TECHNOLOGICAL EXPLANATIONS: THE RELATION BETWEEN STRUCTURE AND FUNCTION OF TECHNOLOGICAL OBJECTS

Peter Kroes, University of Technology Delft

1. THE DUAL NATURE OF TECHNOLOGICAL OBJECTS

A technological object such as a television set or screwdriver has a dual nature. On the one hand, it is a *physical object* with a specific physical structure (physical properties), the behavior of which is governed by the laws of nature. On the other hand, an essential aspect of any technological object is its *function*. A technological object has a function, which means that within a context of human action it can be used as a means to an end. A physical object is the carrier of a function and it is by virtue of its function that that object is a *technological* object. Usually a technological object is the embodiment of a human design and is specifically made to realize a certain function. Function and physical carrier together constitute a technological object. The function cannot be isolated from the context of use of a technological object; it is defined within that context. Since that context is a context of human action, we will call the function a human (or social) construction. Thus, a technological object is a physical construction as well as a human/social construction.

This dual nature of technological objects is reflected in two different modes of description, viz., a *structural* and a *functional* mode of description. In so far as it is a physical object, a technological object can be described in terms of its physical or structural properties and behavior. This structural mode of description makes use of concepts from physical laws and theories and is free of any reference to the function of the object. The language of modern physics has no place for functions, goals or intentions. With regard to its function, a technological object is described in an intentional (teleological) way: the function of a television set is to produce moving pictures, of a screwdriver to tighten or loosen screws (see Searle, 1995). Purely functional descriptions of an object have, from a structural point of view, a black box character in the sense that they do not specify any physical properties of the object: a television set is *something* (whatever it may be) to produce moving pictures, a screwdriver is *something* to tighten and loosen screws.

2. THE NATURE OF TECHNOLOGICAL DESIGN

A closer look at the notions of design and design process also reveals the dual nature of technological objects (see Kroes, 1996). A design may refer to a rough, global sketch that shows how a technological function might be performed, like Leonardo da Vinci's sketch of an airplane. Or it may denote the description of the prototype of an artifact invented and developed in a research laboratory; such a prototype is a concrete realization of a technological function, but is still far away from production (e.g., the first point contact transistor developed in the Bell Laboratories). But a design may also be a set of drawings in which an artifact is described up to every detail of its constitutive parts. In the last case, the makeup of an artifact has been worked out in such detail that its design is a blueprint for its production; all major technological problems, often also those that are specifically related to its production, have then been solved. Usually this is the form in which a design leaves the design or development department. All specifications of the artifact as a whole and of its constituent parts are fixed; at this stage the design and development phase of an artifact have come to an end and it may be taken into production.

Here, the notion of design is taken primarily in the sense of a complete description of a physical object, such that on the basis of that description the object can be made. In modern industry, particularly in big firms, such a design is usually the outcome of a highly *institutionalized* process involving design departments and professional designers. These design processes typically start with defining the commercial requirements and specification of an artifact; the reason for doing so may be an explicit market demand or a technical opportunity that presents itself. At this stage, the new artifact is defined in terms of its global *functional properties and costs*. This stage is usually followed by an inquiry into the technical and commercial feasibility of the artifact. After several other intermediary steps, the design process ends with a complete and detailed *technical/physical* characterization of the artifact, which contains a description of the technical/physical specifications of the artifact as a whole and of each and every part of it. In other words, in the course of the design process *the function to be performed has been translated into a construction to be produced*. The final step is the technical validation/ verification of a design; it roughly consists in showing that a real prototype version of the artifact, existing until then only on paper, indeed adequately performs its intended function.

The overall design process may be divided in various phases or steps that correspond to distinguishable aspects of solving a design problem. Within design methodology the triad, analysis-synthesis-evaluation, is often taken as a starting point for modeling the design process (see, e.g., Grant, 1993). As long as designing is an activity performed by one single individual, these phases are relevant only from a conceptual point of view. As soon as designing becomes a matter of teamwork, which is by and large the situation in modern industry dealing with complex and large systems, the phasing of the design process becomes an important institutional tool for organizing, controlling, and steering the process of product development. A typical example of the division of the design process in various phases, as part of a systems life cycle, is the following given by Sage (1992): requirements and specifications; preliminary conceptual design; logical design and architectural specs; detailed design and testing; operational implementation; evaluation and modification; operational deployment (of course, iterations occur between various phases). It contains several intermediate steps between the starting point of a product development (the fixation of the commercial/functional requirements specification) and the end point of the design and development phase (the detailed technical design of the artefact). Gradually, during the design process, the artifact takes on a definite shape until finally the whole artifact with all its components is uniquely determined in terms of its functional and physical properties.

So the design process typically starts with the description of a required function: something to produce moving pictures, or something to tighten or loosen screws. As we already remarked, a characteristic feature of functional descriptions is that they do not refer to any physical properties of the desired object. The starting point of a design process is therefore a kind of*black box* characterization of a physical system. The task of the designer is to show how the black box may be filled with a physical system such that the required function will be performed by that system. The proposed design should contain a complete description of that physical system. But it is important to note that a design is more than merely a complete description of the physical properties of a thing to be made. A design also contains (at least implicitly) an explanation of how the proposed physical system will be able to perform the required function. In other words, a design also consists of a *technological explanation*, *i.e.*, *an explanation of the function of a technological object in terms of the physical structure of that object*. A technological explanation is an integral part of a design and plays a crucial role in justifying a design: it shows that on the basis of it's physical structure an object will perform a certain function.

3. A PROBLEM: THE RELATION BETWEEN STRUCTURE AND FUNCTION OF TECHNOLOGICAL OBJECTS

The claim that an adequate design contains a technological explanation raises a fundamental problem. It means that engineers are somehow able to bridge the gap between structural and functional descriptions of a technological object: a function, described in an intentional language, is explained in terms of a structure, described in a non-intentional, structural language. How is this possible? What does this mean for the relation between the structural and functional modes of describing technological objects? Can one mode of description be reduced to the other? Is it possible to deduce from a complete structural (scientific) description of an object its technological function, or vice versa? The answer given to the last question is usually negative. For instance, the historian and philosopher of technology, Walter Vincenti, claims, following Polanyi, that the operational principles of technological objects are not already contained in the laws of nature. According to Vincenti and Polanyi, operational principles, which describe how a technological artifact fulfills its function, can not be deduced from those laws (Vincenti, 1990, p. 209):

> Finally, the operational principle provides an important point of difference between technology and science—it originates outside the body of scientific knowledge and comes into being to serve some innately technological purpose. The laws of physics may be used to analyze such things as air foils, propellers, and rivets once their operational principle has been devised, and they may even help in devising it; they in no way, however, contain or by themselves imply the principle. Polanyi makes essentially the same point a bit differently: "The physico-chemical topography of the object may in some cases serve as a clue to its technical interpretation, but by itself it would leave us completely in the dark [about how it achieves its operational purposes]. . . .*The*

> *complete* [i.e., scientific] *knowledge of a machine as an object tells us nothing about it as a machine.*

Apparently, both Vincenti and Polanyi believe that there exists a gap between the functional (technological) and structural (scientific) description of technological objects. Nevertheless, it is standard practice in the context of design, and not only in that context, to relate the structure and function of objects. We will first briefly discuss some ideas about how this is possible.

3.1 Form Follows Function

A rather extreme view on the relation between structure and function in the context of designing takes as its starting point the *form follows function* principle, with "form" being the same as what we have here called "structure." The *form follows function* phrase may be interpreted in two different ways, each of which turns out to be invalid. In the first place, it may be interpreted in a tempora1 sense; then it means that the design process starts with a definition of function and functional requirements and that the form (structure) follows afterwards (in a series of steps specified by some sequential model). Design processes, however, are much more complex and seldom show such a simple linear structure. It is common practice that during design processes functional specifications and requirements fixed at the start have to be reconsidered and readjusted, because they cannot be achieved all at the same time. Therefore, iterations occur. In design processes function and form often crystallize together.

Secondly, on a logical construal, the *form follows function* principle means that form (structure) is a logical consequence of function. In other words, the physical structure is logically implied by the functional requirements. This idea, of course, is hardly worth discussing. It would imply that solving a design problem would be the same as finding the right logical deduction. In most cases, functional requirements are in conflict. Therefore, as Pye (1993, p. 50) remarks: "It is quite impossible for any design to be the logical outcome of the requirements' simply because, the requirements being in conflict, their logical outcome is an impossibility." (In saying this, Pye does not show himself to be a good logician. If the set of statements describing the requirements are contradictory, than any statement, describing whatever design, logically follows from this set of premises.) Whenever the requirements are not in conflict, there is no reason to assume that the design follows logically, since, in general, different designs may satisfy the same set of requirements (this is known as functional equivalence). See Kitcher and Salmon (1989, p. 30). Analogously to the "underdetermination of theories by facts" in science, this could be termed the "underdetermination of designs by requirements" in technology. For more criticism on the *form follows function* principle, see Petroski (1994, chapter 2).

3.2 Function Follows Form:

Situations occur in archeology which, with regard to the relation between structure and function, appear to be precisely the mirror image of those occurring in design contexts. Assuming that certain remains of old civilizations once performed a technological function, archeologists are often interested in reconstructing that function. In such cases the physical structure of an object is known, and the function of the object is unknown. Somehow the function of an object has to be deduced from or to follow from the structure of the object: *function follows form*.

As an example consider stone tools. How is it possible to determine on the basis of the geometrical form of a certain stone and its other physical properties that we are dealing not with a natural object but with an *artifact* produced by early hominids to perform a function? In many cases archeologists succeed in reconstructing the function of objects; that is, they succeed in going from structure to function. According to Shelley (1996) a kind of visual abductive reasoning is involved in these reconstructions. He claims that the result of this kind of abduction is an *explanation* of the (physical) properties of the stone. That explanation is based on the hypothesis that the stone under consideration performed a certain function. So in archeology we see exactly the reverse of what happens in the context of technological design: in archeology the function explains the properties (the structure) of an object; in design the structure explains the function. Abduction, of course, is not a logically deductive form of reasoning, and therefore the relation between structure and function is not deductive. Furthermore, the problem of structural equivalence (the mirror image of functional equivalence) arises because the same structure may perform different kinds of functions. A one-to-one relation between structure and function is not guaranteed.

Apparently, technological designers and archeologists are able to bridge the gap between structure and function, between a structural and a functional description of the world. Somehow they succeed in establishing more or less reliable connections between functional and structural descriptions of objects. In both cases, *explanations* are involved: either the explanation of function in terms of structure, or of structure in terms of function. But a deductive-nomological explanation *à la* Hempel-Oppenheim seems excluded, for that would mean that descriptions of functions could be deduced logically from descriptions of structures or vice versa.

4. A TECHNOLOGICAL EXPLANATION: THE EXAMPLE OF THE NEWCOMEN STEAM ENGINE

To avoid misunderstanding it should be pointed out that a technological explanation, in the sense that term is used here, should not be confused with what is known in the literature as a functional explanation. In a functional explanation the structure and behavior of a (biological, physical, technical) system is explained in terms of its goal or function: Why does the human body have a heart? Answer: to pump blood trough the body. The function explains the structure. There is not much consensus about the nature of this kind of explanation, its relation to other types of explanations, or its role in science. (See Salmon's "Four Decades of Scientific Explanation" in Kitcher and Salmon, 1989.)

This is strongly related to unsolved problems concerning the notion of function itself. Technological explanations are the reverse of functional explanations: a technological function is explained in terms of a structure.

We will now examine in more detail the structure of a technological explanation. Using as an example the explanation of the operation of one of the earliest types of steam engines, namely, the Newcomen engine. The notion of operation refers to the way the function of this engine is being realized. This type of steam engine was the first to be applied in practice for draining mines (from about 1712). Until the invention of the rotary steam engine at the end of the eighteenth century, Newcomen engines had primarily one function: they were used for *pumping water* (Hills, 1970, p. 134). Occasionally, steam engines were also used for other purposes, such as raising coal or ore from mines. During the seventies, Smeaton, for instance, built several "winding engines" (Skempton, 1981, pp. 189-192). He also designed and built steam engines used for blowing furnaces. What is important, however, is that in these cases the steam engines did not drive the winding and blowing machinery *directly*, but indirectly through water wheels. The primary function of the steam engines was to pump water from a lower reservoir to a higher one, from which water flowed to a waterwheel. In other words, in these cases the steam engines were driving pumps for raising water ("a business for which the fire-engine seems peculiarly adapted" according to Smeaton, as quoted in Hills, 1970, p.136). Thus, Newcomen engines were engines for driving pumps and this was their main *technological function* until the end of the eighteenth century.

The Newcomen engine operates with a piston moving up and down in a cylinder. From a *technological* point of view, the operation of the Newcomen engine as a pumping device was well understood already early in the eighteenth century. The earliest descriptions of steam engines, for instance by Triewald (1734) and Desaguliers (1744), contain all the key elements for arguing from the input of steam engines, fuel in the form of coal or wood, to its output, the raising of water or the reciprocating motion of the great beam, which in practice was only used for driving pumps. The role of fire and steam in the technological operation of steam engines was clearly understood. In other words, the main technological function of steam engines could be explained in terms of the design of steam engines, some relevant empirical facts, and actions necessary for operating the steam engine.

Let us take a closer look at some of the essential ingredients of this technological explanation.

First of all, it was a well-established empirical fact that fire had a power to transform water into steam, occupying a much larger volume than the water. According to Triewald, who considers steam to be "nothing but moist air," this fact is the basic principle underlying the operation of steam engines: "From this remarkable quality of the air of expanding when heated is derived the power or effect of the fire-machine" (Triewald, 1734, p.22; if steam is moist air, then the question arises from where all the air comes when water is transformed into steam. Triewald's answer is that (p.23): "all water contains an un-measurable quantity of air. Which can easily be proved by allowing water to stand under the receiver of an air-pump.") Desaguliers also considers this to be the working principle of steam engines. Almost a century later this is still considered by Rees to be the "general principle of the steam-engine" (Rees, 1819, p. 60; Rees in fact distinguishes between two main principles, (i) the generation of high pressure steam by heating water, which explains the operation of high pressure engines [p. 137], and (ii) the creation of a vacuum by condensing steam, which lies at the basis of the operation of the atmospheric machines [p. 75]).

The transformation of water into steam takes place in the boiler.

A second important step in explaining how fire, the input of steam engines can bring about (mechanical) motion, the output, concerns the creation of a partial vacuum with the help of steam. This is achieved in the following way. When the steam valve is opened, steam will flow into the cylinder. Because of the pressure of the steam and the weight of the water in the pump pipes, the piston will move upward until it reaches the top of the cylinder. At that moment the steam valve is closed. Then cold water is injected into the cylinder; this will cause the condensation of steam and the creation a partial vacuum. Triewald describes the creation of a vacuum thus:

> A vacuum is again created without delay and instantaneously in the cylinder, by the cold water, spurting into the cylinder and falling back like a heavy rain, thus condensing the steam orrobbing the air, highly rarefied by the heat, of its expanding power, so that it shrinks. (Triewald 1734, p. 12; see also p. 24).

The creation of a vacuum in a vessel is, furthermore, accompanied by the creation of a force, namely the force of the atmosphere on the walls of the vessel. The existence of this force on an evacuated vessel had been amply demonstrated by the experiments of Otto von Quericke, described in his*Experimenta Nova Magdeburgica*. By a suitable *design*, this force can be exploited as a source of power for raising water. In the design of the Newcomen engine one of the walls of the vessel is a movable piston; the creation of a vacuum causes the piston to move downwards because the condensing steam "is unable to withstand the weight of the atmosphere upon the piston, which is then hastily pressed down "(Triewald, 1734, p. 12). Finally, the force of the atmosphere on this piston is transferred by a mechanical construction (the great beam) to the ends of pumping rods, which by the force of the atmosphere are lifted. As soon as the piston reaches the bottom of the cylinder, the steam valve is opened again and the whole cycle is repeated.

The above chain of reasoning shows that the early steam engine engineers had a detailed understanding of the way in which fire could generate power (for driving pumps) *in a Newcomen engine*. Their understanding was based, on the one hand, on some well-known physical phenomena, namely the expansive action of fire on water, the creation of a vacuum by the cooling (condensation) of steam, and the force of the atmosphere. On the other hand, the design of the Newcomen engine and certain actions (the opening and closing of valves) play an essential role. Without recourse to the detailed design and construction of a Newcomen engine and its mode of operation, they would not have been able at all to explain how fire could generate mechanical motion and how Newcomen engines could perform their function, namely, the driving of pumps.

5. STRUCTURE AND FUNCTION IN A TECHNOLOGICAL EXPLANATION

Schematically, the explanation of the operation of Newcomen engines has the following form:

Schema I

Explanans:	Description of physical phenomena
	Description of the structure (design) of the artifact
	<u>Description of a series of actions</u>
Explanandum:	Description of the function of the artifact

With regard to the issue of the relation between structure and function, the crucial question now is how explanans and explanandum are related to each other. In the case of Newcomen engines the explanandum appears to follow logically from the explanans. The explanans describes in detail a causal mechanism that necessarily leads to the up and down motion of the pump rods. The function of the Newcomen engine, to drive pumps, seems therefore to be reduced to its structure. Note that the notion of structure has to be taken in a broad sense; it not only includes the design of the engine, but also the relevant physical phenomena and the actions necessary for operating the machine. So, contrary to earlier remarks, it looks as if in this example at least there is no gap at all between structure and function. This technological explanation appears to satisfy the conditions of a deductive-nomological explanation.

A closer look reveals that this is not the case, for two reasons. In more detail, the technological explanation of the function of Newcomen engines has the following form:

Schema II

Explanans 1) physical phenomena:
- —transforming water into steam increases its volume manyfold
- —cooling of steam in a closed vessel creates a vacuum
- —the atmosphere exerts a force of 1 kilogram per square centimeter; etc.

2) design of the engine:
- —the steam engine consists of boiler, cylinder, piston, great beam etc.
- —the piston may move up and down in the cylinder
- —the piston is connected to the great beam by a chain; etc.

3) a series of actions:
- —after the opening of the steam valve the cylinder fills with steam and the piston moves up
- —closing of the steam valve and injection of cold water creates a vacuum in the cylinder; etc.

Explanandum: Newcomen engines are a means to move the pump rods up and down, that is, to drive pumps (the function of steam engines).

The first reason why this is not an explanation of a function in terms of structure is that the explanans contains all kinds of functional concepts. Notions like piston, cylinder, steam pipe, steam valve, etc., are all of a functional nature. Especially the descriptions of the design of the engine and of the actions for operating the engine are contaminated by functional concepts.

Can this contamination be undone? Is it possible to rephrase the explanans such that all functional concepts are eliminated and that nevertheless the explanation of the function is not endangered? In principle this appears to be possible. The design of the Newcomen engine can be described by means of drawings and specifications for materials to be used, etc. For instance, a piston can be described in a functional way as an object intended to enclose a volume of steam in a cylinder in a moveable way. But it can also be described structurally by specifying its geometrical form and other physical properties. The same appears to apply to functional concepts used in describing the actions necessary for operating the engine; the opening of the steam valve, for instance, can be described as a change in the state of a subsystem of the engine.

Let us make the assumption that in principle the explanans can be purified in this way of all functional concepts without affecting the validity of the explanation. Then the chain of causally connected events described in the explanans with the help of functional concepts can be turned into a chain of causally connected events described with structural-physical concepts such that the explanandum, the function of the engine, stays the same. (The explanation becomes much more complicated, but that only concerns the pragmatic aspects of this explanation.) In the light of this rather plausible assumption the first argument against the claim that scheme II is a technological explanation of a function in terms of structure becomes not very convincing.

There is, however, a second argument that concerns the explanandum. According to scheme I, the explanandum contains a description of the function of the Newcomen engine; that function is to drive pumps, more in particular to move the pump rods up and down. Does that explanandum really follow from the explanans? The answer is negative. The explanans implies that*the great beam of the Newcomen engine will move the pump rods up and down, not that it is the function of this engine to move those pump rods up and down*. In other words, when we replace the explanandum in scheme II by the statement that the pump rods move up and down, we end up with a paradigmatic case of a causal explanation of certain events.

The foregoing means that we have to distinguish carefully between the following two statements:

(1) the Newcomen engine moves the pump rods up and down, and
(2) the function of the Newcomen engine is to move the pump rods up

and down.

The first statement describes a factual cause-effect relation: the Newcomen engine produces a motion of the great beam and this motion causes the pump rods to move. The explanans of scheme II provides an acceptable explanation of this statement. The second statement is of a very different kind. It says that the Newcomen engine is a means for achieving a certain goal, namely, the up and down motion of the pump rods. This statement does not follow from the explanans. (Compare the following example: the motion of the moon around the earth explains causally the phenomenon of ebb and flood; but the fact that this motion explains this phenomenon does not imply that it is the function of the moon-earth system to produce ebb and flood.) This may be seen as follows. Suppose that the motion of the great beam is used to drive a flywheel in order to produce a rotary motion of a shaft which in turn drives, for instance, spinning machines. Then the function of the *same* object is the driving of spinning machines instead of the driving of pumps (or the driving of a construction that transforms a reciprocating motion into a rotary motion). In other words the Newcomen engine has a totally different function; it has become a means for the realization of a different end. Nevertheless, nothing has been changed in the explanans. So the conclusion would have to be that it would be possible to explain on the basis of one and the same explanans totally different functions in a logically deductive way.

In this respect it is important to pay close attention to the question of what is considered to be part of the Newcomen engine and what not. The pump rods or the flywheel construction are, contrary to the great beam, usually not taken to be part of the engine. This means that the output of this machine is the up and down motion of the great beam. This motion is causally explained by the explanans of scheme II. When another system, for instance a pump or a flywheel construction, is coupled to this great beam, then it is possible, given enough knowledge about that system and the way it is coupled to the Newcomen engine, to causally explain the effect of the motion of the great beam on that system. But the causal explanation of the up and down motion of the great beam of the Newcomen engine does not imply an explanation of the fact that in one context the function of the engine is to drive pumps, in another to drive a flywheel construction.

6. THE GAP BETWEEN STRUCTURE AND FUNCTION FROM A

LOGICAL PERSPECTIVE

On the basis of the foregoing we may conclude that the given explanation of the operation of the Newcomen engine is after all not a *technological* explanation, i.e., is not an explanation of function in terms of structure. So far, we have been unable to establish any link between the structural description of the Newcomen engine and the description of its function. Starting from the structure of the technological object, some physical principles and a series of actions, it is possible to causally explain a phenomenon with certain properties: the up and down motion of the great beam. But to go from there in a logically deductive way to the function of the object is not possible because the same physical phenomenon can be, depending on the context, a means to quite different ends; that is, it can have different functions.

Given that the path from structure to function appears to run into a dead end, let us see how far we can get by approaching the problem the other way around, namely from function to structure. On the basis of the assumption that the function of a Newcomen engine is to drive pumps of a certain type, it is possible to determine what kind of output the engine has to deliver. For the pumps used to drain mines a specific type of up and down motion was required. That motion was necessary for the pumps to operate properly. Thus from the structure of the pumps it was possible to draw up a list of specifications for the required output of the Newcomen engine. These specifications are described in a structural way. In every design process this translation of a required function into structural properties of the system to be designed plays a crucial role.

Let us assume that this translation has the character of a logical deduction. In other words, when x has function F, $F(x)$, then this implies logically that x has certain structural properties (i.e., satisfies certain specifications)

$$S_1(x), \ldots, S_n(x):$$
$$F(x) \rightarrow S_1(x), \ldots, S_n(x).$$

Suppose now that a system y has these properties (satisfies the specifications). May we then conclude that system y has function F? That conclusion is highly problematic, for the argument has the following form:

$$F(x) \rightarrow S_1(x), \ldots, S_n(x)$$
$$\underline{S_1(y), \ldots, S_n(y)}$$
$$F(y).$$

This is a fallacy known as affirming the consequent; a set of properties does not logically imply a function. Again we reach the conclusion that on the basis of structural properties of an object its function cannot be deduced in a logically deductive way.

The foregoing analysis of the relation between structure and function in the case of the Newcomen engine can be summarized in the following way: Schema III

structure		physical phenomenon		properties as		function
of the	→	with	← →	list of specifi-	←	of the
artifact		certain properties		cations		artifact

This scheme represents the complete chain of argument used in the technological explanation of the operation of this kind of steam engine.

7. CONCLUSION

It is a matter of fact that engineers succeed in establishing strong links between the structure and function of technological objects on the basis of technological explanations that have the structure represented in scheme III. Since the two arrows in that scheme point in opposite directions, the relation between structure and function is not of a logical-deductive character. What then is the nature of the link between structure and function?

We will end by proposing a possible answer to this question. Suppose that a causal relation exists between two events *X* and *Y*:

a) *X* is the cause of *Y*.

Whenever *X* takes place, *Y* will occur (under the usual *ceteris paribus* condition that no disturbances occur). Suppose furthermore that it is (technologically) possible to bring about the occurrence of event *X*. Then on the basis of the causal relation a it is possible to draw up the following rule of action or pragmatic maxim:

b) To realize *Y*, see to it that *X* takes place.

According to this rule of action, bringing about *X* is a means to letting *Y* take place, in other words, bringing about *X* has the *function* to produce *Y*. Note that the rule of action *b* can not be derived from the causal relation *a* in a logically deductive way. Nevertheless, we are dealing here with a (technological) rule of action that from a pragmatic point of view may prove to be highly reliable. Whether that is the case depends on whether the causal relation *a* is empirically well established and whether in the given context of action the *ceteris paribus* clause holds.

Let us now apply this to the example of the Newcomen engine. For the combined system of the Newcomen engine and the pump, scheme II contains a description of the causal chain of events that will lead to the up and down motion of the pump rods. When we refer, for the sake of brevity, to the explanans of scheme II as the "putting in operation of the Newcomen engine," then the following causal claim can be made:

a') Putting in operation the Newcomen engine (*X*) will cause the up and down motion of the pump rods (*Y*).

On the basis of this claim, we formulate the following technological rule of action:

b') To move the pump rods up and down (*Y*), put the Newcomen engine in operation (*X*).

This rule of action describes how a certain aim, the up and down motion of the pump rods, can be achieved by performing actions with a Newcomen engine. Within that context of action, the Newcomen engine becomes a means to an end, that is, acquires a function. That function is to drive pumps. The Newcomen engine, however, can perform that function only by virtue of its (physical) structure, since rule of action *b*' is based on causal relation *a*' and the latter can only be derived on the basis of the detailed structure or design of the engine.

According to this line of thought, the transformation of causal relations into pragmatic maxims (a transformation that does not have the form of a logical deduction) makes it possible to bridge the gap between structure and function in a technological design. A technological explanation, therefore, is not a deductive explanation; it connects structure and function on the basis of causal relations and pragmatic rules of actions based on these causal relations.

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