Chapter 1
Complex Systems: The Latest Human Artefact

Nicola Labanca

Abstract Complex systems are presented in this chapter as an emergent social and historical phenomenon related to the making and the using of artefacts. Rather than as the result of scientific discoveries, these systems are mainly seen as the product of a social construction which has affected any department of knowledge and human activity. The proposed account revolves around the idea that the intensive scientific and technical reflections that have taken place in specific historical periods in relation to specific human artefacts have transformed the concepts associated with the creation of these artefacts into central ideas and metaphors around which societies have started being organized while leading to their massive technological reproduction. By building on an historical enquiry on instrumentality developed by a series of acknowledged scholars, this chapter discusses how the nature of human artefacts has changed starting from the twelfth century. In particular, it shows how these artefacts have been mainly seen during subsequent historical phases as organa, instruments, motors and, more recently, as complex systems. In addition, it illustrates how these transformations have been accompanied by as many radical changes in the social imaginary concerning the meaning of human action and in the way in which delegation to machines and agency (i.e. the power to generate a change) has been conceived. The chapter also illustrates how the ongoing transition to renewable energies can reinforce the social construction of complex systems and represents an introduction to the second chapter where the implications of this construction for the energy sustainability of this transition are discussed by the author.

N. Labanca (✉)
European Commission, Directorate-General Joint Research Centre,
Unit C.02 Energy Efficiency and Renewables,
Via E. Fermi 2749, 21027 Ispra, VA, Italy
e-mail: Nicola.labanca@ec.europa.eu

N. Labanca (ed.), *Complex Systems and Social Practices in Energy Transitions*,
Green Energy and Technology, DOI 10.1007/978-3-319-33753-1_1

Introduction

I have had the privilege of being part of the scientific community who contributed to the detection of the top quark at the *Tevatron* collider at the *Fermilab* of Chicago. It is thanks to this opportunity that I could follow the scientific discourse that has developed around the detection of this elementary particle since 1995. That was the first time I could experience what nowadays seems to me a very curious and somehow misleading approach to present and interpret scientific advancements. I was quite young at that time and my readings had been until then mostly focused on the application of the scientific method to physics. My interests widened a bit afterwards and I could in this way realize that the strangeness I will describe probably affected the interpretations proposed by most scientists for the new conceptual artefacts they develop and divulge to the public. What I could identify was the presence and the relevant implications of a misleading interpretation typically arising among physicists, biologists, chemists and other natural scientists, when they explain the detection of new entities resulting from the interaction of given material objects with suitably prepared experimental apparatuses in terms of a *discovery*. The misleading character of this interpretation is generated by a methodological issue linked to a problem of *reflexivity* that can cause confusion among scientific communities and in the general public concerning *what* has been actually discovered. Researchers (notably researchers involved in so-called hard science) seem indeed particularly prone to neglect the fact that what they discover is actually the result of what they have partly contributed to create. Rather than signalling that their discoveries concern the interactions of measurement instruments with material objects prepared under the assumptions of theories developed in a given historical period, they often tend to present the outcomes of their experiments as the unveiling of absolute and eternal truths which could not be revealed beforehand because of still underdeveloped or limited cognitive and experimental capacities.

Because of this it happens, for example, that the Higgs Boson recently observed at the "Large Hadron Collider" (LHC) at CERN in Geneva is not just interpreted and presented as the result of the interaction of portions of matter (prepared according to the assumption of the so-called *Standard Model*) with the very sophisticated experimental apparatus that could be set up by the scientists of the twentieth century. This boson is rather assumed to be as old as the universe itself and capable of explaining how the mass of elementary particles has emerged in an extremely remote past. When generally referred to contemporary science, this apparently slight semantic shift concerning what should be meant by *discovery* is the cause of a series of misconceptions that ultimately result in the cancellation of the historical character of given conceptual artefacts and in the disregard or misinterpretation of the fundamental role played by the historical context for their discovery. Rather than as the result of a social construction, these conceptual artefacts are usually presented as eternal entities whose discovery just results either from a mere accident, or from a linear process of knowledge accumulation, or from the geniality of given scientists. This downplaying of history and of the social context in the processes leading to the creation of scientific concepts and artefacts is not so difficult to be verified. It can suffice to observe how these concepts are usually explained to students at schools and universities. Rather than as the outcome of a social tissue that creates, keeps them alive and can possibly decree their death, these concepts are either presented as the logical implication of assumptions taken within given undisputable theories or as entities whose nature can be easily inferred through intuition or induction. I could make this quite estranging experience several times during my university courses when I have been, for example, introduced to the concepts of time, space, mass, acceleration, speed, etc., through operational definitions whereby it was implicitly assumed that the measurement methods being presented for these physical quantities just served to quantify the extension or the intensity of manifestation of entities actually populating the real world.

What a surprise it has been for me to discover after my university courses that the existence of and the self-confidence of the professors introducing these physical quantities was not so unquestionable, that social communities could and actually had developed a variety of alternative conceptions and ways of life around these entities and that the wide scale application of their operational definitions could sometimes result in a very questionable reorganization and homogenization of societies.[1] The misleading and curiously seductive approach experienced by a university student is a common practice very often adopted by scientists and consists in presenting the *scientific construction* of physical entities as the detection and measurement of *natural phenomena*. The retroactive and distorting impact on the role played by history caused by this practice could hardly be overestimated. It transforms history in a kind of laboratory where all the activities being undertaken are seen as guided or constrained by the presence of recently discovered entities assumed to have always and incontrovertibly constituted reality.

Energy provides a nice example of how everybody is still nowadays trained to this distorting vision of the past. As Ivan Illich noticed already in the 1980s, images, explanations and advertisements of scientists contributing to this distortion abound in the media.[2] Still nowadays, energy is presented as something arcane that everybody has always needed, from the Australopithecus to today's Mr. Smith. Compared to their ancestors, today's people would be the luckiest ones because they can get energy very easily by pushing a button and without unpleasant side effects, at least as long as it is supplied in the most efficient and greenest way possible. It is here not very relevant to question whether this very common understanding of scientific discoveries makes contemporary people actually feel as the luckiest ones (because they would have much easier access to the possibilities disclosed by natural resources compared to forebears) or as the unluckiest ones (because they would not still have the access possibilities that will be disclosed by

[1]On this point see, for example, Bauman (1998).

[2]See Illich (1983).

discoveries of their descendants). What appears much more relevant is that such a view projects human activities within an advancement process whereby old and current knowledge seem to be destined to be continuously superseded by new knowledge whereby an increasing number of artificial phenomena can be explained. *Truth*, or the best approximation of truth currently available, would be represented by the most recent theories of science just because older theories cannot explain the latest phenomenic manifestations observed within the latest laboratories settings. The fact that these manifestations might be just human artefacts and that, within a kind of auto-referential loop, the theories and the assumptions whereby these manifestations are explained are the same theories and assumptions whereby these manifestations are created is apparently deemed not very relevant. I am convinced that this approach to science and to related technical applications is actually a dazzle that implies, or at least facilitates, a progressive cancellation of collective memory while legitimating a continuous activity of destruction and reconstruction. Moreover, I think that this type of blindness impedes highlighting relevant limitations concerning the application of scientific findings to everyday life. After all, if constructions of science are seen as natural entities actually populating everyday life like the tree planted in our garden or the cat living in our house, how could the circumstances of everyday life where their presence should not be invoked be identified?

Yet, our views over the world and our interpretation of past events would radically change when the assumption that conceptual artefacts provided by science represent *eternal* truths is simply released. If these artefacts would constantly be seen as the creation of a given historical period, as something that has had an *origin* and could, therefore, achieve an *end*, then history would get suddenly highly re-evaluated. Previous theories and worldviews considered as something obsolete and not thrust worthy could probably in this way be seen and understood as something capable of disclosing the implicit and, why not, socially negotiable assumptions of apparently undisputable present worldviews. History allows looking at the origins of the present grasp over the world and permits in this way to take to the foreground its implicit assumptions and limitations while possibly offering some glimpse concerning what can be expected in the near future. Having access to past ways of life can allow discovering different ways of perceiving the world and re-discussing present scientific assumptions. This experience can be extremely liberating and can disclose new research avenues. Its possibility is a consequence of the fact that concepts, principles and laws formulated by science are typically constructed and rigorously applied within laboratories under very restricted and controlled conditions, whilst all the details of the dynamics of everyday life escape by definition the reductions and abstractions performed and created by science.

This being said, it would be a big mistake to assume that the above-mentioned possibility can detract from the solidity of the outcomes of the scientific method and from the reliability of technics developed by its application. Energy has, for example, proved an extremely powerful concept to study natural phenomena and its impact on science can be hardly overestimated. This concept and the associated conservation and degradation laws have however originated within laboratories only in the nineteenth century and assuming that in the future they could be complemented by new and alternative concepts and principles to study and reorganize our environment is not an act of irreverence to science. This possibility, however, does not necessarily imply, for example, that it will be possible to extract useful work from a fluid of given heat engines by violating the energy conservation law or the Carnot theorem on heat engines efficiency. As long as natural phenomena are analysed in the thermodynamic framework in relation to the amount of useful work that can be extracted therefrom, no evidence has been so far able to prove the violation of these laws and theorems. Possible new and alternative explanatory principles will probably be adopted, not because these laws and theorems will be violated within laboratories, but because for some reason it will be deemed socially relevant and useful to overcome the inevitable reductions and distortions that can be associated with the application of thermodynamics to study the dynamics of human affairs. Despite, for example, societies are nowadays mostly modelled and described as motors and input–output systems by scientists and policy makers concerned with their energy sustainability, it would be profoundly wrong to assume that the dynamics of resources consumption of human aggregates can be completely captured by thermodynamics laws and that alternative research approaches based on different assumptions cannot improve our understanding of these dynamics in the future.

The general considerations so far reported have very practical implications that I have decided to discuss in this chapter for the case of one of the latest creations of science: complex systems. One of the main reasons for this endeavour is the fact that the notion of complex systems and associated phenomenal principles, although still probably lacking of a common understanding within the scientific community, are becoming omnipresent. Every field of knowledge is being revisited through complex systems theories, this indicating that the fundamental assumptions behind the creation of these entities are becoming invisible. To use Hans Blumenberg vocabulary, they are becoming kind of "absolute metaphors" whereby everything is explained.[3] The fact that some of the notions associated with complex systems can be so powerful to be associated with a reorganization of every aspect of social life is in my opinion astonishing. As much (if not even more) astonishing is the fact that these notions are so abstract that nobody has a clear picture of their meaning. Another connected reason that has stimulated my interest in the topic concerns specifically the implications of the social construction of complex systems for policies that can be implemented for energy sustainability. It might be stated that my endeavour has been animated by the following research questions: How can it be showed that complex systems have been socially constructed? How can they nowadays shape every department of knowledge? How is it possible to become more aware of the biases generated by reflexivity when complex systems science is applied to social phenomena? If complex systems are being socially constructed, then what may be the unexpected impacts of policies for energy sustainability that

[3]Blumenberg (1988).

are designed and implemented by assuming that, rather than being built on a massive scale in every department of human activity, these systems are actual entities obeying to universal and eternal laws? How becoming reflexive aware can generally help avoid unwanted impacts of these policies?

The best approach to address these questions is in my opinion represented by an historical enquiry on instrumentality as first attempted by scholars like Ivan Illich, Carl Mitcham, Jean Robert, etc.[4] Contrary to what is typically assumed, the origins of human artefacts generally named instruments are indeed not prehistorical. They probably have an origin that dates around the twelfth century and have subsequently undergone a series of fundamental transformations leading to the creation of so-called complex systems around the mid-twentieth century. These material transformations have been accompanied by as many transformations in the central metaphors whereby human action has been explained and natural entities have been imagined. By briefly describing these transformations, I would like to take to the foreground the implicit assumptions of present complex systems views and discuss the implications of their massive construction for energy sustainability and for policies that are informed by these views.

How to Intend the Social Construction of Complex Systems Outlined in This Chapter

In order to avoid possible misunderstandings, it is probably better to start by spending some words to clarify how the process of social construction of complex systems is being intended. Complex systems are primarily seen as an emergent social phenomenon related to the making and the using of artefacts. They are seen as the result of a non-deterministic co-evolution occurring within a bundle made of material objects, human habits, technical skills, ideas and narrations about reality and human action. Their construction is therefore not intended as the result of a linear sequence of transformations whereby new ideas and material objects are produced in given historical periods and completely replace preceding ones. On the contrary, it is assumed that, as happens with technologies becoming obsolete, previous ideas and material arrangements generally recede to a kind of background whilst sometimes serving as entry or leverage point for the creation of new material and conceptual artefacts which become dominant for reasons which may be often purely contingent. It is usually very hard, if not impossible, to understand and collect all the evidences needed to describe the dynamics whereby these transformations take place and such description is certainly not an objective of the author of this chapter. The huge difficulties often associated with a causal description do not nevertheless impede to identify the presence of relevant points of discontinuity in

[4]For a detailed account concerning how this historical enquiry has been conceived and developed see Cayley (2005).

the evolution of the mentioned bundle and to study the necessary changes that had to occur in relation to how tools of physical nature were conceived in order to allow the social construction of complex systems. Despite the ultimate reasons that have led to the emergence of these discontinuities might remain obscure, this type of study remains possible. The assumption made by the author of this chapter is that these points of discontinuity have been generated during historical periods when human tools have become objects of a particularly intensive philosophical and scientific reflection and that some of these historical periods coincided with specific periods of development, namely: (1) the time of the invention of mechanical science at the beginning of the twelfth century; (2) the time of the invention of the steam engines and the energy concept around the mid-nineteenth century; and, (3) the time of formulation of cybernetics as a discipline around the mid-twentieth century with its subsequent reformulation of the so-called second-order cybernetics lasting until the 1980s. The impressive technological developments that occurred during these periods have been accompanied by as many radical changes concerning how the making and the using of artefacts have been conceived. These radical changes are assumed to have substantially contributed to the social construction of complex systems and will therefore be described in this chapter in order to discuss underlying assumptions, potentialities and possible drawbacks associated with the massive diffusion of these quite recent artefacts. The proposed account revolves around the idea that the intensive scientific and technical reflections that have taken place in relation to human artefacts during the above-mentioned periods have transformed the concepts and ideas associated with the creation of these artefacts into central ideas and metaphors around which society has started being organized while leading to their massive technological reproduction. In this way, it could happen, for example, that the ideas developed around the technical instruments that were produced starting from the twelfth century made it possible to conceive the world and societies as a gigantic clock mechanism during the following centuries; it could happen that the massive production of steam engines and the thermodynamic principles established since the mid-nineteenth century made it possible to conceive the universe and human beings as consumptive and dissipative energy motors, or that information theories and technologies transformed ourselves and things out in the world into computer processors since the mid-twentieth century. Clearly, specific types of human artefacts and ideas developed around them might certainly have been in circulation before they become an object of social attention and scientific reflection and can continue being used also when largely superseded by new types of conceptual and material artefacts. Instrumental tools have, for example, been in use and described in all cultures since antiquity and continue existing also in the age of complex systems. It is however the fact that scientific and technological thought has transformed their presence into an issue of fundamental theoretical importance that has made their massive reproduction possible and has changed the concepts accompanying this reproduction into central metaphors whereby societies have been and still are being reorganized. When it comes to study how they impact on our environment, how they inform our ideas concerning sustainability of human activities, and how alternative ideas can be formulated, the study of this interplay between scientific reflection and massive production of given types of artefacts becomes much more relevant than any discussion concerning exactly when and how these artefacts and the social imaginary accompanying their reproduction have originated or have disappeared.

From Organa to Instruments

It is not difficult to realize how the distorting effect caused by projecting concepts and views that have been elaborated in specific historical period to previous and remote epochs of the past occurs also in case of the notion of "instrument". The idea that instruments are probably older than the human being is profoundly rooted in the contemporary social imaginary. Examples provided by literature of first humans using instruments typically refer to beings very similar to apes grabbing tree branches, stones or various kinds of bones to pick up fruits, broke nutshells or defend themselves from the assault of wild beasts. The idea that instruments date back to human prehistory is also supported by modern cinematography. Stanley Kubrick's 2001 *Space Odyssey* depicting an ape casting a bone into air that suddenly transforms into a spacecraft illustrates exemplarily how the social imaginary conceives instruments and how they are assumed to have been always present and to just evolve in their shapes and functions within societies. With a few frames, this director has managed to render a supposedly historical evolution of human instruments by reducing the forebears of the first types of utensils and weapons and the complex devices employed to travel into the space to a same matrix. This type of imaginary might perhaps appear very realistic to a hypothetical distant observer, a kind of extraterrestrial being having the privilege to observe from a large distance how the interactions of human beings with their environment have evolved during millennia. When observed from a large distance, the evolution of these interactions may indeed seem to keep some basic characteristics unchanged. Men and women of the ancient Mesopotamia ploughed their fields with oxen to produce the food they needed. Contemporary men and women may have substituted the plough and the oxen with tractors to get their food from the Earth. Overall, the same *end* seems to be achieved by using instruments that apparently evolved to alleviate as much as possible the burden of labour while increasing productivity. Some basic objectives seem to remain unchanged. Occurred changes seem to be limited to the *means* whereby these objectives are achieved.

Unfortunately, these kinds of descriptions and explanations completely neglect how perceptions and interpretations concerning the nature of human relationships with the material world may have changed with time and may have affected the way in which material and conceptual artefacts have been conceived and produced. According to several scholars, important historical discontinuities can indeed be identified concerning the way in which people perceive their relationships with the material objects they use. These discontinuities cannot be noted without considering how the ideas that men and women have about themselves and the surrounding environment have changed. This can be done only by adopting an analysis perspective that, rather than from a large distance, studies human societies from the inside. To identify and understand these moments of discontinuity, it is necessary to analyse cultures and how narrations and assumptions whereby people explain their actions and perceptions change.

This is the endeavour that the scholars I have previously mentioned have attempted in relation to instruments. Ivan Illich in particular has maintained that it is not possible to find any evidence confirming that western societies could conceive human artefacts as instruments before the twelfth century, i.e. there is no evidence dating before the twelfth century and indicating that human tools were seen as means designed and created to allow *any* person achieving predefined ends in the same way as, e.g. a typewriter can be seen as a device designed for any person to print letters of the alphabet on a sheet of paper. Writings by Plato, Pliny and Aristotle show that before that period it was not possible to distinguish, even verbally, between, for example, a hammer, a pencil or a sword and the hand that held them. The hand, the hammer and the hammering unit made of the hammer and the hand were all named *organon*.[5] The perception of human artefacts existing before that century induced to assume that only a particular type of hand could grab a particular type of artefact to perform a particular type of action. What could be defined as an inter-specificity existing between the person using an artefact and the artefact itself was so high to make a distinction between these two elements impossible or irrelevant. These elements were completely integrated and described by a same word. The possibility that a blacksmith, a knight or a baby could, for example, hold a sword to accomplish a same action was simply unconceivable. In order to understand how this could happen, it is necessary to realize that activities accomplished by persons were seen as activities whereby their soul showed its nature, i.e. they showed what this soul was and what it could be. Human activities were seen as activities of their souls. They did not aim at transforming the world. They were rather seen as aiming at transforming human souls according to their destinations. Rather than as autonomous entities, human artefacts were conceived as at the service of a body that was in its turn at the service of its soul. When compared to modern ways of thinking, this kind of imaginary certainly looks quite exotic. As pointed out by Marianne Gronemeyer,[6] a contemporary person asking for a job allowing his/her soul to find its destination would probably nowadays not be left in circulation. Nevertheless, it must have been exactly the fact that artefacts were at the service of persons' body and of their soul that determined this high integration between persons and artefacts (every person is indeed supposed to have his/her own soul and this soul differs from the soul of any other person). Because of this high integration with the person, human artefacts could not cause or be separated from the developments associated with the manifestation of a particular soul. They were somehow perceived as the reflection of this soul and it was mainly for this reason

[5]See Cayley (2005).

[6]See Gronemeyer (2012).

that mass production of artefacts was not conceivable before the twelfth century. Rather than by some technical limitation, this type of production was probably mainly prevented by the social imaginary developed around persons and their material environment. This kind of social imaginary must certainly have also had deep implications concerning how agency and *responsibility* for the effects of actions accomplished by employing organic tools was imagined. As these tools were completely integrated into and at the service of persons' body and of their soul, responsibility had to be necessarily circumscribed to the person who mastered them and could certainly not be ascribed to the tools themselves. In the following paragraphs of this section, it will be discussed how subsequent radical changes occurred in the social imaginary developed around tools will completely reconfigure the problem of agency and responsibility attribution. It has finally to be mentioned that, when analysed under the point of the view of the duality constituted by *persons* and the *material things* they employ to provide for their necessities, the relationship existing at the time of organic tools between the two poles of this duality has to be interpreted as a relationship where the pole constituted by material things and their possible conceptual representations were always submitted and adapted to the pole made of a particular person and the particular soul that manifested itself through the use of these things. In the remainder of this section, it will be shown that subsequent transformations occurred to the human tools can be very usefully characterized in terms of as many transformations occurring in the relationship existing between the two poles of this duality.

As a consequence of a radical change in the social imaginary that occurred most probably during the twelfth century, human artefacts indeed became separated from the body and were not any more principally seen as at the service of persons' souls. Starting from that century, human tools underwent a metamorphosis that changed them into *instruments* that could be used by *any* person to achieve abstract and predefined *ends*. Various hypotheses deserving further investigations have been formulated to explain the nature of this metamorphosis. One of these hypotheses is that this transformation occurred when mediaeval theologians started assuming that God had delegated to the Angels the task of acting upon the world by means of instruments named *corpora coelestia* that were moved around the Earth. Illich maintains that the new type of causation associated with this new version of a myth could have made possible for the first time to conceive specific types of artefacts as a *means* that can be used by *anybody* to achieve given *ends*. The utilization of the *corpora coelestia* as neutral instruments transmitting Angels' intentionality would have led to conceive that also human intentionality could be transferred to neutral artefacts[7] and the idea that men could share with the Angels this capability of administering the world by creating and using instruments would have come for the first time to the mind of the Saxon canon regular Hugh of Saint Victor. This leading

[7]See Cayley (2005). Within the interviews documented in this book, Illich points out that the notion of an instrument whose functioning is mostly independent from the capacity, the will and the intentions of its users may be also closely linked and is coeval to the birth of the idea that sacraments are God's instruments for man's salvation.

theologian and teacher of the twelfth century, whose books became mandatory reading for people seeking for a liberal education until the seventeenth century, would have been one of the first investigators on the nature and origins of tools for manual labour.[8] People have always used tools and reported about their use since the antiquity, but their presence was somehow taken for granted whilst their shape and nature changed from culture to culture, as it happens, for example, with language, until the twelfth century. It would have been only around the year 1120 that tools of manual labour were recognized as a social and philosophical theoretical problem by scholars like Hugh of Saint Victor, Honorius of Augsburg and Theophilus the Priest. As Illich explains to us, the twelfth century was indeed a period of intense technical innovation in north-western Europe with an impressive increase in the consumption of iron, in the number of mills and in the variety of machines that these mills could activate. It is in this period that Hugh of Saint Victor's ideas concerning the possibility of improving tools for subsistence appeared and tools started being studied by science in terms of *means* that can be used by any person to perform specific and predefined actions. The transformations occurred in the social imagery during the twelfth century, would have led to conceive human tools as objects which can embody human intentions and remain clearly detached from the body of the persons using them. This newly perceived separation or *distality* (Cayley 2005) between the instrument and their users would be at the roots of the separation between an objective reality and the subjects who know and act on it by using tools. Whilst persons and their organic tools were seen as highly integrated and inter-specific in the previous centuries, a detachment between these two entities was instead created with so-called "*instrumenta separata*". Organic tools were seen as utensils whose presence was taken for granted. Their fabrication did not result from a conceptual representation of their functions by their users, and handling and usage were probably the main patterns whereby their nature of tools was discovered. There are indeed very good reasons to believe that the description of a material thing as, for example, something "for hammering" is much "more primordial than any conceptual description of a hammer as being of some particular size, shape, weight and colour".[9] Contrary to organic tools, instruments can instead be the result of and have paved the way for engineering design while creating an object–subject dichotomy.

The new perception that developed around human tools would have ultimately resulted from a change in how causation was intended. Causation was indeed mainly explained in terms of the Aristotelian *causa materialis*, a *causa efficiens*, a *causa formalis* and a *causa finalis*[10] until the twelfth century. Whilst persons and their tools could not be distinguished within the *causa efficiens*, the birth of

[8]See Illich (1981), pp. 75–95.

[9]See Mitcham (1994), p. 256.

[10]In his Metaphysics, Aristotle distinguishes among four types of causa: *causa formalis, causa materialis, causa efficiens, causa finalis*. The difference among these can be grasped by the classical example of the sculptor. To make a statue the sculptor (causa efficiens) is supposed to produce changes in a block of marble (causa materials) with the aim of producing a beautiful object (causa finalis) having in mind his idea of the statue to be carved (causa formalis).

instruments and the way in which human intentionality can be transferred to them would have to be associated with a fifth type of causation (named by Illich *causa instrumentalis*) generated within the causa efficiens.[11]

The consequences of the separation established between persons and their instruments are huge and manifold. Large-scale standardization of artefacts became, for example, possible only once this separation was created. At the same time, it became possible to assume that human intentionality could be transferred to objects and two contrasting views concerning agency and the responsibility for the consequences of instruments mediated actions could be generated. It became indeed possible to assume that instrumental tools could be employed by any person provided with sufficient skills and information background without affecting or redefining his or her intentions. For this reason, a kind of neutrality and objectivity was generally ascribed to them, whereas the full responsibility of the consequences of the actions they allowed to perform had to be attributed to the will of their users. Paradoxically, however, it was exactly because of this separation that it became possible to conceive that agency and responsibility could also be entirely attributed to instruments that appeared as able to deeply redefine human intentions with unexpected and often disastrous consequences for humans and their environment.[12] These contrasting assumptions and perceptions, still largely present in contemporary society, have deeply influenced any field of knowledge and human activity since they entered diffusely the public discourse. With instruments, the two poles of the duality made of the persons and of the material things they use during their everyday life became more independent and autonomous.

As pointed out by Marianne Gronemeyer,[13] the artificial separation created by instruments has also radically changed the sense of the existence of human artefacts and of human beings. Contrary to *organa*, instruments are not artefacts at the service of the human soul. With instruments, human artefacts can become independent entities generating effects that can in principle be completely unknown and deserve investigation. At the same time, however, this separation is what makes it possible to conceive for the first time an idea of *delegation* of human tasks to machines. It is this separation or *disembodiment* that makes it possible to think of human artefacts as a kind of automata that can be activated, for example, by pushing a button. With instruments, human artefacts can be changed into autonomous entities to which human action can be delegated and their autonomy is exactly what makes it possible that the effects of their employment escape human control and foresight. Despite their birth makes it possible to think of the world and of

---

[11]Aristotle's *causa efficiens* did not indeed make possible to distinguish between the artefact and the hand handling this artefact.

[12]The current debate on increasing access limitations to weapons for US citizens is an example of this dichotomous perception. Part of the public opinion attributes the responsibility for the increased number of murders being registered in US to the wide presences of weapons among US citizens. Another part (weapons manufacturers especially) maintains that the responsibility for murders has to be ascribed to the will of murderers and not to the weapons themselves.

[13]See Gronemeyer (2012).

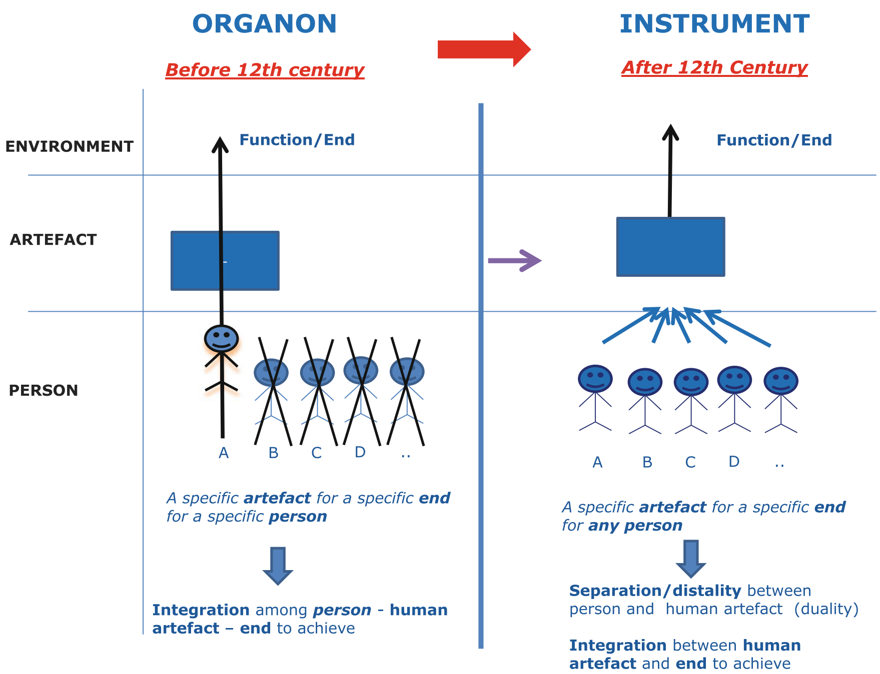

Fig. 1.1 Transformations associated with the birth of instruments

human beings as machines obeying deterministic laws, instruments project on human artefacts a shadow of unpredictability that was unknown before their creation.

The transformations associated with the creation of instruments are schematically illustrated in Fig. 1.1 by distinguishing among persons, artefacts and functions accomplished thereby. However, it has to be stressed that this distinction has just a descriptive function and did not hold, for example, in case organic tools. It has been introduced to illustrate some major metamorphoses occurred in the way in which human artefacts were conceived afterwards.

From Instruments and Machines to Motors

The central metaphors whereby the world and human beings have been imagined have been affected by another radical change that occurred in the mid-nineteenth century. As happened with the transformations that led to the birth of instruments, this later change has taken with it a transformation in the way in which natural phenomena were conceived and delegation to human artefacts was imagined and realized. As briefly discussed in this section, the invention of the energy concept has had a fundamental role in a cultural change that still deeply affects contemporary society. This change has led “motors” to become another central metaphor complementing the metaphor of the “machine” that dominated the social imagery at least until the eighteenth century. Whilst this latter metaphor reflected a Newtonian vision of a universe seen as an ensemble of forces, billiard balls and reversible mechanisms, the universe became a kind of gigantic motor functioning through the degradation of a new type of natural resource serving as fuel input. It is not by accident that the scholars contributing to the widespread application of the energy concept and associated conservation and degradation principles during the nineteenth century contributed also to abandon definitively the chimeric research for the so-called *perpetuum mobile* that has kept several researchers occupied during the previous century. As pointed out by Anson Rabinbach,[14] the invention of the steam engine, the philosophic impact of the *Natuarphilosophie*[15] and the French engineering tradition of Navier, Coriolis, Carnot, Poncelet and others contributed substantially to a cultural revolution that led to imagine the universe and human beings as “motors” fuelled by the new protean entity named energy. The famous lectures given by Hermann von Helmholtz in the 1840s also gave a remarkable contribution to this revolution.[16] Energy and the eminent scholars who contributed to its social construction[17] changed the universe and nature into a gigantic *reservoir* made of a single, infinitely transformable, degradable but not destructible entity that was waiting to be transformed into work. Energy somehow could become the only real substrate existing within and behind natural entities.

It however passes often unnoticed how, despite that common parlance implicitly acknowledges an indisputable ontological concreteness to energy still today, this concept has actually undergone a series of profound metamorphoses within laboratories of physicists and engineers that actually started already in the seventeenth century. These metamorphoses have progressively led to associate energy with a magnitude remaining intact during collisions of rolling balls and springs

[14]See Rabinbach (1992).

[15]This philosophy drew on Shelling and Hegel and postulated the presence of an Urkraft or vis viva containing the secret of energy and life in the universe. It was particularly important in the work of Mayer and Helmoltz who contributed in important ways to the social construction of energy. For further information concerning the link between Naturalphilosophie and the energy conservation principle see for example Caneva (1993), p. 310.

[16]For further information on Helmoltz lectures see e.g. Rabinbach (1992).

[17]Mirowski (1989) points out that the energy concept has to be probably seen as the result of the joint and mutually reinforcing social constructions of invariants and conservation principles taking place in the fields of physics, biology and economics. According to this scholar, the structures of explanation produced in these three different fields have probably always been homeomorphic and would legitimize each other even in the face of possible disconfirming evidences produced in each field. The above-mentioned mutual reinforcement would have been already operating when the institution of money was disconnected from any reference to a particular commodity and became the abstract representation of pure value, when the dual concepts of the organism and of natural selection were established within the evolution theory of Darwin and when the energy conservation and degradation principles were established by physicists and engineers around the mid-nineteenth century.

oscillations, with a primordial entity obeying conservation and degradation principles, with states of electromagnetic fields, with fields symmetries, with time homogeneity.[18] On the one hand, energy has therefore been suggesting since the last two centuries that there is no free lunch, that the whole universe and all human activities are naturally regulated by conservation and degradation principles indicating that there is a cost to be paid for anything we do and that nothing can be created for free. On the other hand, the energy concept has evolved within laboratories in such a way that cosmologists admit nowadays that everything could have begun from a vacuum fluctuation and that the whole universe could actually be a free lunch.[19] Despite these quite recent evolutions and discrepancies in the interpretation of the energy concept, the organization of economies and societies remains entirely informed by the idea that everything happens in the universe thanks to the consumption of the protean entity that has been named energy. The implications of this misconception for how energy sustainability has been and is still being conceptualized will be discussed in a subsequent section. What deserves to be briefly specified here is rather how the rise of the energy concept has changed the way in which human beings and human delegation to machines is conceived. A description of the changes induced in the previously mentioned duality made of persons and the material things they use during their everyday life can be very insightful in this respect. Once again, the modifications occurred in how material tools were conceived mirrored as many modifications in the way in which persons and action delegation to machines were imagined.

As long as human tools were principally seen as instruments, persons and the outside world were identified with clockwork reversible mechanisms. With motors, human action became dependent on the provision and on the optimized consumption of suitable and quantified resources inputs. Delegation to machines assumed in this way a connotation of human *empowerment* to be achieved and/or maintained through the consumption of various forms of energy. Either actions were accomplished by using motors or by human bodies, agency and the reproduction of these actions were in this way associated with and subordinated to the consumption of quantifiable energy resources units. If the disembodiment and separation between tools and human bodies that were generated by instruments led to conceive actions in terms of mechanisms, motors subordinated these actions to the consumption of an abstract entity named energy. Material and physical infrastructures whereby these actions could be realized became a kind of energy *stock* transformers that may work and produce expected outputs more or less properly or more or less efficiently and this change was perfectly reflected in how the shapes of these infrastructures and their integration into the environment changed. Whilst previous machines, like windmills, tended to fit into landscapes and to put into relief specific features of this landscape, the shape of the plants that have started being built since the nineteenth century to extract and store the energy

[18]For further information on these transformations, see Mirowski (1989).

[19]For further information, see Tryon (1973) and Akatz and Pagels (1982).

serving as motors fuel were and still are completely abstracted from the landscape and just stand-up as ready to use objects without any specific aesthetical connection with the surrounding environment.

Moreover, the energy concept has taken with it also a completely new relationship to be entertained with *time*. Energy and the devices relying on energy use that started to be massively built contributed indeed to interpret time as a quantifiable resource that is consumed at a constant pace and whose measurement and consumption can be used to re-organize and control human activities.[20] Energy, time and the associated conservation principles allowed in this way to put human activities under a scarcity paradigm, according to which the consumption of energy and time units needed to perform given activities inevitably causes that less energy and time is available both at the individual and the social level to perform other activities. Needless to say that this scarcity paradigm has been alone the reason for a hugely intensified and more energy efficient delegation to machines whereby people were supposed to liberate their time to perform additional activities. This type of imaginary, however, was fundamentally based on an idea of energy derived from fossil fuels. Despite the thermodynamics laws that have been established within laboratories may induce to think differently, the nature of energy can indeed change and this change can generate different types of social imaginaries and different types of perceptions concerning how human activities can be organized. In the following sections, it will be discussed, for example, why renewable energy is a fundamentally different energy type compared to fossil fuels energy and how a transition to renewable energies implies, among others, a different relationship with time and therefore a different organization of human activities. Energy and time are somehow the two sides of a same coin and a modification in the nature of one side inevitably induces a modification in the nature of the other side. The transformations entailed by the social construction of energy are schematically represented under Fig. 1.2.

From Motors to Complex Systems

The separation or *distality* that instruments have created between persons and their artefacts has made it possible to conceive that any end can be achieved by fabricating means that can be used by the arbitrary hand of an arbitrary actor.[21] Instruments, however, are still entities deeply integrated into the ends they allow achieving. They are indeed conceived and fabricated to perform specific functions and their structure and shape are deeply dependent on these functions. A further fundamental transformation takes place when it becomes possible to assume that a *same* material object can be produced and used by *any actor* to perform *any kind* of function. Human artefacts get so separated in a very particular way from the ends

[20]For further information on this transformation see Perulli (1996).

[21]See Gronemeyer (2012).

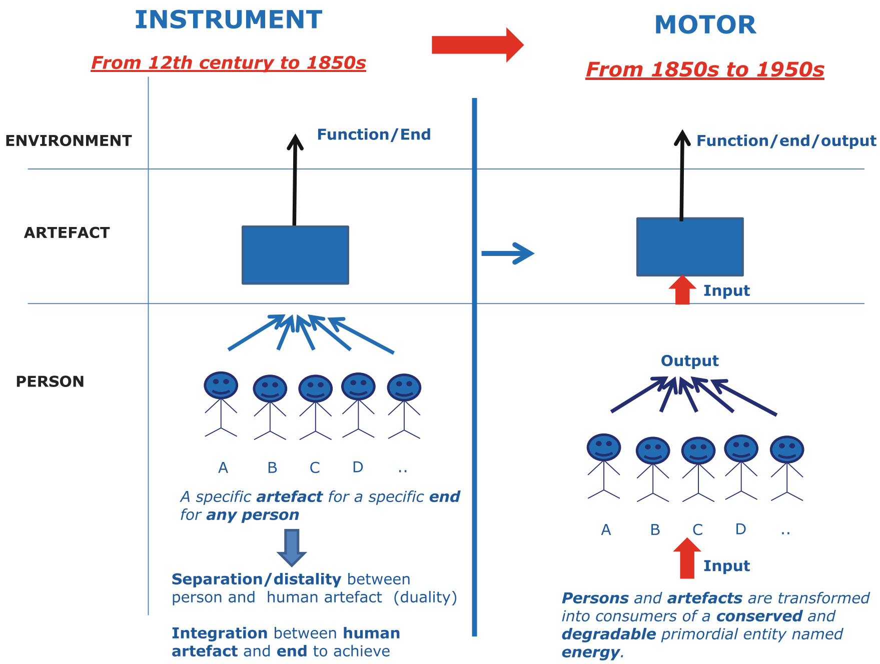

Fig. 1.2 Main transformations associated with the transition from instruments and machines to motors

they allow achieving. This is a fundamentally new and common characteristic of a large series of quite recent conceptual and material artefacts that can be identified with so-called complex systems. The main phases of the social construction of these systems can be found by identifying the main knowledge advancements that have made their large-scale production and employment possible. As the next paragraphs will try to illustrate, the latest phases of this construction occurred probably after the mid-twentieth century and the previously described passages to instruments, machines and motors somehow represent the necessary preliminary conditions for this latest transition. Some of the basic characteristics of complex systems are schematically represented in Fig. 1.3.

The implications of this third type of metamorphosis occurred to material artefacts can be understood by referring to a large series of nowadays very familiar devices embedding human beings within complex systems. Personal computers, smart phones, computer servers, audio-visual systems and all devices generally subsumed under the category of computer and information technology are the most common examples of these types of device. It is indeed quite easy to realize how they allow or are supposed to allow people performing an increasing number of functions. By interacting with a computer, a person can nowadays, for example, send mails, write a text, purchase products, call other persons, etc. With the increase in the number of functions they allow performing, these material objects cannot

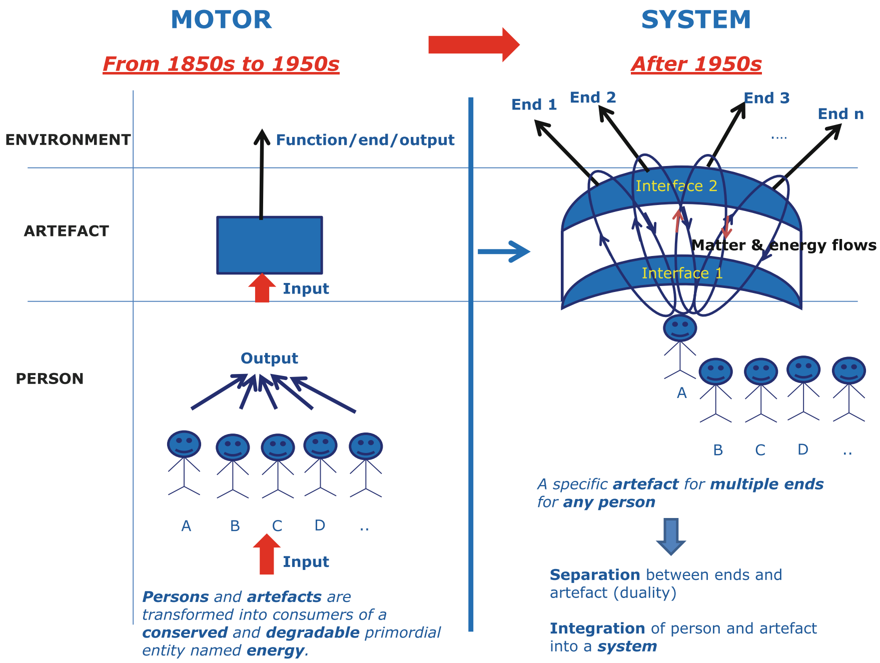

Fig. 1.3 Main transformations associated with the creation of complex systems

anymore be considered as instruments, i.e. as means conceived to allow any person achieving a *specific* end. When they are used by people for most of their interactions with the external environment, they rather become ends in themselves and get in this way separated from each of the specific ends they allow achieving. At the same time, they become more and more integrated in the human body because the increased number of functions they allow performing implies that people have to stay "attached" to them for longer time.

It is for this reason that the transition to complex systems makes human artefacts constituting these systems very similar to kinds of human *prostheses*. Human prostheses are indeed generally assumed to allow disabled people performing the highest possible number of functions compared to normally endowed ones. A prosthesis replacing a missing arm should, for example, allow grabbing, writing, feeding, driving and performing all the other functions that normally endowed people can perform. The higher the number of functions that can be accomplished through it, the better the prosthesis and the higher its integration into the human body. The same principle applies to the types of artefacts previously described. The higher the number of their functions, the closer and the more integrated into the human body they become. The *distality* between user and the used artefact that characterized the age of the instrument gets lost with systems. A man can still decide whether to use or to leave a hammer and the hammer remains the tool of a man as long as this hammer is conceived as an *instrumentum*. When the unit made by a man and a hammer is conceived in terms of a system, this unit becomes a strange entity made of quasi-objects and quasi-subjects, to use Bruno Latour terms,[22] wherein information flows. One part of the system defines and could not exist without the other. Systems are units integrating special types of devices into persons' bodies. If the analogy with a human prosthesis would not be sufficient to illustrate this fact, the quite common experience of the relationship we have started entertaining with computers and cell phones can certainly provide everybody with further insights concerning the nature of this progressively increasing integration. Complex systems represent the tangible realization of the myth of the *cyborg*. It is not certainly necessary that chips are implanted in human bodies for this to happen. When the number of functions accomplished through these new artefacts increases, they start constituting a sort of membrane that inserts itself between our senses and the outside world. Whatever the physical distance existing between us and them, they function as a kind of very thin plastic bag that can perfectly adhere to our body and mediate any relationship undertaken with the external world. Given the high number of functions that they allow accomplishing, they end up shielding and impermeabilizing the body from the outside world. At the same time, however, they can perfectly adhere to the body. Contrary to instruments, these types of artefacts can indeed be extremely flexible and adaptable, this adaptability being due to the fact that their functioning relies on the standardized transmission of an extremely immaterial and protean entity. Whilst instruments standardization relates to their shapes and functions, systems standardization relates indeed to the information codes they employ.

The type of integration between person and artefacts realized within systems should however not be confused with that realized by the organic tools previously described. Systems rely on a double interface whereby a double translation is constantly and actively performed. As it can be probably understood by Fig. 1.3, the first interface translates and reduces acts accomplished by the user into codes and messages that can be processed by the artefact and translates codes generated by the artefact into inputs and messages that can be understood by the user. The second interface translates instead the inputs from and the outputs to the external world. Systems can ultimately be seen as units made by persons integrated into artefacts whose functioning is based on the elaboration of information within very complex feedback loops. Change and stability become in this way the result of positive and negative information feedbacks which generate along system feedback loops following external perturbations. The distinction between action and reaction becomes often meaningless because circular causation loops are the only ontological entities of systems. It follows that the loss of distality associated with systems makes the conceptual category of the person and the distinction between subjects and objects also meaningless. The only elements needed to describe systems dynamics are indeed the above-mentioned information feedback loops circulating between persons and material objects. This loss of distality somehow

[22]See Latour (1993).

also implies a loss of persons' control over the material objects they are interacting with. When the interaction between a person and a material object is described in terms of a system, the interacting parts can indeed constitute a whole pursuing own ends.

Systems can inscribe persons' intentionality into their workings. Heinz von Förster described, for example, a man walking a dog[23] as a system with the man, the leash and the dog forming a unit processing informational signals that manages to make its way down the sidewalk. In the same way, the system made of a man interacting with a modern Internet-connected computer can be described in terms of a two-component unit processing signals to achieve its own ends in the surrounding environment. The possibilities that persons can exercise some type of control over the evolution of "their" systems are therefore markedly reduced or even nullified. As already happened with the creation of instruments, the notion of agency and responsibility for human actions are hence once again profoundly redesigned. A description of the transformations induced in the duality made of the persons and of the things they use to provide for their necessities can be once again very insightful in this and in many other respects. It is indeed not very difficult to realize how the new imaginary associated with the new type of material artefacts constituting complex systems has mirrored a change in the imagery associated with persons and their psychological and organismal dynamics. It can, for example, hardly pass unnoticed how complex systems have contributed to reformulate psychological problems in terms of communication problems linked to how information is processed among and within persons.[24] At the same time, bodies of persons have been progressively identified with immune systems capable of keeping the value of its vital parameters (e.g. blood pressure, glycemic rate, etc.) within predefined variation ranges in a changing environment while body health has been identified with a risk profile, i.e. a list of numbers representing the conditional probabilities that the measured values of its vital parameters may correspond to a system evolution towards a status threatening its own existence. Genetics is then another research field where human and not human organisms have been progressively identified with the information processors representing the central metaphor around which complex systems are being socially constructed, i.e. computers. However, it has to be stressed that, although the transformations that have accompanied the creation of these systems might seem to integrate and completely abolish any distinction between the two polarities of the previously mentioned duality, a more attentive analysis reveals instead that, rather than disappearing, this duality moves from persons and their artefacts to the unbridgeable gap and separation artificially established between complex systems functions and their material infrastructures. The puzzle posed to computers programmers having to find suitable algorithms whereby specific human functions can be reproduced by technological devices is exemplary of the nature of this separation and of how the

[23]See Cayley (2005).

[24]See for example Watzlawick et al. (2014).

approaches that can be elaborated to overcome this separation actually redefine the nature of the problem without resolving the duality at stake. As also mentioned at the beginning of this section, this problem is always and can only be formulated in terms of a *translation* problem consisting in finding suitable information algorithms obeying specific internal logics that can serve to faithfully reproduce these functions. This exercise is undoubtedly stimulating and often provides with extremely useful solutions. Nevertheless, it also progressively and increasingly contributes to create and maintain a separation between an underworld obeying the rules of information theory and an upper world where people continue conducting their everyday life. Either referring to the entities integrating humans and their tools, or to the entities studied by biology, sociology, physics, linguistics, informatics, etc., complex systems take always with them an inescapable and irreconcilable separation between observable functions and meanings and their underlying material or conceptual infrastructures supposed to generate these functions and meanings by following own internal rules. As also discussed in the next section, despite complex systems and science informed thereby seem to propose an holistic view of the world, these artefacts and the associated body of knowledge remain profoundly dualistic.

The type of integration achieved within complex systems entails however also a change in the way in which agency, human delegation and disembodiment are realized. It has been previously mentioned that the social construction of instrumental tools presumably made it possible to conceive human artefacts as autonomous entities to whom human intentionality can be transferred because of the distality created between them and the persons using them. Moreover, it has been pointed out that the subsequent social construction of motors has led instead to conceive delegation in terms of *empowerment* achieved thanks to the optimized consumption of a natural resource named energy. Strange as it may seem, with complex systems, delegation and disembodiment are instead the result of an *integration*. Persons integrated within complex systems have to be imagined as nodes of very wide and highly interconnected information networks. The spatial extension and the strong coupling of these connections enhance incredibly the geographical area that can be covered in very short time and the power capacity that can be activated by single human actions. These same characteristics however render complex systems similar to entities which follow own logics and escape the control of individuals and makes often practically impossible to track the ultimate consequences of single human actions and ascribe some kind of personal agency and responsibility for these consequences. With complex systems, the views of the extremely wide regions of the world that become achievable through artificial prostheses and the actions that can be accomplished thereupon by individuals located in a given place are inevitably filtered by the artefacts these individuals are integrated into and are shaped by a necessarily limited number of circuits and information feedbacks constituting the whole system. Given the wide spatial extension and the strong couplings operating within complex systems, changes occurring within them can however also be dramatic and completely unpredictable. They can occur after a long period of stasis or can repeat after a short time according to unknown frequencies. Too rigid infrastructures can represent a serious obstacle to properly face these types of events in this type of environment. Complex systems require extreme flexibility and adaptability to individuals integrated into them. Because of their characteristic dynamics, they entail therefore a different relationship with *space* and *time*. Motors have, for example, contributed to interpret time as a quantifiable resource that flows, uniformly and uni-directionally, whilst the perception of space that accompanied the diffusion of motor-like devices was informed by material infrastructures symbolized by the huge silos where energy and material resources could be stoked. With complex systems, time becomes instead a discontinuous and punctuated entity whilst assuming qualitative and relational characteristics. Its flowing is marked by single and sudden events whose occurrence in a place depends on a series of ever-changing spatial relationships with other places. Material infrastructures might have to be rapidly disassembled and reassembled and have to become more and more flexible and liquid in order to allow coping with unexpected challenges. All these changes depend substantially on a change in the nature and in the role played by energy sources. Complex systems undergo indeed intensive material and non-material exchanges with the external environment and are *open* by definition; this fact makes their dynamics naturally dependent on exogenous rates of energy supply. Put in other words, energy sources involved in the dynamics of complex systems can more hardly be described only in terms of available and predeterminable amounts of resources *stocks* that can be used at any time. They have often to be seen as *funds*[25] of resources whose utilization occurs according to not pre-establishable rates. The combined changes occurring in how time, space and energy are perceived should not come as a surprise. As already mentioned, these are closely linked and interdependent physical quantities and changes induced in the nature of one quantity mirror the changes occurring in the others and vice versa.[26]

The Role Played by Information in the Social Construction of Complex Systems

The short explanations offered in the previous paragraphs may be sufficient to hint that *information* is one of the main building blocks of complex systems. The type of information at stake is however very particular and its peculiarities have been put into evidence by the seminal works of scholars like Claude Shannon,

[25]For a definition of stocks and funds see for example Georgescu-Roegen (1971). This aspect will be further discussed in a following chapter section.

[26]The fact that changes in the nature of space, time and energy are being inferred through changes incurred in the nature or in the interpretation of observed phenomena should not come as a surprise either. If, for example, the events reproduced by thermodynamics have led to conclude that time flows uniformly in one direction, events reproduced by complex systems can led to conclude that time is discontinuous and punctuated.

Gregory Bateson, etc., starting from the mid-twentieth century. Because of one of the strange curiosities I have referred to in the introduction to this chapter, it is generally assumed that this relatively new type of information has always been present in nature, for example, within the DNA of any biological organism. Contrary to what is generally assumed, there are instead at least three important transformations that had to occur in what has been traditionally meant by information, before this notion could be conceived as a kind of natural entity and contribute to the social construction of complex systems. The main transformation that had to occur has consisted in assuming that *information can exist and play a role in nature without the presence of a human reading it*. Although it could at first sight appear quite irrelevant, the assumption that any (part of any) biological organism and even machines can somehow be regulated by the transmission of something named information is a huge step towards abstraction. This reinterpretation of information has caused a deep change in the nature of this entity and would most probably have been unthinkable without the advancements that occurred in computation science during the first decades of the twentieth century.[27] This has led, for example, to conceive that a particular type of information is available in any biological organisms and regulates their epigenesis and phylogenesis.

A second closely related important change concerning information that has also taken place in the past century is instead responsible for having made of information something that can be calculated. Today, we are probably not very surprised in hearing that information can be reduced to *numbers*. For this to happen, it has been however necessary to think that the information that can be found within any sign and natural manifestation is actually *one* manifestation among a *finite and prefigured number* of possible manifestations. To a certain extent, this is equivalent to assume that anything that can be read or written in the book of nature actually corresponds to one or more combinations of a finite number of letters constituting the alphabet employed by nature. By translating natural manifestations into numerable combinations of a limited number of signs, this change has led to create classifications that may somehow resemble to Classical Age taxonomies[28] whereby all possible identities and differences detected in nature were arranged into ordered tables. Unlike taxonomies that were created at the end of Renaissance, the ordered tables created by the modern notion of information are huge tables written in the binary language of computer technologies. For each of the messages that can be written in this language, it is nowadays possible to assess its so-called information content by calculating the ratio between the number of binary combinations corresponding to this message and the total number of totally possible combinations. Whereas the first mentioned transformation has made possible to think of an abstract entity at work within the natural world, the second one has hence led to reduce it to ordered tables that can be studied and manipulated by using computer

[27]For a detailed description of the evolution of this concept see for example Poerksen (1995).

[28]See for example, Foucalt (1966).

technologies. A fundamental contribution to these changes has come also from Alan Turing and a series of other eminent scholars during the first decades of the nineteenth century.[29] By demonstrating that any function that can supposedly be calculated by humans can be calculated also by a machine, these scholars have contributed to transmogrify also the human part of the natural world into autonomous computational systems whose functioning is based on the elaboration of information.

A third and very relevant metamorphosis in what has to be meant by information relates finally to the nature of the elementary units that constitute it. This nature can be grasped through the definition provided by one of the fathers of the cybernetics: Gregory Bateson. By defining information as "*a difference which makes a difference*"[30] within any natural system exhibiting a mind-like behaviour, Bateson has contributed to give information a purely *relational nature*. Through information, any entity of the natural world comes ultimately to be made of infinite chains of relationships (i.e. differences) with other entities. Rather than from some kind of intrinsic characteristic, objects are defined by their relationships with the surrounding environment. To explain this, Bateson provides a variety of examples ranging from phylogenesis, to phenomenology of perception, to linguistics. When, for example, he disserts on what an *elephant's trunk* is phylogenetically, he concludes that what defines the meaning of the trunk is nothing but the context where the trunk grows from within the elephant's embryo. It is the fact that what we call trunk "stands between two eyes and north of a mouth".[31] The trunk would hence not result from an intrinsic characteristic of a specific embryo part. It would rather be the result of an internal process of communication during embryo growth. Bateson offers a series of experimental evidences that can prove this conclusion. He mentions, for example, the experimental evidence provided by a study of unfertilized frogs' eggs demonstrating that for these eggs "the entry point of the spermatozoon defines the plane of bilateral symmetry of the future embryo". The parts of the frog's egg that can become the frog's nose would hence be defined by their relationships with other egg's parts based on the spatial relationship of all the egg's parts with the axis fixed by the spermatozoon entry point. There would not be any specific internal characteristic that can predestine any specific part of the

[29]See for example Teuscher (2004), p. 216.

[30]See for example Bateson (1972). Terms and expressions like *information, information about a difference, difference that makes a difference* are used interchangeably by Bateson. In order to produce information, two (real or imaginary) entities are needed such that the difference can be immanent to their reciprocal relationship; moreover this difference must be such that information about this difference can be represented as a difference within some information processor (e.g. a brain or a calculator). Each of the two entities producing information is a non-entity if taken alone. A relationship between two parts or between a part at time 1 and the same part at time 2 is needed in order to activate some third component that could be defined as the *receiver*. This receiver (e.g. a terminal sensor in an organism) reacts only to a difference, to a change. As the reaction of the receiver is in its turn nothing but a difference, this reasoning implies that *information is just a difference producing another difference.* See the original explanation in Bateson (1979).

[31]See Bateson (1979).

unfertilized egg to become the frog's nose. Another example is then provided for sensory perception when Bateson illustrates how human eyes require motion to see anything. In this respect, he explains how static objects would disappear from our sight without the tremors that move our pupils along objects borders. It is the variation, the difference generated during our perception by the perceived differences between the static object being observed and adjacent objects and surfaces that makes the perception of the former object possible. A further example to explain the relational nature of information is then taken from linguistics. Bateson wonders in this case what gives meaning to letters, words and sentences and provides the following reasoning to answer this question and to support his thesis. He maintains that the letter "p" would have no meaning if, for example, it were not part of the word "perhaps". The word "perhaps" would have in its turn no meaning if, for example, it were not part of the sentence "perhaps this is soap". This sentence would in its turn have no meaning without the context where it is stated and this meaning would be different if the sentence were mentioned, for example, in a bathroom, on a stage or within the reasoning presented in this chapter. Meaning and information content would therefore be purely relational and depend on a series of piled contexts. In agreement with linguists like Ferdinand de Saussure, Bateson concludes that, rather than from an objective relationship between the sign and the thing this sign refers to, meaning emerges from a series of relational contexts that can be established with other signs. *Signifier* and *signified* are in this way completely separated. Moreover, as the last example would prove, the contexts at stake would always be hierarchically organized and it would never happen that the smaller context determines the characteristics, the evolution and the meaning of the larger context. According to Bateson, hierarchies necessarily cross and entirely organize complex systems, either these systems are constituted by biological organisms or by the aggregates studied by linguistics. Within complex systems, hierarchical organization actually appears already at the level of the two irreducible entities that constitute each elementary sign, each information unit, whatever this information unit may represent. The difference between these two irreducible entities is the ultimate elementary brick where hierarchies are built upon. In other words, systems hierarchies are built upon a duality which is already present in the two irreducible entities whereby the modern notion of information is constructed and which is closely connected to the type of duality mentioned in the previous paragraph. Interestingly, the presence of hierarchies itself would make the evolution of most complex systems highly unpredictable and counter-intuitive. Considering that these systems are *open*, the possibility that higher hierarchies and wider information feedback loops are not taken into account when analysing them is very concrete. This may cause that systems' evolution results the opposite of what can be forecast, especially when assessed in the long term. Paradoxes and unexpected evolutions within complex systems are indeed everyday practice.

The three transformations just mentioned have substantially contributed to the social construction of complex systems. Through them, it has become possible to conceive of single artefacts potentially capable of performing any type of function by integrating any person within larger units. The material world and the human beings had to be integrated and reduced to the common denominator represented by the kind of just described information before these systems could be massively constructed. Any phenomenological manifestation had to be reduced to complex information flows that can be (re)constructed and analysed by calculation machines before complex systems could be presented as one of the latest discoveries by science. The next chapter will further explore these transformations in order to hopefully allow better understanding their nature and the connections existing between the massive construction of these types of artefact and the ongoing transition to renewables.

References

Akatz, D., and H. Pagels. 1982. Origin of the universe as a quantum tunnelling event. *Physical Review D* 25: 2065.

Bateson, G. 1972. *Steps to an Ecology of Mind*. Chicago: The University Chicago Press.

Bateson, G. 1979. *Mind and Nature: A Necessary Unity (Advances in Systems Theory, Complexity and the Human Sciences)*. New York: Hampton Press. ISBN 978-0-553-34581-0.

Bauman, Z. 1998. *Globalization: The Human Consequences*. Cambridge: Polity Press in association with Blackwell Publishers Ltd.

Blumenberg, H. 1988. *Work on Myth*. Cambridge: The MIT Press.

Caneva, K.L. 1993. *Robert Mayer and the Conservation of Energy*, 310. Princeton: Princeton University Press.

Cayley, D. 2005. *The Rivers North to the Future: The Testament of Ivan Illich as Told to David Cayley*. Toronto: House of Anansi Press Inc.

Foucalt, M. 1966. *The Order of Things*. Abingdon: Routledge.

Georgescu-Roegen, N. 1971. *The Entropy Law and the Economic Process*. Cambridge, MA: Harvard University Press.

Gronemeyer, M. 2012. *Wer arbeitet, sündigt: Ein Plädoyer für gute Arbeit*. Darmstadt: Primus Verlag.

Illich, I. 1981. *Shadow Work*. Marion Boyars Inc., 75–95.

Illich, I. 1983. *The Social Construction of Energy*. Published in New Geographies 02: Landscape of Energy (2009). Massachusetts: Harvard University Press.

Latour, B. 1993. *We Have Never Been Modern*. Cambridge: Harvard University Press.

Mirowski, P. 1989. More *Heat than Light. Economics as Social Physics, Physics as Nature's Economics*. Cambridge: Cambridge University Press.

Mitcham, C. 1994. *Thinking Through Technology: The Path Between Engineering and Philosophy*, 256. Chicago: University Chicago Press.

Perulli, A. 1996. *Il Tempo da Oggetto a Risorsa*. Franco Angeli Editore.

Poerksen, U. 1995. *Plastic Words—The Tyranny of a Modular Language*. University Park: The Pennsylvania State University Press.

Rabinbach, A. 1992. *The Human Motor: Energy, Fatigue, and the Origins of Modernity*. New York: Basic Books.

Teuscher, C. 2004. *Alan Turing: Life and Legacy of a Great Thinker*, 216. Berlin: Springer.

Tryon, E. 1973. Is the universe a vacuum fluctuation? *Nature* 246: 396–397.

Watzlawick, P., J.B. Bevelas, and D.D. Jackson. 2014. *Pragmatics of Human Communication. A Study of Interactional Patterns, Pathologies, Paradoxes*. New York: W.W. Norton & Company Inc.