartes one of the main positive features of his philosophy. By employing mechanics and mechanical method, he can fully explain and mentally reconstruct the entire material nature.

1.3. The Place of Mechanics within Philosophy

Along with Bacon and as a consequence of the increasing importance of mechanics during the Renaissance, Descartes redesigns the philosophical domain so that mechanics comes to occupy a central place in it. In the traditional schema of natural philosophy mechanics[42] was just a lower form of mixed-mathematics along with disciplines such as music, optics, astronomy, and perspective. In the Cartesian system mechanics, as science but not as technology, becomes *the* science that studies all nature, being the core of natural philosophy: "the laws of mechanics ... are the same as those of nature." (*Discourse* V, RA 71; AT VI 54)

In the Scholastic-Aristotelian framework the mixed-mathematics have as their proper objects only some parts of nature, i.e. those that can be understood geometrically. For scholasticism, mechanics is a combination of geometry and physics but geometry and physics are profoundly distinct, studying different realms. The combination of physics and geometry in mechanics concern only minor parts of these domains and mechanics apply only to specific small portions of nature[43]. In the new configuration of sciences established by Descartes, all nature is studied by this mixed science because "in everything nature acts exactly in accordance with the laws of mechanics." (To Mersenne, 20 February 1639; CSMK 134; AT II 525) Not only that nature can be studied in all its aspects by mechanics but there is nothing else in the functioning of nature but the laws of mechanics because "the laws of mechanics ... are the same as those of nature." (*Discourse* V, RA 71; AT VI 54) Moreover, mechanics is no more just a marginal part of physics and geometry but it comes to be identified with them. Physics, the centre of natural philosophy, is coextensive with mechanics, thus changing the two-millennial dogma regarding the low status of mechanics, because the nature studied by

42 See Ch. 1, section *2.1. Mechanics*.
43 For an extensive treatment of the status of mixed mathematics, especially mechanics, in the Scholastic-Aristotelian tradition and its transformation in the seventeenth century, see Biener, Zvi. 2008. *The unity of science in early-modern philosophy: Subalternation, metaphysics and the geometrical manner in scholasticism, Galileo and Descartes*, doctoral thesis, University of Pittsburgh.

physics is nothing else but mechanical nature: “it is certain that there are no rules in mechanics that do not hold good in physics, of which mechanics forms a part or species.” (*Principles* 203, RA 270-271; AT VIII 326) Moreover, physics is coextensive with mathematics, the principles of geometry and pure mathematics being the principles of physics, and thus the principles of the entire Cartesian natural philosophy.

> The only principles which I accept, or require, in physics are those of geometry and pure mathematics … And since all natural phenomena can be explained in this way ... I do not think that any other principles are either admissible or desirable in physics. (*Principles* 64, CSM I 247, AT VIII 78-79)

We should distinguish in Descartes’ works two kinds of mechanics: mechanics as science and mechanics as technology. The identification of mechanics with physics and mathematics takes the former as being a science, a theoretical endeavour that explains natural phenomena. By contrast, when Descartes refers to the division of knowledge and places mechanics on the same level with medicine and ethics (*Principles*, Preface, AT VIII 14), he means mechanics as an applied science, an art that deals with the knowledge, design and production of actual machines and mechanisms.

In his correspondence Descartes explicitly affirms this double identity between geometry, physics and mechanics: “*my entire physics is nothing but geometry*” (“*ma Physique n'est autre chose que Géométrie*” - To Mersenne, 27 July 1638; CSMK 119, AT II 268) and “*my entire physics is nothing but mechanics*” (“*toute ma Physique ne soit autre chose que Méchanique.*” - To [Debeaune], 30 April 1639; CSMK 135, AT II 542)

The identity between physics and mechanics is a consequence of Descartes’ modelling of natural phenomena on craftsmen’s mechanisms. If those mechanisms work, then there is no need to presuppose different principles in natural bodies. Nevertheless this identity is not complete because craftsmen’s mechanisms, i.e. the mechanics as technology, have weight, impenetrability, etc. All these are to be reduced to primary qualities by the pure science of mechanics. Descartes retains from this identity only the laws of motion of bodies. Weight, as was conceived by the Scholastics, but also magnetism and other forms of action at a distance, are occult qualities for Descartes. Descartes uses the notion of weight when it explains simple mechanisms (in *An account of the machines by means of which a small force can be used to lift heavy weights*, AT I 435-447), not as a genuine quality (Principles I, 4; IV, 20-24) but as one reducible to shape and motion.[44]

The identity between physics and geometry is imposed by the need for clarity and explanation by the simplest natures. This epistemically gorounded identity is based on the ontological identity that Descartes draws between matter and extension.

2. The Deterministic Evolution of Nature

2.1. Space-Matter

Descartes' cosmology is the consequence of his double identity between physics, geometry and mechanics. In this respect natural evolution is the geometrical rearrangement of matter according to the mechanical laws of motion of bodies. This renders nature geometrically determined by initial conditions and "the ordinary *laws of nature*" ("*les loix ordinaires de la Nature*" - *World*, AT XI 34).

44 Descartes explains gravitation as continuous pushing of large parts of matter toward the centres of the vortices of the universe and the escape of lighter parts toward the periphery. "I have known none of them who did not presuppose weight in terrestrial bodies, but although experiment proves to us very clearly that the bodies we call heavy descend towards the center of the earth, we do not for all that know the nature of what is called gravity, that is, the cause or principle that makes bodies descend in this way, and we must derive it from elsewhere. The same may be said of the void and atoms, of heat and cold, of dryness and humidity, of salt, sulfur, mercury, and all other similar things which some have adopted as their principles." (*Principles*, Preface; RA 225, AT IX 8) Magnetism receives the same kind of mechanical explanation: minute screws emitted by the magnet enter the pores of iron and mechanically move iron toward or away from the magnet.

The initial conditions of Descartes' universe are the arrangements of parts of matter and the external motions that God imposes on them.

> Let us suppose[45] that God creates anew so much matter around us that, whatever direction our imagination can be extended, it no longer perceives any place that is void. (*World* VI, RA 35; AT XI 32)
> Let us add, further, that this matter can be divided in all the parts and according to all the shapes we can imagine, and that each of its parts is capable of receiving in itself all the motions we can also conceive. Let us suppose, in addition, that God divides it truly into many such parts, some larger, others smaller, some of one shape, others of another, as it pleases us to fancy them. Not that God separates them from one another so that there is a void between them; let us think that the whole difference he places in them consists in the diversity of the motions he gives them. From the first instant they are created, he makes some move in one direction, others in another, some faster, others slower (or even, if you wish, not at all). (*World* VI, RA 36; AT XI 34)

The main characteristic of Descartes' matter is that it has no qualities except modes of extension, namely size and shape. It follows that Descartes' matter is nothing but space itself, a conclusion which although not arrived at in the *World* is found at least as early as the letter to Mersenne from 9th of January 1639 (AT II 482) and in later work:

> There is no real difference between space and corporeal substance. It is easy for us to recognize that the extension constituting the nature of a body is exactly the same as that constituting the nature of a space. (*Principles* II 11; CSM I 227; AT VIII 46)

The only difference between matter and space is in the way we conceive of them: we think of space as a seamless continuum while matter is conceived as divided in many parts of different shapes: "The difference between space and corporeal substance lies in our way of

45 Descartes can claim, by employing this device of the fable that, on one hand, the world has been formed as described in Genesis, but that, on the other hand, the physicist can enquire what the properties of matter and laws of motion should be for the world to get, from them, the configuration we know. It is likely that the fable of *The World* is what Descartes considers the real way in which the universe was formed. This is supported by what he writes on this fable in the fifth part of the *Discourse on the Method*. Descartes reaffirms that his narrative is possible, even if "it is much more likely that from the beginning God made it just as it had to be": "So, even if in the beginning God had given the world only the form of a chaos, provided that he established the laws of nature and then lent his concurrence to enable nature to operate as it normally does, we may believe without impugning the miracle of creation that by this means alone all purely material things could in the course of time have come to be just as we now see them." (AT VI, 45; CSM I, 133-134)

conceiving them." (*Principles* II 12; CSM I 228; AT VIII 46) Besides, unlike the geometrical figures that geometers draw on paper, God really divided space-matter into parts. "God divides it truly into many such parts, some larger, others smaller, some of one shape, others of another, as it pleases us to fancy them." (*World* VI, RA 36; AT XI 34) Besides this real division into figures effected by God there is no difference between real space-matter without motion and geometers' space. There are no internal or external qualities, forms, colours, weights or any other principle of differentiation.

> To that end, let us expressly suppose that there is no form of earth, fire, or air, nor any other more particular form, such as the form of wood, stone, or metal. Nor does this matter have the qualities of being hot or cold, dry or wet, light or heavy, or having some taste, odor, sound, color, light, or similar quality in the nature of which it might be said that there is something that is not known manifestly by everyone. (*World* VI, RA 36; AT XI 33)

Moreover, God's real division of space-matter is chaotic, without any order, such that the result is highly arbitrary. "He imposes *no order or proportion* on it, but composes *the most confused and disordered chaos* the poets could describe" (*World* VI, RA 36; AT XI 35; my emphasis)

2.2. Change in the Material World

In this chaotic real division of space-matter, which allows no void between adjacent parts, God introduces motions. Each part receives its own quantity of external motion. And while the figures into which God divided matter and the initial quantity of motion are unchangeable, unless God intervenes, the subsequent changes in the world are fully determined by the mechanical laws of motion. Ultimately, the initial conditions seem to be not at all important.

To arrive at the actual state of the world it is sufficient that primordial chaos, however it may be, follows the mechanical laws:

> For God has so marvellously established those laws that even if we suppose that he has created nothing more than what I have said, and even if he imposes no order or proportion on it, but composes the most confused and disordered chaos the poets could describe, they are sufficient to make the parts of that chaos disentangle themselves and dispose themselves in such good order that they will have the form of a most perfect world, one in which we would be able to see not only light, but also all the other things, both general and particular, that appear in the real world. (*World* VI, RA 36; AT XI 34-35)

Space-matter divided chaotically into shapes of different figures and moved by the external forces given by God to every such part constitutes alone this primordial universe. This universe contains none of the "real qualities" that are ascribed to natural bodies by Scholastics, unless they are interpreted as nothing more than specific motions and shapes: heat is a very rapid movement, red is a certain movement of subtle matter, etc.

> And, unless I am mistaken, not only these four qualities, but also all others, and even all the forms of all inanimate bodies, can be explained without needing to assume anything in their matter other than the motion, size, shape, and arrangement of its parts. (*World* V, RA 34; AT XI 26)

Moreover, sensible qualities are not going to emerge into the nature as we know it because nature is nothing else than this moving matter. "I make use of that word [nature] to signify matter itself, insofar as I consider it with all the qualities I have attributed to it taken all together" (*World* VII, RA 37; AT XI 37) No other qualities than shape, size and arrangements of parts can be encountered in the primordial chaos or in subsequent nature. The only difference between the primordial chaos composed only of moving parts of space and the world that we perceive is the different and regular arrangement of those parts brought about by collisions that follow the mechanical laws of motion.

> In order to understand this better, you should recall that among the qualities of matter we have assumed that its parts have had various motions from the moment they were created, and furthermore that they all touch each other from all sides without there being a void in between them. From this it follows necessarily that from then on, from the time they began to move, they also began to change and diversify their motions by colliding with one another. (*World* VII, RA 37; AT XI 37)

The motion that Descartes has in mind breaks with the traditional motion viewed primarily as qualitative change. Cartesian motion is nothing else than change in location. The minute parts of space-matter change their relative positions and exchange quantities of motions between them.

> As for me, I do not know of any motion other than the one which is easier to conceive of than the geometers' lines, the motion that makes bodies pass from one place to another and occupy successively all the spaces in between. (*World* VII, RA 38; AT XI 40)

Consequently, Descartes offers three simple laws of motion that are sufficient, along with their unspecified corollaries, for matter to develop in the actual nature: the law of inertia, the law of exchanging quantities of motion, and the law of moving along straight lines.

> I shall here set out two or three of the principal rules according to which it must be thought that God causes the nature of this new world to act, and which will suffice, I believe, to enable you to know all the others. The first is that each particular part of matter always continues in the same state unless the collision with other bodies forces it to change that state. ... I suppose as a second rule that when a body pushes another, it cannot give the other any motion unless it loses as much of its own motion at the same time, nor can it take any of the other body's motion away unless its own motion is increased by as much. ... I shall add as a third rule that, when a body is moving, even if its motion most often takes place along a curved line and can never take place along any line that is not in some way circular, as has been said before, nevertheless each of its parts individually tends always to continue its motion along a straight line. (*World* 7, RA 38-39; AT XI 38-44)

Descartes' cosmology offers a deterministic image of natural evolution. Natural evolution is nothing more than a geometrical rearrangement of parts of matter according to three mechanical laws of motion. Descartes does not take his explanation just as a possible course of nature but he is convinced that nature necessarily evolved in this way and he writes to Mersenne that he can mathematically prove the evolution of nature.

> I would think I knew nothing in physics if I could say only how things could be, without demonstrating that they could not be otherwise. This is perfectly possible once one has reduced physics to the laws of mathematics. (To Mersenne, 11 March 1640; CSMK 145, AT III 39)

From stones to human bodies, everything is a rearrangement of parts that do not interact except by exchanging their quantities of motion. From the primordial chaos, nature transforms into a mechanical machine, i.e. its parts are so wonderfully arranged that it brings about marvellous results.

> The third passage I thought worth commenting on is towards the end, where you say 'The matter of the universe exists as a machine.' I would have preferred to write 'The universe is composed of matter, like a machine' or 'All the causes of motion in material things are the same as in artificial machines' or something similar. (To ***, March 1642; CSMK 213; AT V 546)

One consequence of this view is the rejection of any other possible explanation for natural phenomena.

> I will add only that I have not yet met anything connected with the nature of material things for which I could not very easily think up a mechanical explanation. (To [Brasset], 23 April 1649; CSMK 375; AT V 346)

As for other explanations of phenomena developed in chemistry or natural magic, theories fairly important for Bacon's treatment of natural evolution, Descartes reject them altogether:

> I wholly subscribe to Your Excellency's judgement about the chemists. I believe they use words in an uncommon sense only to make it appear that they know what they do not know. I also believe that what they say about the revival of flowers by their salt is only a fiction without foundation, and that their extracts have qualities other than those of the plants from which they are taken. We can experience this very clearly, given the fact that wine, vinegar, and brandy, which are three different extracts made from the same grapes, have such different tastes and qualities. Indeed, in my opinion, their salt, sulfur, and mercury differ from one another no more than do the four elements of the philosophers, or than water differs from ice, foam, or snow. For I think that all bodies are made of one and the same matter and that there is nothing that makes any difference between them, except that the small parts of the matter that make up some shapes as distinct from others are arranged differently from those that make up the others. (To the Marquis of Newcastle, November 23, 1646, RA 275; AT IV 570)

Into this mechanical deterministic nature, Descartes introduces a new principle of motion, the only force that can modify the inexorable deterministic evolution of nature: the motion that the human mind exerts on the human mechanical body:

> I had realized that there are two different principles of motion – one, indeed, plainly mechanical and corporeal, depending only on the force of the spirits and the arrangement of the organs, can be called the corporeal soul, and the other incorporeal, that is, the mind, or that soul I defined as thinking substance. (To More, February 5, 1649, RA 296, AT V 276)

Given the fact that the human soul or mind exerts influence only on the pineal gland, the only change that it can make to the mechanical world is the change in the representations (images of ideas, memories, etc.) that exist on that gland. There is a two-way movement that passes through the images on the pineal gland that explain the influence of body on the soul and of soul on the body. The animal spirits form corporeal images of external things on the pineal gland which bring about ideas in the soul. On the other hand, the soul imprints ideas as corporeal images on the pineal gland, moving this gland at mind's will.

> The two [visual] images in the brain form only one on the gland, which, acting immediately upon the soul, causes it to see the shape of this animal. ... [T]hese spirits enter these pores, they excite a particular movement in this gland, which is instituted by nature to cause the soul to be sensible of this passion. ... And the whole action of the soul consists in this, that solely because it wills something, it causes the little gland to which it is closely united to move in the way requisite to produce the effect that relates to this volition. (*Passions* 35-41; RA 309-311; AT XI 356-360)

This minute changes, formation and modification of corporeal images, produce great changes in the movements of animal spirits.

> But after examining the matter with care, it seems to me I have plainly recognized that the part of the body in which the soul exercises its functions immediately is in no way the heart, nor the whole of the brain, but merely the most inward of its parts, namely, a certain very small gland situated in the middle of its substance and so suspended above the duct through which the animal spirits of its anterior cavities communicate with those of the posterior, that the slightest movements taking place in it may alter very greatly the course of the spirits, and, reciprocally, that the smallest changes occurring in the course of the spirits can do much to change the movements of this gland. (Passions 31; RA 307; AT XI 351-352)

An important aspect of Cartesian system is the fact that the corporeal images on the pineal gland resemble neither the external body, nor the idea in the mind. The corporeal images that form on the pineal gland are nothing else but symbols for both external bodies' images and ideas in the mind. The same must be true of the mind's idea of a machine which being imprinted on the pineal gland will determine the material production of that machine.

Once new images are formed on the pineal gland as a consequence of the mind's influence, they exert their power over the body in the usual mechanical way in which pineal gland's images exert their power in animals devoid of a mind through the animal spirits. The images on the pineal gland do not have qualities, being only patterns of flow of animal spirits.

In this way Descartes emphasize the role of dis-resemblant representations both for knowledge and for action, because, on the one hand, they are the only means by which the immaterial soul triggers changes in the mechanical world, and, on the other hand, the physical world is known only through the formation of these representation that do not resemble the physical world.

3. Technology

3.1. Utility as a Genuine Value

Descartes argues that man-made artefacts and natural objects are identical from an ontological point of view, i.e. their nature is determined by nothing but the size, shape, arrangement and movement of their parts. But for technology to become an accepted theory and practice in a culture still dominated by Platonic and Aristotelian contempt against it, one should provide stronger arguments for its intrinsic value. Technology is worth-pursuing because technology is useful. And in its usefulness rest all its value. Plato and Aristotle never denied that technology is useful, but their understanding of utility was different. First, the material utility of technology is *relative* to the user of technology, since it is just a mean for personal material goals, which in turn was instrumental to higher purposes. Second, technology has no intrinsic intellectual or moral value; it is neither a possible source of knowledge nor a mean toward human flourishing.

During the Renaissance these two arguments against technology are dismissed. As we already showed, Galileo and Bacon argued for the necessity of using technology and experimental settings in order to discover the secrets of nature. After Galileo and Bacon it became evident that knowledge of nature is impossible without the use of experiments. Especially for Bacon, only successful technological reproduction and production of objects and processes is the warrant of our knowledge about nature. But the material utility of technology remained a *relative* value.

Before Descartes, there were two arguments for the material value of technology: a theological one, formulated by Hugh of St. Victor and Francis Bacon, and the evaluative argument of Georgius Agricola. Hugh of St. Victor and Francis Bacon argued that technology is worth-pursuing for its material "fruits", because it would restore the paradisiacal state of man before the Fall. According to this line of argumentation the value of material products of technology is in fact dependent on the moral value of the prelapsarian human condition. And technology is valuable only as long as it restores the prelapsarian condition. A still more modern argument is that of Georgius Agricola, as he compares the relative damages and relative benefits of technology and concludes that, given the benefits, it is preferable to pursue technology than to reject it. "If we remove metals from the service of man, all methods of protecting and sustaining health and more carefully preserving the course of life are done away with." (Agricola, Book I)[46] Thus, technology acquired an universal value, as contributing to the general flourishing of humanity, but still remained dependent on other highest values.

Descartes makes the decisive modern step and establishes utility as a genuine value, giving technology a solid metaphysical ground. In order to transform utility from a relative and spurious value into an autonomous and genuine one, he states that the only values that can be known by human beings through the natural light without the help of divine grace are

46 See Ch. 1, section *2.3. Mining and metallurgy*.

those relative to our free will, i.e. the values instituted by *ego cogitans*. His argument starts by affirming that God's will and the final purpose of man cannot be known:

> We ought to beware lest we presume too much in supposing ourselves to understand the ends God set before himself in creating the world … [i.e.] that by the powers of our mind we could understand the ends he set before himself in creating the universe. (*Principles*, RA 262-263, AT VIIIa 80-81)

Because of that lack of knowledge, which involves not only the ends of the universe but also the ends of man, human beings have to establish their own ends in accord with the best knowledge that can be obtained through the natural light. Descartes identifies as the supreme good the thing that one judges to be the best:

> What I here call 'pursuing virtue' [is to live] in such a way that his conscience cannot reproach him for ever failing to do something he judges to be the best. (*Passions*, CSM I 382, AT XI 442)
> To pursue virtue in a perfect manner [means] never to lack the will to undertake and carry out whatever [one] judges to be best. (*Passions*, CSM I 384, AT XI 446)
> We always do our duty when we do what we judge to be the best, *even though our judgement may perhaps be a very bad one* (*Passions*, CSM I 391, AT XI 460, my emphasis)

This last part, "even though our judgement may perhaps be a very bad one", which testifies to human fallibility and the finitude of human intellect, shows that the ultimate ground of the good is human free will. Therefore, whatever one judges to be the best is the supreme universal value that has to be pursued. In the case one conducts his intellect according to the right rules for directing the mind, what one judge to be good is really the good. The will cannot choose evil[47] while the intellect presents clearly and distinctly what is good:

47 "Were I always to see clearly what was true and good, I would never deliberate about what is to be judged or chosen." (Meditations, RA 125, AT VII 58)

For, given that our will tends not to pursue or flee anything unless our understanding represents it to the will as either good or bad, *it suffices to judge well in order to do well*, and to judge as best one can, in order also to do one's very best, that is to say, to acquire all the virtues and in general all the other goods that one could acquire; and, when one is certain that this is the case, one could not fail to be contented. (*Discourse*, RA 58, AT VI 28, my emphasis)

Only the ignorance than came from the finitude of human intellect can determine our will to choose what is not good, but not because it wills the evil but because it cannot see the ultimate good, the purpose established by God. This lack of knowledge that derives from the finitude of the human intellect does not mean that the domain of values disappears but only that it is redesigned in such a way that it is instituted by the *ego cogitans*. And because what is useful for the well-being of humanity is judged to be good, utility becomes a genuine and autonomous value. Bacon still maintains that material utility is relative to the eternal plan of God, while Descartes considers that material utility is essential for the human earthly well-being and creates an autonomous system of values, in which utility occupies a central place. Human beings have to pursue "those things that are most useful to us":

It seems to me that only two things are required in order to be always disposed to judge well: one is the knowledge of the truth, and the other is the habit of remembering and acquiescing to this knowledge every time the occasion requires. But since only God knows all things perfectly, it is necessary that we content ourselves in knowing those things that are most useful to us. (To Elisabeth, 15 September 1645, LS 111, AT IV 291)

Among "those things that are most useful to us" one finds, in the *Discourse*, medicine and mechanics, i.e. technology:

It is possible to arrive at knowledge that would be *very useful in life*: … the invention of an infinity of devices that would enable one to enjoy trouble-free the fruits of the earth and all the goods found there, … the maintenance of health, which unquestionably is the first good and the foundation of all the other goods of this life. (*Discourse*, RA 74, AT VI 61-62)

Thus, Descartes gives a metaphysical foundation for utility and, consequently, for technology. But technology is not worth-pursuing only for material benefits. Science can progress only with the data obtained from an almost infinite number of experiments. Moreover, metaphysics itself is backed up by technology because with the help of the technologies of vision it can be shown that the material world is composed of nothing but shape and movement.

3.2. Technology of Vision

The importance of scientific images is noticeable in the Renaissance, but Descartes takes it to the climax. During the Renaissance there are two main uses of illustration in scientific and technological books. The first one, common to the *Theatres of Machines* and other technical works, employs images to depict the functioning of a given machine or of a simple mechanism. The second use is the one that appears in Vesalius' *De humani corporis fabrica* in which the human body is faithfully depicted. Descartes synthesises the two uses and presents the human body as a machine composed of simple mechanisms. In addition, every complex organism is conceived as a machine composed of simple mechanisms. Both the human body and the rest of the material world function mechanically and the mechanisms can be visualized. Moreover, he implies that, regarding physics, things that cannot be perceived and cannot be deduced with certainty do not exist. Consequently, the technologies of vision become very important both metaphysically, because they show what are the basic components of the material world and that things such as intentional species, weight and void, do not exist, and scientifically, because they show how these basic components are assembled together and how they function.

The technological enhancement of vision provides us much important information about the world and surpasses the power of senses and even of the imagination. In certain ways, the technological enhancement of vision offers a much more reliable image of an object than do the unaided senses.

> The conduct of our life depends entirely on our senses, and since sight is the noblest and most comprehensive of the senses, inventions which serve to increase its power are undoubtedly among the most useful there can be. And it is difficult to find any such inventions which do more to increase the power of sight than those wonderful telescopes which, though in use for only a short time, have already revealed a greater number of new stars and other new objects above the earth than we had seen there before. Carrying our vision much further than our forebears could normally extend their imagination, these telescopes seem to have opened the way for us to attain a knowledge of nature much greater and more perfect than they possessed. (*Optics*; CSM I 152; AT VI 81)

The telescopes enable us to perceive more than the imagination could create out of sense perception and give a greater and more perfect knowledge of nature. One of the important things in the use of technologies of vision is the fact that the images offered by telescopes are to a greater extent in accord with reason than the images offered by unaided senses. Descartes shows that there are two images of the sun, one "quite small", "drawn from the senses", and one "several times larger than the earth", "derived from astronomical reasoning, that is, elicited from certain notions that are innate in me" (*Meditations*, RA 115, AT VII 39). Only the second one is real and this is in accordance with the image offered by technologically enhanced vision.

> Descartes' valorisation of astronomical observation and its equation with reason and innate ideas reveals the technological character of his thought. The world of experience is reduced to illusion, whereas the mathematical-optical world view more intimately corresponds to and reflects the nature of human reason. (Judovitz, 1993, 79)

In the case of the sun, its real properties can be deduced from the first principles by reasoning alone[48] but, for the more particular things, observations and experiments are necessary because they cannot be deduced with sufficient certainty from those principles. Consequently, the development of visual technologies becomes very important for the knowledge of material world: "inventions which serve to increase [sight's] power are undoubtedly among the most useful there can be." (*Optics*; CSM I 152; AT VI 81)

As already shown, the most important characteristic of technological inventions is their usefulness. This claim does not represent a novelty, but what is important in the Cartesian conception is the scope of this usefulness. Telescopes are useful for theoretical knowledge. Technological devices are not used anymore only to make human life easier but to redesign the entire edifice of knowledge. On technological inventions rest, as also for Bacon, the theoretical superiority that Moderns have over Ancients: "these telescopes seem to have opened the way for us to attain a knowledge of nature much greater and more perfect than they possessed." (*Optics*; CSM I 152; AT VI 81) Moreover, technological devices come to occupy a central place in the theoretical endeavour because they are not only handmaids of science but the necessary condition of its development.

Visual technology will help us to see those spatial arrangements that build up the entire nature. This will certainly improve our knowledge of the world beyond the wildest imagination of the ancients. Moreover, it will probably give humans the capacities to manipulate those minute parts, contributing thus to a further development in technology.

> And, so that the difficulty which you may find in constructing these last telescopes does not discourage you, I wish to advise you that although their use is not as

48 "First, I have tried to find in general the principles or first causes of all that is or can be in the world, without considering anything but God alone, who created the world, and without deriving these principles from any other source but from certain seeds of truths that are naturally in our souls. After that I examined what were the first and most ordinary effects that could be deduced from these causes; and it seems to me that by this means I had found the heavens, stars, an earth, and even, on the earth, water, air, fire, minerals, and other such things that are the most common of all and the simplest, and, as a consequence, the easiest to know" (Discourse, RA 74, AT VI 64)

> attractive as that of those others (which seems to promise to lift us into the heavens and to show us, there on the planets, bodies that are as unique and perhaps as diverse as those we see on the earth), I nevertheless judge them much more useful, because by means of them we will be able to see the diverse mixtures and arrangements of the small particles which compose the animals and plants, and perhaps also the other bodies which surround us, and thereby derive great advantage in order to arrive at the knowledge of their nature. For already, according to the opinion of many philosophers, all these bodies are made from nothing but the parts of the elements, differently mingled together; and according to my view, their total nature and essence - at least of those that are inanimate - consists in nothing but the size,[49] shape, arrangement and movement of their parts. (*Optics*, PO 172, AT VI 226-227)

One of the reasons for which this type of telescope – in fact Descartes described here the still unknown compound microscope – is very important for Descartes is its capacity to confirm Cartesian ontology. By using this telescope, we will be able to see what Descartes' metaphysics deduced by reasoning alone, that matter is nothing but bodies whose nature consists only of size and shape and are arranged in specific configuration and move according to simple mechanical laws. The microscope image of plants, animals and humans will reveal nothing but shape, size and movement, thus proving empirically his ontological claims.

This new perception, technologically enhanced, can eventually reach the level of viewing the minute particles of space-matter that compose all bodies, including human bodies. The "organs minute enough to escape our senses" will become visible and in this way we will have the possibility to represent in geometrical drawings the entire machine of the human body. That should be the first step in the construction of an artificial man. Those drawings will be the blueprint, the design or the description that craftsmen need to proceed to actual construction. Of course, a further problem, untouched by Descartes, is the manipulation by craftsmen of such minute parts.

The *Optics* can be read from different perspectives. From a metaphysical point of view, it explains what light and vision are, which kind of entities exists and which do not: for

49 The quoted translation gives here the term "weight" for the French term "la grosseur." As mentioned earlier, weight is not a genuine quality of bodies.

example Descartes implicitly rejects here the intentional species.[50] From a scientific point of view, the *Optics* provides the laws of refraction and reflection and also the physiology of sight. Given the importance of technologically enhanced perception we can interpret the *Optics* as, in part, a technological treatise, which aims at expounding the construction of visual instruments. Assuming the technological perspective, the first six discourses of the *Optics* provide the scientific and metaphysical background, the necessary theoretical instruments for technology. This background makes possible a clear and comprehensive treatment of technology.

In the seventh discourse of his *Optics* Descartes inquires into the technological problems and solutions of enhancing human vision. The *Geometry* and *Optics* are not only examples of applications[51] of Descartes' method but the necessary instruments in pursuing both science and technology. The former, because matter is nothing but spatial parts that can be fully described and rearranged geometrically;[52] the latter, because it allows us to improve the perception of the actual configuration of matter and to prove the metaphysical description of the material world. After describing in the first six discourses of the *Optics* the process of vision, Descartes discusses in the last four parts the technology of enhancing vision. In these last parts of the *Optics*, "The means of perfecting vision", "The shapes that the transparent bodies must have in order to deflect rays through refraction in all the ways which are useful to vision", "The description of telescopes" and "The method of cutting lenses", Descartes is concerned primarily with technology. From their analysis we can extract a great part of the Cartesian conception of technology.

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50 For the clash between Cartesian and Aristotelian metaphysics in the *Optics*, the exchange between Descartes and Fromondus is very instructive. See especially Fromondus' objections 4 to 9 (AT I 404-406) and Descartes' replies (AT I 416-420).

51 Descartes did not compose the *Discourse on Method* as the main work for which the three essays are just applications, but he designed it only as an introduction to his essays which otherwise would be quite heterogeneous after the suppression of the *World*, i.e. the complete system of his science.

52 Despite Descartes' programmatic praise of mathematics, he uses almost no mathematics in discussing physical phenomena.

> Now, that we have sufficiently examined how vision operates, let us summarize in a few words, re-examining all the conditions which are required for its perfection, so that, considering in what manner it has already been provided to each by nature, *we can make an exact enumeration of all that still remains for art to add to it*. We can reduce all the things that must concern us here to three principles, namely the objects, the internal organs which receive the impulses of these objects, and the external organs which dispose these impulses to be received as they ought. (*Optics*, PO 114, AT VI 147-148, my emphasis)

Vision depends on three factors: the objects to be seen, the external organs that by transformations specific to optical geometry create on the retina an image at scale of the objects, and the internal organs that transfer this image – not as an image but as nerves' movements – to the pineal gland. The last four parts of the *Optics* is dedicated to the improvement of external organs. The objects are not to be modified, because the knowledge of them is at stake. The modification of internal organs in order to faithfully transfer the retinal image seems to be, again, morally, i.e. for all practical purposes, impossible.

> Then, concerning the interior organs, which are the nerves and the brain, it is also certain that we could not add anything to their fabric through art; for we could not make a new body (*Optics*, PO 114, AT VI 148)

In this passage, we take certainty to represent the above-mentioned moral certainty which means that, given contemporary scientific and technological knowledge, a reconstruction of nerves or brain is not to be expected. The problem of "making a new body", the problem analysed in the beginning of this chapter, is raised again by Descartes as a desirable, although impossible, purpose of technology. And again Descartes takes a mild position regarding the impossibility of this technological problem: "for we could not make a new body; but if the doctors can help here in some way, this does not belong to our subject." (*Optics*, PO 114, AT 148) Medicine, which is one of the branches of mechanical geometrical physics along with mechanics and ethics, may be able, in Descartes' view, to enhance the internal organs. Given the fact that medicine is the science and art of the mechanical body, this enhancement can be reduced to mechanical considerations. The difference between mechanics, in this case optics, and medicine is that while the former constructs new objects that do not exist in nature, medicine deals with the perfection of natural organs. Medicine's aim is to perfect natural organs, to render them more suitable for their natural purposes.

> But these things belongs rather to medicine, whose purpose is to remedy the deficiencies of sight through the correction of natural organs, than to *Optics*, whose purpose is only to minister to the same deficiencies through the application of other organs that are artificial. (*Optics*, PO 126, AT VI 164-165)

Thus, Descartes engenders the idea of a medical technology that could improve the internal structure of the human body, but he does not directly address this issue, despite the fact that he already composed, five years earlier, in 1632, the treatise on man, in which he explained the workings of internal organs, muscles, nerves, etc., on the model of artificial fountains. Certainly, from those considerations regarding the workings of the machine of human body, one can propose some possible improvements. But, given the state of contemporary technology, they are most probably morally impossible. And Descartes does not offer such proposals because he lacks most of the relevant empirical data, data which he tried to acquire during his entire career through dissections of plants and animals.

Nevertheless, if one analyses the optical system of sight in Descartes' terms, it becomes evident that the technology of vision must be supplemented with medical technology in order to realize Descartes' aim of perceiving the corpuscles of space-matter. The nerves that receive light are influenced by more than a single ray and the image is blurred for very small or distant objects. Therefore, however perfect our telescope technology may be, it cannot provide the desired results given the distortions caused by the magnitude of nerves that cannot pick up the light rays individually.

> The back of our eye is covered by the ends of optic nerve-fibres which, though very small, still have some size. Thus each of them may be affected in one of its parts by one object and in other parts by other objects. But it is capable of being moved in only a single way at any given time; so when the smallest of its parts is affected by some very brilliant object, and the others by different objects that are less brilliant, the whole of it moves in accordance with the most brilliant object, presenting its image but not that of the others. ... For often the things depicted in such pictures appear to us to be farther off than they are because they are smaller, while their outlines are more blurred, and their colours darken or fainter, than we imagine they ought to be. (*Optics*, CSM I 174-175, AT VI 146-147)

Leaving aside the problem of the internal organs of visual perception, Descartes concentrates upon the enhancement of vision by external prosthesis.

> Thus, only the external organs – among which I include all the transparent parts of the eye, as well as all other bodies that we can place between the eye and the object – remain for us to consider. (*Optics*, PO 114, AT VI 148)

Descartes maintains that almost always natural organs are better than artificial ones, on the grounds that the first emerge through the application of the simplest rules given by God, while the latter are arrived at by the human search for some local enhancement that cannot take into account all the complexity of nature.

> We will always have to take care, when we thus place some body before our eyes, that we imitate Nature as much as possible in all the things that we see she had observed in constructing them; and that we lose none of the advantages that she has given us, unless it be to gain another more important one. (*Optics*, PO 117, AT VI 152)

Descartes repeats the ancient theme of art that imitates nature but for different reasons. Nature does not differ essentially from the artisan's mechanics but she developed as perfectly as possible given the simple laws of mechanics and taking into account all contingencies involved. Therefore, usually, the natural solution of bodies' configuration is beyond human design possibilities because of the huge amount of information needed. Still, in certain particular cases, natural abilities can be extended by technological prosthesis even against the natural configurations, if in doing so important needs of humans are to be met. Moreover, in specific domains, the technological inventions render the natural mechanism useless, as the prosthesis is able both to replace all natural features and even to add some new ones.

> When we use these telescopes of which we have just spoken, inasmuch as they render the pupil useless, and inasmuch as the opening through which they receive the light from outside performs the function of the pupil, it is also this opening which we must dilate or contract, according as we wish to render sight stronger or weaker. (*Optics*, PO 123, AT VI 160)

3.3. A New Science: Technological Design

The elevated status of technology changes also its scope. The scope of technology, of mechanical arts mainly, until Bacon and Descartes, was the production of useful material things. Technology was the domain of craftsmen. Descartes sees as the most important characteristic of technology not the production itself but the invention, the design of new technological devices. And because the invention of new technological devices rests on the knowledge of the first principles and the knowledge of natural philosophy, the most important part of technology, namely the design, comes to be a proper endeavour of the natural philosopher. The most important part of technology is not the actual production, which can be performed by almost everybody, but the invention of the needed artefacts. The production of designed artefacts is less important and does not require theoretical skills but only attentive following of the designer's instructions.

> Should anyone desire to possess everything relevant to this, such as instruments, machines, automatons, and so on, even if he were a king he could never, by spending all the treasure in the world, afford everything he would require. And in fact there is no need for all this; it is enough to know the description of the relevant instruments, so

that when the occasion demands it, we can make them ourselves or have them made by craftsmen (To Hogelande, 8 February 1640; CSMK 145; AT III 724)

Moreover, the design process is purely intellectual, since it involves the formation of the idea of the machine in the mind of the inventor. Such an idea can have only three causes:

either some such real machine has been seen beforehand, in accordance with whose likeness the idea has been formed, or a great knowledge of mechanics, which is in this intellect, or perhaps a great subtlety of mind by which one might even invent the machine without any previous knowledge. (*Reply by the Author to the First Set of Objections*, RA 150, AT VII 104)

The first case is not about inventing something but merely remembering a previous experience, and the last case can be thought of as good fortune. Both situations are rejected by Descartes as improper ways of creating technological devices (*Optics*, AT VI 81). Therefore only the pure intellectual creation of the idea of the machine based on the knowledge of theoretical mechanics can be considered genuine invention and the proper way of doing technology.

The status of craftsmen remains almost the same as for Aristotle. Their importance rests on the skilful manipulation of instruments in the process of transforming raw materials into artefacts. Besides the skills acquired in the manipulation of instruments, their work is nothing else than mindless production. Descartes insists on the weak intellectual capacities of craftsmen in the beginning of the *Optics*, when he affirms that his description of artefacts is so simple, without involving theoretical knowledge, so that a craftsman could make them.

And since the construction of the things of which I shall speak must depend on the skill of craftsmen, who usually have little formal education, I shall try to make myself intelligible to everyone; and I shall try not to omit anything, or to assume anything that requires knowledge of other sciences. (*Optics*; CSMK I 152; AT VI 82-83)

The same lack of importance of craftsmen for the development of technology is reaffirmed in a letter to Mersenne in which Descartes distinguishes between practical and theoretical issues in creating artefacts and leaves out from his description the practical concerns.

> As for your advice about what I ought to add to my Optics concerning old men's eyeglasses, I think I have included enough on the theory of this on page 123; and *as for the practical questions, I leave that to the craftsmen*. (To Mersenne, 15 November 1638; CSMK 130; AT II 447, my emphasis)

Descartes' distinction between practical and theoretical issues of technology has established a division between design and effective production of artefacts. Design involves both invention and a large amount of theoretical knowledge about nature. The theoretical knowledge needed in the pursuit of technology was already mentioned in Agricola's *De re metallica*, but he did not make the distinction that Descartes draws between designer and craftsman. Nicholas of Cusa pointed to the other aspect involved in technology, namely human inventiveness, but he did not link this capacity to theoretical knowledge. Descartes, by contrast, is aware of both the importance of human inventiveness and the necessity of a theoretical background in developing technology. He transforms technological inventiveness, which nowadays is known as technological design, into an autonomous subdivision of technology, and assigns its pursuit to the natural philosopher. As for the production of artefacts, it represents the easiest part of technology, so that Descartes can write to Hogelande that "we can make them ourselves or have them made by craftsmen." (To Hogelande, 8 February 1640; CSMK 145; AT III 724)

Like Bacon, Descartes criticize the fact that previous inventions were the product of chance and did not benefit from the help of the scientific endeavour: "But to the shame of our sciences, this invention, so useful and admirable, was found in the first place only through experiment and good fortune (*l'expérience et la fortune*)." (*Optics*, PO 65, AT VI 81) Mere chance or even experiments that are not based on scientific knowledge and valid principles are to be rejected as ways of technological development. This is the reason why Descartes proposes and engages in a scientific-based technological design. The invention of new devices is a much important issue for him and it should be dealt with inside the philosophical domain. He views telescopes as one of the most important inventions and its development as a desirable purpose for science and philosophy.

> In the *Dioptrics* I intended to show that we could make sufficient progress in philosophy to attain by its means a knowledge of those arts useful to life, because the invention of the telescope, which I there explained, is one of the most difficult ever attempted. (*Principles*, Preface; RA 228, AT IX 15)

Moreover, even after having been invented, the telescopes did not raise the curiosity of philosophers so that a proper study of them has not yet been conducted.

> And on this pattern alone, all the others that we have seen since then made were done, without anyone yet, to my knowledge, having sufficiently determined the shapes that these lenses must have. (*Optics*, PO 66, AT VI 82)

Descartes takes upon himself the burden of offering the necessary scientific background of this invention, and thus helping the further development of the technology of vision. He is aware of the importance of technological inventions and, on the other hand, of their slow advancement, and for this reason he makes the discussion of enhancement technology of vision an important part of his work.

> But inventions of any complexity do not reach their highest degree of perfection right away, and this one is still sufficiently problematical to give me cause to write about it. (*Optics*, CSM I 152; AT VI 81)

From Descartes' division of the last part of *Optics*, the four discourses that engage with the construction of telescopes, the domain of technological design can be subdivided into four areas of research. First, it is the inquiry into the human needs that are to be fulfilled and the aims of the technological devices. In this particular case, it is necessary to enhance human vision with instruments that would make possible observations of very distant or minute objects. Second, the designer should analyse the proper materials that would serve his purposes. The material properties as well as the specific geometrical forms have to be examined so that they best fit the intended use. In doing so, both experimental information about specific ways in which different materials reflect light as well as geometric descriptions concerning the patterns of light transmission in certain mediums are to be provided. Third, the proper design process deals with the actual geometrical form of the device. This part integrates the previous analysis of practical needs, materials and scientific knowledge involved in the realization of a blueprint of the specific device. The forth and last part of the design process consists of the descriptions of the procedures required to produce the device. In the case of telescopes, Descartes describes step by step the procedures that the craftsmen should follow in order to cut the lenses and arrange them such as the desired result obtains. He even designs a machine for cutting lenses, thus rendering some of artisans' work unnecessary.

3.4. Mechanical Technology

Descartes singles out the technology of vision as very important both for science, because it provides empirical data, and for metaphysics, because it can prove some of Descartes' own claims about the material world. The other main part of technology that he considers is mechanical technology, the construction of machines, which, as Martial Gueroult (1968, 236-237) observed, represents the other starting point through Descartes' philosophy, that begins with the machines to reach metaphysics. The first starting point is metaphysics which is nothing else than the foundation of science and science is developed only for "the invention of an infinity of devices that would enable one to enjoy trouble-free the fruits of the earth and all the goods found there." (*Discourse*, RA 74, AT VI 62)

For Descartes, technology ceases to be an art and becomes an applied science, more precisely the practical side of physics.

> It has always been known, for example, that wind and water can move bodies with great force; but the ancients did not sufficiently investigate what the effects of these causes could be, and so did not apply them, as they have since been applied in mills, to many things which are very useful to human society and notably ease the burden of human labour, and which ought to be the harvest of true physics. Consequently we can say that the first sort of problem, in which causes are sought by way of their effects, constitute the entire *speculative side of physics*, while the second sort of problem, in which effects are sought by way of causes, constitutes the entire *practical side*. (*Rules*[53], CSM I 77, AT X 471-472, my emphasis)

As a consequence, the craftsman's workshop ceases to be the seat of technology, and the proper place for doing technology becomes the philosopher's desk. Once the speculative examination of nature is done, through deduction from the first principles added by observations and experiments, the philosopher has to apply this knowledge by designing machines that are "very useful to human society" and "ease the burden of human labour." Technology is not primarily the product of artisanship but a part of science. Along physics, as the science of matter, mathematics is also crucial for the development of technology. "Mathematics has some very subtle stratagems that can serve as much to satisfy the curious as to facilitate all the arts and to lessen men's labor." (*Discourse*, RA 48; AT VI 6) The mechanical art is just a blind endeavour without physics and mathematics, and Descartes

53 This fragment is from the second edition of Antoine Arnauld and Pierre Nicole's *Logic or the Art of Thinking* (1664). In chapter 2 of book 4 they paraphrase the thirteen rule with an additional fragment that correspond to a missing part from available manuscripts of Descartes' *Regulae*.

harshly condemns the common practice of mechanics that is not based on science. “That is what many do, who study mechanics apart from physics, and rashly manufacture new instruments for the production of motions.” (*Rules* V, RA 11; AT X 380)

Descartes based the entire endeavour of mechanical technology on a very simple principle that is sufficient, by deriving its consequences, for the design of every useful machine.

> The invention of all these machines is based on a single principle, which is that the same force that can raise a weight of, say, 100 pounds to a height of two feet can raise a 200-pound weight to a height of one foot, or a 400-pound weight to a height of six inches, and so on, supposing such a force is applied to it. (To Huygens, 5 October 1637; an account of the machines by means of which a small force can be used to lift heavy weights; CSMK 66-67; AT I 435-436)

In the same letter to Huygens, Descartes explains the physics of all simple mechanisms that are needed for the construction every possible machine, those being the pulley, the inclined plane, the wedge, the cog-wheel, the screw and the lever. He accepts that there are many other things to be considered in a comprehensive treatment of mechanics but he is confident that the knowledge of these six simple mechanisms is more than sufficient for the construction of every machine.

> It would be useful if those who devote themselves to inventing new machines knew no more about this subject than the little I have written here, for they would be in no danger of going wrong on their own account, as they often do when they assume other principles. Moreover the machines of which I have given an explanation can be applied in all sorts of different ways. There are countless other things to consider in mechanics which I am saying nothing about, as I have filled up my three sheets of paper, and you did not ask for more. (To Huygens, 5 October 1637; CSMK 73; AT I 447)

Descartes based technological design, as well as his physics and metaphysics, on very simple principles and he is confident that by applying these principles in the drawing of machines, by building them up from these simple mechanisms and artfully drawing the relations between them, the result will be as clear as possible. Such a drawing will be understandable by everyone, without prior knowledge, and every artisan will be able to construct the depicted machine. “And all this is, it seems to me, so clear that one need only open one’s eyes and consider the diagrams, to understand it.” (*Optics*, PO 141, AT VI 185)

Although the design, the drawing of a machine, is clear and represents all that is required in order to produce the desired artefacts without further knowledge, the actual production requires the skill of artisan. Nevertheless, the skill is acquired through practice and it does not affect the centrality of design.

> If craftsmen cannot immediately carry out the invention explained in the *Dioptrics*, I do not believe one could say, on that account, that it is bad; for, inasmuch as skill and practice are needed to make and adjust the machines I have described, without any detail being overlooked there, I would be no less astonished if they were to succeed on the first try than if someone were able to learn in one day to play the lute with distinction simply because he had been given a good score. (*Discourse* VI, RA 81; AT VI 77)

As Descartes mentions many times in his writings, the actual production is the least important thing in a technological endeavour because it can be realized by everyone who possesses a good drawing of the desired device and have some manual skills. Descartes conceives technology as being to a large extent science not by a mere reconsideration of the status of the well-established *ars*/*τέχνη* domain, the domain of creating useful and beautiful artefacts by craftsmen, but by inventing a new realm at the previously thin boundary between science and *ars*/*τέχνη*. The domain of material production, designated by the term *artes mechanicae* during the Renaissance, is transformed by Descartes into the domain of mechanics, comprising both the science of mechanics and the actual construction of mechanisms. Any form of useful material production, i.e. technology, is subsumed under the heading of mechanics understood in the modern sense as the pure and applied science that deals with the motion of bodies. Technology has thus a very wide domain of application, since in nature there are no qualities that cannot be reduced to the motion, shape and arrangement of bodies. It can, at least theoretically, reproduce every aspect of nature, from human bodies to rainbows, and produce an infinite number of useful devices. Also, technology overlaps with science because all its aspects can be fully described in terms of physics and requires scientific knowledge and scientific investigation for its development. The bodily skills and the practical knowledge, which were essential for the ancient definition of useful material production, become unnecessary for the modern scientific approach.

The most important aspect of modern technology is the relationships established between it and science. For the Ancients and the subsequent tradition until the Renaissance, technology is a type of endeavour, or even knowledge as for Aristotle, that has little to do with theoretical knowledge.

In Descartes' work we can discover three main themes that concerned this redefinition of the relation between science and technology. First, as previously mentioned, technology as technological design becomes science proper, Descartes rejecting the old opposition between theoretical knowledge and art. Second, technology becomes a precondition for science, since the capacity of pursuing knowledge is conditioned by technological artefacts used in experiments. Thirdly, Descartes changes the aim of natural philosophy, from the knowledge of the world *per se*, at which the Schools' aimed, to the knowledge of the world for the construction of useful artefacts.

> For these notions [regarding physics] made me see that it is possible to arrive at knowledge that would be very useful in life and that, in place of that speculative philosophy taught in the schools, it is possible to find *a practical philosophy*, by means of which, knowing the force and the actions of fire, water, air, the stars, the heavens, and all the other bodies that surround us, just as distinctly as we know the various skills of our craftsmen, we might be able, in the same way, to use them for all the purposes for which they are appropriate, and thus render ourselves, as it were, *masters and possessors of nature*. (Discourse VI; RA 74; AT VI 61-62; my emphasis)

4. Conclusion

Descartes establishes in his writings some of the most important characteristics of modern technology. He conceives of utility as a genuine value based on the centrality of *ego cogitans*, creates the category of technological design as the most important and purely scientific part of technology, and establishes the unbreakable symbiosis between science and technology at the expense of manual skills and practical knowledge.

Chapter IV

Bacon's and Descartes' Legacies

Bacon and Descartes represent a radical change in the history of philosophy. Although their principal aim is the reformation of philosophy as the basis for a scientific approach toward reality, they are the first philosophers to consider technology as an essential part of their endeavour. The emphasis that they put on technology, which includes the indissoluble link between technology and the investigation of nature, is one of their most important legacies. Moreover, the centrality of technology in their systems tremendously influenced their way of pursuing philosophy and the content of their ontology and metaphysics, which has in turn influenced later philosophy. In this last chapter I will compare their philosophies with an emphasis of the views that pertain to technology; and I will then analyse their common legacy regarding technology, a legacy that remained unshaken until the second half of the twentieth century.

1. Bacon's and Descartes' Project

1.1. Bacon's Influence

It is certain that Descartes was aware of Bacon's works, since he mentions them in his correspondence. Although Descartes is very reluctant to admit that he was influenced by others, he highly regards Bacon's works, his method and his scientific aims. As the letter from

Huygens, dated 25 January 1642, proves, Descartes admired Bacon and regretted the fact that he could not continue his work: "I remember that that was one of the reasons you were telling me one day to regret the death of Baron Verulam: because he was so careful and liberal in particular experiments." (AT III, 778-779) There are three more mentions of Bacon in Descartes' extant letters, each of them to Mersenne, showing Descartes' admiration of Bacon's method. These occurrences allow us to identify the possible works that Descartes may have consulted and to estimate the extent of Bacon's influence on Descartes.

In the letters to Mersenne (January 1630, 23 December 1630 and 10 May 1632) Descartes mentions some of the things that he takes from Bacon. One of them is the list of qualities extracted either from *Novum Organon* or from *De augmentis scientiarum*:

> Thank you for the qualities you have derived from Aristotle; I had already made another larger list, partly derived from Verulam and partly from my own mind, and this is one of the first things I will try to explain, and it is not as difficult as you might think; because if the foundations are laid, they will follow by themselves. (Descartes to Mersenne, January 1630, AT I 109)

In the other two letters to Mersenne, Descartes speaks about Bacon's method of doing experiments, to which he has no objections and doesn't need to make any adjustments.

> You want to find a way to make useful experiments. To this I have nothing to say other than what Verulam had written, except that, without being too curious to find all the little particulars concerning a thing, first it is necessary to make the general collections of all most common things ... As for the most particular things, it is impossible not to do a lot of unnecessary and even false [experiments], unless you know the truth about these things before doing them. (Descartes to Mersenne, 23 December 1630, AT I 195-196)

Here Descartes expresses his deductive approach to experiments, i.e. the fact that, *pace* Bacon, one has to possess the first principles of science before doing any experiment. But once these principles are known, the best method to pursue experiments is Bacon's.

In the letter to Mersenne from 3rd of May 1632 Descartes refers probably to Bacon's *Parasceve ad Historiam Naturalem et Experimentalem*, where the latter discusses the utility of a history of heavenly bodies described with all their possible characteristics, and advocates the pursuit of Bacon's program of research:

> It would be very useful if some such person were to write the history of celestial phenomena in accordance with the Baconian method and to describe the present appearances of the heavens without any explanations or hypotheses, reporting the position of each fixed star in relation to its neighbours, listing their differences in size and colour and visibility and brilliance and so on. … Such a work would be more generally useful than might seem possible at first sight, and it would relieve me of a great deal of trouble. (Descartes to Mersenne, 3rd of May 1632, CSMK 38, AT I 251-252)

If for the experiments Descartes does not fully accept Bacon's method of rejecting all assumptions and principles, he nevertheless appreciates his way of making observations. This is somehow curios because, while Bacon distinguishes between observations and experiments and assigns to them two different histories, Descartes uses only one word, *expérience*, to refer to both.

The last mention of Bacon appears in a published work of Descartes', in the first prefatory letter to the *Passions of the Soul*, written by an unknown "Parisian friend", who is said to have edited the volume. As the story presented by these letters goes, the prefatory letters appeared without Descartes' first reading and approving of them, Descartes allowing his "friend" to publish whatever he thought appropriate. Such an approach toward his own publications is uncharacteristic of Descartes, who was extremely cautious in his choice of the material to be published, sometimes even discussing with Mersenne the choice of the most appropriate words. In these prefatory letters, which give a general assessment of Descartes' works as aimed to be beneficial to all mankind by providing a science-based technology and medicine, Descartes is compared with Bacon and his similar technological aims are emphasized:

> I've also seen the *Instauratio Magna* and the *Novus Atlas* of Chancellor Bacon, who seems to me to be, of all those who wrote before you, the one with the best thoughts concerning the method that should be used to guide Physics to its perfection; but all the income of two or three of the most powerful Kings on earth would not suffice to carry out all the things he needs for this end. ... I don't think you need as many sorts of experiments as he imagines since you can make up for many by your ingenuity and by the knowledge of the truths you've already found. (*Passions*, Prefatory letters, SV 14, AT XI 320)

The author of this prefatory letter has not been identified and the letter did not acquire an important role in the secondary literature concerning the overall aims of Descartes' philosophy. However, Hiram Caton, in his article "Descartes' Anonymous Writings: A Recapitulation" (1982, 307-308), has argued that the anonymous Parisian is Descartes himself. The correspondent claims a complete ignorance of the prefaced work but "he ... copies Cartesian terminology and produces accurate paraphrases of the unseen work." The claim of complete ignorance excludes Clerselier as the possible author, because in the letter from 23rd of April 1649 Descartes writes to him that "I have been indolent in revising it and adding the things you thought lacking, which will increase its length by a third" (AT V 354, CSMK 376). This proves that Clerselier saw at least two thirds of the work. The other proposed author of the letters was Picot, who is excluded by Caton because he "only supervised its *distribution* in Paris, the printing itself being done by Elzevier in Amsterdam [and] Descartes dispatched the *printed* text to Paris." (Caton, 1982, 307) The *Passions* were published in Amsterdam and none of Descartes' correspondents in Paris could have supervised the publication. There is also a tension between the fact that Descartes writes to Carcavi in 17 August 1649 (AT V 392) that he has not yet send the *Passions* to his friend, and the fact that the last prefatory letter that supposedly accompanied the work is dated 14 August

1649 (AT XI 326). Moreover, the above-quoted passage from the prefatory letter, that claims the superiority of Descartes' method because it reduces the number of required experiments, is similar to the view expressed in the letter to Mersenne from 23 December 1630. But if this letter is Descartes' own then he is a declared Baconian philosopher in what concerns the aims of philosophy: the practical, i.e. technological, progress of mankind based on the new science. As Caton (1982, 309) puts it, this preface "confirms the whispered remarks of the *Discourse* that metaphysics is only a detour, a pause made 'once in a lifetime' on the way to the real goal of philosophy - a mathematical, technological physics." If we read the letter as written by Descartes himself, we see that it is programmatic, that it insists on the necessity of complementing the rationally-deduced physics with many and costly experiments that will be extremely useful for "this life", that it insists on a similar development of medicine and that Descartes acknowledges his debt to Bacon. From this perspective we can see Bacon's writings on technology as a good introduction to Cartesian philosophy. Descartes is thus, on his own account, a Baconian with a better method:

> Bacon advocates a program that his own method could never achieve: Descartes is the Baconian with the necessary means. ... Descartes has not usurped Bacon's place nor is he Bacon's rival; he is a student who outstripped his teacher in the one essential way by contributing the essential means to the project first set forth by the teacher. (Lampert, 1993, 154)

The quoted letters to Mersenne allow us to see the similarity between Descartes' and Bacon's research projects and methods, as well as the works of Bacon with which Descartes was familiar, but they also show their methodological differences. The prefatory letters also corroborate the claim that Descartes was familiar with Bacon's works, that he admired his method and that their aims were similar. The works that are most probably referred to in Descartes' correspondence are: *Parasceve ad Historiam Naturalem et Experimentalem*, *Novum Organon*, both published in 1620; *De augmentis scientiarum*, published in 1623; and possibly *The New Atlantis*, published in Latin in 1633 with the title, mentioned in the letter, of *Novus Atlas*.[54] In all of these works, Bacon presents his conception of technology, its aims, its methods and its scope.

Given Descartes' affinity with and admiration for Bacon, it would come as no surprise if many ideas concerning technology are similar in both authors. Descartes' emphasis on the importance of technology as well as the new relation between science and technology could be a consequence of Bacon's influence. Given the fact that Bacon and Descartes diverge on other ontological and scientific issues, their respective conceptions of technology are somewhat different; but the main characteristics of technology that they propose are similar, and those could be regarded as a strong nucleus infused into modernity through their philosophies: the common aim of transforming man into the possessor and master of nature through technology, the necessity of a new medicine, the necessity for experiments in science, etc.

Both Bacon and Descartes were considered by later philosophers as the great reformers of philosophy, especially by the Enlightenment, which recognized the importance of science and the mechanical arts for the development of humanity through technology. The Encyclopaedists highly regard their trust in the mechanical arts as the source of human progress. Bacon's and Descartes' influence is visible from the title of the Encyclopaedists' project, which emphasizes science and the mechanical arts: *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers*. It was the first general encyclopaedia to devote much attention to the mechanical arts. In his famous *Preliminary Discourse* to the *Encyclopaedia* Jean Le Rond d'Alembert expounded the Enlightenment values and foundations and mentioned Bacon as the most important thinker that, "born in the middle of the most profound night" for science, brought light into philosophy. Bacon's division of

54 The title is absurd because it refers to mountain Atlas and not to the lost island that Bacon had in mind. Earlier, in 1631, it was translated into French as *L'Atlas Nouveau*.

human knowledge is the model on which the *Encyclopaedia* is constructed, with special emphasis on experimental science and mechanical arts. The second thinker in the order of importance for the Encyclopaedists is Descartes: "Au chancelier Bacon succéda l'illustre Descartes." (D'Alembert, *L'Encyclopédie*, *Discours préliminaire*, 1751, 25)

1.2. The Differences

Although the characteristics of technology laid down by Bacon and Descartes are similar in many and important aspects, their conceptions arise from different philosophical approaches. These differences concern the ultimate structure of matter (inert corpuscles vs. active atoms), the status of first principles (rationally deduced vs. induced from experience), the scientific model (mathematical sciences vs. biological sciences); these differences have deep consequences for their conceptions on technology. The major striking difference in this respect is that between Descartes' passive and inert corpuscles and Bacon's active atoms. Given the fact that for both philosophers technology is completely natural, their approach to the ultimate constituents of nature determines the essence of the technological endeavour. If nature is composed of inert corpuscles, then technology is a matter of spatially arranging these corpuscles in order to produce the desired effect when external motion is applied. The machines of Descartes serve only to transform one motion, applied externally, into another, more desirable one. But, if nature is composed of atoms that have internal potential motions, then technology should assist this active matter to actualize its desired potentialities. Bacon's method for assisting nature takes the same form, that of arranging matter according to scientific rules, not necessarily geometrical, but the outcomes are "marvellous" because they are not just the transformation of external motion but the emergence of new natural motions. In fact, Bacon recognizes that these new natural motions exceed the domain of mechanics, and he labels them as magic. Thus, given the hidden potentialities of nature, Bacon will need much more experiments than Descartes.

Another very important difference, which might be a matter of conceptual evolution during Early Modernity, is the status of the technological designer. The pre-modern[55] view was that the craftsmen are those who produce the machines from the stage of their conception until the completion of the finite product. Bacon makes a first step in isolating the process of designing from that of actual production. In *New Atlantis* he refers to 'Pioneers' or 'Miners' that create new experiments, new artefacts and machines, and examine them. Their results will be communicated to the whole society only if the 'consultations' establish that these 'experiments' benefit society. Therefore the designing process, which is not totally separated from the process of production, still diverges from mere production. For Bacon the designing of new artefacts is the responsibility of certain scientists-craftsmen. For Descartes, the separation between design and production is complete. The scientist designs the new artefact without any involvement in its material realisation. The design is completely *a priori* and comes from the perfection of human understanding. If the machine is well conceived by the intellect and skilfully executed, the actual machine will work. Again, such an *a priori* scientific design is possible only if matter is lacking any active powers of its own so that no "marvels" could be expected.

> This idea of a machine contains this "objective skill" ... Various things could be reckoned to be the cause of this skill: either some such real machine has been seen beforehand, in accordance with whose likeness the idea has been formed, or a great knowledge of mechanics, which is in this intellect, or perhaps a great subtlety of mind by which one might even invent the machine without any previous knowledge. (*Reply to the First Set of Objections*, AT VII 104, RA 150)

55 I use the term 'pre-modern' to refer to conceptions regarding technology that precede those of Bacon and Descartes.

The design is nothing but the formation of the idea of the artefact in the mind of the scientist through the possession of a "great knowledge of mechanics."

Finally, Bacon and Descartes are divided by the paradigmatic science that should govern the pursuit of technology. For Descartes the paradigmatic science is mathematics, in the form of his own algebraic geometry, while for Bacon it is natural science, with special emphasis on biological aspects. This difference is spelled out by McClellan III & Dorn (2006, 296) as the difference between "classical sciences", i.e. astronomy, mechanics, mathematics, and optics, that are apodictic and deductive in character, and "Baconian sciences", "primarily the systematic study of electricity, magnetism, and heat", that are experimental and inductive. As a consequence of this division one can consider the existence of a "Cartesian technology", dealing primarily with mathematically-based machines, and a "Baconian technology" concerned with the construction of artefacts that would force nature to produce certain outcomes.

The two research programs considered technology as a whole and the differences consist only in the way of framing the explanation. Both Bacon and Descartes considered mainly the same technological outcomes of their practical philosophy but these outcomes arise from different processes. Although "all things considered, the Classical sciences were not experimental in approach" (McClellan III & Dorn, 2006, 296), Descartes argues that every natural phenomenon is reducible to mathematical *qua* mechanical explanations. And since mechanical explanations involve working mechanisms that materialize those explanations, Descartes includes experiments and technologies as a major part of his system. For Bacon the integration of experiments and technology into his philosophical system is readily available, since "the Baconian sciences were generally more qualitative in character and experimental in approach, and they therefore depended on instruments to a much greater degree than their Classical counterparts" (McClellan III & Dorn, 2006, 296). An important fact about Bacon's and Descartes' integration of technology and experiments into the core of philosophical endeavour is that in Descartes' work the Classical theoretical sciences are tremendously transformed into down-to-earth applicable sciences, while Baconian sciences come into existence as sciences from previously being mere ignoble crafts. As such, Bacon and Descartes, taking as their respective starting point different extremities, create a middle ground between *scientia* and *banausic arts,* both understood in their pre-modern sense. On this middle ground, the birth of modern science and of modern technology takes place. Thus, modern science is and has to be, by its origins, applicable. Also, by its origin, modern craftsmanship must be scientific. Hence, the modern understanding of technology as "applied science."

2. The Technological Paradigm

2.1. From Mechanisms to Machines

An important feature of seventeenth century philosophy is its mechanistic character. Natural phenomena are to be explained through mechanic workings and arrangements of material parts. Although Bacon is not a mechanist, he affirms that the only possibility to produce change is the rearrangement of material parts by creating the appropriate configuration for the manifestation of atom's potentialities. Eliminating these potentialities of matter, Descartes shows the importance of mechanical explanations and the reducibility of every natural change to local motions and interactions of material constituents. What singles out Descartes in this philosophical endeavour is the consideration of complex machines. Galileo already argued that all natural phenomena are constrained by mechanical laws, but there is a great difference between accepting the mechanical explanation of all phenomena and adopting an overall mechanical ontology. As Helen Hattab has shown, it was relatively easy for the late Scholastics to reconcile the philosophy of Aristotle with mechanical explanations, especially because of the conflation between mathematics, physics and mechanics based on the *Questiones Mechanicae*, wrongly attributed to Aristotle:

> By gradually conflating the objects of mechanics, physics, and mathematics, Aristotelian commentators on the *Quaestiones Mechanicae* held out the promise of providing secure mathematical demonstrations of physical phenomena. (Hattab, 2009, 221)

A completely mechanical ontology requires the concept of the "machine", a principle that can individuate things in nature, that can serve as an adequate replacement of the "substantial form", and that can explain the complexity and the stability of the macro level. Descartes is aware of the importance of the concept of "machine", which he often uses, and in the conversation with Burman he insists on the necessity of a philosophical consideration of machines: "We don't think in terms of machines as much as we should, and this has been the source of nearly all error in philosophy." (Conversation with Burman, JB 22, AT V 174) This text shows the importance for Descartes of considering technology, i.e. machines, for the understanding of his work. The importance of the concept of "machine" can be proved not only by the conversations with Burman, in which Descartes explicitly mentions its importance, but also by the frequency of the occurrence of this concept in the Cartesian corpus. There are approximately two hundred occurrences of the concept "machine" in his works and extant letters, more than half in connection not to artefacts but to the "machine of our body" ("*machine de notre corps*" or "*machinamentum humani corporis*"), to the machine of the earth and to the machine of the universe.

Machines do not play just a heuristic role in Descartes' work but they are the principle of explanation that can replace substantial forms. The machine differs from mechanism because it offers an explanatory model. Be the world atomistic, corpuscular or mechanic, it still needs an explanation of how it works at the macro level; of how it preserves its stability and complexity. The machine offers the explanatory mechanism that allows mechanical philosophy to "save the phenomena." Mechanisms alone could not provide such an explanation and additional premises would be necessary. Neither the Ancient atomists nor anybody else before Descartes had provided such a macro level mechanical explanation. Descartes changes this situation by his explicit idea of the machine and his implicit idea of design. Every individual complex thing in the material world is a machine, a complex combination of simple mechanisms, and the Cartesian world works because of the design of such machines. Consequently Descartes does not need any more a substantial form infused by God into matter but only a design, a specific arrangement of corpuscular matter. Moreover, the design of a natural machine is not infused by God. The divine design is non-interventionist, and this makes it so perfect because the "form" or the design of a machine emerges by self-arrangement of matter that follows the simple eternal laws of motion, established by God from all eternity.

This Cartesian redefinition of metaphysics from one based on mechanisms, a feature that he had in common with Bacon and Galileo, to one that puts the machines at the core of the philosophical endeavour, represents the major breakthrough that allows one to speak of a completely new paradigm, a technological philosophy and not just a mechanical philosophy.

2.2. Medicine

The aims of technology according to Bacon and Descartes are not only the machines that would eliminate the external burdens of life. Both philosophers put on the same level of importance the advancement of medicine. The consideration of the human body as a machine by Descartes or at least as a completely natural phenomenon by Bacon and the possibility of constructing a new and better body are amongst the more revolutionary and central claims of both. The application of the concept of "machine" to the human body is a feature of Cartesian philosophy that cannot be emphasized enough:

> Among his many considerable achievements, Descartes was the first to extensively and systematically introduce the machine metaphor into the biological sciences, exploring the poetic and conceptual possibilities of a mechanical theory of life. (Vaccari, 2008, 287)

Descartes considers medicine, mechanics and morals as the most important fruits of his new philosophy, all of which being direct consequences of his technological physics.

> This is desirable not only for the invention of an infinity of devices that would enable one to enjoy trouble-free the fruits of the earth and all the goods found there, but also principally for the maintenance of health, which unquestionably is the first good and the foundation of all the other goods of this life; for even the mind depends so greatly on the temperament and on the disposition of the organs of the body that, if it is possible to find some means to render men generally more wise and more adroit than they have been up until now, I believe that one should look for it in medicine. (*Discourse*, AT VI, 62, RA 74)

Bacon in *New Atlantis* emphasizes the medical advancements of his technologically-driven society, describing something similar to a modern hospital with various departments that contribute to the well-being of man through techno-scientific means:

> [We] cure some diseases, and ... prolong life in some hermits that choose to live there; ... We have a water [made in imitation of the natural sources and baths] which we call Water of Paradise, being, by that we do to it, made very sovereign for health, and prolongation of life. ... We have also certain chambers, which we call Chambers of

> Health, where we qualify the air as we think good and proper for the cure of divers diseases, and preservation of health. ... We have also fair and large baths, of several mixtures, for the cure of diseases, and the restoring of man's body from arefaction: and others for the confirming of it in strength of sinewes, vital parts, and the very juice and substance of the body. ... We have also parks and enclosures of all sorts of beasts and birds which we use ... for dissections and trials; that thereby we may take light what may be wrought upon the body of man. ... [We] resuscitate some [animals] that seem dead in appearance; and the like. We try also all poisons and other medicines upon them, as well of chirurgery, as physic. ... We have dispensatories, or shops of medicines. (Bacon, III, *New Atlantis*, 156-161)

Both Bacon and Descartes criticise the contemporary state of medicine and argue for its development on scientific and experimental bases. Both promote the experiments on animals that would inform human medicine, Descartes undertaking such experiments himself. For Descartes, the human body is a machine that should be treated as such, that is, in the way an engineer repairs a machine. There are three main goals to be achieved by scientific medicine: the restoration of health in the living body, the prolongation of life and maintenance of youth, and the creation of better human bodies. Especially this last point represents a novelty that testifies for the new conceptualization of the human body as a machine that could be perfected.

Bacon's and Descartes' aims are not limited to the restoration of health and the prolongation of life but extend to the creation, through prosthesis, of a new, better body for man. Descartes wants to create, through medicine, men "more wise and more adroit" (AT VI, 62) while Bacon's "new face of bodies" (Bacon, IV, *Preparative*, 253) can well refer not only to inanimate and animal bodies but also to human bodies. McClellan and Dorn affirm that nowadays medical technology represents the fulfilment of Bacon's and Descartes' dream:

> In seventeenth-century Europe René Descartes articulated the modern vision of scientific medicine, that is, medical practice continually advanced and perfected through research and improved scientific understanding. In the nineteenth century, as we saw, the ideology of scientific medicine began to become a reality with anaesthesia, antisepsis, the germ theory of disease, and modernized hospitals. But only in more recent periods does Descartes's vision seem at least partially fulfilled, with

> scientific medicine and science-based medical technologies in full flower in today's industrial civilization. (McClellan & Dorn, 2006, 396-397)

2.3. Embedded Technology: Utility

The imposition by Descartes and Bacon of machines and mechanical inventions as a central feature of the philosophical endeavour, both as a mode of explanation and as the genuine goal, constrained natural philosophy to become a technologically-minded undertaking. From now on, although more in theory than in actual practice, natural philosophy is to be concerned with the creation of useful artefacts.

Mechanical philosophy contains at its core, as Des Chene (2004) claims, a technological imperative: knowledge should construct and be confirmed by experimental setups:

> With the advance of mechanism, two new skills became requisite for a natural philosopher. The first was that of deriving conclusions mathematically from laws (treated as axioms) and initial conditions concerning the locations, shapes, and motions of bodies. The other requisite skill was the ability to generate experimental setups (or observational situations) capable of putting to the test conclusions drawn from theory. (Des Chene, 2004, 71)

These experimental setups imply, in most situations, the construction of artefacts and machines that would isolate and produce the examined phenomena. The claim that the scientific conclusions must be experimentally verified comes to involve the claim that scientific instruments should be constructed. To do science becomes thus a technological endeavour because some scientific claims are not accepted if they do not come from very accurate observation, i.e. aided by instruments, or from elaborate technological experiments. The technologies used for scientific purposes are not just means to obtain new data but they also are a form of theory confirmation. Bacon does not conceive of any other form of confirmation for the laws of nature discovered through experiments but the fact that their technological applications, i.e. the experiments of light and the experiments of fruit, function. For Descartes truth is ultimately grounded in the veracity of God and the subsequent certainty of mathematics, but still, the knowledge of particular things is based not on direct deduction from the first principles but on an indefinite number of observations and experiments, on the functioning of technological devices. And, consciously or not, all modern scientists accepted these imperatives that Bacon and Descartes introduced through their claims for a "practical philosophy."

Moreover, for Bacon and Descartes this requirement of constructing machines goes beyond the "mere" scientific interests. The construction of useful machines, Bacon's experiments of fruit, is the natural and necessary outcome of philosophy. Philosophy remains sterile, a mere Scholastic enterprise, if the machines that would eliminate the burdens of life are not constructed as its results.

> The perception of science as useful knowledge found its foremost ideologue in Francis Bacon. Bacon pointed to gunpowder, the compass, silk, and the printing press as examples of the kind of worthwhile inventions potentially forthcoming from systematic investigation and discovery. (Bacon neglected to say that these technologies arose independently of natural philosophy but, no matter, for future scientific research promised similarly useful devices and techniques.) Among the castes of laborers Bacon envisioned for a scientific utopia, he set aside one group, the "Dowry men," especially to search for practical benefits. In categorizing different types of experiments, Bacon likewise specified that "experiments of fruit" must be combined with "experiments of light" to produce practical outcomes. His influence in the world of science was largely posthumous, but it proved no less powerful for that. (McClellan III & Dorn, 2006, 246)

The utility of knowledge as well as the necessity for empirical results of philosophy are just some of the elements that Bacon and Descartes, through their advocacy of technology, bring into modern philosophy as unchallenged features. Along with these come the themes discussed above of the relations between technology and science, technology and nature and technology and morality.

Bacon's and Descartes' appreciation of machines and their utility for human life represents a complete reversal, a revaluation, of central values of Antiquity. Until the Renaissance, it was unacceptable to rank utility among the appropriate aims of knowledge:

> In an almost complete reversal of modern values, utility *per se* and divorced from higher considerations of virtue, remains [for Plato and Aristotle] the least important product of the arts and sciences, ranking even bellow recreation. True knowledge must ask "for the sake of what." The answer "for the sake of utility" was merely to beg the question in much the same way (but from the opposite perspective) that today advocates of the humanities in education are often greeted with the question, "Yes, but what are they good for?" The danger of technology according to one strand of classical thought is that it provides technique but not purpose and increases human powers without also supplying guidance for the proper use, if any, of inventions. (Whitney, 1990, 32)

This revaluation, the imposition of utility as a central value, remains one of the most powerful legacies of Bacon and Descartes that informs all Modernity up to the present. The imposition of utility as a central value, a trend that begins in the Renaissance,[56] is completed by Bacon and Descartes. And their arguments arise from the central place that technology occupies in their philosophical systems. Technology, acknowledged or not, becomes the pivot of the modern scientific and philosophical endeavour. As one sees from subsequent developments in philosophy and science, Bacon and Descartes succeeded in introducing technology as a central feature of science and philosophy, at the expense of metaphysics. Despite the fact that later philosophers focused on metaphysical issues, the technological

56 "Although not absolutely new, claims for the social utility of science began to be widely asserted in the seventeenth century, the conviction that science and scientific activities can promote human welfare and should therefore be encouraged. The ideology was activist and contrasted with the Hellenic view of the practical irrelevance of natural philosophy and the medieval view of science as the subservient handmaiden to theology. The ideology for the social utility of science sprang from more than one historical source. Renaissance magic and Hermeticism, with their belief in the possibility of controlling forces that permeate the universe, represent one route from which emerged the doctrine that knowledge can and should be made useful and practical. Alchemy, in both its medicinal and metallurgical forms, exemplifies another." (McClellan III & Dorn, 2006, 245)

characteristic of Bacon's and Descartes' science and philosophy was more powerful than other tenets of their works.

All branches of the tree of knowledge proposed by Descartes aim at the improvement of human life and they are meant to be useful. Bacon and Descartes' philosophical considerations on technology impose utility as a central value. The science that Bacon and Descartes strived to create is not an aim *per se* but it is pursued because it can reduce the burdens of life and bring wealth and health to human beings. In continuation of Renaissance thinking, which had put man at the centre of the philosophical concern through its humanism, Bacon and Descartes were highly sensitive to human well-being. The difference between them and Renaissance thinkers rests in the specific content of this well-being. As clearly stated in various places, Bacon and Descartes had in mind the material well-being of man, attainable through technology. The utility was understood specifically as material utility, i.e. science and technology should be useful to material pursuits.

> Knowing the force and the actions of fire, water, air, the stars, the heavens, and all the other bodies that surround us, just as distinctly as we know the various skills of our craftsmen, we might be able ... to use them for all the purposes for which they are appropriate, and thus render ourselves, as it were, masters and possessors of nature. This is desirable not only for the *invention of an infinity of devices* that would enable one to enjoy trouble-free the fruits of the earth and all the goods found there, but also principally for the *maintenance of health*, which unquestionably is the first good and the foundation of all the other goods of this life. (*Discourse*, AT VI 62, RA 74, my emphasis)

The material ends that are acknowledged by both Bacon and Descartes are mechanical devices that would do the works that burden human life, the creation of new things that would render life more pleasurable, preserve health and prolong life.

Together with the promise of more useful devices and the idea of a continuous 'artificial revelation', Bacon and Descartes embedded in their respective science and philosophy the idea of technological progress. The research into and the production of useful technologies is an unlimited process that has to be continuously pursued by scientists for the creation of a new world, “a new face of bodies”, that would transform the world into a place more appropriate for human life. Bacon viewed this process as a cyclical unlimited development in which the advancements in experimental technologies would sustain the creation of new “experiments of fruit”, which in turn require new “experiments of light.” For Descartes, technological advancement is dependent on acquiring a more perfect knowledge of mechanics, which is physics and ultimately mathematics. Thus they absorbed and modified the Renaissance idea of progress, which implied primarily the moral and humanistic progress through books, classical literature and fine arts. The new idea of progress was less concerned with the perfection of human soul than with the perfection of material conditions for human life, i.e. the preservation, prolongation and improvement of human life.

2.4. Technology and Science

One important aspect of technology is its relation with the previously established realms of human knowledge and ontological domains. The conceptualisation and the centrality of technology change the status of nature, knowledge and morality while also creating new relations between these and the previously ignored domain of material production. I must stress the fact that before Bacon and Descartes a well-established autonomous domain of technology (mechanics or mechanical arts as they define it) did not exist. Even if the category of mechanical arts that subsumed all material production existed from the twelfth century on, it was just a theoretical distinction without many epistemological and ontological implications. Once mechanical arts came to occupy a central place in the philosophical systems of Bacon and Descartes and became a constant background characteristic of modern philosophy, technology changed and reformed the epistemological and ontological realms.

Given the fact that every physical entity can be created, at least theoretically if not practically, by mechanical arts, all the universe is but a machine, a mechanical experiment of God. Knowledge is also reformed by technology assuming a central place in philosophy. Knowledge is primarily concerned with mechanics and mechanical arts, the trunk of the Cartesian tree of knowledge being identified with physics which is nothing else for Descartes but mechanics. Thus Descartes transforms natural philosophy, i.e. science, into mathematical physics. Equally, he transforms nature into a technological product. Finally, the domain of values and morality is transformed by technology, because new human aims and a new framework for explaining and changing human behaviour become available.

The most pervasive legacy of Bacon and Descartes is that the domains of science and technology, i.e. theoretical knowledge and material production or, to use pre-modern terminology, between *scientia* and βαναύσων τέχναι,[57] come to overlap to a large extent. Bacon and Descartes rank *artes mechanicae* and mechanics at the core of natural philosophy and emphasise their scientific character. Bacon is the first to centre his philosophy on the mechanical arts, making them a central part of physics, both as the source of knowledge, his "experiments of light", and as the ends of knowledge, his "experiments of fruit." Bacon's ideas are taken up by Descartes, who provides the theoretical basis for the transformation of mechanics into science, although this identification is based upon an implicit difference between theoretical mechanics and applied mechanics, i.e. mechanical arts proper. Specifically, Descartes gives a new meaning to *scientia*, in order to make it identical with mathematics and mathematical certitude. *Scientia* (ἐπιστήμη) is defined by Aristotle as "the quality whereby we demonstrate" through syllogistic deductions from first principles. Mathematics is certainly not syllogistic in character and, as such, it is not a science. In Early Modernity there were attempts to show that at least some of the mathematical demonstrations are syllogistic, but demonstrative methods such as *reductio ad absurdum* are in principle

57 Vulgar or mechanical arts, or, in Latin: *artes illiberales*, *artes vulgares*, *artes sordidae.*

non-syllogistic.[58] Descartes bites the bullet and affirms that mathematics is science, moreover that it is the only science, and identifies it with physics and with mechanics, formerly known as a vulgar art (AT VI 54, AT VIII 78-79, AT II 525, AT II 268, AT II 542). These conceptual shifts and new conceptual identifications (*scientia* = mathematics = physics = mechanics) create the pervasive definition of technology as applied science, a definition that begun to be challenged only in the second half of the twentieth century. For Bacon and Descartes technology is applied science and represents a great and very important part of science, at the expense of pure science. Their followers will focus mainly on pure science, accepting uncritically that definition of technology as applied science. Nevertheless, contemporary scholarship makes a clear distinction between technology and applied science.

> If one is engaged in science in order to increase one's understanding of the world, one is doing pure science, whereas if one is doing science in order to solve problems regarding human activity, one is doing applied science. ... So science is pure to the extent that its aims are internal to scientific practice (truth, demonstration), with minimal intrusion of external aims (money, status, social welfare). In contrast, applied science refers to science applied to external aims, typically in commercial or governmental projects. ... The consensus from recent scholarship is that neither engineering nor technology is accurately characterized simply as applied science, because both involve forms of knowledge and skill that are not derivable from scientific theory or experiment. While engineering and technology employ science among their elements, they are distinguished from applied science by their cognitive content. ... In pure science, it is considered preferable to limit false positives ... rather than false negatives ... That is, it is seen as worse to accept a falsehood than to reject a truth ... An epistemological value judgement of this sort is usually seen as healthy, cautious skepticism, a virtue when doing science. ... But the aim of science applied to practical matters is not the maximization of truth. If it is to be seen as the maximization of something, it is the maximization of welfare, and once welfare is a concern then rationality demands a consideration of values other than purely epistemological ones. (Woodruff, 2005, 1552-1553)

Bacon and Descartes did not consider such differences, for their aim was to raise the status of technology to that of science. Bacon establishes a clear distinction between physics and metaphysics as pure knowledge and mechanics and magic as applied knowledge, but

58 Biener, Zvi. 2008. *The unity of science in early-modern philosophy: Subalternation, metaphysics and the geometrical manner in scholasticism, Galileo and Descartes*, doctoral thesis, University of Pittsburgh.

mechanics is still a part of natural philosophy and not a craft, while Descartes considers mechanics as science when it concerns the explanation of physical phenomena, as ingenious applied science when it concerns the design of new machines, but as vulgar applied science when it concerns the material realisation of those machines. Although it is the same mechanics, Descartes uses it differently when he explain light and vision than when he designs the machine for cutting lenses, and is employed still differently by Ferrier when he constructs the machine and cuts lenses lacking the theoretical basis and only following Descartes' indications.

Even so, the aim of pure physical knowledge was truth and demonstration only as those values assure the success of practical applications. Truth comes to be valuable in their systems not *per se* but as a mean to attain practical outcomes. Their views created the myth of inseparable union between science and technology and the definition of technology as applied science, a definition that is sustainable neither conceptually nor historically.

> The myth that the theoretical innovations of the Scientific Revolution account for the technical inventions of the Industrial Revolution found reinforcement in the common belief, which has been challenged repeatedly in these pages, that technology is inherently applied science, a belief only partially true even today when research and development are indeed often conducted in close contact. In the eighteenth and early nineteenth centuries it was almost never the case. ... The scientific enterprise itself continued to be shaped in a Hellenic mold, largely divorced from the practical applications, and technologists and engineers proceeded without tapping bodies of scientific knowledge. (McClellan III & Dorn, 2006, 290-291)

2.5. Technology and Ethics

A less considered change brought by the centrality of technology is the modification of morality. As already shown, through technology, Bacon and Descartes introduced material utility for human earthly life as a central value of their systems. Moreover, by emphasizing the beneficial role of technology, they argued for the development of technology by any means.

> It was Bacon who most forcefully articulated the distinctively modern ethics of technology. In The Great Instauration (1620), on the basis of a moral vision of human beings as unjustly suffering in the state of nature — a vision supported by his creative deployment of Christian revelation — Bacon criticized Greek philosophy as a vanity of words and prayed for a new beginning in which natural philosophy would pursue knowledge linked to power. … In further contrast to the ancients, for Bacon technical change is inherently beneficial because it enhances human welfare and autonomy. (Mitcham, 2005, 1151-1152)

As Lord Chancellor of England, Bacon discussed, along with moral considerations regarding technology, social and political issues that are still present in contemporary debates on technology governance. On the one hand the picture of an all-powerful closed class of scientists that would lead society is disturbing. On the other hand, the perils and the complexity of technology seem to require rational governance guided by experts.

> For those who share Bacon's vision of scientific progress, it [*New Atlantis*] is an inspiring vision of how modern science and technology could promote a good society. For those who disagree with Bacon, it is a disturbing depiction of how a scientific elite could use manipulation and secrecy to rule over a docile people. … The scientific philosophers must hide from the general public those experiments, inventions, and discoveries that would be harmful if they were open to full public view. This implies that scientific and technological innovation can be dangerous for society, and therefore it needs to be regulated by those with the wisdom to understand the ethical problems of such innovation. The critics of Baconian science see this as confirming their fear that modern science and technology shape social life without the free and informed consent of ordinary citizens. (Arnhart, 2005, 132-133)

Another debated idea is that of progress that becomes self-contradictory in a world in which natural ends are eliminated because one cannot give necessary and sufficient criteria for what "better" means:

> In the realm of technology, there are objective criteria for comparing and evaluating changes because artifacts are means to ends defined by their makers. Given the intended purpose of a camera, for example, one model can be said to be better or worse than another. But because the notion of purpose or end in relation to nature was abandoned in modern science, there is no basis in science or in technology for judging the value of the ends to be served by technologies and therefore no basis for judging that changes to natural entities are improvements. This isolation of ends from means creates an ethical gulf between technical knowledge and its applications that was only fully appreciated in the second half of the twentieth century, a gulf that further undermined claims of progress even in science and technology. (Goldman, 2005, 1520)

3. Conclusion

The examination of the relation between the Bacon's and Descartes' views of technology demonstrates the great similarity of their conceptions. Technology is for them a central theme and they create the framework of the modern way of thinking about material production. Continuing the Renaissance trend of revaluation of the dismissive attitude of the Ancients toward technology, they put utility and human material well-fare as central values that guide their investigation. The aims of natural philosophy is to create a scientific-based medicine that would prolong life, maintain health and create better human bodies, and a scientific mechanics that would eliminate the burdens of human life. They also advocate the creation of a technology-based science, showing that and how science and technology overlap to a great extent, and providing the means for an unlimited progress of both.

Conclusions

The contemporary understanding of technology is indebted to Bacon and Descartes, who challenged the pre-modern conceptions regarding useful material production. Although the production of artefacts has been a constant activity of humans since the dawn of history, the Ancient world tended to disvalue it, considering it a lower endeavour that aims to satisfy ignoble material needs. Technology, according to Ancient Greek thinkers, cannot surpass nature but can only bring small improvements to it; moreover, there is a difference in kind between natural things and technological artefacts; the activity of inventing and producing useful objects is unsuited for the nobility and for free men; there is an irreducible gap between proper knowledge and the production of artefacts. This approach toward technology is completely reversed in Bacon's and Descartes' works: material utility comes to be considered a genuine value; nature can be completely transformed through technological inventions, and even the human body can be improved by prostheses; natural things and technological artefacts are identical in their constitution and function; the invention of new artefacts becomes a proper endeavour of the natural philosopher; thinking about artefacts, or machines, is raised to the status of proper knowledge, while mechanical arts and mechanics become the core of natural philosophy. These ideas regarding technology became the familiar background of the contemporary approach toward material production; accordingly, to understand the magnitude of Bacon's and Descartes' paradigm shift it was necessary to analyse it against the pre-modern view. Moreover, in order to emphasize their powerful influence I had to approach their works from the technological perspective, since an epistemological analysis fails to rend justice to and to clarify some of the core ideas of their philosophy: utility, the centrality of mechanical arts and mechanics, the scope and scientific character of technology, the similarity between nature and technology.

Until the beginning of the seventeenth century the approach toward technology was to a large extent shaped by Aristotelian views. Technology was considered ignoble and vulgar and the term used for useful material production, i.e. *banauson*, reflects this Ancient and medieval contempt (Introduction, 1). Aristotle, as well as Plato, deny citizenship to artisans because they are too involved with material objects (Ch. I, 1.1 and 1.6). Aristotle argues for irreducible gaps between technology and nature (Ch. I, 1.2) and between technology and knowledge (Ch. I, 1.4), and classifies technology among the lowest human activities. The only positive approach toward technology before the Renaissance is that of Hugh of St. Victor, who classified technology under the general heading *artes mechanicae* and considered it as a possible mean to restore the prelapsarian condition. Nevertheless, only during the Renaissance counterarguments to the Aristotelian conception begin to be voiced. In a variety of domains, such as mechanics (Ch. I, 2.1), alchemy (Ch. I, 2.2), mining and metallurgy (Ch. I, 2.3), and natural magic (Ch. I, 2.4), Renaissance thinkers bring arguments pertaining to the similarity between nature and technology, the value of material utility, the importance of technological knowledge, the role of invention, and the possibility to mathematize nature. A conceptual breakthrough of the Renaissance is the idea that nature can be known through artefactual prostheses, experiments and laboratory reproductions (Ch I, 3.5), what Derek de Solla Price called 'the principle of artificial revelation'.

Against this background shaped by the Scholastic-Aristotelian conception and shaken by Renaissance revaluations, Bacon introduces mechanical arts as the core of his natural philosophy and aims at the creation of a 'New Philosophy, or Active Science', i.e. a philosophy that would invent artificial objects for eliminating the burdens of life. Bacon considers mechanical arts as a model for his philosophical research (Ch. II, 1.2), as the privileged domain of knowledge, and as the necessary outcome of his philosophy (Ch. II, 2.4). He argues for the identity and continuity between nature and technology (Ch. II, 2.3) based on the idea that nature is composed of active atoms whose potentialities of motion can be unfolded according to human needs, creating thus “a new face of bodies, another universe or theatre of things” (Preparative, Works VIII 357). He presents nature as one of many possible unfoldings of a primordial chaotic distribution of active atoms, both in his scientific and methodological expositions (Ch. II, 2.1) and in the comments on the wisdom transmitted by Ancient myths (Ch. II, 2.2). The unfolding of the useful “face of bodies” is the aim of his philosophy and he presents, both in his theoretical works and especially in the *New Atlantis*, the method for technological development (Ch. II, 2.5). Bacon assigns three roles to technology: that of correcting and improving the senses by means of instruments and prostheses (Ch. II, 3.1); that of acquiring knowledge of nature through ‘experiments of Light’ (Ch. II, 3.2); and, the most important role, that of creating new and useful artefacts, medicines, plants, etc., i.e. the ‘experiments of Fruit’ (Ch. II, 3.3).

The proper modern approach to technology is that of Descartes, who considers the entire physical universe as being a gigantic machine composed of inert corpuscles whose functioning is completely described by mechanical laws of motions (Ch. III, 2.1 and 2.2). As a consequence, technology becomes identical with nature, and mathematics, physics, and mechanics overlap and become the core of natural philosophy, while creating new artefacts and human prostheses becomes a matter of an *a priori* design based on mechanical knowledge, leaving out the possibility envisaged by Bacon of a technology based upon material potentialities. Descartes considers mechanics as the only principle for explaining the physical world, to the extent that even the human body is nothing else but a machine. Thus he expands both the scope of technology, which now encompass everything physically conceivable, and the human possibilities of action, since everything is a matter of mechanical contrivance. Along with the idea that the human body is a machine capable of being mechanically repaired and enhanced, the most powerful legacies of Descartes is the imposition of utility as a genuine value (Ch III, 3.1) and the conception that technological invention is a matter of a priori mechanical design (Ch III, 3.3). Therefore, unlike Daniel Garber (1992), who is interested in the interplay between first philosophy and natural philosophy, I focused on a different interplay, equally important to my mind, that between theoretical philosophy and practical philosophy, i.e. technology, the envisaged practical and materially useful consequences of Descartes' writtings.

I tried to show that Bacon and Descartes gave a central place to technology in their endeavours and that this fact is insufficiently emphasized in the secondary literature. Technological development, the identity between nature and technology, the importance of material utility, and the scientific character of technology are common features of Bacon’s and Descartes’ works. Descartes was probably influenced by Bacon in his emphasis on technology as the proper outcome of natural philosophy (Ch IV, 1.1), and although they follow different methods and start with different ontological assumptions (Ch. IV, 1.2) they leave a common legacy regarding technology that they infused into modernity. They argued that science and technology overlap to a large extent and that technology is applied science. They imposed the idea that knowledge should be materially useful and created the prospects of a technological medicine that aims not only at maintaining health but also at prolonging life and at creating new bodies through prostheses. The traditional conception that undervalued technology becomes obsolete in the first half of the seventeenth century, when Bacon and Descartes publish their writings, and technology acquires a new status, a new scope and new determinations.

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*** Bacon's and Descartes' writings were mentioned in the List of Abbreviations on page vi.

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