An Evolutionary Account of Technological Development

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Abstract

> *If 'nothing in biology makes sense except in the light of evolution' (Theodosius Dobzhansky, 1973)1, then, does nothing in technology make sense except in the light of evolution?*

This study will seek to construct an *evolutionary account of technological development*. To this end, it will consider and analyse a variety of theoretical proposals. In this thesis I will survey existing evolutionary accounts found in socio-cultural and engineering sciences, and will evaluate how these theories have been formulated. The study will look at evidence and theory, and it will consider the formalisation, visualisation and conceptualisation of ancestral-descent relationships in socio-technical systems.

In recent years, this area of study has gained momentum among experts from different academic, scientific and theoretical backgrounds, particularly those working in the fields of theoretical and engineering science, technology, and in the development of social-technical systems. 21st century biologists, social scientists, philosophers, economists, and technologists have instigated lively and thought-provoking interdisciplinary discussions about the feasibility of quantifying and modelling macro and microevolution in technology. Neo-Darwinian theory and modern synthesis theory have prepared a framework for a more effective discussion than ever before. The question asked by many researchers in this area is how microevolution can bring about macro evolutionary events in socio-technical systems. However, any evolutionary account of technology requires the application of conceptual tools and special theoretical foundations for study that do not necessarily match those traditionally used in the study of the organic world. Therefore, to address how microevolution can influence macroevolution in technological design, it is important to establish an evolutionary account of modular systems in technology in order to depict the patterns and processes that have evolved over time in the process of design.

The main principles that govern Darwin's evolutionary scheme according to natural selection suggest that every system in nature uses variation, reproduction and heritability in order to evolve. The simplicity of the general principles that govern the theory of evolution in biology has enabled it to be generalised as a theoretical framework in other academic and research fields. However, the

1 Theodosius Dobzhansky (1973*) Genetic Diversity and Human Equality* Basic Books, New York

existence of directionality and intentionality in the production of artefacts makes it necessary to extend the definition of, and to re-examine, evolutionary mechanisms and classic notions of synthesis. For example, Simondon's theory of concretization considers the horizontal transmission of technicality in systems.[2] Additionally, Baldwin and Clark argue that the theory of modularity is a powerful conceptual tool which can be used in different fields, and this theory sheds light on how extended evolutionary operators work in technological systems.[3]

It is possible to find similarities between evolution in natural history and the developmental history of modern technology. Historical objects in the two fields are connected together through the idea of reproductive descent. This thesis will investigate how the *unit of selection* affects the process of evolution and the hierarchical classification of modular systems, and how evolutionary mechanisms bring about evolutionary change in design space through time. It will explore how different evolutionary operators interact to cause 'phenotypic' effects. The main challenge of the thesis will be to explain developmental patterns found in socio-technical systems, and in the biological selective regime, into an extended synthesis. To this end, a scientific investigation of shared research is required, and emphasis will be placed on how this unifying approach can delineate evolutionary mechanisms, functional theory and evolutionary methodology of design, evolutionary operators, and phenotypic-genotypic distinction in technology.

It is apparent that evolutionary theory can be used for theoretical planning in the growth and development of technical-social systems. The basic principles of Darwin’s theory of evolution notes that each system (which can), under a selective regime, achieves properties including variation, reproduction and heritability, in order that the system can evolve. Academics who study the growth and development of technology in the context of an evolutionary-historical process often use the idea of genetic transfer for inspiration.

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2 Gilbert Simondon *On the Mode of Existence of Technical Objects* Jérôme Millon (2005)
3 Carliss Y. Baldwin and Kim B. Clark *Design Rules: Vol. 1 The Power of Modularity* (2000)

Introduction

Is an 'evolutionary' approach towards studying developmental patterns in the artificial world possible? Can it give us a new understanding of different fields of knowledge, and can we discuss artificial science alongside natural science? As part of its research process, this thesis aims to address questions such as these. Are biological models suitable for understanding socio-cultural evolution? While these models may have introduced some much-needed methodological rigour into the field of humanities research, and although they represent an important area of interdisciplinary research, they fail to capture some key aspects of cultural transmission. In particular, innovations that are combinatorial, or require some depth of learning for adoption, seem largely intransigent to biological models.

This thesis will consider the development of a model, which can capture the dynamics of technological change, and one, which is inspired by the biological evolutionary approach. In biology, one of the key advantages of Darwin's theory of evolution is that 'macro-evolutionary' patterns and trends can be explained in terms of 'micro-evolutionary' processes, such as selection, drift, and mutation. The same advantages can be gained by viewing socio-techno change as a Darwinian evolutionary process. Here, 'macro-evolutionary' patterns and trends can be explained in terms of 'micro-evolutionary' processes, and sometimes the researcher can borrow concepts used in biology (e.g. artefactual selection or technical drift) in order to explore technical micro-evolutionary processes that have no parallel in genetic evolution (e.g. non-random 'guided variation'). Lewontin outlines the three main general principles of Darwin's theory as follows:

1. Different populations have different morphologies, physiologies and behaviours (this is known as phenotypic variation).
2. Different phenotypes show different survival and reproduction rates in different environments (this is usually referred to as physical capacities with differential fitness).
3. There is solidarity between parents and offsprings in association with future generations, in that fitness is inheritable.[4]

There is some dispute among academics about the validity of applying a 'genetic evolution' approach in other fields. Jablonka & Ziman note that the 'cultural evolution' model cannot be a

4 R C Lewontin 'The Units of Selection' Annu Rev. Ecol. Syst. (1970) pp.1-18

direct imitation of the 'biological evolution' model.[5] However, they also note that the basic framework of biological evolution theory can be preserved when thinking about technology, because one can find similarities between natural history and the developmental history of modern technology. It is possible to observe and examine the reproductive descent of both organisms and artefacts. However, it should be mentioned that, over time, different theories have developed in these two different scientific fields, and those that study the patterns of the gradual growth of a material culture have the potential to present different views of the selection process.

The idea of Mendelian inheritance not only succeeds in filling a gap between variation, selection and transmission, but this work develops a framework that can be used to examine how evolutionary theories in other fields work. However, evolutionary theory, as applied in other fields, necessitates the formulation and use of adequate conceptual tools, and special theoretical foundations, which do not necessarily match those used to examine the organic world. In other cases, evolutionary theories used in other field facilitate their own version of selective process.

Disputes about the nature of technology, the manner of industrial growth, and its development and its interaction with society continue to this day. Over time, more and more thinkers have considered the relationship between technology and society in various fields of science and philosophy. For example, Francis Bacon considered the effects of technology on society for the first time,[6] and Karl Marx explored the idea that technological innovations might result in the progression of socialism and communism.[7] In the 20th century, thinkers such as Simon (1969)[8], Mokyr (1998, 2000)[9], Basalla (1988)[10] and Simondon (2005) further contributed to the subject of the growth and development of technology.[11] I will refer to the work of these theorists throughout this research.

Identifying a distinction between technologically made and naturally reproducing objects is the first step towards exploring how the development and growth of technology is both distinguishable from

5 Jablonka and Ziman (2000) 'Biological Evolution: Processes and Phenomena' in *Technological Innovation as an Evolutionary Process* (Ed: Ziman J.) Cambridge University Press, Cambridge pp.13-27.

6 Farrington, Benjamin Francis Bacon, *The Philosophy of Industrial Science (*1951)

7 *Karl Marx – Stanford Encyclopaedia of Philosophy.* First published Tue 26 August 2003 substantive revision Mon 14 June 2010. Retrieved 4 March 2011

8 Herbert A. Simon *The Science of the Artificial* (1969) MIT Press, Cambridge, Mass, 1st Edition

9 Joel Mokyr 'Science, Technology, and Knowledge: What Historians can learn from an evolutionary approach' in *Neither Chance nor Necessity: Evolutionary Models and Economic History* (1998) and 'Natural History and Economic History: Is Technological Change an Evolutionary Process?' Lecture (April 2000)

10 Basalla *The Evolution of Technology* Cambridge University Press, 1988

11 Gilbert Simondon (2005)

and related to the evolutionary biological process. Simon defines artificial objects based on their goals and functions, and he considers technological evolution as a directive-oriented process.[12] Intentionality in design by humans aims to protect technological innovation from the process of random mutations, but in theory of design, directionality and randomness is a complex subject. A weak account of directionality can be noted in the biological world (Darwinism), Lewens believes that genetic mutation embodies a form of design (directionality), because some mutations are more probable than others are, but this does not necessarily mean these mutations have better qualities.[13] In technology the human designer often deliberately and directly contributes towards design improvement. However, it could be argued that there is a convergence in the concepts of directness in design innovation and evolutionary genetics. When working within social-technical systems, the designer has to work with the raw materials, energy sources, and the environmental, political and commercial conditions available to him or her. Indeed, the selection process only really plays a role in the directiveness of a set of variants of existing differential fitness.

The evolution procedure in technology as inspired by genetic transmission can reach some level of technicality transmission from the basic element level in the system to its phenotypic level. Technology grows by means of engineering procedures, which are related to the quality of technical objects and design methodologies. By applying the theory of self-organisation in biology, Simondon describes the final steps of producing technology and the process of the technical identification of a technical system as 'technical concretization'.[14] Indeed, technical objects in their progressive stage move towards self-organization as an organism. It must be remembered that external observers such as operators in control rooms etc. that interact with the external world control technical systems. However, the idea of the concretization criterion considers systems as independent of such external observers. However, concretization may also refer to ‘functional concretization’, which relates to the creation of a multi-function component. Vincent Bontems suggests it is historical progress and ‘historicality’ that contributes to concretization, rather than aesthetic aspects, which are trans-historical.[15] However, it is important to note that the external appearance of technology can sometimes play a role in classifying the technical maturity of a

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12 Herbert A. Simon (1969)

13 Tim Lewens 'Innovation and Population' in Functions in *Biological and Artificial Worlds: Comparative Philosophical Perspectives* Edited by Ulrich Krohs and Peter Kroes (2009) p.153

14 Gilbert Simondon (2005)

15 Vincent Bontems 'Gilbert Simondon’s Genetic ‘Mechanology’ and the Understanding of Laws of Technical Evolution' in *Techne 13:1* (Winter 2009)

system. Indeed, external appearance can contribute towards establishing concretization-oriented factors. For example, in the aviation industry, hydrodynamics plays an important role, and the architecture and configuration of a system can affect the functioning of a system. In this thesis, I will consider a non-liner developmental pattern of technical change in terms of historical models initiated by evolutionary function theory.

In Simondon's view a linear and monotonous developmental programme in technology does not exist. Simondon evaluates the development of technology by looking at non-linear patterns. He suggests that elements develop individually, and that individual elements develop in sets until new elements result over time.[16] For example, the steam engine was placed into a steam locomotive and then into a system of transportation, and then an entire system was established based on steam technology. Then, over time, the steam engine was replaced by an electric motor, and this led to a transportation system reliant on electric energy.[17]

To understand Simondon's non-linear evolutionary theory, an accurate understanding of what he calls 'associated milieu' is of crucial importance. Associated milieu refers to when a technical object is not gradually matched to an 'associated milieu' in a systematic fashion, but when this matching takes place thoroughly and at once. When an artefact is immediately placed in certain operational and proficiency conditions, a system of natural elements is constructed surrounding the technical object, which are not completely artificial, and these play the role of intermediary between technical elements and natural elements. For example, hydraulic cooling systems in industry can play such a role. During a CDQ project when an engineer extinguishes coke by dry quenching, the red-hot coke reaches 1050^{o}C and is placed in special modules. Then a neutral gas flow is blown under the modules to cool the coals. The neutral gas blown from the upper hatch of the container lowers the coal heat to the extent that it becomes suitable to be transferred to the furnace, and this makes the coal ready for implementation of the next thermal operation, which produces copper. In these conditions, the neutral gas and cooling system play the role of associated milieu for the CDQ project. In addition, a power generation system is placed laterally besides the CDQ unit in order to make use of the heat of exhausted neutral gas for electricity generation. A boiler, a steam turbine, and a condenser are embedded in this accessory unit in order to generate the power. Thus, the fluid

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16 In Simondon`s theory 'individuals' are equivalent to artefacts, and 'sets' are equivalent to systems.

17 Marc J. de Vries 'Gilbert Simondon and the Dual Nature of Technical Artefacts' in *Techne 12:1* (Winter 2008). This research is part of the Dual Nature of Technical Artefacts study that was started in 2002 by Peter Kroes and his group at the Delf University.

carrying the boiler is the 'associated milieu' for the set of coal and neutral gas. Therefore, this environment is relative to the system in which it operates.

Evolution in technology can be related to the system of Darwinian adaptation (meaning adaptation with its environment), since an artefact can be considered as an interface between an external environment (an environment in which the artefact operates) and an internal environment (ingredients and the internal structure of the artefact itself). Co-ordination between two internal and external environments may account for the sorting process of technical change. Lewens speaks about technology changing like a sorting process. For example, ions on a metal surface match with their environment after time, and artefacts match in with their cultural-economic environment.[18]

As well as the physical structure and functional nature of the artefact, recognising the environment in which the artefact works becomes important, because function acts as an intermediary between the environment and internal structure. Thus, an artefact's fitness can be considered as a kind of design 'sorting' element which is directed towards meeting the market's and the user's needs. This idea mostly concerns the empirical question of what forces are involved in the selection process. Additionally, the biological world can be compared with the technological one when we consider such things as environmental issues, organism solutions and traits purposes. Academics and researchers have examined the application of directiveness and adaptiveness in the technical and organic worlds. According to Griffiths, two main general ideas about design engineering can be defined:

1. Reverse Engineering - This deduces propounded problems by examining the environment and the limitations of solutions, which can be adapted to any problems, posed.

2. Adaptive Thinking: This reverses the deduction direction. It makes use of recognising the adaptive issues of an organism in order to predict probable solutions.[19]

In this regard, nature operates like a design procedure in the evolution processes, and we as humans interact with the design process and solve design problems when we examine internal structures, and engage with limitations and environmental constraints.

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18 Tim Lewens (2009) p.140

19 Paul E. Griffiths 'Functional Analysis and Proper Functions' in Brit. J. Phil. Sci. 44 (1993) pp.409- 422

Since a specific structure demonstrates different adaptive characteristics in different environments, creative design needs to execute strategies that can place a related phenotype in the best environmental conditions, with the help of specific operators and genotype structures. These developmental strategies create the conditions for phenotype acquisition. However, developmentalist theorists argue against the process of adaptationalism, which confirms selection pressure on phenotypes. When using the 'artefact model' it can be assumed that different components, which construct a system, have a role to play in the overall capacity of the system. They co-operate in the system's fitness, even if they do not have evolutionary and design history, and only by means of the role they play in the current system can they contribute to the system's fitness. This approach, which looks at the presence of traits and a biological or artificial structure without paying attention to the historical past, is called a systematic analysis of function, and it can be compared with etiological explanations of function theory.[20]

The presence of intentionality in engineering design, and the conscious selection mechanism (in accordance with market demands and functional requirements) grants directionality to engineering procedures in technology in terms of non-linear developmental patterns. To understand non-linear evolutionary theory, an accurate conception of the artificial environment, and the physical structure and functional nature of artefacts is crucial. Certain structures interacting in different milieu find different adaptive properties based on the actions of evolutionary operators. Although using evolutionary strategy is promising for shaping developmental patterns in technology, scientific progress and in economic theory, the distinctions between biological systems and technical-social systems highlights the importance of the preparation of a distinct conceptual framework for this kind of model. In this respect, the most important idea to consider is the presence of human desire and intention in the production of artefacts, and the idea that purposeful design is at the centre of such consciousness. Purposeful design is the intentional sensitivity of technological innovation toward human needs, social conditions and aesthetic aspects. The positive internal and external adaptation of a system may follow the optimality model. With this idea in mind, an engineering/design approach would try to find the adaptive factors,

Traits are essential in the evolutionary process, and every population possesses traits in order to evolve. However, these traits are not necessarily made up entirely of biological entities. Silby

20 Robert Cummins 'Philosophy of Science Association' in *Philosophy of Science,* Vol. 44, No. 2 (Jun. 1977) pp.269-287

explains that individuals within a population have unique characteristics. He defines the characteristics of a human population as follows:

- The capacity to compete for resources.
- Uniqueness of character of the individual within the population.
- The capacity for reproduction.
- Production of offspring, which have some, inherited characteristics.
- The production of offspring that are unique, and who possess characteristics that their parents lack which are created by particular evolutionary operators like mutation and re-combination, etc.[21]

It can be seen that an evolutionary account of the pattern of scientific progress[22] and an epistemological one[23] can be proposed. Games theory and economic theories can also be evaluated using such strategies. The structural similarities between evolutionary processes in biology and in technology remind us that technological innovations can be exposed to evolutionary variations, under the influence of operators. Although these evolutionary similarities are promising in order to shape an evolutionary strategy for technology, there are some ways in which biological systems differ from techno-social systems, and this is why it is so necessary to prepare a distinct conceptual framework from biology for such a model.

One of the great differences between a biological and a techno-social system is the presence of human will and desire to shape artefacts. When purposeful designing is placed at the centre of consciousness, technological innovations are not blind to human needs, social conditions and aesthetic aspects. Although Weismanian 'character' is absent in variations presented for selection in technology, the presence of Lamarckian traits can be found in the field of technical knowledge, and acquired traits can affect engineering procedures. Of course, there are other differences that can be found and analysed as a basis for selection, and I will discuss these in Chapter One.

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21 Brent Silby (2000)

22 Stephen Toulmin, Ronald N.Giere, Michael Bradie, Wevner CalleBaut, Pik Pinxten, Louis Boon, Richard S.Wesfall & L.Janathan Cohen are just some of the scientists who explored this subject.

23 Campbell-1974, Riedl-1984, & Lorenz-1967 explored this subject.

Chapter One of this thesis explores the basic conceptual and theoretical elements of the artificial and evolutionary worlds. In this kind of exploration, it is important to consider the role of the 'unit' of selection, and to examine the unit of selection in the context of its role as replicator. This approach helps to resolve ambiguity at the level of selection. In the past few decades, much debate has taken place among evolutionary biologists about the level and unit of selection. Selection is the result of replicator and interactor operation. An item is considered a replicator if it transfers its structure intact to the next generation following reproduction. The main principle of Darwin's theory of evolution is the idea of *natural selection* and *survival of the fittest*, and this can be used to inform the contribution made by phenotypic effects in fitness. By considering these ideas, the evolutionary patterns of technological growth can be established. Using an historical-etiological approach it can be seen that adaptation occurs in the process of creating artefacts and systems that are used optimally in context (which have fitness). This adaptive process (in recursive practice) can be related to optimality in technical-social systems.

Technique and technical knowledge, engineering procedures, design traditions, aesthetic aspects, and commercial and economic aspects can have an effect on what is understood as the *unit of selection*. In this approach, a mentifact is considered a *unit of selection.* This idea views the cohesive whole as including the artefact and all activities involved in its production, use, maintenance, and developmental patterns (like design methodology, engineering procedures, etc.) which act to achieve the stable reproduction of the technical systems. Chapter one assesses different units of selection, as they have been interpreted by different academics, and the different frameworks within which innovation and variations in technical-social systems occur.

An understanding of how evolutionary theory works in technology is crucial in order to discover how these two worlds (artefactual and natural) interact with each other. Chapter Two looks at whether it is possible to distinguish artefactual kinds from natural kinds, and whether the artefactual world is determinable ontologically and epistemologically. A theory of the artefact should be able to establish coherence of physical-chemical and intentional aspects. However, examining artefactual kind is not merely an analysis of structural properties. Intentionality plays a central role in human artefactual design, construction and use.

Chapter Three discusses why technical systems are considered the product of a design process. The product and process of design is linked together, and the methodology of design as it affects technical systems as a product of the design process is examined. An understanding of evolutionary mechanisms as they work in the design space is a pre-condition of an evolutionary theory of technology. Design methodology is involved with the improvement of the design process. John S. Gero talks about activities such as formulation, synthesis, analysis, evaluation, re-formulation and the production of a design description.1 These procedures look at how function, structure and behaviour are linked together in the design process. Based on the evolutionary methodology of design, new innovative elements (structural, behavioural and functional elements) enter into the design space in terms of a means-end system in different environments. By looking at adaption to milieu, this methodology may provide solutions to the different problems posed by different environments.

Chapter Four looks at different fundamental theories about function, such as intentional function theory, system function or causal-role theory, and etiological-evolutionary theory. By presenting existing theories of function, it is possible to consider whether one single theory of function can be used to answer all questions about how function works. I will review existing theories and examine the advantages and disadvantages of these theories. The chapter considers the distinction between proper function, accidental function, and malfunction. Over the past decade, discussion about intentional, evolutionary-etiological, and systematic interpretations and approaches, or a combination of these approaches, has instigated debate and conflict among theorists. This thesis will consider these debates in detail. These debates have led some theorists, including Robert Cummins, to modify their previous theories (Cummins modified his theory in his 2002 essay entitled *Neo-teleology)*. The subject of 'malfunctioning' is one of the most common causes of conflicting argument. Therefore, in order to overcome theoretical obstacles, conjunction and disjunction combination theories are frequently used by academics in order to try to present a comprehensive interpretation of function. Some of these theories look at functional analysis from the perspective of the use plan or the action-oriented activities involved in production, design and use. In this chapter, I will provide an historical-evolutionary account of function, and I will present a discussion about how the interpretation of function can be used in an evolutionary model of technology.

Planning a dynamic evolutionary theory for technology means that a method is needed in order to

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1 John S. Gero 'Creativity, emergence and evolution in design' in *Knowledge-Based Systems* 9 (1996) pp.435-448

link the past to the future events. It could be argued that, in technology, modularity plays the same role as heritability does in the world of nature. Evolutionary mechanisms that act on the unit of selection are a requirement for evolution. Baldwin and Clark[2] look at the dynamic possibilities of modular operators in complex systems, such as splitting a design and its tasks into modules, substituting one module design for another, augmenting and adding a new module to the system, inverting to create new design rules, and porting a module to another system. The ***six operators*** act across modular architecture, and I will examine how ***two*** operators work within modules, replicating, combining and extending. Some modules bring about variation in the architecture of modular design, and others are sources of diversity and act as the search paths of modules. In addition, genetics-like operators act on modular structures to create differential fitness in terms of adaptive patterns which leads to optimality.

2 Baldwin and Clark (2000)

Chapter One

The Foundations and Conceptual Elements of Evolutionary Technology

The basic principle of Darwin's theory suggests that each system, under a selective regime and properties including variation, reproduction and heritability, is enable to evolve. The difference between biological systems and technical-social systems has led to the formulation of distinct conceptual frameworks. In order to establish an evolutionary account for technology, I will consider fundamental elements and a conceptual framework. In this regard, I will review theories that examine adaptive patterns and the Unit of Selection in technology. I will propose a two-sort theory for Unit of Selection for the artifact and all relevant activities that are required for stable replication. The presence of intentionality in engineering design and the conscious selection mechanism (working in accordance with needs and functional requirements) defines the distinct adaptive criteria in technical systems.

1.1 Adaptive Form and the Selection Process in Technology and Biology

One of the most valuable ways of looking at evolutionary theory in biology is to consider the nature and variety of an environment's selective pressures. Technological evolution is the process whereby technical systems adapt to the environment, and this process can take place with more speed than a genetic one. It is useful to specify which level, under what patterns, technology adapts to an environment, and to what extent the developmental programs included in the engineering design can influence the selection process.

Edward Constant (2000) and researchers such as Akich and Latour (1992) and Law (1997) examine the distinction between material and social aspects of technological change, and they argue that technology is established by human and non-human factors as fixed networks. They suggest that fitness or adaptation without stable unity and coherence between these factors does not have any meaning.

For biological systems, adaptation refers to a process whereby, in a historical-etiological word, an organism survives in response to environmental problems. When considering the nature of an adaptation process in technology, it is reasonable to question what limitations there are for adaptive forms, and which part of the technology structure is involved with this adaptation? The theory of Darwinian evolution, based on natural selection and survival of the fittest, points to the contribution of the phenotypic effects of an organism to its fitness, and this creates a relationship between adaptation and fitness. This is not a one-way or linear relationship, and the existence of optimum solutions against adaptive problems does not necessarily result in fitness. For technological systems, we can study evolutionary patterns, algorithms and strategies in order to show how a technical trait adapts within a social-artefactual environment. In other words, artefactual selection acts on the artefact based on optimal design, and, indeed, design is optimal concerning context of use. Optimality is the result of developmental programs, which are subject to internal restrictions (the internal environment), and selection pressures (the external environment).

I will review three strategies in which adaptation is conceived for technological systems. John H. Holland shows how a system is exposed to adaptation (the fittest phenotype) by a mixture of operators that operate on the structure of various systems. He specifies how operators and structures can be identified in different fields of study.[3]

Fields	**Structure**	**Operators**
Genetics	Chromosomes	Mutation and recombination etc.
Economic planning	Mixes of goals	Production activity
Control	Policies	Bayer's rule and successive approximation etc.
Physiological psychology	Cell assemblies	Synapse modification
Game theory	Strategies	Rules for iterative approximation of optimal strategies
Artificial intelligence	Programs	Learning rules

Table 1: John H Holland- Comparative Operators

An entity is shown to be optimal, and subsequently, adaptive when operators operate in each of the named systems, when obtainable structures are set, and when the limitations governing a developmental program are identified in an adequate time. The desired trait is selected based on the context in which it is located. The concepts of optimality and gradual growth are not the only two theories that can be used to explain the design process. In the car design and manufacture industry, over time better vehicles are produced that are faster and safer than previous models, and designers create and produce new models based on their knowledge and experience. Therefore, optimal design results in producing better vehicles. However, can we argue that innovations in the aviation industry have come about due to the design optimisation of cars, or that the innovation and design

3 John H. Holland *Adaptation in Natural and Artificial Systems* University of Michigan Press (1975)

of spacecrafts has resulted from optimality in the design of aircrafts? Although, shared cross industry innovation does take place, can it be argued that innovations in one technological sphere always lead directly to innovations in other technological spheres? In nature the fittest species do not evolve directly as the effect of the gradual evolution of its predecessors; mutation and randomness play a part in the natural process of evaluation, and these concepts help us to analyse and understand nature. Therefore, it is possible that technological innovation incorporates mutation and randomness also. It is possible to consider that in technological design, new generations of artefacts incorporate traits that are the result of randomness, mutation and adaptation.

David Perkins identifies the selective forces to create a history of optimal forms using three distinctive strategies, as follows:

1. Adaptation by revision
2. Adaptation by selection
3. Adaptation by planning[4]

Adaptation by revision is informed by Lamarckian theory whereby innovations and variations are exposed to a trial and error process, and are based on a recursive procedure (in technology fields) and epigenetic inheritance (in biological fields), and, then, as a result, more adaptive forms are created. Physiological adjustments are like a muscle strengthening, and a form of learning takes place through adaptation by reviewing what operates in the life cycles of individual organisms. One of the restrictions of this adaptive pattern is its need for intelligence. The process of evolution through adaptation by means of revision means that significant knowledge is needed of the fitness perspective. Of course, this intelligence and knowledge does not imply the need for consciousness, because the muscle strengthening process is a mechanism without consciousness. For example, although the body-shape of a fish in formation is adaptive to physiological hydrodynamic knowledge, it does not necessarily have awareness of hydrodynamic criteria. The second restriction is that even if this adaptive process is directed consciously, the desired knowledge may need revisions to meet special environmental and local needs, in a given time-space. The classic mechanic paradigm in relation to energy and mass remaining at high speeds occurs in science. However, in the history of technology changes in engineering procedures and techniques based on

4 David Perkins (2000), *Technological Innovation as an Evolutionary Process* Edited by John Ziman p.379 Cambridge University Press

environmental conditions (which can include engineering, social, and technical environments) occur frequently. This pattern can provide directness and efficiency for the adaptation process.

Adaptation by selection follows a Darwinian pattern. In other words, variations and innovations are adapted to the environment by the selection process. Of course, the optimal model is bound to the developmental program of the related system, and it is bound to pressures and external adaptive problems that inform the need for selective historical modifications. Therefore, the main question here is, to what extent can a part of a system contribute to fitness. Adaptationists consider the process by which lineages change as a designing process. Therefore, we cannot consider only present contributions in the capacities of complicated systems, but also it is necessary to follow the historical facts about functional role in adaptation.[5]

Biological organs and technical systems both promote their ability through the adaptive process. Adaptation can take place on two levels: behavioral and technique-genetic levels. Designers may acquire experience and technical knowledge by means of interaction with environmental conditions based on a trial and error process, as organic entities do unconsciously. Technical and organic entities may adapt their behaviour based on their internal expectations of environment to achieve goals. Innovations are produced in new design spaces in which designers explore new structures, behaviour or function in terms of their experience and knowledge. Production that does not meet market demands or that is not chosen by users will be set aside, as the process is in organisms. However, although we can find similarities in both fields, it is knowledge and the ability to transfer this knowledge to the next generation that defines consciousness in the technical field. Lewens' Artefact Model explores these issues and looks at the similarities between organisms and artefacts. Lewens evaluates the biological world based on available solutions following the adaptive process, and he explains 'historical process' that results in the emergence of artefacts and organisms.[6]

5 In Chapter Two, I will discuss the different interpretations of function, such as systematic function and historical-etiological function.

6 Tim Lewens 'Innovation and Population' in *Functions in Biological and Artificial Worlds: Comparative Philosophical Perspectives* edited by Ulrich Krohs and Peter Kroes (2009)

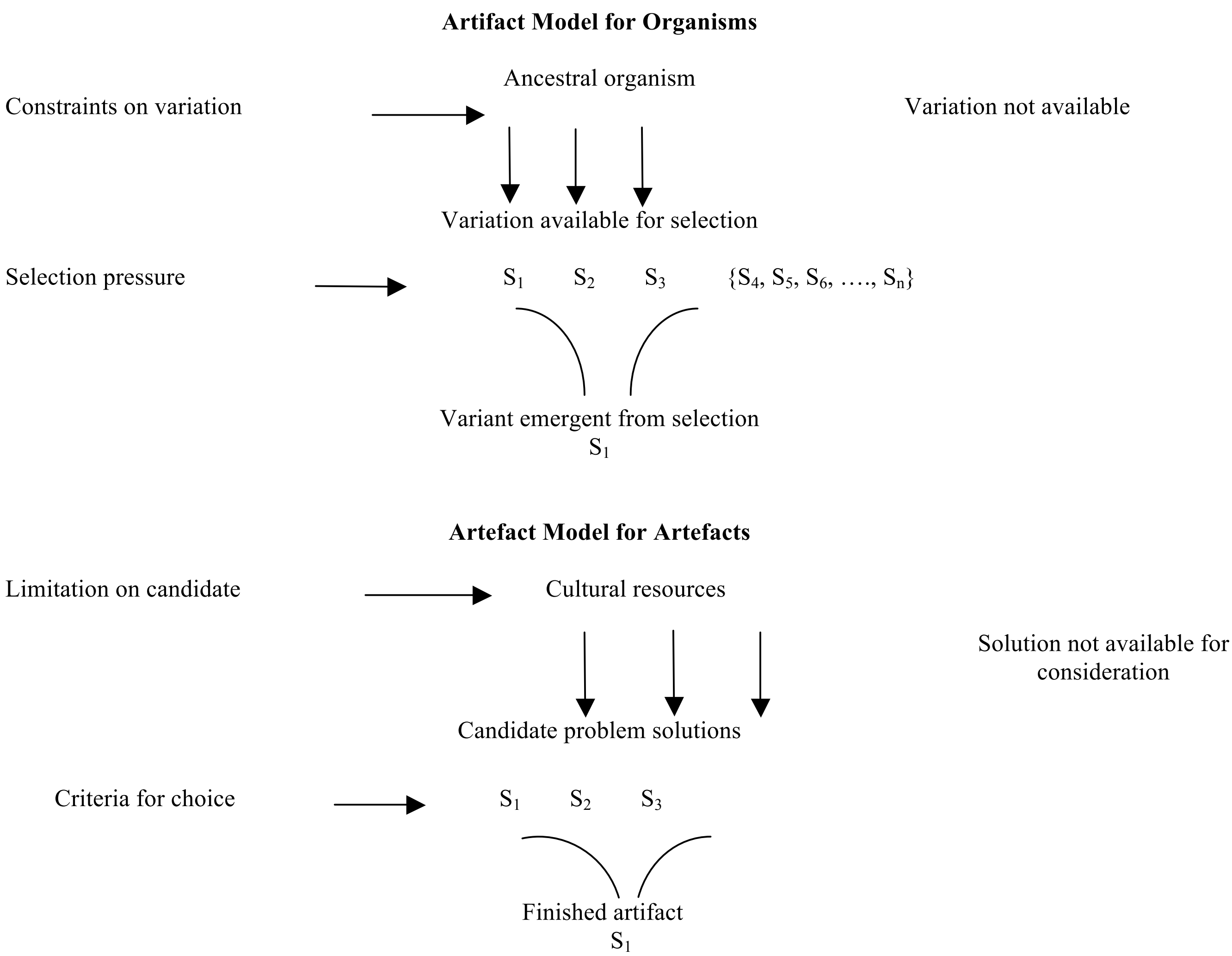

Figure 1: Artefact Model for Organisms and Artefacts

In the two patterns shown above, the similarities between adaptive forms in the biological and technological worlds are clearly seen. In both models, the selection process operates on the solutions' set or candidates (which are bound by some limitations). Therefore, the organisms and artefacts models follow similar explanatory principles. Usually, designers produce and test all obtainable structures from specific operators. The selection process that is used for technical, aesthetic, commercial and legal production operates using 'candidates' with respect to resource limitations. Therefore, it seems that by promoting this theory of adaptation, Perkins avoids the traditional criticisms that are levelled at adaptation theory.[7] Perkins considers an abstract-cognitive concept called a fitness landscape. Here the main idea is that in an abstract environment, adaptive

7 David Perkins (2000)

forms use cues to reach the summits of geometrical place. This reminds us of gold explorers, and the closeness reached to summits determines degree of fitness. This abstract geometrical space known as the 'Klondike' fitness landscape has four traits as detailed below:

1. Wilderness Gaps: In the wilderness gap, there are only few solutions available for selection. The analogy in the organic world is that there are only a few fitness forms, and in the innovative world, only a few choices can be made and only a few solutions ever expand into a presence in the market.

2. Plateau Gaps: This idea refers to more expansive areas where there are only a few guiding signs for solutions to be able to reach upper regions of fitness. Therefore, this flat area does not provide substantial direction in an investigation process.

3. Canyon Traps: Exploration in this territory often takes place within a closed area. However, it is associated with low fitness results and suitable solutions are often created unexpectedly using different approaches.

4. Oasis Traps: in this region, exploration is undertaken based on pseudo-solutions, and it is necessary to pass through this region in order to achieve a suitable solution.

Therefore, although the space proposes investigation strategies in order to find suitable solutions, it seems that the model does not provide an answer to common criticisms about adaptation theory, which includes criticisms such as the issue of drift, developmental program limitations, and functional commonality.

In the biological world, drift and selection are not forces that act on individual entities. Therefore, this issue cannot be analysed in the design of hand-made artefacts specifically. Evolutionary theory describes the interaction between various forces and phenomena, and, therefore, in order to describe changes in the gene frequencies of future generations, aspects such as drift (which has a statistical nature), selection, mutation, and simple mistakes, etc. should be considered. It is the nature of drift and selection that persuades Elliott Sober[8] and Richard C. Lewontin[9] to believe that it is not

8 Elliott Sober 'Likelihood, Model Selection, and the Duhem-Quine Problem' in *The Journal of Philosophy* Vol. 101, No. 5 (May 2004) pp.221-241

9 R. C. Lewontin (1970) pp.1-18

possible to predict the direction of a system, and its future, simultaneously.[10] In their view, the causal processes involved in organism creation are different in that two phenotypic traits might be created with combination, and the selection of one may cause the reproduction of both. Therefore, although they are in one organism, their causal role is different in the selection process.

Functional commonality acts as a warning for adaptationist, in that different ‘types’ may provide similar answers to adaptive problems and pressures, and one can demonstrate these warnings in technological development. In the field of biology, examples of solutions that do not have a common descent, and do not have the same origin embryologically, are called 'Analogy'. All similar traits that work under adaptive convergence are similar structurally, and those that are created from the same origin embryologically are known as 'homology. The standard sample of such adaptive convergence can be seen in the wings of insects and birds. Although, historically, insects used their wings as a way of adjusting body temperature, ultimately they found a flying function. In the field of artefact design, this issue is of importance for determining the functional nature of a system’s components, especially when we look at the reverse engineering approach from the viewpoint of modular systems. In archaeology, it is not possible to deduce the function of an ancient artefact only by relying on the structural information an artefact displays. In design tradition, usage context and social and economic limitations can impose their own selection criteria on an artefact’s evolutionary history. Lewontin's[11] research focuses on the constructive and active interaction of organisms within their environment and how they can improve their habitat in order to promote adaptation, and, hence, fitness.

Constructionist theory looks at conceptual and logical problems relating to adaptive thinking. In contrast to artefacts, organisms create their own niche, and indirectly affect selective forces. For example, we know that a beaver makes changes to his habitat by constructing a dam, and in doing this, the beaver creates its niche. Developmental theory is primarily interested in knowing what phenotypes are allowed to work in the developmental program (which is established based on the organism's internal qualities), while adaptation theorists are more interested in the manner of the phenotype changes in fitness.

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10 This theory looks at the statistical nature and non-determinism of macrophysics (kinetic theory of gases) rather than referring to the basic particle physics (photoelectric effects). There is significant dispute among contemporary academics about the theoretical-philosophical results of relativity and basic particle physics in this regard.

11 R. C. Lewontin (1970) pp. 1-18

In the production of technical artefacts, co-adaptation can be related to market demand, the user's needs and intentions, and the sources available for the designer to work with. In genetics, environmental niche prepares various opportunities for an adaptive design, and the system selects the obtainable structures. Geoffrey Miller specifies the two types of selection process in what he refers to as Darwinian engineering.[12] These are as follows:

1. The engineers use their common sense and knowledge in order to classify alternative designs based on possibility. These designs can be created by algorithm or computer simulation. Therefore, the computer can learn the path of human responses for evaluation, and imitate the neural network involved in humanistic evaluation. The evaluation function can be a combination of common sense and engineering principles.

2. An alternative evolutionary method is evaluation in terms of consumers and users. In modern business, manufacturers can affect consumer taste through interaction, and the user can co-operate in the design and production stages.

Evolutionary algorithms using interaction-al evaluation (the interaction between user and designer) is a strategy that integrates design, construction, marketing, and sales in a unique system. Therefore, the richness and variety of material culture will increase by introducing the end-user as one of the factors of evolutionary-interaction-al selection. However the user's judgement may import aesthetic aspects into the design process, whilst in genetics, the mathematical language in respect of the fitness function is evaluated based on the probable number of examples similar to the phenotype in the next generation. Therefore, fitness as related to genotype has an effect on its population, and, thus, fitness is at the heart of genetic algorithms that are involved in realising multi-objective optimisation in artefacts. This means that fitness is evaluated based on positive or negative effects on the next generation of devices.

Holland describes the performance measure of adaptive design in different fields, such as genetics, economic planning, and game theory as follows:

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12 Geoffrey Miller (2000) in *Technological Innovation as an Evolutionary Process* Edited by John Ziman Cambridge University Press

Field	Performance Measure
Genetics	Fitness
Economic planning	Utility
Control	Error function
Physiological psychology	Performance rate (in some contexts, but often unspecified)
Game theory	Pay off
Artificial intelligence	Comparative efficiency (if specified at all)

Table 2: Typical Performance Measure[13]

The selective forces in technology cannot be compared directly with natural ones in the biological world, because of the variant of 'human intention' (which includes the designer and the user). However, the selection process generally operates on a population of creatures (biological or artificial) which possess phenotypic variations due to their interaction with the environment (interactor units). Therefore, along with the reproduction of interactors, the transfer of replicator units to the next generation results in lineage as time passes. However, determining the nature of the evolutionary unit that plays the role of replicator in the evolutionary process of technology is of crucial importance.

1.2 Replicators and Interactors and their Role in the Selection Process

One of the most important elements in the selection process is the unit of selection, and the determination and limitation of the unit of selection is important for any investigation of historical-evolutionary cohesion. Selective forces act on the unit of selection if it replicates itself and is copied many times in next generation. Therefore, the unit of selection can be expressed as a vehicle. Generally, selective entities can be termed as replicators, and their copies as interactors; this is why these terms are always context-dependent. Replicators build interactors, and they interact with their environment to become adapted. David Hull divides down this concept further to examine replicator and interactor units in a way that removes ambiguity regarding selection levels.[14] Hull

13 John H. Holland (1975)

14 Hull, D. L. (1988) 'Science as a Process: An Evolutionary Account of the Social and Conceptual

defines his terms as follows:

1. Replicators: These entities replicate their structure directly.
2. Interactors: These entities interact with their environment as a coherent whole and produce different counterparts.[15]

Over the past few decades, the identification of the level and unit of selection has been a source of dispute among evolutionary biologists. These disputes have centred on discussions about genes, organisms, cells, and species. Selection is a result of the operation of replicators and interactors, and both these entities need to occur in natural selection. If there is a replicator but no interactor, then selection will not occur. In Hull's view, a replicator only operates when it has structure and is able to transfer this structure in the replication sequence. Generally, genes are considered replicators, and organisms are considered interactors. Of course, assigning a replicator is context-dependant and path-dependant. Sometimes an organism, cell or genome is considered to be a replicator (Dawkins elects the gene as a replicator, whilst Lewontin[16] treats an organism as a replicator, and Alexander[17] treats species as a replicator) Dawkins believes that species cannot operate as replicator, although its genome might, if produced asexually.[18] He defines the three traits of a replicator in his 1976 book *The Selfish Gene,* and argues that a replicator reproduces samples of itself in order to achieve longevity in the evolutionary process, and to achieve fecundity in order to create copies of it-self and to gain the ability of fidelity.

The success of genetics in the 20th century was mainly due to the way it succeeded in specifying the fundamental unit of hereditary variation (the gene) and the processes that result in inheritance. Jablonka and Ziman[19] note that the basis for understanding genetic engineering and biotechnology is DNA, and the manner of genetic information transfer to proteins, gene construction on chromosomes, and gene expression.

Development of Science' in *Darwin: A Norton Critical Edition, 3rd Edition,* Philip Appleman Ed (2001), Chicago: University of Chicago Press pp. 361–363

15 Hull D. L. (1981) 'Units of Evolution: A Metaphysical Essay' in *The Philosophy of Evolution U.J. Jensen and R. Harré* (eds.), Brighton, England: The Harvester Press, pp. 23-44; reprinted in Genes, Organisms, Populations, R.N. Brandon and R.M. Burian (eds.), Cambridge MA: MIT Press, 1984.

16 R. C. Lewontin 'The Units of Selection' Annu Rev. Ecol. Syst. (1970) pp.1-18

17 Alexander, R. D. and Borgia, G. (1978) 'Natural selection, altruism, and the levels of organization of life' *Annual Review of Ecology and Systematics* 9 pp.449-474

18 Richard Dawkins *The Selfish Gene* (1976) New York City: Oxford University Press

19 Jablonka and Ziman (2000) 'Biological Evolution: Processes and Phenomena' in *Technological Innovation as an Evolutionary Process* (Ed: Ziman J.).pp. 13-27. Cambridge University Press, Cambridge

Genes are made up of DNA and instructions known as genomes. A genome is a large community of genes, and genes are chemical instructions that are coded into DNA which direct the development and progress of the cell. A zygote contains the parent genetic information, and based on this, a genetic development pattern in phenotype is established. Living things operate using instructions found in their structure, and cell machineries are used for transferring genetic information from DNA sequences to various types of proteins and RNA molecules. Therefore, an overall collection of DNA is considered as an organism's potential inheritance power. The list of instructions that are included in the genome, and that exist in organism cells, can be defined as the genotype.

The distinction between genotype and phenotype is one of the conceptual foundations of 20th century genetics, and is based on the idea that an inheritable part is separated from a part which is not able to transfer from one generation to the next. Phenotypic emergence is the result of interaction between the genotype and its environment. However, this interaction is not a reaction; it only means that many organisms build their environment and affect the way the genotype interacts with its environment. Hence, a mutual interaction is made between the interactor and environment. In plants, various methods of expressing genotype can be seen, and propagating by slip can share identical genotypes in various environments, which develop various phenotypic effects.

However, as Jablonka points out[20], there has been research conducted into microorganisms that doubts the consideration that all variations that occur in DNA are blind and indifferent to environmental effects, and it seems that environmental pressures can have some effect on variations in DNA. This body of research offers a second theory about inheritance. The controversial theory of an epigenetic inheritance system (EIS) helps to establish similarities that are useful for the study of cultural evolution patterns. Epigenetic theory shows how evolution by natural selection can operate in a system of acquisitive variations, and it explains the interaction between selective processes and the constructor; it takes us beyond the digital information.

1.3 Memetic Knowledge and Unit of Selection in Technology

The selection process is very complicated because it operates between various levels of organisation

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20 Eva Jablonka and Marion J. Lamb (1995) *Epigenetic Inheritance and Evolution: The Lamarckian Dimension* Oxford University Press

or structure.[21] Probably one of the most challenging aspects of evolutionary theory is choosing a unit in technological changes on which the selection process operates, since such a theory cannot be understood without attention being paid to social phenomena. In the following paragraphs, I will review different theories that consider the mentifact as a unit of selection in technology.

The accumulation and transfer of technical knowledge is part of cultural inheritance. As such, in order to be able to analyse how a developmental process interacts with artificial elements, we need to gain a better understanding of the transmission process in the accumulation of technical knowledge, as well as basic technological knowledge and the dynamic character of the development process in technology. Replicators can be thought of as fundamental units, which embed themselves into a vehicle; their success or failure depends on their ability to produce successful vehicles. Vehicles reproduce replicators and, respectively, they create vehicles. The idea that cultural transmission can play the same role as genetic transmission, and can operate as a kind of non-genetic form of evolution (like language evolution) inspired Dawkins[22] to consider the 'meme' as the replicator in the cultural evolutionary process.

The 'meme' (like the gene) can transfer copies of itself in order to retain continuity in the evolutionary procedure, and that the 'meme' is the basic unit of cultural transfer. Melodies, ideas, key words, fashion, construction methods and architectural techniques are examples of this replicator. The meme can jump from one brain to another through an imitation process, just as genes do in a gene pool when they spread themselves from one body to another with the help of sperms or zygotes. Dawkins names the 'meme' as replicator in cultural evolution (like the gene in biology) and he compares the survival of a gene in a gene pool to the survival value of a meme in a meme pool, and he suggests that some 'meme' are more successful in the meme pool. This follows the model of natural selection. Dawkins notes three survival criteria: *longevity, fecundity and fidelity* that are valid for meme copying.[23] The techno-meme is composed of technical ideas, technical knowledge and techniques, and can be thought of as the software for the fundamental unit of selection in technology. A techno-meme may spread out through learning, training, and imitation, which transfers to the next generation of industry. Such units are capable of replicating and responding to selective pressure, and they may evolve through heritability, variety and

21 Hull D.L. (1988) p.477
22 Dawkins (1976)
23 Ibid p. 194

mutation. Spreading the techno-meme is a genetic-like activity and is done by means of the behaviour of the host. If they propagate less, then their population may become extinct. Alternatively, others survive and by means of genetic-like operators, they spread out to the next generation.

Therefore, based on this theory, since technological innovation is part of culture, it is referred to as memetic. The techniques and procedures involved in production, and the aesthetic and economic factors governing technology can be distinguished from the artefact's structure. It is also possible that the evolutionary unit in technology can be explained according to social forces, but the problem here is that such forces lack general and public criteria; they are more related to idiosyncratic states and local conditions. In biology, although the general goal of selection may be to increase adaptation with an environment, the goals for lineage may be variable, but not because variation in genetics is blind, nor because of the non-intentional nature of natural selection, but because various aspects of the environment are constantly changing.

Derek Gatherer accepts the idea of the meme as the informative unit inside the brain. He proposes a theory of behaviourism for overcoming the problem of a non-definable meme-host relationship.[24] Our understanding of the idea of the meme has been developed by specifying two concepts, both proposed by Dawkins; he refers to these concepts as Dawkins-A and Dawkins-B. Dawkins theorises about these concepts when he talks about *the extended phenotype;* he considers the meme to be the information that is placed in the brain. Gatherer explains these concepts as follows:

- Dawkins A: Based on the 1976 definition, a meme is a cultural transferring unit that consists of ideas, fashions, techniques, beliefs, etc.

- Dawkins B: This is a revision of Dawkins' 1976 theory. Dawkins feels he has not been clear enough about the distinction between the role of the meme as replicator, and the phenotypic effects or meme products. Therefore, he theorises about *the extended phenotype*. In Dawkins' opinion, a meme is an information unit placed in the brain, but it has a certain structure that is realised in the communication instruments used by the brain in order to save the information. Phenotypic effects may be in the form of words, music, visual images, fashions, and face and hand movements. Dawkins' orthodox approach considers the meme as information that has settled in the brain.

24 Derek Gatherer *Why the Thought Contagion' Metaphor is Retarding the Progress of Memetics* (1998)

Dawkins' theory is based on the idea that cultural traits are transferred from one person to the other, as are viruses and genes. Therefore, cultural evolution can be understood using the basic mechanisms that are involved in biological evolution (e.g. replication, variation etc.). Therefore, just as gene frequencies are necessary for the genetic population, meme frequencies are necessary to the memetic population. This interpretation focuses on non-observational elements, and is limited to the neural patterns and units in the brain that are the carriers of certain ideas, behaviour or specific attitudes which are then communicated to other people directly or indirectly, and this transfer can spread to people within a society[25].

This interpretation is the foundation for External-ism and Behaviour-ism theory, which places emphasis on a quantitative approach, and considers the study of cultural evolution in order to show the frequency of change in a cultural population. This idea leads Gatherer[26] to be interested in the notion of the meme as part of a theory of expanding innovation, which concerns the production and development of artefacts and their corresponding cultural utilisation in a way that is not compatible with Dawkins B theory. The meme is defined as an observable cultural phenomenon such as behaviour, an artefact, or an objective of information, which is copied, imitated or learned, and may be reproduced within a cultural system. Objective information consists of instructions, norms or rules, procedures and social institutions, all of which are observable. Non-observable parts, such as beliefs and behaviours are learned by trial and error (tacit knowledge), and are distinguishable from the definition of a meme.[27]

Behavioural-ism theorists like William Benzon[28] compare an entire physical culture to a gene, and suggest that a culture expands from artefacts, expressions, writings, paintings and art works etc. Therefore, by reversing the standard memetic (a meme exists inside the brain, whilst its behavioural properties exist outside of the brain), mental processes set up as phenotypes, and physical objects as genotypes. I will refer to 'memotype' or 'genotypic meme' to define the role equivalent to a genotype (information transported by the gene and passed to the next generation). Additionally, I will use the term 'phenotype' or 'phenotypic meme' to discuss the role equivalent of a phenotype (the external

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25 This idea is similar to the 'mental viruses' idea proposed by Brodie, whereby ideas are transferred from one mind to another through imitation or communication. Brodie, R. (1996) *Virus of the Mind: The New Science of the Meme*. Integral Press, Seattle.

26 Gatherer (1998)

27 If tacit knowledge is copied through observation, it is classed as a meme by means of learning.

28 William Benzon 'Culture as an Evolutionary Arena in *Journal of Social and Evolutionary Systems* 19(4) (1996) pp.321-362

emergence of an organism as it is assigned by the interaction between genotype and environmental traits). An understanding of the nature of the evolutionary unit and the role of DNA in the process of Darwinian engineering (and its role in separating lineages in the selection process) is vital to understanding the Darwinian process. Understanding fundamental differences between the meme and the gene, even though both play a replicator role in genetics and memetics, can help give us an understanding of the 'mentifact', which is the base evolutionary unit in technology.

Dawkins[29] points out two fundamental differences between the gene and the meme, as follows:

1. Memes, unlike genes, do not occupy a distinct locus completely, nor do they have an identifiable allele. In the case of genes, when we talk about the phenotypic effects, there is not a difference between behaviour produced by a brain with or without the meme.

2. When we talk about a meme, we need to question whether the copying process is similar to that of the gene.

In genetics, genes can only transfer from parents to offspring (known as vertical transfer), but it is possible for a meme to transfer between different people within a society by means of horizontal transfer. Therefore, in cultural transmission, generational transfer is not always necessary, and information can be transferred much more quickly. Furthermore, the variation in a meme occurs more easily from novel memes because of the existence of more available resources, and the selection process is more efficient because of what Campbell [30] refers to as *vicarious selection*. Therefore, memetic evolution is quicker and more efficient than genetic evolution. In comparison to genes, memes have more fecundity, and less copying fidelity because of their plastic properties, and this increases evolve-ability.

In contrast to the behavioural theorists, Robert Aunger considers memes as *brain structures*, and builds a theory about change in technology by focusing on the relationship between memes and artefacts.[31] He argues that a set of neurons indicating brain states transfers the neuro-meme to the next node. Therefore, technology evolves by means of co-evolution between memes and artefacts.

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29 Dawkins (1976) p.112

30 Campbell, D. T. (1960) 'Blind Variation and Selective Retention in Creative Thought as in Other Knowledge Processes' *Psychological Review 67,* pp.380-400

31 Robert Aunger 'What's Special about Human Technology?' *Cambridge Journal of Economics 34* (2010) pp.115-123

Here, the artefact is the unit of selection, whilst the selection pressures that operate on it are interactors. In addition, they can be replicators for memes, as observed in the phenomenon of computer viruses. multiple relationships with memes are formed based on these different roles, and co-evolution exists in all cases because memes create artefacts, and artefacts may interactively feed memes in order to change them or produce a newer type. Both memes and artefacts follow their own selection pressures. If memes are ideas or techniques, then their phenotypic expression is an artefact or behaviour. For example, cooking instructions stored in the brain are a set of meme, and the prepared food is the phenotype.

However, artefact production is simulated in the mind based on the brain's structural arrangement, where various alternatives are tested based on competitive advantages. This simulated process may occur in the research and development process (R & D), or in the market. Inventing new artefacts can occur based on the mutation or re-combination of techno-memes. Therefore, in this view, the techno-memes only transfer from brain to brain. In addition, the reproduction of techno-memes is not really a transferring process, because transferring a memetic unit to people in a population needs media and carriers, which have enough stability to show phenotypic expression without changing the form.

In a strong account, the meme makes contact with people in society, and reaches the stage of phenotypic appearance that is created from brain structures and mental conditions (the memo-type). In other words, memes go through a process of memo-type expression. This introspective memetic process is when technology is at a stage where it emerges as a memo-type (in the human mind) but does not have any plan for transferring this phenotype to the outside world.

Change and progress in technology are realised in society when technical knowledge and engineering sciences play a main role. In contrast to Aunger, Joel Mokyr[32], criticises 'the blind variation with selective retention' model. Instead, Mokyr develops an evolutionary model of technological progress that comprises a general interpretation of the dynamic of a population’s history by means of sets of evolutionary units. He distinguishes between the underlying structure that determine traits (although they are not determined completely) and the manifested entity that can operate in the role of evolutionary unit.

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32 Joel Mokyr 'Innovation and Selection in Evolutionary Models of Technology: Some Definitional Issues' presented to the Conference on Evolutionary Models in Technology in Wallingford, England on Jan. 9-12, revised June 1997.

Indeed, general interpretations of 'underlying structure' and 'manifested entity' in different fields may extract their own specific functions and methods. For example, in biology they can express the genotype and phenotype respectively. In evolutionary epistemology, the knowledge base, as espoused by Campbell (1974), of which the elements determine the properties of cultural entities, can be analysed in terms of its role in underlying structure. Cultural units, such as ideas, traditions and techniques, and so on can be considered as a manifested entity.[33] Based on this view, techniques used in the economic history of technology can be considered as evolutionary units in the dynamic process that links the past to the present. Technique can play the role of manifested entity in the technological field. Mokyr indicates these possible techniques with the symbol λ, and he shows the useful knowledge equivalent to underlying structure using the symbol Ω.[34] One of the most important parts of evolutionary theory is being able to map useful knowledge Ω into sets of *feasible techniques.*

Mokyr defines three basic principles in the Darwinian model that comply with the above-described process.[35] One of these is the relationship between underlying structure and the manifested entity, which in biology is the relationship between genotype and phenotype. Useful knowledge includes scientific knowledge and beliefs about the natural world, whilst technological knowledge considers rules and relationships between artefactual phenomena, engineering science, and rules governing over natural world. In addition to descriptive knowledge, this kind of knowledge adopts a normative stance, which is the result of a system of rules relating to empirical situations. Therefore, this theory is 'more operational' than cognitive. This is why science is constantly trying to explain, describe, and observe, and renew abstract concepts based on universal rules. However, the production and research of technology uses rules to control natural phenomena and to manipulate natural structures to meet human needs. Therefore, there is a difference between scientific predictions (which are concerned with finding proof) and technological predictions (which are concerned with the manner of influence on events and tools).

One of the central principles in the evolution model concerns the interaction of Ω and λ. How does

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33 Campbell D.T. 'Evolutionary Epistemology' In *The Philosophy of Karl R. Popper* edited by P. A. Schilpp, pp.412-463. LaSalle, IL: Open Court.

34 Joel Mokyr (1998) 'Science, Technology, and Knowledge: What Historians Can Learn from an Evolutionary Approach' in *Neither Chance nor Necessity: Evolutionary Models and Economic History* (1998)

35 Mokyr derived this word from the work of Simon Kuznets.

a change in useful knowledge, which is the carrier of information about the natural world, engineering science knowledge, and cultural beliefs, cause changes in engineering processes and construction instructions and patterns? Aristotle believed that knowledge and technology belong to two different fields of human experience, and, therefore, he separated theoretical knowledge from practical knowledge.[36] Based on Aristotle's observations, a difference between 'knowing-that' and 'knowing-how' can be distinguished. Scientists working in the field of scientific knowledge can explain phenomena, and evaluate the truth of scientific theories according to efficiency, safety, value, and aesthetic aspects etc. in order to prepare norms for technology to be used by practical engineers who evaluate the function and efficiency of engineering processes, and design and use patterns, techniques, and artefacts, etc.

In order to analyse the development of technical knowledge, Walther Vincenti divides technological knowledge to three parts: descriptive, prescriptive, and tacit knowledge.[37] These three fields of knowledge inter-act with each other, and they involve different levels of industrial production. The interference co-efficient of these knowledge levels is directly related to the type and structure of the artefact, production instructions and techniques, design procedures and traditions, and engineering norms and standards, etc. this establishes one of the most challenging theories in the history of technological knowledge, which examines the relationship between useful knowledge and technique. The goal of science is to access the reality of the external world, which is then described based on experiment and evidence, whilst technology wants to change, control and manipulate the outside world according to human needs and demands.

The rules and traditions of design and engineering are based on empirical research resulting from trial and error, and even if the rules are based wrong principles, this may result in techniques that survive the selection process. The application of descriptive knowledge uses descriptive rules, which have been formed because of experience and practice. However, although these sorts of rules seem to describe phenomena in a similar way to scientific rules, they only prescribe an operation partially, and they still do not work within the complete framework of scientific theory. These rules have general structures and principles that explain technological knowledge. Descriptive knowledge includes technical specifications of equipment and structural-physical properties, and, hence, it can

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36 Layton, E. (1974) 'Technology as Knowledge' in *Technology and Culture,* 15(1), pp.31-41
37 Walther Vincenti *What Engineers Know and How they Know It: Analytical Studies from Aeronautical History* The Johns Hopkins University Press (1990)

determine the presence of scientific knowledge in technical artefacts.[38] Therefore, it is useful to consider the evolutionary model of the techno-meme on two levels: a) in respect of the evolutionary interpretation of engineering science progress, and b) in respect of the effect of this conceptual evolutionary progress on technology.

Mario Bunge defines technological knowledge as theory, grounded rules and technical information.[39] He divides theory into two main sections as follows:

1. Substantive theory[40]
2. Operational theory

The close relationship between substantive theory and scientific theory can result in fields of engineering and applied sciences such as thermodynamic rules, fluid thermal systems, and engineering heat transfer, and the design of parts and rules governing electrical systems etc. Essentially, substantive theories relate to the application of the almost real conditions of scientific theories, such as flying theory, which is a function of dynamic flow. These theories prepare knowledge about the activity subject, for example the machine. Operational theories are a cross over between scientific theories and technology, and they bring technology one-step closer to its operational level and empirical conditions. Operational theory relates to the operation itself, and this is the starting point of the relationship with human activity, and the combination of human and machine in almost real conditions. In game theory, operational researchers who make decisions about the flow of urban traffic are using operational theory. In moving from applied science to technological knowledge there will be an encounter with substantive theory, which brings about the engineering-scientific method and background. Substantive theories only allow scientific methods to pass, so operational theories will inherit the scientific method. Based on this, Mitcham explains that it is within the realm of construction where substantive theory has been widely used whilst operational theory has been widely used for application. [41]

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38 Herschbach (1995) believes that the framework of theoretical explanation in descriptive knowledge is not completely grown.

39 Bunge (1966) 'Technology as Applied Science' in *Technology and Culture* Vol. 7, No. 3, Summer, 1966

40 In Polanyi's view, substantive theory is systematic technology which stands against empirical technology which results from descriptive rules, Mitcham (1978)

41 Mitcham (1978) p.257

1.4 Evolution of the Scientific Part of the Techno-meme

Discovering to what extent scientific theory affects technological theory has been the subject of much debate throughout the 19th, 20th and 21st centuries. Establishing the engineering sciences after the industrial revolution, and basing industry in part on scientific discovery, became the popular norm. However, this interaction between science and technology can be indirect and it does not just include scientific rules acquired from scientific theories. For example, the pre-hypotheses behind the design of the mechanical watch is one which uses Galilean equations to show mathematical order and the formalism that governs the behaviour of the world.[42] Alternatively, the use of scientific rules in the field of Research & Development (R & D) as taken from functional and basic research is another example.

It is possible to explore the designing of an artefact's physical structure according to its function. However, the testing and evaluation process for prototypes implies putting the artefact through the rigour of scientific experiment and testing. Engineering science is involved with the interactions of physical factors in machines and artefacts, and with the idealisation of machines like thermal machines, for example, which rely on proficiency and efficiency. This indicates that engineering science differs from the idealisation and abstraction of basic science. However, apparatus like MRI scanners and transistors are good examples of the effects of scientific progress on the development of technology. However, scientists and theorists have often disputed the priority and recentness of the influence of science on technology in this field, and vice versa. [43]

Industrial innovations in their historical stage may have appeared through a trial and error process, and probably without comprehensive scientific research. If the breeze of science had not blown on them, then these artefacts would still be non-efficient and non-proficient. For example, the rules of fluid mechanics served to help the functioning of water turbines. In addition, an understanding of the gram in mathematical explanations and differential equations had an influence on the creation of the dynamo (generator) or gramophone. In addition, Longmire's electronic equations were used to help convert power stations. Carnot's principle was used to show how the diesel motor could be useful and proficient and the principles of electricity and electrodynamics' rules have contributed

42 Layton (1974) p.31

43 Marc J de Vries and Peter Kroes investigated examples such as the steam engine and the can opener (which was made by Brabantia, the Dutch company) and named these as examples in a historical reasoning theory about the effects technology has on science and vice versa.

towards vehicles, as we know them today. In addition, the rules of fluid mechanics have helped to grow air transportation systems, and to facilitate a scientific perception of hydraulic systems and combustion chambers.

The accumulation and growth of engineering-scientific theories in the field of descriptive-normative knowledge has had a direct and indirect effect on the evolutionary model of technology. Researchers such as Bondi look at the relationship between science and technology in the same way as they view the relationship between the bird and egg.[44] Epistemologists such as Campbell (1974), Bradie (1986) and Callbout (1987) try to present recognition in humans as a biological phenomenon. Bradie [45]divides the evolutionary theory in two distinct but related sections in order to describe the epistemological reasoning, as follows:

- The Evolutionary Epistemology of Mechanisms (EEM): This relates to the development of a biological reasoning for selective-ism, which interprets in order to develop and evolve the cognitive mechanisms of organisms, i.e. the brain and neural systems etc.

- The Evolutionary Epistemology of Theories (EET): This is an effort to infer the biological model of selective-ism for developing human knowledge, especially scientific knowledge. Therefore, the evolution of recognition mechanisms and cognitive products such as science, culture and technology, can be the result of biological evolution. In EET, scientific and epistemic theories evolve in a similar way to evolution in biology.

In this regard, M. A. Notturno[46] distinguishes the two concepts of evolutionary epistemology as follows:

- Scientific change can be described as an evolutionary process conforming to Lamarckian and Darwinian principles, in the same way as Campbell (1974) describes the Popperian methodology of conjecture and refutation in an evolutionary model.

- Understanding the cognitive capacity of humans and other animals in terms of evolutionary

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44 Hermann Bondi 'What is Progress in Science' in *Problems of Scientific Revolution: Progress and Obstacles to Progress in the Sciences* edited by Ron Harre (1975) p.4

45 Michael Bradie 'Should Epistemologists Take Darwin Seriously?' in *Evolution, Cognition, and Realism: Studies in Evolutionary Epistemology* edited by Rescher, Nicholas (1990) p.33

46 M. A. Notturno 'The Evolutionary Turn: A Role for Philosophy in *Evolution, Cognition, and Realism: Studies in Evolutionary Epistemology,* Edited by: Rescher, Nicholas (1990)

development in a way that increases survival value. These capacities have survival value in their own biological niche.

We impose our own theories and interpretations on our observations. Therefore, scientific theories are not the result of observations, but they are conjectures that are selected or omitted by testing. Therefore, the growth of scientific knowledge can be seen as adaptation in an evolutionary process (an approach to truth). Each time, there exists a set of observational statements that are accumulated in scientific theories that are the outcome of scientists' interaction with the environment. What evolves from this is a set of theories, and these theories contain an observational logic that gives each theory a rational credit or fitness in relation to observational statements, and is the criterion of empirical statements in science.

Thomas Samuel Kuhn[47] outlines a developmental approach for scientific progress that is different from that purported by most philosophers of science. Kuhn believes that it is the consensus of scientific society and scientists, which sets the criterion for the progress of theories. He rejects any criteria for reasonable selection between theories[48]. Kuhn's understanding of the levels of progress and change in science is as follows: pre-science, normal science, crisis, revolution, new normal science, and new crisis. In short, he suggests that scientific society goes from one paradigm to another while facing insoluble problems and the above-mentioned circle continues. The non-continuous results from the change process of paradigms, and paradigms become non-measurable based on criteria, methodology, and world-view etc. This gives the scientific revolution an exclusive and non-accumulative transition. Stephen Toulmin (1972) Ronald N.Giere (1970), Lakatos (1970) and Laudan (1984) are the most important theorists who engage with Kuhn in this field.

In contrast to Kuhn, Toulmin's analysis[49] suggests that humans (by means of their various cultures and historical eras) have a mental loyalty to certain different sets of concepts. He suggests that the role of concepts in the growth and expression of knowledge is only possible by considering their relationship with conceptual development and evolution in the past. Therefore, scientific progress is

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47 Thomas S Kuhn *The Structure of Scientific Revolutions* (1962) The University of Chicago Press

48 Positivists, including members of the Vienna circle discussed logical positivism, verification-ism, falsification-ism, and analysed the selection criteria for theories.

49 Stephen Toulmin (1972) *Human Understanding: The Collective Use and Evolution of Concepts* Princeton University Press p.133

not merely a descriptive explanation of developmental patterns, and it is not necessary to equate rationality and logicality in scientific growth. Toulmin focuses on rationality and interpretation to explain continuity and change in rational enterprises, and he looks at the mental content that forms the conceptual population. This population is a reflection of the balance between the innovative factors that are responsible for the appearance of variations in populations, and for selection factors that revise them by developing suitable variations.

Of course, selection between intellectual variations can be a complex process because every intellectual innovation has the potential to optimize our understanding in one aspect, and confuse it in another aspect. Therefore, we do not know if criteria such as prediction, inheritance, domain, accuracy, and empirical efficiency, etc. are functional and measurable in every case, since methodology, theoretical models and basic questions in the scientific field and in historical processes include gradual change.

Intellectual Enterprises are created in the same way as organic types, and defined as separate scientific disciplines. Each discipline is attributed fundamental goals, methods and concepts. The intellectual content of these scientific fields can change over long periods, and subsequently, intellectual methods and goals change more slowly. It should be noted that each scientific field has a recognisable continuity, which can be unstable, particularly as a result of selective forces that cause changes to its content. Although continuity is created, long-term changes can transfer or substitute scientific content.

Continual changes involved in a gradual process. In each scientific field, intellectual innovations come from a current pool of ideas and techniques, but only a few innovations find a place in the canon of the scientific field that is transferred to the next generation of scientists. Therefore, the permanent creation of intellectual innovations is balanced with the continual process of selection. In suitable conditions, this process can be interpreted in order to achieve stable adherence of a certain scientific discipline, and also for the fast transfer of information in a new and different scientific discipline. Therefore, the main principles of Darwinian Theory that theorise on the continuity of organic types and their methods of change (based on the perpetuation process of innovation and selection) are met as a result of intellectual changes.

Humans with curiosity and intelligence keep the flow of innovation or intellectual variations stable. Popper (1963) describes scientific method as a dialectical succession of conjectures and refutations that can be interpreted as an evolutionary model. Ecological conditions, variation and selection can result in effective scientific change.

Sometimes, the selection process in the scientific field operates to gain accreditation of a competitor's innovations in response to intellectual-environmental demands. Intellectual variants and concepts that co-exist with them are designed to meet these demands. Therefore, words like competition, benefit, demand and success are comprehensible in intellectual evolution by seeing them in the historical process of intellectual variations and selection in the scientific field. From this viewpoint, we can consider that scientific fields are made up of an evolutionary set of processes and techniques that are used to consider theoretical and scientific issues. In addition, we can consider the idea that science is an evolutionary set, which comprises organisations, institutions, and humans who use certain techniques and processes.

Over the years, theorists and technologists have explored these ideas. William Whewell (1794-1866) tried to organise morphology of scientific progress. Larry Laudan[50] sees scientific theory as an effort to solve empirical and intellectual issues about the intellectual world. He argues that scientific progress is achieved in three ways, as follows:

- When a substituted theory succeeds in solving empirical issues better than previous theories have done.
- When the theory succeeds in order to solve an irregular case.
- When intellectual agreement is created between competing theories.

Most of the evolutionary models of science, unlike those of the positivists and falsifiers, explain theory as a unit of progress in science. this model looks at scientific theories in the form of structures which rely on research programs, and which comprise a hard core and a protective belt. What evolves from these models, are abstract things like a population of theories or concepts, or a research program.

In contrast, Ronald N Giere suggests using the scientist as the base unit for analysis.[51] He looks at

50 Laudan (1977) Progress and its Problems: Towards a Theory of Scientific Growth ISBN 978-0-520-03721-2

51 Ronald N. Giere 'Evolutionary Models of Science' in Rescher Nicholas (Ed) *Evolution, Cognition, and Realism: Studies in Evolutionary Epistemology* Lanham, NewYork, London: University Press of America

growth in the population of scientists rather than growth in the population of concepts and theories.[52] However, intellectual evolution involves the evolution of a scientists' society, which can reproduce, as well as pose questions about growth and change in scientific theories and the evolution of individual theories. Questions about truth, reality and progress can logically be separated from evolutionary observations. Therefore, in many ways, Giere follows Quine (1969) who makes epistemology natural, not because of evolutionary theory, but as a cognitive science.

The second idea that Mokyr proposes about the Darwinian model is that each basic evolutionary model must comprise a dynamic system of change over time, and a probable process of definable properties that can relate the past to the future. As previously mentioned, he considers technique, routine, and procedures as selection units.[53] In the biological world, stable changes occur through mutation (or random changes), and evolutionary direction occurs by selection on organisms carrying those changes. In technology, new items occur in the useful knowledge sphere (change in Ω) which is then involved in a random process of mutation and selective retention. Such mutations may be explained by phenotype (λ). If they are not mapped in λ, they can be kept in Ω, and be activated at a certain time as a part of adaptation to a changing environment. In engineering science, theories like aerodynamics, heat transfer, vibration, and hydrodynamics, etc. each have such an experience in their stages of technological growth. Techniques may also reproduce themselves by learning, both practically and empirically.

The imitation and repetition process, like that present in memetics, can be considered as the techno-meme replication process. A phenotype can be constructed based on wrong theoretical concepts, superstitions or traditions, but it may survive because of its positive interaction with the environment in the selection process. He calls such techniques *singleton techniques*, and an example of this is using cinchona bark to cure Malaria.[54] Techniques are created in a socio-economic environment based on human needs. Therefore, a significant part of knowledge, like the natural mutations in biology, may or may not be used directly in production stages. Technique as a construction instruction, and methods used to manipulate nature, are distinct from operational principles that explain how objects work together. This is similar to the algorithms of computer

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(1990) pp.127-171

52 A scientists’ society consists of 6 groups: science in general, scientific fields (physics, chemistry, etc.), sub-domains (such as geo-physics etc.), investigation experts, investigation groups, and individual scientists.

53 Mokyr (2000)

54 Ibid

programs that can explain the manner of production and manipulation of nature's powers.

Techniques that operate in the role of replicator can be transferred from one generation to the next, and simultaneously appear as the phenotypic expression of knowledge, but due to a lack of integration, other vehicles and techniques are eventually used. We can classify the main classes of vehicles as follows:

- *Techno-social System*: The place where the techniques are embedded. For example, the technique of working and using train station. Of course, other carriers of technique are able to change the use of patterns and operational methods. An example of this might be when we use a chair to stand on to getting access to something. Therefore, artefacts, as phenotypes, or as the phenotypic expression of instructions and procedures for engineering and construction, can be the carrier of technique.

- *Experienced People:* Technical information can be stored in books, dictionaries, electronic memory, etc. independently of being used or not, and in the minds of experts and technologists.

Therefore, it seems that technique in itself cannot work in interaction with environment in the role of interactor, but vehicles can be used in interaction with the environment for techniques related to use, and for reproduction, when the re-production instructions are proposed. Tacit knowledge can be found in the technique itself, and, to a large degree, is the result of judgment, skills and individual acts. In *The Tacit knowledge*, Michael Polani[55] distinguishes different phenomenological aspects, such as semantic and ontological.

To a large extent, situational knowledge relates to interpretation by the individual mind, and it is related to individual properties and experts. It can be distinguished from other knowledge based on accessibility. One of the characteristics of inaccessibility is that it cannot be expressed formally, and, therefore, diagrams and images etc. are used to imagine it. This kind of knowledge can be transferred via training as part of the relationship between the supervisor and trainer. It is possible for a significant part of industry and modern technology to be influenced by these kinds of traditional and non high tech skills.

Situational knowledge, which can include technical knowledge and commercial rules and techniques, brings a personal and individual dimension into the knowledge held by experts and

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55 Polani (1966) *The Tacit Dimension.* London, Routledge University of Chicago Press 2009 reprint

experimenters. In his review of the aviation industry, Walter Vincenti distinguishes six conceptual tools that, he argues, contribute to technological knowledge.[56]

1. Fundamental concepts in design (operational principles and normal configurations).
2. Criteria and technical specifications of the design.
3. Theoretical tools (mathematics, reasoning and the rules of nature).
4. Quantitative data (descriptive and prescriptive).
5. Practical principles.
6. Design instrumentalities (procedural knowledge).

The concept of design implies that rules and principles govern the relationship between components in a system, the architectural plan, and the locating of those parts. Standards of basic engineering always affect prototypes. In addition, theoretical tools, such as plan drawing software and technical calculations (like the calculations relating to static force in a steel structure and calculations relating to pressure resistance in hydraulic systems) are the tools that enable engineering science.

Physical-chemical traits can link to functional aspects, for example the order of activities in a technical system's components (such as a production line). In addition, geographical, local, political, and social factors and limitations could be classed as influencers of situational knowledge. It can be seen that situational knowledge plays an important part in technical innovation.

The third factor that Mokyr considers as important in the Darwinian model is fertility and super-fecundity. This means that for the selection process to be able to operate within the system, there are always more entities than those that actually enter the environment. As mentioned before, the selection mechanism operates on two levels in respect of technique and useful knowledge. In technology, the intellectual selection process occurs by the selection of production methods, physical-chemical structures, the use plan and final products, in which companies, experts, and users (market pressure) can be classed as selectors.

There are similarities between Mokyr's evolutionary model of technology and the biological one. Changes in useful knowledge Ω occur by blind variations and selective retention. However, the emergence of new techniques by chance in every evolutionary system may face resistance because

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56 Vincenti (1990) *What Engineers Know and How they Know It: Analytical Studies from Aeronautical History* - The Johns Hopkins University Press.

these changes are rarely what the system needs. Sometimes optimal mutation occurs without attention to previous knowledge, such as the discovery of X-rays for example (by Rontgen in 1895) or when the smallpox vaccine was discovered. Then, the next operator is a re-combination one that is the appearance of techniques that are the result of new forms of useful knowledge recombination. This re-combination can also occur in the production of certain artefacts like installing a combustion engine on a balloon. Therefore, both natural selection and biological innovations occur hierarchically. In addition, the function of a technological or biological structure can be used for a different goal from that which it was selected for it, and a trait with a specified function shows another behaviour or operation during its own selective history.

Of course, in technology, designers may not be able to predict the alternative function of a structure in an adaptive environment. Natural selection can optimize the available structures for the current functions. The idea that the function and operation of industry may change throughout its evolutionary history is investigated by Vrba & Gould, and they devise two different concepts of fitness:

1. A trait that has been shaped in the past for a particular function (adaptation) can now be considered for a new function (exaptation).

2. A function that does not carry a direct act of natural selection, and is considered as a side effect of a trait.[57]

How birds use their wings is one of the classic examples of this kind of thinking. Wings were first used as a way of regulating the body temperature of living creatures, but they evolved to be used for flying. In fact, the function of wings changed from being a system of temperature regulation to a flying system during historical evolution. In addition, artefacts can show this kind of change in function also. Mokyr places emphasis on the Lamarckian idea of technological evolution, and the reflection from Ω to λ. Whether a technique is ever used or not it has a subset in Ω a named epistemic base, and this evolutionary model is illustrated below:

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57 Gould, Stephen Jay, and Elizabeth S. Vrba (1982) 'Exaptation — a missing term in the science of form' *Paleobiology* 8 (1): 4–15.

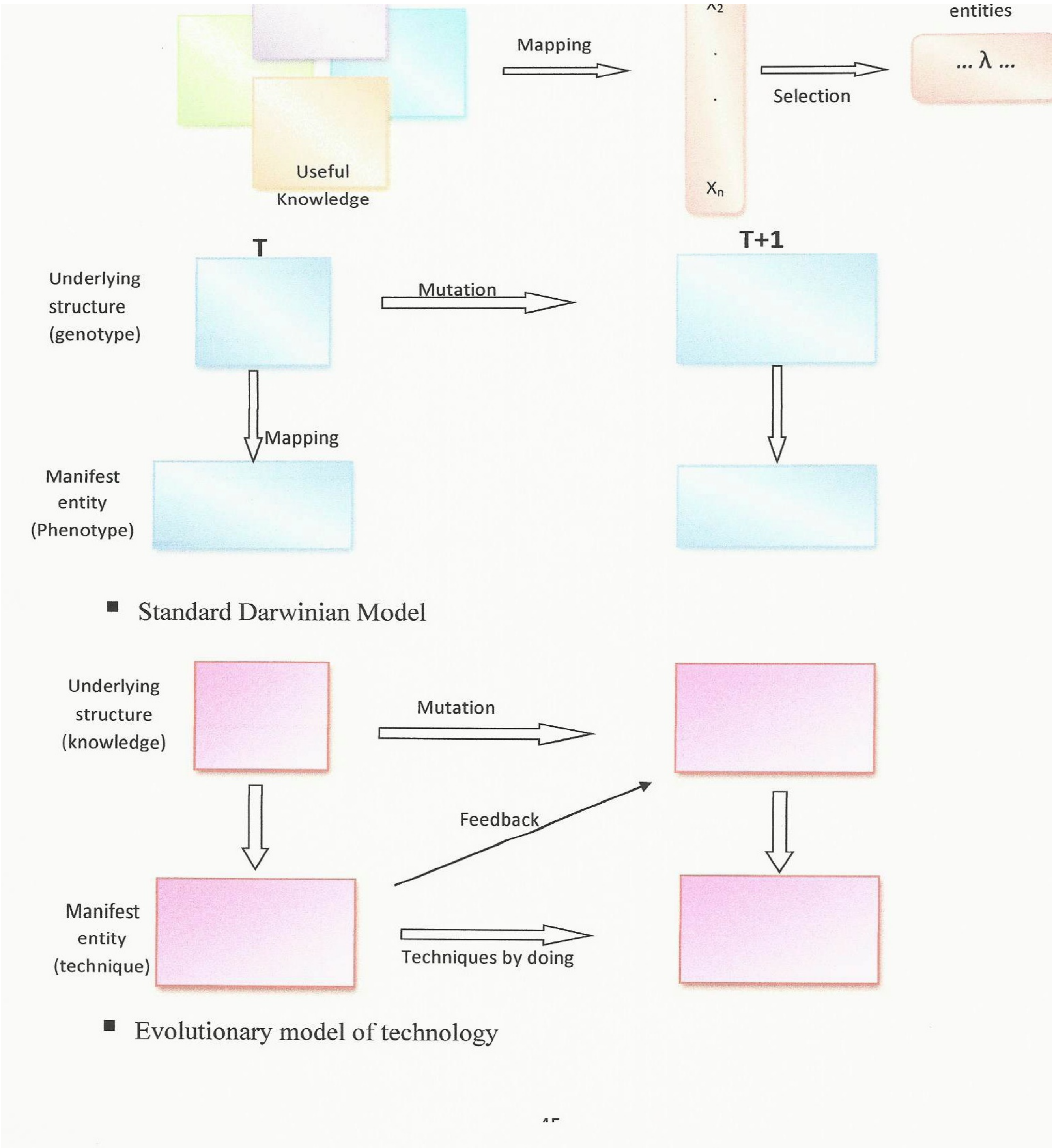

Figure 2: Darwinian Standard Model and Evolutionary Epistemological Model of Technology[58]

58 Joel Mokyr 'Natural History and Economic History: Is Technological Change an Evolutionary Process?' This is the draft of a lecture. (April 2000)

Technical knowledge and techniques are effective factors in the process of technological development. Other aspects that can contribute to this process are design traditions and procedures, aesthetic, and social and legal aspects. In addition, restrictions resulting from the use of resources and technical-constructive aspects can give direction to the evolutionary process in technology. Scientific methodologies and tools can be effective contributors to any research processes, but the majority of technologies are not constructed based on these factors alone, nor do they have less dependency on them, except in fields such as biotechnology and pharmacology that concern exploration rather than design. It depends on human factors for the emergence of its vital power, and is subject to various limitations.

Focusing on knowledge to develop technology is necessary, but it is not enough to explain technology. Concepts, techniques, procedures and cognitive ideas are part of a social-material interaction that makes technology more effective as an activity that influences the real world. Engineering sciences can determine design space based on concepts that result from science, but the effort to transfer technological art to a science has never been successful. Science rarely produces optimal or enough 'operants' for technological functions, as the scientific-ation of technology does not necessarily create a satisfactory productive language.

Stankiewicz[59] emphasises that design space is determined and developed in almost all technologies, and new 'operants' are created as the evolutionary base unit by random explorations, or by research or fusion with pre-existing design spaces. Research regimes require a minimum basic knowledge that is placed under vicarious testing techniques within a structured research environment. This results in effective heuristic research. Therefore, final solutions are realised in the form of artefacts or particular technologies, rather through designing or following a transfer process from exploration to design. The following processes can be considered as process of transferring from discovery to design.

1. Reverse Engineering: The science oriented analysis of natural systems that humans intend to take control of such as biomedicine and biochemistry.

2. Analytical Deconstruction: A science-oriented analysis of available technology to describe scientifically its functional principles. This scientification creates a priori design space. For

59 Stankiewicz *Technological Innovation as an Evolutionary Process* Edited by John Ziman Cambridge University Press (2000)

example, the effort to identify principles governing the function of a steam engine has led to basic knowledge that is used to construct currently used steam turbines.

3. Fusion: An important trait in modern technological development is fusion with an already available technology, or with a specific scientific field. Scientific structures can play a key role in these technologies. For example, chemistry is combined whit mechanical engineering and establish engineering chemistry, or result of combining microbiology and biochemistry is molecular biology.

Some of the most important technological theorists, historians and evolutionary economists have considered the artefact as an important unit of selection. Basalla (1988), Petroski (1992), Farrel (1993), and Kauffman (1995) consider artefacts as phenotypes on which the selection process acts. Nelson and Winter consider the unit of selection as an 'organisational routine',[60] whilst Ziman looks at it as a type of technical idea and refers to technological 'memes'.[61] Dennett suggests that the meme is equivalent to an idea, and based on this, he explained the genotype in terms of concepts and phenotype in terms of the physical effects of such concepts.[62] Therefore, in his view, technology is the phenotypic appearance of technical ideas (the memo-type). Artefacts are memetic vehicles from which ideas are created in the brain.

According to Asunción Álvarez, Dennett's ideas about the memo-type have syntactic character.[63] Dennett suggests that pure formal entities follow a meaningless mechanical process, and although phenotypic manifestation is of a semantic nature, the terms are only meaningful subject to interpretation. This transfer of information in cultural evolution is thought of as a lingual-neural concept of information. Syntactic concepts in theory may be understood in relation to the brain structures which surround them, and based on this, meme is primarily a semantic classification rather than syntactic one. Meme refers to the phenotypic appearance (semantic) of a mental representation (syntactic). This subjective theory views technical artefacts as the semantic phenotypic expression of syntactic mental entities. Álvarez explains the contrast between genotypes and phenotypes in memetics based on following approaches:

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60 Nelson & Winter (1982)

61 Ziman (1996)

62 Daniel C. Dennett 'The Interpretation of Texts, People and Other Artifacts' *Philosophy and Phenomenological Research* Vol. 50, Supplement (Autumn 1990) pp.177-194

63 Asuncion Alvarez 'Three Memetic Theories of Technology' *Techne: Research in Philosophy and Technology Vol. 9*, No. 2 (Winter 2005)

	Cognitive/mentalist representational/internalist memetics	**Behavioral externalist memetics**	**Neuromemetic**
Memotype (memetic genotype)	Mentifacts	Artefact	Brain configuration
Phenotype (memetic phenotype)	Artefacts	Mentifacts	?

Table 3: Asunción Álvarez - Table of Memetic Terms

Standard memetics considers artefacts' as phenotypes or as the phenotypic expression of concepts. Based on an internalist viewpoint of memetics, technology is seen as the phenotypic appearance of an intellectual genotype, which is in a humans' mind. Behavioural memetics considers mental representations not as the starting point for the analysis of cultural transfer, but in terms of the demand for definable and authorised units. It should be noted that there could not be a complete symmetry of evolutionary units, natural selection and evolutionary processes in biology in the creation of technology. Artefacts lack essential vital elements for evolutionary development and are created out of human desire and conscious effort. Various elements in technology can play various roles in a hierarchical classification. These various elements are set out by Fleck as below:

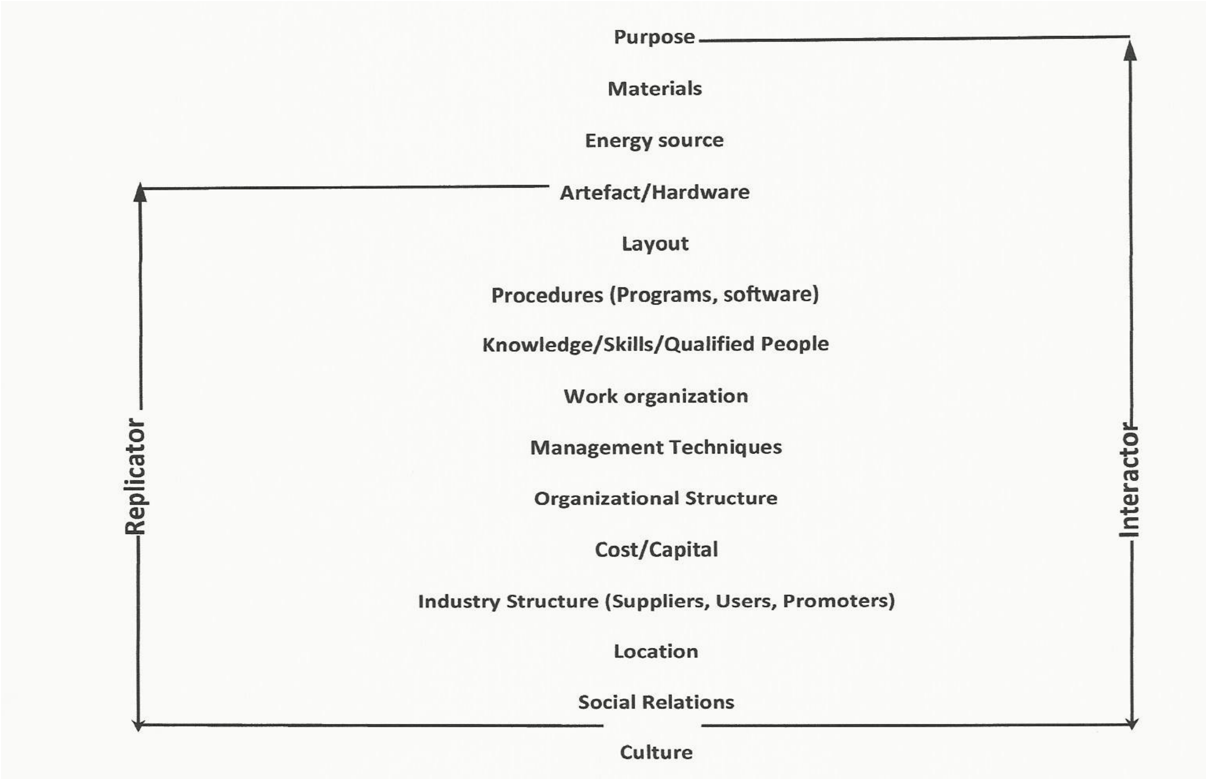

Figure 3: Fleck's Hierarchical Classification[64]

There is a need to identify a building block that can be used as a fundamental unit when examining the development process of structures at different levels, one that works as replicator to transfer an intact structure to the next generation. These units need to include all elements with which the technology interacts, such as cultural, technical and organisational aspects. Therefore, in this thesis, the word 'mentifact' will be used to identify a *unit* of *selection* in technology which is under the process of artificial selection, and one which shows that the artefact can interact with its artefactual environment as a dynamic expression of technology.[65] It can be used in an indexing role to define the degree of artificiality of a technical system, and how it finds a role in artificial processes. Human intention, either in production or in usage, is vital to the development of the design space. An evolutionary theory that focuses only on the artefact as the gene can be compared to looking at bones whilst ignoring the soft tissues.

Changes in technology are related to the conscious deliberation and foresight of human agents. Many theorists suggest that this is an extreme opinion, especially in the light of the principles of biological evolution. The debate about the extent to which the variation and selection process

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64 Fleck (2000)

65 In the final chapter of this thesis, I will talk about modularity as a dynamic process that can relate the past to the future in the evolutionary history of technology. We can consider modules as interactors in modular systems and the selection process operates on them.

sometimes involves conscious and foresighted selection still continues. For example, theorists such as Philip Brey (2008) investigate the contrast between natural selection and artefactual selection. Selection by humans occurs with an awareness of the effects on the desired object, and the consequences of these effects. Therefore, when humans are involved in selection, the process of natural selection does include intentional and forward-looking activities. This type of selection can also be seen in the animal kingdom, for example, when animals select their own mate, when the hunter selects the prey, when animals select the environment in which they live and interact, and when parents select which one of their offspring they should feed more and protect more. However, the main difference between the processes of natural selection and artificial selection is that in artificial selection, phenotypic traits linked to the goal of meeting pre-determined demands. In other words, artefactual selection, unlike natural selection, is purposeful. Therefore, both of the processes involve a kind of forwarding looking procedure, and the difference lies in purposefulness of these activities.

In evolutionary processes in technology, designers play the main role in creating purposefulness variations in artificial products. Designers and producers do not have complete awareness and control over the value of fitness in the market, because multiple and different factors are involved in the competitive environment of consumption. Based on this, it can be said that the, 'blindness principle' exists in the technological development process. Marzia Soavi[66] found other differences between how selection theory can work for artefacts and for organisms as follows:

1. There is no single rule that distinguishes the inheritable characteristics of artefacts from non-inheritable ones.

2. Items and elements of equal types of artefact are not always a copy of each other.

3. In biological entities, the total number of elements involved in production as related to the type of given entities (e.g. types with sexual and asexual reproduction abilities) is certain. However, for artefacts, a new design may be inspired by different types. Therefore, sometimes there is a weak relationship between artefacts of one type, and this is due to the designer’s inspiration from previous artefacts.

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66 Marzia Soavi 'Realism and Artifact Kinds' in Functions in the Biological and Artificial World by Ulrich Krohs and Peter Kroes (2009)

For a better understanding of the selection process as it operates in the social-technical world, it is necessary to try to specify the evolutionary unit (a unit which selection acts upon). It should be recognised that artefacts, technical ideas, or even techniques could not be considered as an analysis unit in the theory of technological evolution. In order to develop the concept of the 'mentifact' as the unit of selection in the current analysis, it is important to look at two similar concepts. One concept is theory in terms of unit of the artefact-activity couple, which examines the dynamic analogous of an artefact's static state. This theory examines a set of artefacts and the human activities related to it in connection with use and production. Looking at this theory helps to establish the minimum necessary and adequate conditions that work at the lowest level of the selection process, and it encompasses all the factors involved in production, use and development of an artefact according to the extent of complication of the technology.

when discussing the 'artefactual part of the mentifact', it is necessary to consider all things as 'artificial things' in Randall R. Dipert's wording. These things include linguistic utterances, works of art, and performing a play.[67] Dipert's theory considers how natural phenomena are affected by deliberately actions in order to meet needs. Of course, this does not result in giving the quality of artificiality to every object that is tainted by the existence of intention and goal. For example, our body grows and uses organs for various uses, but organs are not classed as artefacts, although they may be used artificially produced, and there may be what can only be described as artificial traits working in our bodies. The thesis will examine the limitations of artificial types and distinguish them from natural types in the next chapter. Another aspect of the evolutionary unit is the 'software' that is involved in creating technological development. Software is usually discussed as part of the idea of technological procedure. These procedures can consist of organisational aspects, design traditions, engineering procedures and techniques, exploration operations, and operation and maintenance. A mentifact needs to act as a coherent whole in order to achieve stable reproduction in technology. Fleck[68] considers the artefact-activity couple, and uses as functional integrity test for the evolutionary unit in order to establish long-term stability. This test is an example of what makes up the role of technological replicator in the aforementioned coupling. This is illustrated as below:

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67 Randall R. Dipert *Artifacts, Art, Works, and Agency* Temple University Press (1993)

68 Fleck (2000) in *Technological Innovation as an Evolutionary Process* Edited by John Ziman p.379 Cambridge University Press, 2000

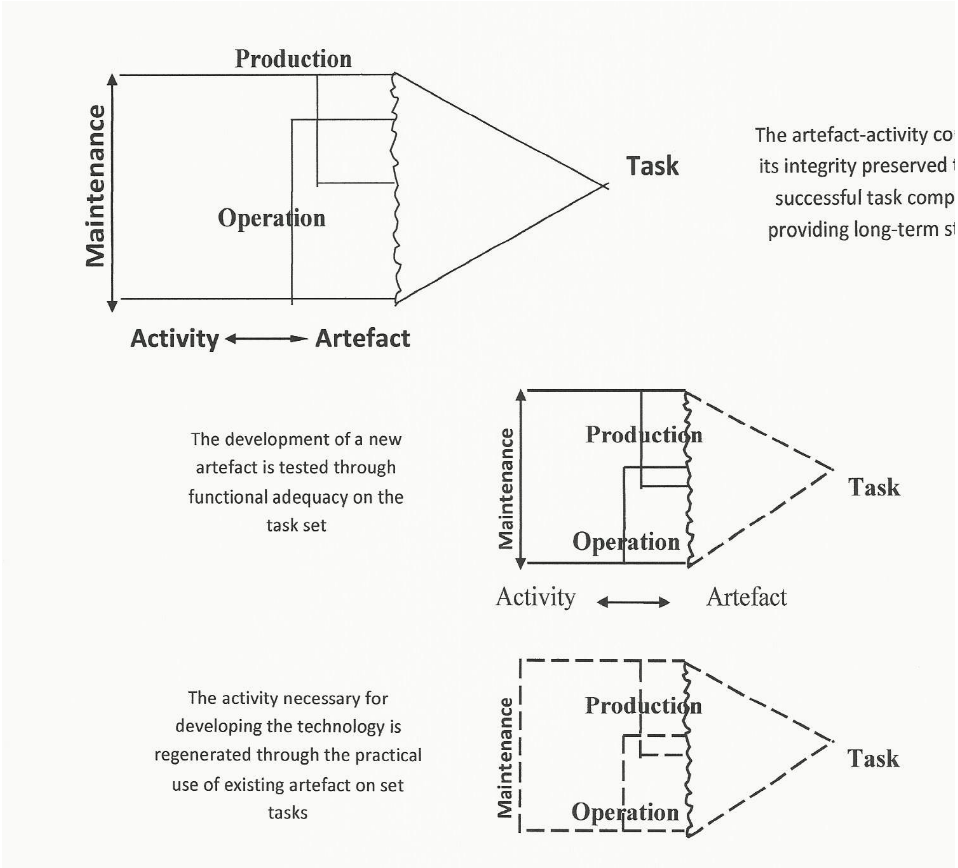

Figure 4: Fleck's Artefact-Activity Couple

Although this cycle of functional integrity does not guarantee to trigger an evolutionary mechanism, when resources and conditions change, it can resemble an evolutionary approach, and, therefore, has the ability for stable reproduction based on an understanding of means-end relationships. Changes can affect the other elements in a feedback circle from both the artificial and technological, and results in evolution in a stable pattern. Of course, these revisions may be destructive and non-useful, just like biological mutations, or they may change according to external conditions. In addition, they may have no effect on the technological development procedure, for example like producing a motorcycle in India, or making a Samurai Sword in Japan. Therefore, the above outlined reproduction process justifies the essential conditions for an evolutionary process.

We need to apply practical reasoning to prepare a description of the means-end hypotheses for the progress of activities in order to justify conditions for efficiency. Means-end reasoning allows for adjustment in the real world in order to realise an optimal situation. Subsequently, this can be related to actions that result in a change in the current state of affairs.

Technological lineage may be distinguished functionally in the reasoning of means-end theory. The

Mentifact could distinguish various lineages productively by means of looking at the tacit characteristics of related activities. The casual relationship prepares enough conditions to limit the lineages, which avoids multi-functional issues.[69] This method can be applied well in order to analyse the transferring, operation and maintenance of technology. For example, after establishing a factory and starting and operating production plants, the production lines need maintenance and spare part replacements.

In most cases, the generation of spare parts and equipment is classed as being outside of the range of production, and different manufacturers can offer different and new types of part. These alternatives often comprise of their own parts, each that has its own particular appearance, construction and/or function in operation and maintenance. although the Mentifact is stable, if the resource conditions or basic goals change, the reflective cycle of functional integrity will become unstable quickly. However, if these changes are useful, the Mentifact will follow them to reach a stable point. Examples of such adaptation in technological history are widely seen. Therefore, mutation or productive variations can affect the mentifact.

Technological change is an evolutionary process based on artefact-activity coupling (which is a combination of artefact, knowledge, organization and ect). This coupling is able to operate in technological development dynamically, and it operates as both replicator and interactor. Theorists such as Richard Stankiewics examine the cognitive aspects of technology, but they do not accept the technological paradigm, and criticisms against such model usually originate from those who favour a scientific paradigm. Critics of the ‘paradigm approach’ argue that technological paradigms consist of concepts, methodologies, and particular issues and solutions that are not measurable, and they argue that the idea of change does not include the continuous growth of accumulative-evolutionary development. More importantly, ideas that are used as criteria for progress may have different meanings in various paradigms. As a result, Stankiewics decided to introduce the concept of a 'design space'.[70] The element that grows in evolutionary history is the 'design space', and this space accumulates technological knowledge using a problem-solving approach such as the cognitive-empirical mechanism. However, a design space is a combined space that is produced by oprants.

69 I will talk more about functional interpretations and theories in Chapter Three

70 Stankiewics (2000)

Oprants must include routines, components and operational units in order to define the relationship between function and structure (process). Therefore, each artefact or technical system is a configuration of oprants, which can access primary constructive oprants by the analysis of systems and artefacts. in evolutionary terminology, oprants are techno-memes in the inheritance process of technology. Therefore, it is the design space that is exposed to changes.

Arranging oprants can facilitate the problem solving process, and oprants move forward to stability, reliability and transparency in an adaptive process. Stankeiwics[71] divides the unpredictable evolution of design space into four more or less distinct regimes:

1. The craft regime.
2. The engineering regime.
3. The architectural regime.
4. The research regime.

The craft regime works when personal experiences are accumulated and transferred from teacher to pupil. These skills are context-dependant, and selection usually occurs based on final use. *Engineering regimes* appear when a complexity of artefacts and standardisation is achieved. Therefore, design activity is distinct from manufacturing and production processes, and engineering sciences is one of its fundamental parts. *Architectural regimes* appear when multi-functional systems are designed that are related to the development level of previous regimes. However, these regimes differ from classic engineering regimes because this design process is connected to the integration and internal capability of the artefact, and the architectural designer must consider the functions and relationships with the user also.

Architectural knowledge, like craft knowledge, transfers and accumulates with difficulty, because implicit knowledge (tacit knowledge) and subjectivity are mixed into the equation. In the last chapter of this thesis, I will talk about modular systems and I will analyse their nature thoroughly based on the development of architectural procedures apparent in technology.

Research regimes develop design space by exploring and revising oprants. In traditional technologies, such explorations are the subsidiary and random result of regular technical activities

[71] Ibid

like manufacturing and production. In advanced technologies, engineering sciences play a crucial role. The effect of knowledge upon innovation and technology development has been discussed, but it can be seen that the history of technology is also full of random innovations. For example, in 1954, when observing the effect of radiations on a bar of chocolate, Spencer accidentally discovered the main technology behind the microwave oven. In addition, the artificial sugar (saccharin) was discovered by Falberg based on a similar kind of event. These accidents are accepted in the selection process because increase objective functions. The analysis of the evolutionary unit and the artefact selection process cannot be performed completely until the artefact's nature and the functional-constructive aspects that comprise to construct it are described completely. An investigation in this respect will be undertaken in the next chapter.

Chapter Two

The Metaphysical and Ontological Aspects of the Artefactual World

Understanding the artefactual world in order to examine how evolutionary theory works in technology is crucial. Looking at how artefactual interactors work can help this process. Chapter Two will concentrate on the question of whether artefacts are distinguishable from natural entities, and whether the artefactual world can be determinable ontologically and epistemologically. A theory of artefacts should be able to establish coherence in respect of physical-chemical and intentional elements, and analysing artefacts should not comprise merely a raw analysis of their structural properties. This chapter will look at metaphysical theories that show that a functional analysis is not sufficient to determine an artefact's membership of the artefactual world. Identity criteria links to artefactual kinds, and I will explore the use of the concept of Fregean cardinality and relativism in order to examine the identity of artefacts.

2.1 Artefactual Kinds and the Theory of the Artefact

Is it a good idea to try to distinguish artefactual kinds from natural kinds? Any response to this question must surely consider whether the practice of describing Darwinian theories in the context of technological growth can move beyond the status of general metaphor. When considering the development of artefactual kinds in relation to Darwinian theories of the natural world, it could be argued that examples of natural entities are those entities that share one or more fundamental properties. These properties can be used to identify the constructive elements and structures of natural objects. we can distinguish natural objects from artefactual objects in terms of function and intentions involving in design, manufacture and use of it. For example, Randall R. Dipert explains that *artefactual things* can comprise linguistic utterances, works of art, and objects that are constructed with the intention of maker, designer or user.[1]

Artefacts can be seen as basic components that are used to construct an artefatual kind. Therefore, in order to specify an artefactual kind, it is necessary to look at theories of the artefact. In this context, it is also necessary to look at particular concepts and conceptual tools that play a role in the artefactual world. The interaction of an artefact with a milieu can be affected by factors that are not usually considered when looking at the interaction of natural objects with their environment. Artefacts are constructed purposefully, and human interference plays a part in their structure. Therefore, the historical-intentional property of an artefact usually plays a main role in its artificiality, and such traits are considered when determining the object's function. Artefacts that are designed by humans are made in order to meet human needs, and users benefit from them based on a means-end idea. The purposefulness of the artefact can be one distinction criteria used to distinguish artefacts from entities in the natural world. However, because of the presence of multiple functions for artefacts (for example, aesthetic, legal, and lawful, etc.) purposefulness cannot be considered as preliminarily concept of intentionality.

Levinson presents a historical-intentional account of artefacts in the world of art.[2] In this regard, all artifacts are part of the process of historical evolution. The intentional creation of artefacts creates a stable identity for them, and a use plan maintains the historical-intentional framework of technical

1 Randall R. Dipert, *Artifacts, Art, Works, and Agency Temple University Press* (1993) Dipert argues that intention is not always a necessary condition for the creation of artefactual traits.

2 Jerrold Levinson, 'Extending Art Historically in *The Journal of Aesthetics and Art Criticism* Vol. 51, No. 3, Philosophy and the Histories of the Arts (Summer 1993) pp.411-423

systems. However, even though human knowledge about techniques and raw materials etc. may change over time, intentional connection results in the establishment of artefactual kinds. Some theorists think of artefacts as the institutional definition of art, and, therefore, they do not consider the background of the historical-intentional interpretation of artefacts.[3] However, in spite of criticisms surrounding this approach, it is worth remembering that, from a epistemic point of view, we may never be able to identify or classify items fully, because a historical approach is limited according to how far back we can 'look back into the past'. However, the risk of a lack of complete and necessary knowledge of the past is irrelevant because, if an intentional background for works of art is not discoverable, it will still be generalised into the artefact, and, it will never be possible to work out the exact number or nature of intentions involved in the construction of an artifact historically.

Before attempting to establish a theory of artefactual kinds and their nature, it is necessary to consider concepts such as intention and purpose in order to discover how intentional action is involved in the process of production and use. Using this approach, it is possible to generalise the boundaries between artefacts and non-artefacts, in order to examine the distinction between artefactual and natural kinds. One common concept of technology is the manipulation of natural objects, and physical-natural environments in order to meet human needs and purposes. In this context, it can be presumed that technology is a particular configuration of actions and natural components that leads to the production of artefactual systems. A sequence of actions brings about alterations and changes and includes software and hardware engineering. However, many questions can be raised about the boundaries between artefactual and natural kinds. Is every object or action that meets a human goal or human needs an artefatual one? For example, if we plant a tree to cast a shadow, is this tree now an artefact? In addition, when we genetically breed animals, should we then consider them to be artefacts? These ideas remain open to discussion, and lead back to the question of the extent to which human beings and all their actions and creations are part of nature. Can humans work to change nature intentionally?

In order to explore further the development of artefacts, Paul Bloom developed a theory based on Levinson's historical-intentional ideas.[4] Bloom does not determine a theory of artefactual kinds based on physical structure and a use plan, but he manages to clarify why something can be classed

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3 Dipert (1993) points out to Dicke (1984) as an example.

4 Paul Bloom Intention, *History, and Artefact Concepts Cognition* 60 (1996) pp.1-29

as an artefact, which is successfully created with the intention to belonging to that specific kind. His theory explains why certain objects are members of the artefactual world, even if they are different from some other members of that kind. This explains why some properties like shape, for example, are more important than other properties such as colour, for example, when determining membership. It is important to prepare a framework that can be used to show how malfunctioning objects are separated from functioning ones, and how innovation produces successful artefacts.

In artefact theory, accounting for malfunction and innovation are particularly important endeavours. Artefact theory is not reducible to the straightforward analysis of the physical-chemical properties of objects, and we cannot infer an object's function without considering the design and use context. Artefacts leave a footprint of intentional action that has been used to improve and construct them. However, it is necessary to ask the question, can the intended function or current use of an artefact be considered as a criterion to determine its artefactual kind? Is having a common function and use a necessary and sufficient condition to limit the criterion? An investigation of the criterion used to recognise artefactual kinds needs to gather a true description of an artefact by means of incorporating the classification of objects, by taking into account an ontological approach. In this way, a historical-intentional interpretation can be achieved which can determine the elements that contribute towards assigning the artifactuality.

Dipert [5]explains the main schema of objects and events classification as follows:

1. There are completely natural objects that are neither modified nor considered for a particular use.

2. There are useful objects with a particular use that can be classified into two categories:
a) Those that are not intentionally modified for a desired usage are called natural instruments.
b) Those that are intentionally modified for a desired use are called tools.

3. Tools can be further divided into two categories:
a) Artefacts that are intentionally modified in order to be recognised as tools; and
b) Non-artefactual tools that are revised for improved usefulness.

Artefacts themselves can be divided into four more categories that are detailed:

5 Dipert (1993)

1. Those that have communicative purposes;
2. Those that have expressive purpose;
3. Those that have artistic purpose;
4. Those that have practical purpose as distinguishable from the above three kinds.

An artefact may have more than one purpose, and/or the desire, and origin intention may not be the considered purpose for current use of artefact, then this classification system is not meant to be exclusive and rigid. Indeed, intention is one element that defines an artefact, and this intention can include the intentional use of natural objects (instrument), or the design and construction of artefacts. However, to proceed to a consideration of the metaphysical aspects of an artefact's conception, it is necessary to ask questions such as 'does intention only mean human intention?' For example, a beaver uses pieces of wood in order to build a dam, so, in this case, do we classify these pieces of wood as tools? In addition, to what extent can the objects of non-intentional human production be classified as artefacts? For example, a pathway can be created between a village and a farm because many people have trodden down the pathway by using a particular route over time. Therefore, although artefacts can have a common function, this common function cannot prepare the necessary and sufficient conditions for membership of the kind. For example, humans often use a screwdriver as a can-opener, or a chair as a stool or stepladder. Therefore, how important is the actual intentional function of an artefact in terms of applying means-end reasoning?

According to intentional theory, artefacts cannot change because they are created by means of successful intention, to have a desired function. However, physical appearance and chemical-physical structure cannot prepare the necessary conditions to limit the artefact's kind. Although physical appearance and chemical-physical structure may have an affect on determining the function, and consequently the kind, they do not prepare the necessary conditions for membership. Malt and Johnson note this idea when they discuss the use of ancient objects used for decoration, and they talk about a 'family resemblance' theory in which various functional and structural factors can be effective for determining our interpretation of membership.[6]

Therefore, outlining a satisfactory theory in order to categorise an artefact's membership of a group is required when considering the intentional factors of its historical design and use. In addition,

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6 Malt, B.C. and Johnson, E.C. (1992) Do artefact concepts have cores? *Journal of Memory and Language,* 31 pp.195-217

functional properties can determine membership of category. Function can be described and prescribed by the designers of artefacts, and it is the general tendency to accept the intentions of the designers that contributes towards us gaining an epistemic knowledge of an artefact. However, over time the intended function or functions of an object may change. Thus, historical relationships may be important in membership. However, the potential use of an object can assign an object to being a member of a category. For example, when we sit on a rock, we use it as a chair without thinking of any historical connection. In addition, any similarities of feature between a new object and a previous one of its kind can be considered as important in the perception of its function and intentional origin.

Therefore, when thinking about the distinctions between natural and artefactual objects, it is necessary to ask the question, can artefactual kinds be equivalent to real kinds? Consequently, can a dependent identity be considered for them? Therefore, determining artefactual kinds by the connection of function to a productive intention may pose some theoretical problems. Function is not a rigid criterion for artefactual kinds; an object might be used in an unusual way, and therefore, is not classifiable based on the function it performs. The designer's intention and the functional concept of an object may be specified in the design and production process, but the production phase is only the physical realisation of an object just before its operating stage. Prior to the production stage, a research phase takes place that follows instructions and generates ideas for the design process. The important thing is that the production process must be somewhat successful, and this success can be evaluated by two distinct factors: in the conceptual design phase, it is assumed that physical constraints should be enough to ensure the performance of the desired function of the object, and in the physical realisation phase, the object should meet structural requirements which are specified by the designer.

The physical realisation and design phase may be intertwined to the extent that the distinction between them becomes impossible. Physical realisation might not only be concerned with performance intentions, but also be concerned with creative aspects. This means that function cannot always be related to the designer’s intentions. Function might originate from the intention of the users, or a use plan, rather than the designer. Another factor to consider is how an object's function relates to the components of the artefact. One way in which an artefact is produced is by means of trial and error. In such conditions, the designer may ignore how the artefact performs a desired function, and how different parts are shared in the total activity. Therefore, a strategy of accepting intentional criterion is not always a realistic way of examining an artefact's components.[7] With these ideas in mind, Soavi [8] outlines a theory based on the intentions of an artefact's designer as follows:

An object can be 'K' an artefact kind, if and only when 'O' is produced for the input-output system of the structure of the interactor object.[9]

To clarify the meaning of this definition, it is important to clarify the interpretation of the word 'function' when it relates to artefactual objects. In this context, the word 'function' is used in terms of the input-output of a system, which realises a final state based on certain primary conditions. Alternatively, it may refer to intention involved in the realisation of the technical artefacts. In addition, 'function' might relate to the use plan (the user's intention) rather than just to the designer's intention. The interaction with a system prepares the true conditions an object needs in order to perform and be used for a specific function. Of course, these proper use conditions do not always involve an intentional idea of use, and, based on this, in some cases, we cannot say that the proper use of an artefact has been intentional. Consequently, the malfunction of artefacts introduces an element of ambiguity.

The object's structure, which includes all components related to its functional aspects, should provide a description of materials and dimensions. This functional description relates to the structural-physical description of the object, and is known as the functional-constructional description. This criterion provides a reference point for a description of the object's structure kind, which avoids the problem of multi-realisations. The artefact's kind is determined by the raw functional descriptions related to the functional-structural description, which is related to designing. Therefore, if a proper function is considered, then no gap is created between the function and the membership of a kind. However, restricting artefactual kinds based on functional features, without specifying its deliberate history would be an incomplete way of analysing function.

Crawford L. Elder[10] talks about 'culturally generated kinds' (CGKs), and his theory takes into

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7 The trial and error stage is for finding out the structural restrictions of an object.

8 Soavi (2009)

9 Sometimes it refers to function.

10 Crawford L. Elder, 'Realism, Naturalism, and Culturally Generated Kinds' in *The Philosophical Quarterly* Vol. 39, No. 157 (Oct. 1989) pp.425-444

account not only an artefact's kind but also its cultural inheritance, such as social behaviours (like jokes and promises) and social institutions (like marriages and legal contracts, etc.).

they are real kinds only because they have enough necessary common properties.[11] This kind of theory calls for a definition of realism that refers to a set of beliefs that are about components of the world as understood and received by particular believers, which are not set apart from main mistakes contained in a belief set. Artefacts and social entities do not meet a 'realism criterion' mind-independence because they relate to human intentions. Amie. L. Thomasson[12] challenges this view of realism and poses three viewpoints:

An Ontological View: Kinds dependent from human beliefs and procedures in their nature.

An Epistemological View: Gaining knowledge and awareness about kinds based on substantive discovery despite the possibility of error and ignorance.

A Semantic View: based on this view, referring to a kind via causal relationships, other than those linked to independent concepts and beliefs.

A semantic and epistemological approach cannot be applied to classify artefacts because of the ontological differences they have with natural objects. Therefore, in this respect, it is necessary to formulate a different theory for examining ontological aspects, semantics and epistemology in respect of objects and their relationship to the human mind and social sciences. The strong account of Realism claim that not only does the world exist, but also it has a certain structure that exists independently from the mind. There are kinds 'K' that are independent from the mind and are not mental states, and have natural borders (defined according to the Independence Principle). To have a natural border means that these kinds are not human conceptions that suffer from error or ignorance.[13] However, the error and ignorance principle can be used as a criterion to limit the natural borders of a kind.

As a result, classifying artefacts in terms of their common causal/functional capacities cannot be

11 The common properties of CGK referents are metaphysically necessary in order to be a kind.

12 Amie L. Thomasson, 'Realism and Human Kinds' in *Philosophy and Phenomenological Research,* Vol. LXVII, No.3 (November 2003) pp.580-609

13 The ignorance principle states that the membership condition of (K) a kind may be unknown to someone. The error principle states that as natural borders are not determined by accepted beliefs or principles, then beliefs may mainly be wrong.

considered, because multi-functioning and malfunctioning artefacts may make problems with membership of a kind. Therefore, any classification based on desired function has a better possibility of considering both malfunctioning and proper artefacts. However, we cannot view intention alone as being enough to classify a kind. It is necessary to examine historical productive elements as they refer to desired properties.

2.2 The Identity and Sortal Structure of an Artefact

Identity criteria can be linked to artefactual kind. In the classic definition of an artefact, an object is made intentionally by an agent. Agents design and produce artefacts by using acquired knowledge and/or instructions that guarantee the achievement of a desired goal. The ascription of goals by a rational agent may face restraints, including presumed goals that are always relative to an artefact's user.[14] Intentional production is an essential property for the existence of an artefact because an object is placed among artefacts only if it is the product of intentional production or use. The human design process carries the intention of creating an object with properties that can meet human needs. Therefore, in these cases, an artefact is always tied up with a productive intention.[15] However, at least one of the intended characteristics should be a description of sortal category in relation to other objects. This not only contributes towards determining an object's identity, but it prepares a criterion for its distinction from other objects.

The origin of an artefact, the author's intention, and the structural-physical properties of the components can reveal sufficient and necessary conditions to limit its identity. For example, a pen has a sufficient set of superficial characteristics, but something that has an equivalent nature does not necessarily make something pen. Rather, a certain set of particular characteristics makes a pen. Nominal kind members do not have a hidden common nature, but we can give them analytical characteristics based on their form and function as nominal kinds. Artefact terms are a sub-class of what are called 'nominal kind terms', simply because if an artefact kind has a common nature, then the artefact's terms can be referred to them.

14 Pawel Garbacz refers to artefacts that are used for the production of other artefacts as 'artefact-oriented'. Similarly, he refers to artefacts that follow other goals as 'human-oriented'. Pawel Garbacz *The Four Dimensions of Artefacts* KR pp. 289-299 AAAI Press (2004)

15 Hilpern called this a *Dependence Condition.* Hilpinen, R. (1992) *Artefacts and Works of Art* Theoria, 58: pp.58–82

By using the Fregean Cardinality Concept and Relativism, Massimiliano Carrara[16] investigates whether an artefact can be thought of as a sortal concept or not. Relativism aims to identify the relative relationship of a kind or concept. An artefactualist's hypothesis is that an object and an artefact do not possess an identity criterion, and sortal concepts do not possess an identity criterion. Therefore, relative identity is treated as term for artefacts, because identity is always relative to the total term of the certain artefact kind. Further, the concept of cardinality is relative, and the reasons that justify cardinality can also be used to justify relative identity. Therefore, for relativists, relative identity is similar to cardinality and there is nothing that can be simply measured and counted.

There can be a sortal concept, if, and only if, it carries an identity criterion. Although a property is not necessary for all samples of category, it is necessary to have a common criterion for all of its samples. It is not possible to select a synchronic and diachronic identity criterion for all artefacts. An object is an artefact if and only when it is a product of human intentional manufacturing, and human intentional manufacturing is a process where by an object is materially created from a design. Therefore, intentional manufacturing is a necessary property for artefactuality. From the discussion of these theories, we can proceed to two outline further theories about how objects come to be referred to as kinds:

1. The definitional proposals of Katz and Fodor[17] discuss a definitional theory for artefacts in a 1963 article 'The structure of a semantic theory.'
2. Eleanor Rosch & Carolyn B. Mervis[18] investigate the internal structure of categories, and talk about the proto-typicality criterion as a function for referring items to kind, because categorisation requests the necessary properties for membership. Their main hypothesis is that members of a category can be named when they possesses family resemblances and properties which overlap each other[19].

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16 Massimiliano Carrara, 'Relative Identity and the Number of Artefacts' in *Techné 13* (2) (2009) pp.108-122 The next chapter will look at identity criteria from the view of Baber (2000) who reduces it to a relationship between the basic and constructive elements of artefact.

17 Katz and Fodor (1963) The Structure of a Semantic Theory http://www.biolinguagem.com/biolinguagem_antropologia/katz_fodor_1963_structure_semantictheory.pdf/

18 Eleanor Rosch and Carolyn B. Mervis, 'Family Resemblances: Studies in the Internal Structure of Categories' in *Cognitive Psychology* 7 (1975) pp.573-605

19 The structure of the proto-typicality criterion is close to 'cue validity' theory as a model of classification, because it concerns the idea of shared properties, which by validity of a cue are determined based on total frequency among the discussed categories. Therefore, the family resemblance principle can be restated according to cue validity theory, because properties which have the most distribution in one category, and

‘Family resemblance' illustrates a structural principle rather than a procedural model. Therefore, prototype structure carries distinctive properties that are usually used in defining the category. Based on family resemblance the proto-typicalities are those that share the most properties with the member of their own category, and have minimum resemblance with other categories. Rosch and Mervis[20] consider three different types of category, as follows:

i) Super-ordinate semantic categories: like furniture and automobiles that are abstract and share few properties for membership. These categories comprise items that are related to each other by family resemblance.

ii) Basic level semantic categories: Artefacts like chairs and automobiles comprise objects with a level of abstraction that are built from basic level categories. Although membership of this category comprises an infinite numbers of objects, family resemblance definitions can imply the creation of a set.

iii) Artefactual categories: This category shapes prototypes under consideration.

Appearance together with function can make a different contribution to how a person judges the specification of an artefact’s kind, in terms of the relatedness between members of categories and the proto-typicality of these members. To an extent, categorisation may restrict analysis to the extent of similarities with original members (prototypes) of the category. However, the intentional action of the agent (the designers and users) is a key factor in assisting to specify membership of a category. In this sense, membership of a category takes into account both the functional and structural aspects of an artefact.

Prototype theory argues that membership of a kind can be inferred based on properties like function, common use and physical appearance. However, a historical-intentional analysis views a chair-shaped object as something that a person can sit on, because we naturally infer that such objects are successfully built in order to be a member of a specific kind based on previous and historic function and use. Although there are similarities between these two opinions, there are explanatory differences. The difference between the two theories involves the prediction of non-

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the least distribution another category, are the most valid cues in that category.

20 Eleanor Rosch and Carolyn B. Mervis, 'Family Resemblances: Studies in the Internal Structure of Categories' in *Cognitive Psychology* 7 (1975) pp.573-605

specifiable and ambiguous superficial shapes and forms. In prototype theory something is considered as the member of a kind to the extent that it possesses the form of the other normal members of the kind, but it is also possible to consider artefacts which do not have a 'normal', 'usual' or 'similar' appearance to be an artefact of the same kind. Therefore, prototype theory cannot ascribe 'abnormal' artefacts to a kind.

The logic of intentional-historical theory also faces this dilemma in cases which possess ambiguity in constructive intention or when constructive intention cannot be exactly determined. Similarly, innovative artefacts also pose problems for categorisation and definition. Prototype theory suggests that we should consider an entity as the member of an artefact's kind to the extent that it is similar to other recognised artefacts of that kind, while intentional-historical theory invites us to consider other factors such as a person's perception of a modification of an artefact based on the physical structure and proper function.

When a designer produces a prototype, his/her activity is focused on the properties which he/she intends to place into the artefact, and this process might involve innovation and the creation of properties that previous examples of the same kind of artefact do not possess. Therefore, he/she has a substantial idea of what he/she intends to design.[21] Design by intention has epistemological results, because human ideas find a path to determine traits and the nature of artefactual kinds. In Rosch and Mervis' 'Proto-typicality Theory'[22] the interpretation of family resemblance is an interpretation of prototypes based on distribution of properties rather than their simple repetition (this is the factor that also distinguishes family resemblance from the cue validity definition). However, this means that there could be a distribution of properties that fall into contradictory categories rather than those that only fall into the category being focussed on. Therefore, the following needs to be considered:

1. The distribution rather than the frequency of properties has the most symmetry with prototypes in the natural category. Distribution is related to calibration of proto-typicality in super-ordinate categories. The size of the items' frequency (which is not necessarily related to properties repetition) is not related to proto-typicality in the categories.

2. Overlapping characteristics within contradictory categories have distributional properties and not

21 Kinds of properties that are related and are the result of intention to realise them in an artefact
22 Rosch & Mervis (1975)

simple frequency properties (sometimes the distributional property is equivalent to the simple frequency).

Therefore, prototypes in the natural categories are items with the highest cue validity. The more prototypical the member is, the more properties it shares with other members of the category, and it has fewer properties with contrasting categories. Based on this, a prototype is a member of category that reflects structure as a whole. Looking at historical-intentional theory, there is a close conceptual relationship between agent intentions, the artefact and the nature of an artefactual kind. Due to this, certain forms of epistemic privilege exist in respect of the nature of artefactual kinds. Attempts to answer critics of this theory have been made by explaining that manufacturers, especially of modern technology, may not have information about the nature of the artefacts being produced, because design can be separated from the manufacturing and production processes. This ignorance occurs when people work on different production lines, and any perception of a conceptual relationship between artefact and manufacturer is not needed, and the manufacturer may someone that is causally related to the physical existence of the object (manufacturer means everyone who is involved in the creation of the artefact by intention, even if they have a causal role in production). Therefore, in order for something to be an artefact it is the result of a controlled intention to produce it.

The epistemic relationship mentioned above is not gained between all manufacturers and artefacts, for example, objects that are built by animals like the beaver that builds a dam. Therefore, it should be emphasised that to be classed as a constructor of an artefact, it is necessary to assume the substantial instructive intentions of the constructor, which results from engaging in an intellectual relationship with the artefact.

The idea of epistemic privilege always poses the questions, 'is the manufacturer actually the manufacturer, is an object really an artefact, and does a particular artefact really belong to a particular artefact kind?' Not knowing the answers to these questions weakens the epistemic relationship between the manufacturer, the artefact and artefactual kind. Thomasson[23] suggests that a manufacturer is someone who has certain intentions to create an object from a certain kind. Where these intentions are substantial and involve particular criteria to control activities, then they should

23 Amie L. Thomasson 'Artifacts and Human Concepts in *Creation of the Mind: Essays on Artifacts and their Representation,* Stephen Laurence and Eric Margolis, eds. (2009)

be successful in performing their intentions.

It should be considered that although technical and social artefacts are related to human intentions and beliefs, their methods of realisation and existence are related to engineering procedures and chemical-physical properties.[24] Therefore, although they do not meet a realism criteria (by existence and nature), they are not purely mental constructions. Epistemology and ontology are approaches used to investigate and classify scientific and natural kinds, and for considering the dual nature of artefactual kinds, and they cannot be used to consider fabricated artefacts. Therefore, it is necessary to formulate an ontology based and epistemological understanding of dual nature.

24 Social artifacts gain a kind of relational function based on collective and organisational agreements.

2.3 Ontological and Metaphysical Reflections on Artefacts

Epiphenomenalists believe that all causal powers operate at a fundamental subjective level. [25] These theorists try to prepare a hierarchical picture of nature, suggesting that fundamental level entities are real. In this section, I will examine two main approaches used to analyse artefact ontology.

Lynne Rudder-Baker[26] proposes a 'constitution view' theory. She uses the example of a bronze statue to challenge the view of philosophers who propose that it is the relationship of a material thing to the thing itself that defines its identity. According to 'constitution view', all coherent objects, except the basic elements, are built up of aggregates of objects. This view is in contrast to that of philosophers like Aristotle and Leibniz, [27] etc. who suggest that artefacts are ontologically incomplete. In Rudder-Baker's theory artefacts can have ontological status, and this is why constitution is important. Unlike identity, which is timed and probable, constitution creates an integrated relationship without identity. Constitution is the glue of the world in that reality can be found in different kinds, and each object is constructed of a primary kind. An existing primary kind

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25 Jonathan Schaffer formulates this reasoning as follows:
- Distinctness: Higher-level entities are distinguishable from their lower-level components.
- Micro-power: Lower-level entities are causally potent.
- Exclusion: Both higher level and lower level entities cannot be causally potent.
- Epiphenomenalism: Higher-level entities are causally impotent.

Jonathan Schaffer *Is There Fundamental Level.* Nous 37:3 (2003) pp.498-517

26 Lynne Rudder Baker 'Why Constitution is Not Identity' in *The Journal of Philosophy,* Vol. 94, No. 12, (Dec. 1997) pp.599-621

27 Aristotle defines the sufficient and necessary conditions to understand an object as an artefact as detailed below:

- Artefacts should lack an internal principle of change or inertia (except via its matter).
- An artefact should lack the capacity to make itself or its species stable.
- An artefact should ontologically be related to another thing that is not a substance.
- An artefact should have a low-level of unity.

The first criterion establishes the sufficient and necessary conditions of a boundary between the artefactual and natural world. Therefore, animals and plants are substances, to the extent that they have capacity for their own survival in nature, and natural objects are ontologically dependent on species. Therefore, in Aristotle's viewpoint, animals and plants meet the first criterion that is a sufficient and necessary condition for essentialness. However, artefacts do not have a high-level of integration, and they owe their primary existence to a designer. Therefore, they can meet the first criterion, and artefacts do not have any substantial-ness because they have low-level integration.

Keith Bustos 'The Nature of Artefacts: An Aristotelian Response to Katz' Second Annual Meeting, Joint IAEP-ISSEE Conference (2005) is the most basic constructive level of entities. Each object has its own primary kind, and entities with different primary kinds have different *persistence conditions.*[28] Therefore, construction is the relationship between things that have different primary kinds. An entity cannot lose the properties of its primary kind, but it can still exist at the same time. Primary kinds are constructed by function and structure, or from components.

In this way, artefacts are made up of aggregates of things, and an aggregate is determined by the elements in it. The elements in an aggregate can be determined by their own primary kinds. Therefore, the aggregate may include items with different primary kinds. This concept is explained by using the example of chair. A chair is made up of a certain aggregate of woods and nails. The primary kind of aggregate is constructed of a primary kind of wood and a primary kind of nails. The wood is built of an aggregate of molecules, and a nail is built of iron atoms. Therefore, the aggregates of wood and nails are themselves constructed by the aggregate of natural non-artefactual things. However, what distinguishes an artefactual primary kind from other primary kinds is proper function, where the proper function is based on the producer's intention. Therefore the properties of a primary kind have ontological importance.

Human agents create artefactual entities; ascribe function, and specify components. However, what makes artefacts different from animals and plants (which are the result of biological evolution) is the interference of human intention in construction and use. However, the question still remains as to whether the nest that has been constructed by the bird can be classed as an artefact or not? This is probably the most important question that needs to be considered when trying to establish the link between biology and technology. This question is important because it would seem that function and purpose play a central role in the creation of artefacts.[29] The evolutionary process as it appears

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28 Lynne Rudder Baker *The Ontology of Artefacts: Philosophical Explorations* 7 (2004) pp.99-112

29 In contrast to, Aristotle, Katz believes that the ecosystem possesses artefactual ontological elements. It could be argued that ecosystems possess the power to change or place inertia on that which occurs in the ecosystem itself. Therefore, an ecosystem can re-balance and maintain a certain level of stability after a minor disorder; it has the power to optimise itself. Katz (1992) *The Big Lie: The Human Restoration of Nature*
However, Bustos emphasises that this cannot be a classed as criterion for change in a high-level entity, because changes in the ecosystem are due to the nature of entities which are in it, and not the ecosystem itself Bustos (2005). This becomes clear in the example of the mule, which is a genetically modified creature. Creatures such as the mule do not have the ability to survive and reproduce themselves, and therefore we should consider Aristotle's idea that substantiality must be potent. However, although some entities may not have substance, it is clear that they have substantiality when we consider other criteria.

in artefact construction can be examined by considering these elements. In other words, a chair does not evolve independently to become another something that prohibits its use as for sitting on.

Based on the constitutionist view, artefacts have ontological status because there are artefactual primary kinds, and the properties of a primary kind give ontological status to non-derivative bearers. However, the aggregate may be without structure, function and causal interaction, and an aggregate cannot be something higher than the items already in it. Therefore, artefacts have an ontological status equivalent to natural objects, but aggregates do not have this ontological importance. However, the realisation of an artefact depends on purposeful human action ontologically.

In contrast to Baker, Houkes & Meijers[30] investigate the extent to which we can apply a proper ontology to the general interpretations that account for the relationship between objects of a high order and their material base. These researchers consider the constitution view and the supervenience view to find out if these views can meet the criteria of a proper ontological artefact or not? The criteria that they propose are *un-determination* and *realizability constraints*. *Un-determination* determines that an ontological view of artefacts must show that there is no one-to-one relationship between function and structure *Realizability Constraints* determines that an ontological view of artefacts should provide us with understanding of ascribed function in terms of components. Therefore, it is necessary to establish conceptual framework that can be used to consider the dual nature of an artefact. Ontological adequacy criteria are usually involved in engineering procedures that have roots in structural properties, in terms of human intentional activities.

Justifying the function ascribed to artefacts is of epistemological concern. In order to specify the position of the artefact in analytical philosophy, from a metaphysical viewpoint, some questions can be raised about persistence conditions and the relative identity of artefacts. An ontological adequacy criterion tries to understand multiple relationships between function and artefact structural components. According to the constitution view, structure is defined as a causal relationship between things with a different nature. Un-determination in terms of function can be interpreted by referring to different sets of conditions, and the relationship between function to structure can be

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30 Wybo Houkes and Anthonie Meijers 'The Ontology of Artefacts: The Hard Problem' Stud. Hist. Phil. Sci. 37 (2006) pp.118-131

interpreted by determining the range of proper aggregates (components). The un-determination constraint examines the use plan, rather than the intention of designer and manufacturer.

The ontology of an artefact should be bound to *realizability*, and it should enable us to understand the possibilities of an artefact and its functions. In other words, ontology prepares an understanding of the interaction of the components of the artefact. For example, this can be seen in standard engineering procedures for design, maintenance and repair processes, and when finding out the reasons for failure. The relationship between an object with its material base is exclusively dependent on conditions.[31] We can interpret malfunction, but function inference remains without ontological support. Houkes & Meijers propose a *supervenience* theory in the context of the philosophy of the mind.[32] The main idea of this concept is that if two individuals are physically identical, then they cannot be mentally different. This theory allows a top-bottom multi-realisation, but there still remains the problem of the bottom-top relationship. For example, two persons who are physically similar are not necessarily similar in mental or functional super-venience properties.

Constitution theory provides artefacts with an ontological importance. Artefacts are created of different aggregates with different causal powers and persistence conditions. Therefore, the abilities and capacities of artefacts determine an artefact's primary kind, rather than its materials. For example, what makes a car a car is its ability to drive, and not its aggregates of metal and plastics etc., which are its constructive aggregates. However, a broken down car does not have the ability to drive, and based on this we can say that a broken artefact ontologically lacks reality.

Following on from the construction theory, in 2009 Rudder-Baker presented her deflationary theory, and cemented her reputation as a 'practical realist'. Deflationary theory considers a distinction between concepts, such as language and human interests, and what really exists. Rudder-Baker[33] describes two aspects of this view:

Eliminativism: Based on this approach, there are no artefacts, there are only raw materials and basic elements that are configured and formed artefact-wise. When an artefact is destroyed and

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31 Conditions refer to a set of intentions, voluntary actions and beliefs.

32 Houkes & Meijers (2006) - three ideas are discussed i) If two entities are indistinguishable in their basic properties, they are also indistinguishable in their super-venience properties. ii) Super-venience properties are related to or determined by basic properties. Therefore, mental traits have multi-realisation in a physical structure, and iii) Non-reductionism: super-venience properties cannot be reduced to the properties of lower levels.

33 Lynne Rudder-Baker 'The Metaphysics of Malfunction' in *Techne* (2009)

broken, there will be only a change in the combination, formation and the order of its elements.

Reductionism: Artefacts exist conceptually because the names of the artefacts refer to aggregates of material that are formed artefact-wise and in space-time.

Ontologically these two approaches are similar, and there is no ontological difference in reality if an artefact is destroyed. Both approaches agree on what exists are only elements which are organised in certain way. The only difference which remains is, 'can such an order of components be classed as an entity or not?' Reductionism sees the artefact as an order of particles, but eliminativism cannot refer the term of an artefact to anything, because the mereological sum in an aggregate of elements cannot be seen. Although there is nothing more than an aggregate of elements in the context of both approaches, in the first approach this aggregate is not an object, and in the second approach an aggregate is an entity that we can conceptualise. Then, regarding the deflationary view, artefactual concepts do not tell us anything about reality.

Function is dependent on intentionality and is comes from aggregates that are organised artefact-wise. Social-technical artefacts exist but they do not have any existence without the application of the mind. The mind-dependent and mind-independent metaphysical distinction faces ambiguity in an analytical philosophy. The mind-dependent and mind-independent metaphysical distinction faces problems of ambiguity in the context of analytical philosophy. This opens the door to combining an epistemological and metaphysical approach to looking at artefacts. The world has ontological importance because it includes human products and concepts.

2.4 The Dual Nature of Artefacts and the Coherence of Functional and Structural Aspects

In contrast to natural objects, technological objects are created based on the integration of structural aspects that originate from a geographical configuration, and physical-chemical properties. They can be described in the context of physical laws, and their functional aspects come from intentionality and the means-end embedding system. However, in order to raise the technological argument, we need to address the ascription of function to physical-chemical components. This has proved to be a controversial task among theorists, because function is concerned with a normative stance, which is not determined based on physical-chemical properties. Physical objects when placed in the context of human activity can obtain technological properties, and consequently acquire artificial property. Objects become artefacts due to the intentional process of design and use.

It is difficult to discuss functional descriptions in the context of a physical-chemical description. Design methodology which is involved a dual nature may refer to a general rough sketch to show how a technical function is operating, or it may show integrated realisation in a prototype. At this stage all technical specifications of components are specified.[34] Then, the design process starts with a description of the function of the object, and the designer looks at structural components and configuration. Of course, it is important to notice that a design is something more than a complete description of the object's physical properties and it also consists, at least implicitly, of an explanation of the way in which the object will carry out a required function. Such explanations might be technological explanations that differ from functional explanations (the ascription of function to the structure) which are an explanation of the manner of functional realisation. This explanation places a normative stance within itself.[35] Therefore it is possible to say that an artefact should show certain behaviours, particularly behaviours that are connected to proper function. Proper function refers to reasons and purposes behind their design, constitution and use, which creates an explanatory link between function and structure.

Kroes[36] imagines a technological explanation. In this respect, he explains the function of a steam engine as a example, and asserts that we should consider both natural phenomena and empirical facts (like producing steam from water using fire) and certain related activities (like opening and shutting the valves off and the manner of creating rods to move the mechanisms) which combine to perform the function of The Newcomen Steam Engine. He provides a technological explanation of the steam engine as below:

1. The physical phenomena:
- Converting the water into steam which multiples the volume.
- Cooling the steam in a closed area that creates a vacuum.
- The atmosphere pressure imposes a power equivalent to 1 kg/cm2.

2. The design:

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34 The next chapter will look at the specifications of the design of artefacts and the evolutionary methodology of the design process

35 Chapter Four will discuss the concept of the normative, and will investigate functional theories.

36 Peter Kroes (1998)

- A steam engine is made up of a boiler, a cylinder, a piston, etc.
- The piston moves up and down in the cylinder.
- The piston is connected to the great beam by a chain.

3. Related activities:
- After opening the steam valve, the cylinder is filled with steam and moves upward.
- By shutting the steam valve off and injecting the cool water, a vacuum is created in the cylinder.

In this explanation the steam engines are means that move the pump rods up and down (which is the function of a steam engine). The explanation includes functional concepts such as a description of the piston and the cylinder that is based on describing the motor design, and the actions involved in that operation. This explanation is only one description of the function of a steam engine, which relates to the conditions of the up and down movement of the motor rod, rather than the movement of the motor. It is not an explanation of proper function in terms of structure, rather it is a description of an interpretation of how the artefact's function is performed and it tells of the behaviours that are constructed based on chemical-physical properties. In order to ascribe proper function based on actions, the relationship between the explanans and the explanadum cannot be successful[37]. According to the rule of actions and preliminary-final conditions, we can confer the function of an artefact, but without embedding the explanation into a means-end system, it is not possible to ascribe proper function. What is inferred from the explanation of the steam engine is that if the desired artefact is going to be used for a purpose, it needs capacity to gain a function.

It is important to consider that we may explain a phenomenon causally as having properties with a technical object's structure, with physical principles and actions, but we cannot infer the object's function inductively and logically, because an equivalent physical phenomenon can be applied for a completely different purpose, depending on the use context. However, transferring the causal relationship in practical terms prepares the ground for Kroes to aim to bridge the gap between the structure and function of an artefact.

In a 2006 article, De Ridder[38] presented a mechanistic explanation of an artefact's function based

37 Kroes explains that we can easily use the explanation appertaining to the engine for a spinning machine without making any change to the explanation. Therefore, it is possible to determine logically different functions of an inductive method based on explanation.
Peter Kroes (1998)

38 Jeroen De Ridder 'Mechanistic Artefact Explanation' Stud. Hist. Phil. Sci. 37 (2006) pp.81-96

on two explanatory strategies in order to point out the human role in the explanation of an artefact. De Ridder outlines a *mechanistic explanation* in contrast to a *technological explanation* to specify and highlight the role of human action in an explanation, but his description is silent about the components with which this behaviour is performed. The explanans in the *mechanistic explanation* is based on behavioural roles and the mechanisms in the physical-chemical structure that create the behavioural roles. De Ridder[39] explains how artefacts can show various behaviours by outlining two strategies:

1. The 'Top-Down' strategy deals with the relationship between general behaviours and the sub-behaviours of components, in order to prepare a behavioural understanding of the function of the artefact. Based on this strategy, general behaviour is decomposed into sub-behaviours, and general behaviour realisation is described on the basis of this. Therefore, this strategy relies on a behavioural analysis rather than a structural analysis. A sub-behaviour can be performed by one or more structural parts.

2. The 'Bottom-up' strategy deals with the structural forms of components in relation to general behaviour, and prepares a structural understanding. This strategy separates the structural components based on the artefact's geometric configuration, and consequently shows which structural part and chemical-physical property produces which behaviour.

These two strategies supply each other in the design process. Designers should be able to give an interpretation of the property of materials and components, and the behaviours that these components present.

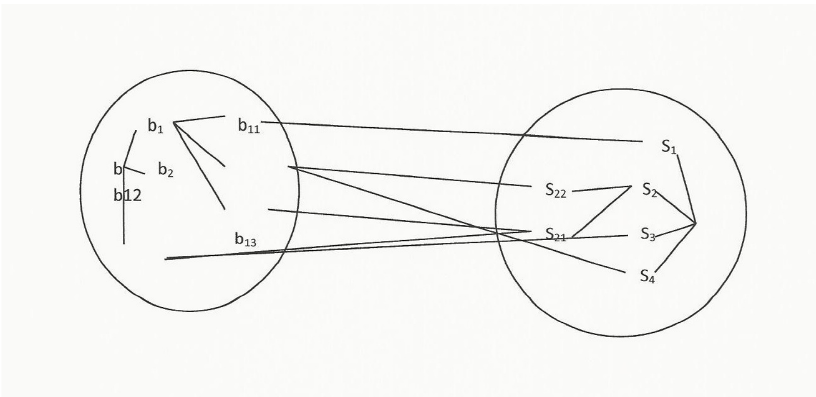

Figure 5: De Ridder's Schema for Sub-behaviours

39 Ibid

Behavioural descriptions based on causal mechanisms prepare a normative stance when placed in the context of human activity. In the context of an artefact's use, purposefulness causes a change in the state of affairs and gives functionality to objects. Therefore, we can distinguish the object's use based on the intentional act from the use of a passive agent.[40] However, we need a conceptual framework to describe the physical and intentional/functional aspects of an artefact. It is possible to use intentional theories of function as a starting point to look how agents refer to the working of artefacts in a means-end relationship. This concept of an artefact combines two different worldviews:

1. We can consider the world in such a way that it includes physical objects that interact with each other in causal relationships.
2. We can consider part of the word as including human agents that act in the world based on knowledge and reason.

As far as artefacts are physical objects, they can be placed in a physical concept of the world, and as far as they have related purpose functions, they can be placed within the context of intentional concepts. However, both aspects are necessary to describe the artefact.

Kroes and Krohs investigate inference patterns in separate articles that examine the integration between structural and functional description. In *'Coherence of Structural and Functional Descriptions of Technical Artefacts'* Kroes selects practical inferences from among explanatory, analogical and practical inference patterns.[41] However, these inferences cannot prepare a complete basis for coherence of structural and functional descriptions for technical artefacts, because every kind of interpretation of coherence should refer to intentional forms. The question of coherence between function and structure is about the relationship between the parts of the conception of an artefact's structure and its function. Coherence is the idea that structure and function in artefacts are connected to each other in such a way that any change in one creates effect in the other.

Logical connection between physical and functional language may lead to an epistemic analysis of

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40 This agent can comprise human action that does not have any purpose, or the production mechanisms' action that is not placed a means-end process.

41 Peter Kroes 'Coherence of structural and functional descriptions of technical artefacts' Stud. Hist. Phil. Sci. 37 (2006) 137-151

coherence. Of course, this gap in the logical-structural description is related to proper function and not accidental function. Coherence and consistency relate to what kind of relationship is possible between structural and functional propositions. The consistency of a system of propositions does not imply a high degree of coherence, because causal relationships play an important role in the coherence of physical objects. Non-consistency does not imply non-coherence, although it may not be considered as a positive sign for coherence, and one conceptual framework may be more coherent than another may. The explanatory coherence between functional and structural propositions does not work according to the D-N model, although we can explain the general behaviour of objects causally based on component behaviours by using physical knowledge. This explanatory connection can connect structural propositions to functional propositions.

The second kind of relationship which coherence creates is analogy. Although this coherence is weaker than the previous one, an analogy between structural and functional experience may refer to coherence. Mapping the hypotheses between components and sub-functions, between propositions about capacities, and propositions about the relationships between sub-functions, prepares a basis in order to describe functions based on structure and vice-versa. Of course, this connection between capacities and sub-functions need not necessarily be explanatory, but it may be referenced based on the experience of a physical structure to function.

The third kind of relationship is deductive coherence, which has a human application for mathematical and moral theorems, but practical inference has the ability to connect the means-end relationships with causal structural relationships. In other words, the means-end relationship may be related to the causal relationship. To the extent that functions are part of means-end relationships, they may connect also to causal relationships[42].

Therefore, the explanation of a function in terms of structural components is based on a practical inference, despite any theoretical inferences that may exist. This kind of inference is the main framework of a structural and functional description's coherence, because the technical function is

42 Kroes (2006) suggests an example:
1. Someone wants to build a habitable cottage.
2. It will be habitable only if it becomes warm.
3. Therefore, the cottage should be warm.
1 notes the end action, 2 notes the causal relationship between temperature and habitability, and 3 notes the practical necessity to perform an action.
Kroes takes this example from Wright (1963) p.160.

action-oriented concept, and activities are directed by practical reasoning. The coherence issue cannot be generally considered without considering intentions. Practical reasons that connect functional and structural descriptions together should also import intentions. The discussed practical inference shows that an object is a necessary device to access purpose based on its causal capacities in certain conditions, and, therefore, it may refer to a certain function. In other words, the pattern of practical reasoning is enough for claims about proper function based on structural descriptions.

In his 2009 article, Ulrich Krohs talks about coherence between the functional and structural, and refers to the dual nature of artefacts.[43] An investigation of these two models results in an interpretation for coherence, because for coherence to occur a relationship is required between the elements of these two models, consistency alone cannot result in coherence.

Krohs tries to reconstruct a sandwich structure. Like Hooks & Meijers (2006), Krohs does not accept the super-venience theory for artefacts, and, therefore, he rejects functionality as an emergent property of technical and biological systems. Based on this, he does not agree with the reductionism of these systems to physics, because function has a normative property that distinguishes it from other properties. A function may still be given to artefacts with malfunction. it is determined by objects, their relationships with each other, and function. This is a theory about physical-istic relationships and functional relationships. However, Krohs' does not explain how these two statements interact.

In contrast to Kroes, Krohs selects an interpretation called 'coherence by analogy'.[44] Krohs places emphasis on mapping relationships in order to reconstruct the idea of *two-sorted theory* as a functional theory that is needed in order to refer function to the components of a system, and present a description of the interaction of the two aspects. The role of function theory is to show relationships between the physical-istic and the intentional aspects, and to show how multi-realisations and functional relationships can be studied in a context-dependent way. As mentioned in the previous chapter, Simon considers the interaction of internal structures and the external

43 Peter Krohs *Structure and Coherence of Two-Model-Descriptions of Technical Artefacts* Techné 13:2 Spring (2009)

44 The example of the transistor is used to show the analogical coherence in the sandwich structure of the two-sorted theory element. Therefore, the multi-realisation of an artefact function is seen in a context-dependent way. Ibid

environment of an artefact that seemingly suggests a link between purpose and an artefact.[45] Indeed, that the environment with which the artefact interacts is an environment of human activity, and not merely a physical environment. Krohs[46] looks beyond this concept, and he changes the idea of an environment of human activity to an environment of human description, which takes into account problems that arise due to multiple correspondences between the functional and structural models.

Most of these model-based theories refer to 'no-function-in-structure'.[47] This principle argues that the rules for specifying the behaviour of each system's components cannot refer at all to the manner of general function. The function of a device refers to its expected use, and the behaviour of how this function is imposed. A description of the function of an object taken from the structure without looking at knowledge about use its context is inadequate. This absence warns us that an intelligent agent should be positioned in the 'use' context of an artefact, and this leads to the consideration of the social aspects of artefacts.

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45 Herbert A. Simon *The Science of the Artificial* (1969) MIT Press, Cambridge, Mass, 1st edition
46 Ulrich Krohs (2009)
47 Anne Keuneke and Dean Allemang, 'Exploring the No-function-In-Structure principle' J. Expt. Theor. Artif. Intell 1 (1989) pp.79-89

2.5 Analysis of Collective Purposefulness Based on the Social Aspects of Technology

In this section, I will look at a concept of technology that gives weight to the social aspects and engineering procedures involved in production. The purpose of this section is to provide an interpretation of social activities that are involved with subjects that have a 'pre-told dual nature'. Although necessary causal powers can be related to a function's reference in the chemical-physical combination, we cannot prepare a proper theory for artefacts without considering these social intentions and activities. Artefacts are made and used in a social context, and, therefore, social factors affect the technology. Social factors cannot only affect use patterns, but they can affect the design and process of the production of artefacts. Social factors may affect both physical-material and functional forms.

The function of an artefact is related to structural properties and physical capacities, and the intentions of designers, manufacturers and users. Without intention, there will be no function and purpose, and if we eliminate the function from an artefact, there remains nothing more than a physical object.

Searle presents an ontological view of the world that considers that there is no fundamental gap between social technical artefacts and the physical world.[48] For Searle, artefacts have observable and user relative properties.[49] An artefact meets the conditions for artefactuality in order to be used by the user, and to be placed in an intentionality process. This can also be true about objects with biological functions. However, it is important to note that whenever anyone talks about function, the person make reference to a value system (which suggests purpose or a kind of etiology) which is pre-assumed as a value about the biological function of survival. This interpretation of assignment of function has raised some criticism, but Searle[50] distinguishes three classes of function that he uses to investigate criticisms of his interpretation of function with reference to objects:

1. Agentive function: The user and designer refer to the function to artefacts, and these artefacts include technical artefacts and social objects like tools and money. The causal power of technical objects is dependent on their internal structure, but the causal power of social objects is given to them by collective intentionality and has a demotic power.

48 Searle, John. *The Construction of Social Reality* New York: The Free Press (1995)
49 This theory can be used to examine basic particles in physics.
50 Searle (1995)

2. Non-agentive function: Functions like the function of the heart pumping in the body of a living creature. These biological functions may be considered in a historical-evolutionary context.

3. Status function: A sub-set and particular kind of agentive function. Based on this, an object has a function because it has a status that is prepared for something else based on collective intentionality. In order to give a status function, there is a need for collective agreement in the arena of institutional-legal power rather than in respect of the chemical-physical properties of artefacts.

Searle provides the example of a screwdriver because its physical properties enable it to operate as a screwdriver. However, for Kroes this is a controversial example because this tool is involved in a normative judgment.[51] Therefore, normative and real observations are tied to each other. However, there is ambiguity in Searle's interpretation in respect of his causal function interpretation, based on collective intentionality and the inherent properties of object, where the function assignment is based on collective intentionality, and its performance is subject to inherent properties. The assignment of agentive function only meets a necessary condition, and it fails in meeting the sufficient criterion, because it does not prepare an interpretation for the difference between proper and accidental function.[52]

The second critical approach is that purported by Miller.[53] Miller criticises Searle’s ideas about cognitive states, and in contrast to Krose, Miller argues that Searle's interpretation does not consider the necessary conditions for artefactuality in respect of passive observers that’s why observer should be causally active agents. Therefore, if an artefact has never been used, it is still an artefact, but if artefacts are used for another purpose than that which they were designed for, then they are no longer that kind of artefact. For example, some antique artefacts may be used for decoration, rather than used for the purpose of their main function.

Artefacts should have properties related to the purpose of their use and properties that are related to the using agent. For example, a pen should be able to both write and be placed between the user’s fingers. Considering these two institutional and non-institutional factors, artefacts have an

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51 Peter Kroes 'Screwdriver Philosophy; Searle’s analysis of technical functions' *Techne 6:3* (Spring 2003) pp.22-35

52 The issue of malfunction is the second point of Kroes’ criticism of Searle's interpretation.

53 Seamus Miller 'Artefacts and Collective Intentionality' *Techne 9:2* (Winter 2005) pp.52-66

intentional dimension and a physical dimension, and the distinction between them is controversial.[54] Functions are imposed based on both the use patterns of users and the designers' intentions. For technical artefacts this imposition of function is mostly due to the structural properties of the artefact, and for social artefacts function is obtained based on collective agreements. For Searle, imposing a function does not only include ascribing a function, but a state with demotic properties. However, for Miller it is the strong connection between function and properties that poses problems, and how properties can be driven from the function idea when they are connected with intentionality.[55] Therefore, for Miller, demotic powers are a necessary condition for the existence of an institutional artefact.

In contrast to Searle, Scheele[56] also considers this subject and criticises Searle's reasoning on two fronts:

1. Social observations in the best state are necessary conditions and not sufficient conditions.
2. Proper function finds an objective framework in a biological area that can be used for evaluating the artefact's use.

In biology, function is evaluated based on evolutionary history and the capacities which it has for survival, and not the purposes those organs may have. Chapter Four of this thesis will examine biological function from the perspective of an evolutionary-etiological interpretation.

We cannot ignore social aspects in order to ascertain proper ascription. The importance of social aspects is highlighted through the example of when the function of an artefact is changed based on social processes.[57] This kind of change in functionality is completely observable in modern industry, and usually it occurs as the result of collective agreement and an evaluation of competent users. Therefore, when a chair is commonly used as a stool, this commonality does not change the

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54 Miller proposes that we can distinguish between objects based on the purpose of different function.
1. A non-institutional artefact creates changes in the physical world based on its function or purpose.
2. An institutional artefact creates changes in the institutional world based on its function or purpose.
Miller discusses four ideas based on Searle's work: the imposition of function, the demotic power of people and institutional objects, the distinction between constructive and regulative rules, and collective intentionality.
Miller (2005)

55 Miller (2005)

56 Marcel Scheele 'Function and use of technical artefacts: social conditions of function ascription' *Stud. Hist. Phil. Sci.* 37 (2006) pp.23-36

57 Some believe that even if building use changes, it cannot change the intention of its original function and use.

proper function of the chair, i.e. no one claims that the proper function of the chair is now a stool, but the alternative use is accepted as another use of the chair. Therefore, in an action based theoretical approach, the analysis and explanation of an artefact is more important than its function, and function ascription occurs because of how the artefact is used for human purpose. Of course, we should consider that this approach focuses on the rational reconstruction of use (activity).

The influence of social aspects can be analysed by considering that they have necessary conditions, but are not enough to ascribe function and use alone. Social structures are not stable over time in relation to the methods of natural mechanisms. Social structures only exist due to the activities that make them limited or capable. Therefore, social structures are dependent on the activities of human agents and their understanding of structures. Social relationships reproduce and transfer in technical activities. Techno-social artefacts have partly social aspects and partly technical aspects. Therefore, if society is destroyed, only the social part will be removed.

Therefore, artefacts originate as a result of social activities that derive from a set of values, activities, and social relationships. Artefacts can be understood socially because they originate when technical objects are inserted into a social network, and then the artefact is used as part of various social relations, and is reproduced and transformed. Artefacts as social objects can be further examined by looking at the work of Peter Mc Laughlin (2005), Alfred Nordman (2007), Amie L. Thomasson (2007 and 2008) and Allan Gibbard (1975).

Chapter Three

Evolutionary Methodology of Design

The subject to be discussed in this chapter is evolutionary methodology. Technical systems are considered to be the product of a design process, and an understanding of how evolutionary mechanisms work in the design space is a pre-condition for the formation of an evolutionary theory of technology. Design methodology is concerned with the improvement of the design process. John S. Gero[1] *describes the design process as the formulation, synthesis, analysis, evaluation, re-formulation and production of a design description, and, due to the performance of these procedures, function, structure and behaviour are bonded together. The exploration of design can enable new elements to be discovered based on additional or substitutional patterns, through relational knowledge. Design methodology is related to the design product, and an understanding of evolutionary design methodology can facilitate a greater understanding of creative design space.*

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[1] John S. Gero and Udo Kannengiesser, 'The situated function-behaviour-structure framework' *Design Studies 25* (2004) pp.373-391

3.1 The Theoretical Structure of Design

An artefact can be considered to be the product of a design process. Previous chapters have discussed the dual nature of the structural and functional aspects of an artefact. However, we cannot construct a complete image of a technical object and discuss its position within the social-cultural environment without considering the methodology and processes involved in designing technical objects. Kroes[2] suggests that when we examine design methodology we cannot avoid questions about the nature of designing products, for the two main reasons outlined below:

1. The design process and the design of products are linked together in such a way that a conception of the nature of the design process needs an understanding of the nature of designing a product and vice versa.
2. Design methodology is involved in design process optimisation, and, therefore the quality of a designed product should be considered.

When design methodologies are concerned with the quality of a design, they take a normative stance. Designing involves human cognitive power in order to meet certain needs. The concept of design implies the undertaking of a purposeful activity which will change the state of affairs, and which begins with a concept of certain design space demands and issues. The design process starts with an understanding of functional needs, and leads to a structural formation that is realised in a simple linear movement. The particular knowledge involved in this process consists of both formal knowledge and the personal, empirical, and, often, tacit knowledge of the designer. Basic and detailed engineering, process design, and flow sheets are all involved in the design process[3].

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2 Peter Kroes 'Design methodology and the nature of technical artefacts' see front matter Design Studies 23 (2002) pp.287-302

3 Hubka and Eder classify the properties and aware nesses involved in the design process as follows:
1. Engineering science knowledge (basic knowledge) concerns the strength and mechanics of materials, the materials' properties, the constitution of the technology, and principles of mathematics and physics, etc.
2. The experience resulting from related engineering processes indexed in relation to functions, action, operation modes, and maintenance, etc. for products of one type.
3. The knowledge relating to constitution, resources, marketing and selling.
4. Procedures, methods and techniques that can make the design process more effective and programmed.
5. Methods and techniques that can help the designer describe and communicate the design.
6. Institutional and executive standards and techniques.
7. Knowledge of tools and working equipment that can help the designer perform their duties.
8. Knowledge of standards, codes, and options, etc.
9. Market knowledge, artistic and aesthetic knowledge, and related areas

Design knowledge is constructed based on rules and criteria, some of which are drawn from the personal experience and tacit knowledge of the designer. Other knowledge is gained from market information and engineering norms. However, it should be remembered that this knowledge is not always explicit, prior to the technology being designed.[4] The history of mechanical engineering demonstrates many examples where empirical action (design and manufacturing) has been gained prior to theoretical knowledge. For example, thermal machines were created before thermodynamic science. Therefore, it should be considered that scientific-engineering theories have helped the process of the growth of technology. To some extent, design is dependent on scientific knowledge and engineering norms, but it cannot be explained using these concepts alone. In respect of the design process, many questions can be asked, such as how are design concepts related to the artefact? Is designing a necessary or efficient condition for the creation of the artefact? What are the cognitive processes involved in designing? What is the relationship between designing and the artefact?

Dorst investigates the structure of design problems. He looks at design problems as undetermined problems, which are placed between two paradigms of the design methodology[5]. The nature of undetermined problems in the design space may lead to the evolutionary aspects of the design process. However the levels of indetermination in a design process highlight the problem space and solution spaces. The design process does not necessarily have to refer to prior methods in order to explore problems in the existing design space, and the problem space and solution space can develop in tandem with each other inherently. Multi-realisation and the variety of function in terms of physical-chemical structure, and vice versa, show the recursive path of the design space.

Some design problems are indeterminate because the designer is free to face these problems according to his or her personal experiences, abilities and style of thinking. An understanding of human needs and how environments can be changed encourages a conceptualisation based on

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V. Hubka and W. E. Eder, 'Design Knowledge: Theory in *Support of Practice Journal of Engineering Design*, Vol. 1, No. 1 (1990)

4 Methods of acquiring such knowledge include induction, deduction, analysis, generalising, concretizing, comparison, the systematisation of experiences, and observations of design practice etc.

5 Kees Dorst 'The Problem of the Design Problem' in Cross, N.G. Edmonds, E.(eds) *Expertise in Design-Design Thinking Research Symposium 6, Creativity and Cognition Studies Process* Sydney (2007). The subject of design methodology was first discussed at a 1962 conference in London, although Zwicky (1948) is regarded as the first to refer to design methodology. Later, Hall (1962), Asinow (1962), Alexander (1964) et al. and Cross (1993) discuss this subject.

personal and individual elements. Human cultural-social environments prescribe certain values and purposes, and, these, along with physical environments, help to form ideas behind purpose, function, behaviour and structure in the design process.[6] This means that although the exact purpose of a required design can be specified, the actual functions and behaviours needed to realise the artefact are not always specifically considered in the design process. We can get a clearer image of this approach to design, an evolutionary methodology, and its paradigm, by preparing an intellectual framework that looks at links between social-cultural environments and physical environments.

A structural description comprises the geographical-geometrical and chemical-physical properties of an artefact. The designer creates a design solution in a design space by considering structural qualities. A description looks at the behaviour of processes and the object's behaviour in certain conditions. The object operates within an external environment in a certain way, and this is called behaviour. Function and behaviour are both related to physical properties. A purpose is created in order to be linked to a human value system (based on usefulness). We can assign purpose based on function, and we may attribute different functions to an object based on our intentions (of course these functions are linked to an object's behaviours).

The process of movement from purpose to structure in the design process is illustrated in the figure below:

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6 Cross thinks of the design process as an ill-structured problem-solving activity. Nigel Cross 'Science and Design Methodology: A Review' *Research in Engineering Design* (1993) 5: pp.63-69

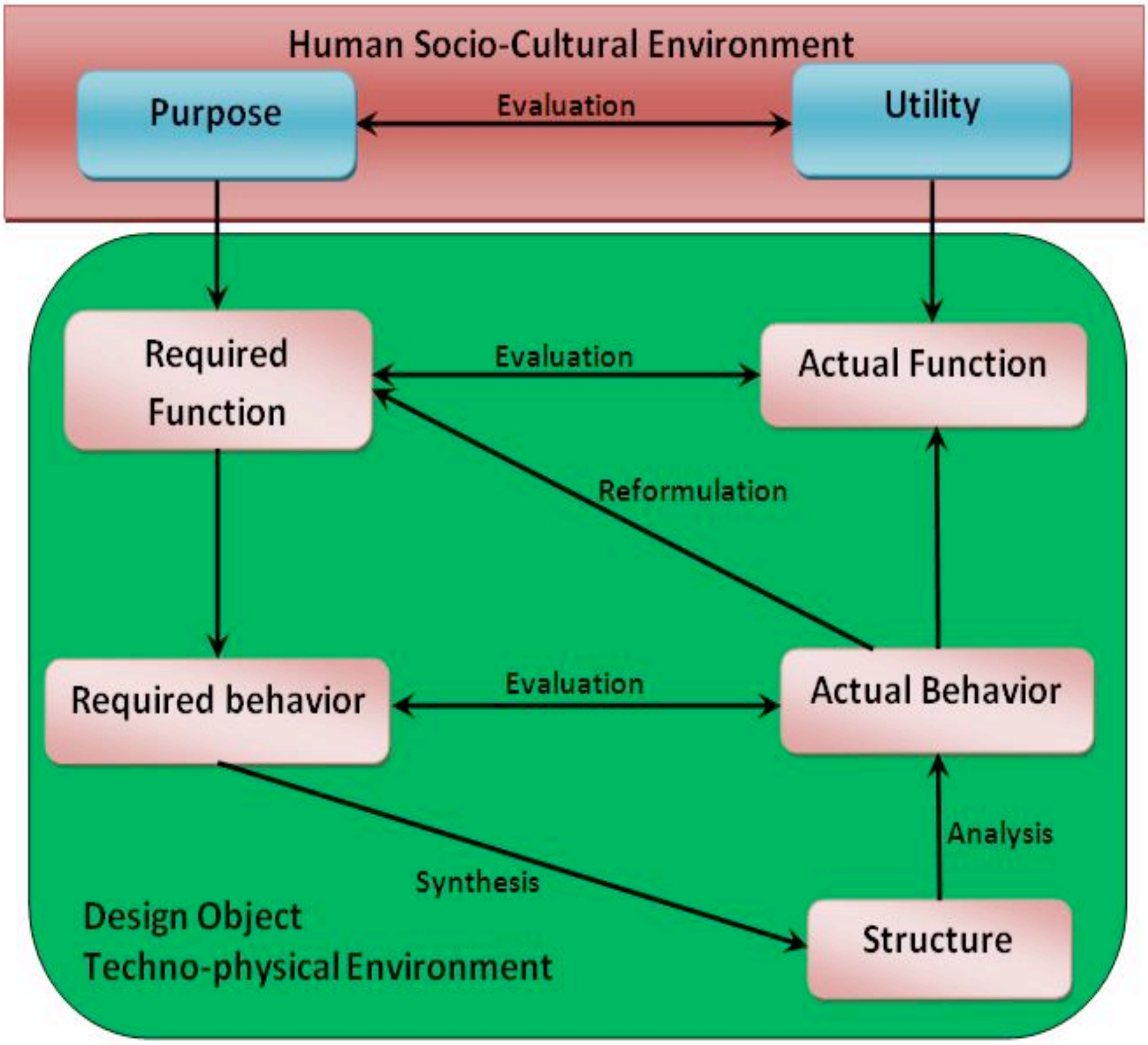

Figure 6 – The Process of Movement from Purpose to Structure in the Design Process

Rosenman and Gero[7] defined Synthesis as the process of interpreting structure in terms of required behavior and Analysis as the process of deriving actual behavior in terms of structure. By considering phases of analysis, a rational reconstruction of design methodology can be seen. Design levels show how concepts are formulated based on needs that are rationally organised. A rational problem solving process is the main paradigm of design methodology as noted by Simon.[8] In this theory the problem space is rationally searched in order to find solutions.

One of the main hypotheses of the rational reconstruction process is the existence of a certain and

7 M. A. Rosenman and J. S. Gero 'Purpose and function in design: from the socio-cultural to the techno-physical' *Design Studies 19* (1998) pp.161-186

8 Simon's theories are discussed in Chapter One

definable design space. This design theory focuses on the constructive role of the designer as a reflective agent, and the design of a possible solution by forming an action.

There is no need for a priori structure in order for a design process to move towards a solution space. In the late 1970s Feyerabend challenged the idea of rational and objective methods that result in providing suitable solutions in design.[9] He suggests an idea of methodology in which variation is given importance based on human and structure-oriented viewpoints (where mind perception and reality structure are related to each other). In the 1980s other theorists challenged the linearity of design methods and favoured a pluralistic approach. The creative design process as a reflective dialogue between situation and conditions, and it can be described in the context of the concept of reflection-in-action[10] as a consideration of orientated perception in terms of a current situation. In this way, design emerges as a symphonic process. This concept focuses on implementation, from reflection to perception, and suggests that designers search for various solutions in their problem-solving space by thinking and investigating during the design process that incorporates individual thoughts and experiences.

However, this is a reflective perception and it has a deep effect on the manner of interpreting certain conditions, and the manner of the creation and development of design solutions. It is the task of the designer/s to perceive problem space and functional requirements in terms of existing sources and raw material.[11] Simultaneously the designer prioritises how the design will work, and, consequently, criteria will appear for future evaluation. During the process of designing, designers come to new perspectives based on actual and potential situations and conditions. This is accompanied by new ideas, new criteria, and a new semantic and visual language that triggers reformation. Of course, their personal experiences and knowledge affects their reflective perception, and these perceptions will incorporate market information, engineering norms and tests of users in other areas etc. Consequently, new solution space leads to innovative prototypes, and there is a focus on revising and optimizing the models and prototypes. Blueprints are a mental image used by

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9 Paul Feyerabend 'Against Method: Outline of an Anarchistic Theory of Knowledge' (1975) in M. Radner & S. Winokur, eds., Analyses of Theories and Methods of Physics and Psychology, Minneapolis: University of Minnesota Press.

10 Katja Tschimmel, 'Design as a Perception-in-Action Process' (2011) in *Design Creativity* (2010). London: Springer Verlag. Pp.223-230

11 This stage is the same as Schon's naming stage in Donald Schön (1983) The Reflective Practitioner: How professionals think in action. London: Temple Smith.

the designer, and an evaluation of the models at this stage can trigger revisions or fundamental reforms.

Therefore, it is clear that perception and reflection interact with each other during the design process, and both are important for the originality of design solutions in order to achieve a definition of reality. By taking these perceptions into account, description of design cannot be formed based on the priori classification of design problems. Although design problems can be investigated and classified rationally, in the designer's view they are thought of in a place-time situation.[12] Then, the designer must move from the classification of the design to thinking about design situations and conditions.

Garbacz distinguishes between the theoretical ideas of design and the actual engineering description.[13] The design engineering description considers design principles and stages, while the theoretical idea is related to the design in general and the states of the objects. Design incorporates an intentional state of affairs, and that a special relationship exists between designing and describing the design structure. This is connected to the relationship between the corresponding parts of these states. Designs are similar to other aspects of reality such as objective and subjective components. They can manifest in physical objects of different kinds such as maps and images etc. that are considered and represented by rational agents. The objective factors of an artefact may remain stable, but the subjective factors can change. For Ulrich and Seering, [14] function sharing is part of a stage of evaluation in technology. Function sharing in mechanical design means performing many functions using one structural element. Whenever a structural element encompasses more than one functional element, a function-sharing situation is created. The function sharing procedure might omit structural components or modified design space. Choosing a structural element may produce side effects, which will need to be evaluated as part of the design process. The omitted structural element will correspond with the functional component, which is supported by other structural elements.

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12 The next chapter will talk about 'context-aware' as a concept in evolutionary methodology for designing.

13 Pawel Garbacz 'What is an Artefact Design?' Techné: Research in Philosophy and Technology Volume 13, Issue 2, Spring 2009 The fact that the artefact may have more than one design enables us to distinguish between artefact token and artefact kind.

14 Karl T. Ulrich and Warren P. Seering 'Function Sharing in Mechanical Design' Design Studies Volume 11, Issue 4, (1990) pp.223–234

In mechanical design, artefacts may do not have equal structures or behavior, but they may do have equal functions and purposes. Artefacts can share functions but the value criterion of human society imposes various purposes on an object. For example, knives have the function of cutting due to a perception of functional requirements, and a use plan is constructed by the communication of intentions. For example, some knives with the same structural components may have a function to cut bread, or to cut cheese etc; there are different functions of cutting, but ultimately the overall purpose is geared towards feeding humans. Agents (including users and designers) construct their own interpretations in the physical-structural elements of designing. The existence of confusion about methods of use, concepts, and various theories that are involved in engineering norms brings about the theoretical dynamic of design research, and unnecessary plurality and multiplicity in design theories and concepts.

Love suggests a methodological analysis in order to remove these concerns, and to achieve more accurate concepts and design theories. [15] This meta-theoretical approach can help prepare a tool for analysing communications and situations of validity in respect of concepts and theories. Theories and concepts are obstructions that are placed in an inter-dependent hierarchy. In the lower levels of obstruction there is a direct perception of reality, where the information available for people is gained via the senses. The highest level of obstruction is related to the beliefs and values connected with essential fundamental subjects. For example, stress can be defined as force per unit area. The concept of obstructions to power is related to more coherent concepts of obstructions relating to the physical object's movement. Love[16] proposes a meta-theoretical solutions approach, as detailed below:

1. The direct perception of reality. For example, we sit on chair, and we watch the sunset, etc.

2. The objects description. This is the simple description of objects, procedures and systems. For example, a vacuum cleaner, the body of a car, etc.

3. The behaviour of elements. The description of the behaviour of elements that exist in objects procedures and systems. For example, the aerodynamic mechanism of an aeroplane body and the

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15 Terence Love 'Philosophy of design: a meta-theoretical structure for design theory' see front matter Design Studies 21 (2000) pp.293-313

16 Ibid

mechanism of air flow around it.

4. Mechanisms of choice: Descriptions about methods and choices constructed around objects, procedures or systems, and the manner of evaluating solutions.

5. Design methods: When theories and suggestions are described about design techniques and methods. For example how a chair is designed.

6. The structure of the design process: Theories about the structure of the design process. This can be affected by culture, artefact type, and other similar conditions and properties. For example, this includes methods of design and the construction of artefacts in various and different industrial societies.

7. Theories about the internal processes of the designer's association: A description of the reasoning of theories and recognising how designers work individually, and in a group, and the cultural effects of their reasoning.

8. General design theories: The details of general theories that describe the general activity of design and its relationship to objects - for example, the design activity of a turbine.

9. Objects theory and design theory epistemology: The analysis and discussion of the critical study of nature's basic criteria, limitations and the validity of design knowledge. For example, what is a design theory? What does it include or exclude? On what hypotheses do these theories stand?

10. Design ontology: The ontology based philosophical study of design theory and design activity. This includes an investigation of human values, fundamental hypotheses and the values of researchers, including theoretical criticisms.

From the above, it can be seen that levels 2 and 3 are related to objects, levels 4-7 are related to the design process, and levels 8-10 are related to the philosophical aspects of design. The theories relating to the design process include elements with fewer abstract entities. It is at levels 2 and 3 that a detailed description of a technical object will be considered. The first concepts of mechanical design are encountered with the environmental conditions. However, the problem is solved in the initial and final states of the system. The process of designing itself includes an analysis of how changes can occur from the initial state to the final state.

Mechanical design is an abstract need that creates a product during the problem-solving process. Therefore, for a classification of design techniques, we need information about objects, and about the environment and the design process. For a complete description of the human environment, its properties and resources should be considered. One aspect of intentional theory is that certain activities are interpreted based on a means-end system, and functions are referred to as activities or objects. Technical artefacts are objects with a technical function, and a physical structure, which are intelligently designed, produced and used. The design process is a direction-oriented process in which the rationality of intentional agents causes the adaptation of the means to end.

Talking about a technical artefact is meaningless without reference to the context of human action. Consequently, because function is accepted as part of the intentional concept, talking about function is meaningless without considering the context of intentional action. For Kroes the technical artefact is related to key properties, as described below: [17]

1. The concept of physical structure.
2. The concept of technical function.
3. The concept of human intentional action.[18]

These properties are portrayed in a schematic as shown below:

17 Kroes (2002)

18 Simon considers the artefact environment as equivalent to human action, while Kroes reduces it to human description.

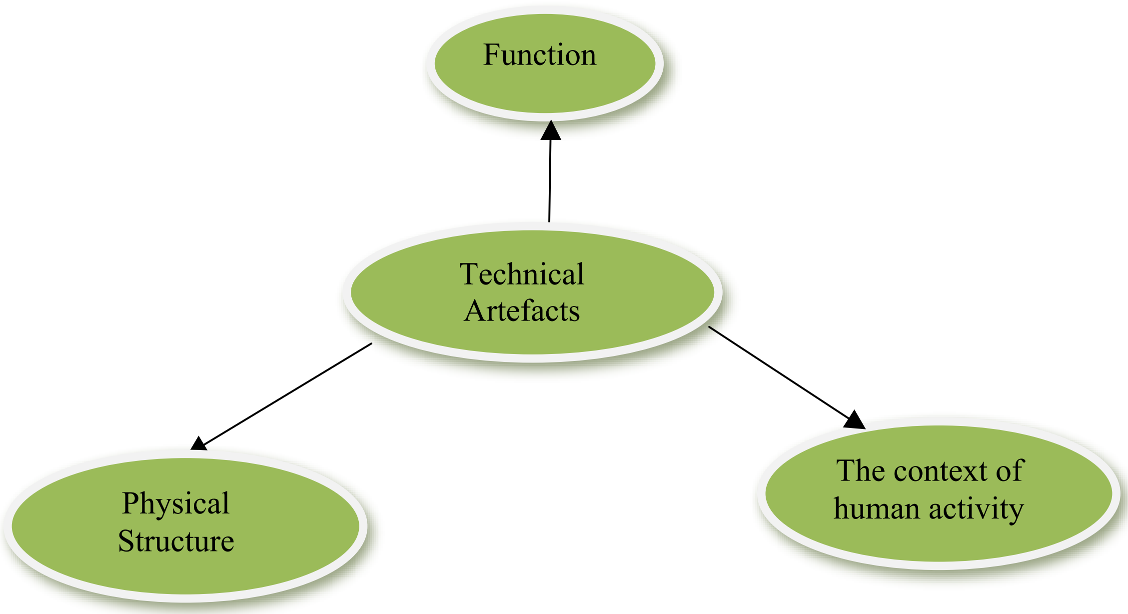

Figure 7: Kroes' schematic of the dual nature of artefacts

This diagram shows the difference between Kroes' analysis and Simon's analysis. Firstly, the 'purpose' idea that Simon proposes is replaced by Kroes' 'function' idea. We may ascribe a function to artefacts, but this is not the main aim or the end. Secondly the 'environment' idea[19] is replaced by the 'human activity' idea.[20] This is important because only environments that refer to the context of human activity are applicable to artefact construction, and not every kind of environment. Without such environments (processes and activities) the function idea loses its concept. Although the origin of design theories can be placed in scientific methods, scientific methods are not the only pattern of the behaviour that can be examined in relation to problem solving. Design methodology studies a pattern of behaviour used for inventing and creating things that do not exist. However, the third generation of design methodologists place emphasis on the evolutionary pattern of the design process, together with a combination of the two previous approaches, and they take a creative look

19 Simon's 'environment' idea is discussed in previous chapters. In his view, the artefact is a kind of common surface between an internal and external environment, and the artefactual science focuses on the common surface of these two models, where the physical structure realises itself in an external environment.

20 Human activity consists of a design context and use context, from which the artefact shows itself in these two different methods. The function idea loses its concept. (Kroes, 2002)

at design methodology.[21]

3.2 Creative Design

This section will discuss and investigate the intellectual framework behind the design process from the perspective of an evolutionary methodology, as noted by Gero et al.[22] In the technological history of the production of artefacts; the process of design has enjoyed a paramount status for many years. However, during the past twenty years, modern technological design has gradually become separated from construction, production and manufacturing activities. Thus, design is now analysed as a distinct field. In addition, an evolutionary methodology of the design process is being studied in order to examine the creative design space. A design prototypes concept is important when thinking about an evolutionary perception of design, because it prepares a meta-schema for design that can be seen as part of the evolutionary process. This is the same role that organisms play in biological evolution.

A design prototype can be both a structure and a vehicle for genetic-like material, which shows certain behaviour (fitness) in an activity context. A design description/prototype allows for showing how genes are explained as structures. Such descriptions can help to explain the relationship between structure and behaviour, and the relationship between behaviour and functions. As mentioned before, design is a purposeful and direction-oriented process in that it requires the functions for human needs to be visualised in the design description. A design description (which will be, from this point onwards, referred to as 'D') can be presented in the form of maps or tables, and gives a description of structural elements and their relationships. Gero considers the general model of design as the process of the activities listed below:

1. Formulation
2. Synthesis
3. Analysis
4. Evaluation
5. Reformulation

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21 Hahka (1982), Palhl and Beitz (1984), Cross (1989), Pugh (1991)

22 Gero wrote important articles about the design process. Especially the FBS model of design and evolutionary methodology.

6. Production of design description [23]

Before looking at a pattern that shows the operation of these actions in the design process, it is necessary to define the following set of signs and stages:

B_e = (expected behaviour) - a set of required behaviours.

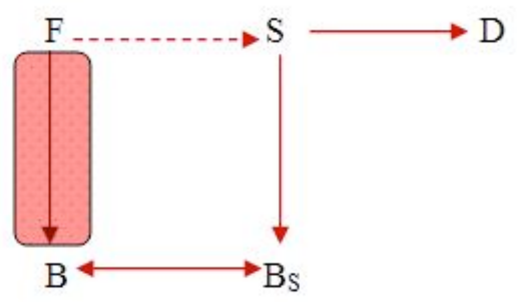
B_S = a set of the structure's actual behaviour.

D = design description.

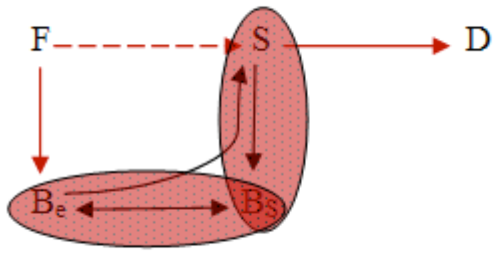
→ =Transformation

↔ = Comparison

1. The Formation Stage. This stage considers the transferring of function to expected behaviours.



2. The Synthesis Stage. During this stage, function is transferred to behaviour. This expected behaviour is used for selecting and synthesizing structure, and is based on the knowledge of behaviour caused by structure.



3. The Analysis Stage. This stage infers behaviours placed on the structural elements.

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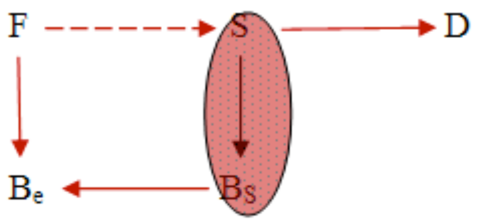
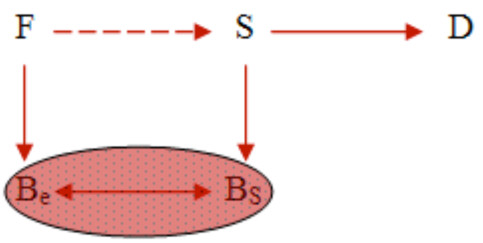
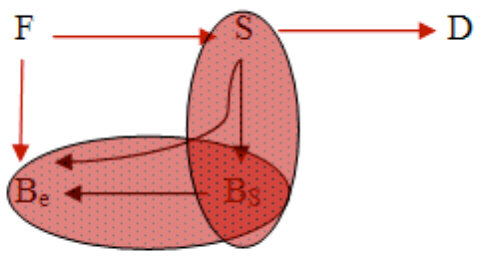
23 John S. Gero 'Design Prototypes: A Knowledge Representation Schema for Design' Journal AI Magazine, Volume 11 Issue 4, (1990) pp.26-36



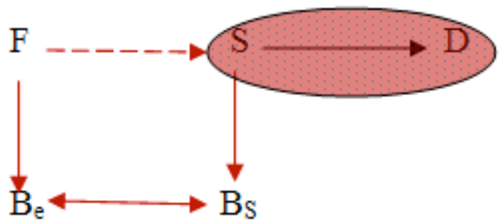
The Evaluation Stage: During this stage, acquired behaviour from structure is evaluated together with expected behaviour.



The Reformation Stage: This stage may occur when the comparison evaluation between structure behaviour (B_s) and expected behaviour is not satisfactory. This can lead to a change in expected behaviour, and functions are determined based on this.



The Production of Design Description Stage: During this stage a description of the components', structure and their relationships is presented in order to achieve the required function. During this stage we can create a direction from structure towards function by looking it up in the catalogue.



The design process operates according to the designer's perception of context. Therefore, designing is an activity which changes the physical world due to the presence of intentional elements. The intentionality element in the design process tells us about the goal-oriented activity for the purpose, but this can be distinguished from the problem-solving process. However, the routine design process and rational problem-solving process are both goal-oriented processes. In an evolutionary perception of the design process, the goals are not always fixed or stable. According to the above definition, design is also a constrained activity. There are constraints and limitations that affect the designer's capability to achieve goals. These limitations can comprise available resources, knowledge and experiences, production mechanisms, and economic and political conditions, etc.

Design can also be viewed as a decision-making activity. This approach looks at the value of structural variables that are decided during the design process. An exploration definition is important in order to develop a theory of creative design. Explanation can be placed against the research process that is concerned with routine design and certain and pre-determined state space. However, an exploration approach develops a problems space, and this is why new solution space may expose new problems. A design prototype includes behavior, structure and function according to the above-mentioned schema. Primary design prepares a translation of behaviour based on structure and function.

The research process in routine design space proceeds to search for a potential solution. Therefore, creative design is the usually result of exploration taking place in the developing design space, and this adds new variables to the design.[24] Design description evolves by adding or replacing new variables, and, consequently, prototypes can be optimised.

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24 Gero talks about innovative design as concept that is similar to the routine design concept, where the design moves in a certain state space of potential designs. However, what distinguishes innovative design from routine design is the value of variables. The result is a similar design or structure but with an innovative appearance.

Research to find a solution in a certain design space is considered for all possible design spaces in the routine design process. However, if we want to consider creative design, we should introduce a model that can be used to acquire knowledge during the design process. In other words, the problem space itself changes during the process, based on the results. Design space can be divided into three sub-spaces as follows:

1. S, Structural Space (often-called decision space).
2. B, Behaviour Space (often-called operation space).
3. F, Function Space (which is the Artefact's end).

In the next section, I will examine an evolutionary methodology called FBS. However, for now, it is necessary to outline the processes which take place during design space revision, because creative design occurs when a new variable is introduced into the design, and, then, the design space undergoes change. Two classes of possible change can be distinguished as 'addition' and 'substitution'. From the 'addition' viewpoint, a new state space will include a main state space, i.e. new variables are added to available variables. From the 'substitution' viewpoint, a new state space does not include the main state space because some variables are removed and some are added. Rosenman, Gero and Maher[25] explain the processes that have potential power to add and substitute variables as follows:

1. Combination: Adding part or all of a design prototype to an available design prototype. Usually structural variables are added.
2. Analogy. This can be defined as the process by which coherent aspects of conceptual structure surrounding a problem or an issue are transformed to another problem or an issue.
3. Mutation. This is the change in variables in the design prototype. It can directly occur in structure variables, or like mutation in genetics, in coded representations (the genotype) of the structure (the phenotype).

The added variables to the design space can be divided into two kinds as follows:

1. Homogeneous additions: the added variable is of the type that other variables have been in the

25 M.A. Rosenman, J.S. Gero and M.L. Maher (1994)

design before.

2. Heterogeneous additions: the added variable is of a different type from other variables that have been in the design before.[26]

Therefore, available knowledge is enough for the addition of homogeneous variables that can develop the design space. When heterogeneous variables are added to the design space, the available knowledge is not enough to reconcile design to the available design space, and this phenomenon is called 'emergence'.[27] Similarly, the three processes that have the capacity to substitute variables are as follows:

1. Mutation: This process substitutes heterogeneous variables, and removes some available variables.

2. Analogy: This is a process whereby production is substituted by heterogeneous variables, especially when the substitution of related structural variables is caused by behaviour and functional analogies.

3. Emergence: This is an important process in the substitution of variables. Emergent schemas can develop through genetic engineering. In fact, genetic algorithm makes a natural selection and evolution process in nature, which can be used as a model in the artefactual world. This theory is inspired by mechanisms, which occur in the natural selection process that are used for adaptation of population and the environment. [28]

Then, the addition effect occurs when a homogeneous variable is added to the design space, and the substitution effect occurs when the heterogeneous element is introduced into the available state space.

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26 John S. Gero and Thorsten Schnier, 'Evolving Representation of Design Cases and Their Use in Creative Design' in *Computational Models of Creative Design* (1995) pp.343-368

27 Gero notes the role emergence plays in an evolutionary process and discusses how the emergence of a phenomenon, which is implicit, and emergence properties play an important role in the introduction of new variables. Emergence is not only limited to structure. It can also relate to behaviour and function.
John S. Gero (1996) pp.435-448

28 Rosenman et al. (1994)

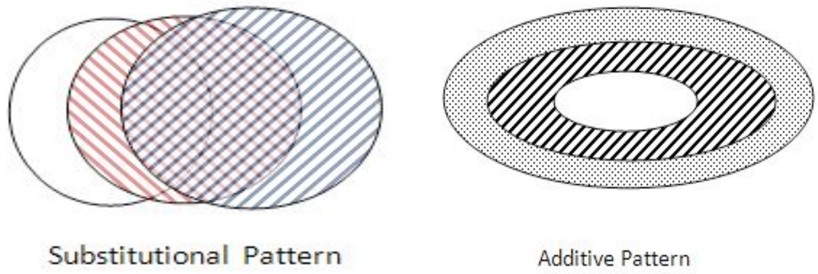

Figure 8: Gero's Addition and Substitution Effect

In the natural world, the evolutionary pattern connects the fitness of active organisms with capability to survive. Genetic operators go through a gradual process of revision and optimisation in interaction with the environment. However, the model of evolutionary approach in design concerns a testing and quality control that is evaluated in terms of innovative variables. Creativity in design is evaluated based on the fitness function (behaviour), and new solutions are produced from available solutions using evolutionary mechanisms.[29]

DNA base	Bit	Action/instruction/procedure rule/operation
Gene	Character/feature	Set of actions/sub-routine
Allel	Feature value	Specific action/instruction
Chromosome	String	Set of actions/instructions
Genotype	Encoded structure	Structure/set of design state
Phenotype	Decoded structure	Design solution/object/artefact design case/instance
Organism	Solution	Basic element/component
Protein	Building-blocks	Class/schema/design prototype
Species/class/group/behaviour	Schema/objective fitness values/pay-off	Behaviour/measure of performance
Survival	Optimization of O.F./ fitness function	Function/purpose/intent
Environment	Problem context/domain	Socio-eco environment/context (requirement/domain)
Fitness/potential for survival	Relation of objective values to optimal values/efficiency	Satisfaction of requirements/efficiency
Bio-chemical process	Computational/symbolic process	Form generation (geometric/physical)

Table 4: John S. Gero's Table of Comparative GA & Design

29 Natural evolution places emphasis on the existence of random processes in production and selection, while in design methodology processes are placed in the framework of contextual and relational knowledge.

Creativity focuses on different points of the design space in order to optimise the design. Therefore, this kind of action will not be random; it is a goal-oriented action that is a necessary condition for the creative design process. However, creative design can be explained as the ability to perform goal-oriented shifts of focus in the search process.

3.3 FBS Framework: Explaining an Evolutionary Methodology in the Design Process

Gero & Kannengiesserin outline the FBS framework by examining the concept of situatedness as the dynamic interaction between different environments and constructive memory. In a dynamic perception of the design process, eight fundamental processes act among function (F), behaviour (B) and structure(S) variables, as set out below[30]:

1. Formulation (Process 1): transferring the design requirements explained in function (F) to the expected behaviour (B) - the behaviour that is expected to acquire the function.

2. Synthesis (Process 2): transferring the expected behaviour (B) to the solution structure (S) which can show optimal behaviour.

3. Analysis (Process 3): acquiring actual behaviour from a synthesized structure.

4. Evaluation (Process 4): evaluating the behaviour resulting from structure (B_s) with the expected behaviour (B_e).

5. Documentation (Process 5): creating the design description (D) for production.

6. Reformulation Type 1 (Process 6): in the conditions where actual behaviour is not satisfactory, some changes are created in the design state space based on structure variables or ranges of values.

7. Reformulation Type 2 (Process 7): in the conditions where actual behaviour is not satisfactory, some changes are created in the design state space based on behaviour variables.

8. Reformulation Type 3 (Process 8): in the conditions where actual behaviour is not satisfactory, some changes are created in the design state space based on function variables.

These processes can be visualised as shown below:

30 John S. Gero and Udo Kannengiesser ' (2004) pp. 373-391

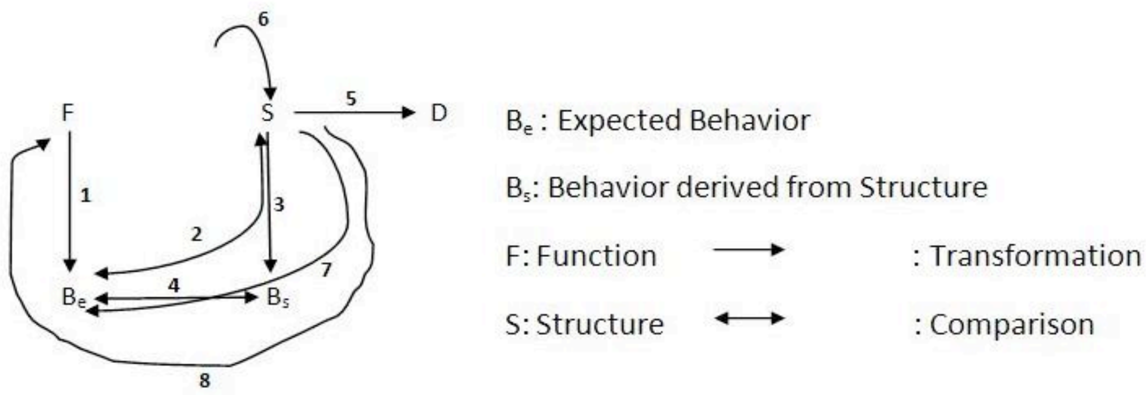

Figure 9: FBS Framework

Design comprises a process of transference between various worlds, whereby artefact behaviour is adapted in an artefactual environment. The designer creates the design state space by purposeful and intentional actions, but the nature of the action that is called design may be subject to a process of evaluation. Perception of behavioural and structural space may change during design actions. Therefore, the idea of situatedness is a reflective-recursive process that concerns interaction between designer and the environment, and determines the design route. Interaction, situatedness[31] with construction and constructive memory[32] prepares a base for our perception of the design process. Based on the FBS model and reformulation processes (structure, behaviour and function) the knowledge is reconstructed from past experiences. Tacit knowledge is not fixed in the time of creation (the main experience) but is, somewhat, a function of current conditions. New tacit knowledge can emerge as new interpretations of the main experience, and this is seen as a reconstruction process rather than a fixed status.

The re-formulation process can consider as renew tacit knowledge. Every new design space (the new values and criteria that emerge from new variables of this space) potentially prepares an opportunity for re-formulation. In this concept, design can be understood as the order of operation of the current constructive process. Therefore, formulating the structure (s→s') and behaviour (s→B'$_e$) to design can produce creative properties. Describing available designs within the FBS conceptual framework prepares a satisfactory framework for routine design, where functional, behavioural and structural variables are determined, and what remains to be determined are the

31 Gero took this idea from Dewey (1896) in order to develop it in FBS framework.
32 This concept is taken from Dewey (1896) and Bartlett (1932).

values of structural variables and the reasoning of relative networks between those variables. However, where variables are not pre-specified, we move into the field of creative design.

One of the mechanisms used to introduce new variables in the design space is analogy-based design. Some designs from different fields may have analogies in their structure. A description of a design structure comprises elements that specify which constructive elements exist in the design. These components are static in the structure space and are added into the dynamic process and operation. The goal of an analogy-based design process is acquiring new ideas about the structure variables of an old design using analogy-based function and behaviour.[33] In this system, old design elements (resource design) are formulated based on analogy and an investigation process.

The network knowledge between these elements, which expresses the link between function and behaviour, is communicated during the process of transferring to design. However finding analogy in designs is only possible by using a design description[34].

In design, the causal relationship route goes from structure to behaviour, and, consequently, to function. Therefore, from using a causal explanation we can infer behaviour from structural components, and then determine function. This causal knowledge flows in the FBS route and prepares fundamental causal knowledge, which enables us to argue for design by analogy. Structure and behaviour, and behaviour and function, is not a one to one correspondence. Structure can produce various behaviours based on the context in which it operates. Analogy is counted as an important process in creative design. If someone wants to solve a problem using analogy then that person should search for problems that are somehow similar to the problem. In design space, source problems and solutions are specified. Therefore, the designer can prepare a solution by adapting the new problem from source, and use a solving process using the source problem.

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33 Design prototypes are known as analogy-based when they show analogy-based functions and behaviours, originating from a structure based on analogy.

34 Qian and Gero talk about analogy in relation to the design process. They emphasise that a design prototype has an ability to meet the requirements of an analogy-based mapping process in terms of knowledge representation. They develop their design prototype idea by considering the addition of qualitative causal knowledge. Qian and Gero outline the characteristics of an analogy based design process as follows:
1. There is a qualitative causal relationship in respect of the manner of acquiring function in design structures through related behaviours.
2. There is design knowledge.
3. Distinguished categories of function, behaviour and structure.
L. Qian and J.S. Gero 'Function-Behaviour-Structure Paths and Their Role in Analogy-Based Design' in *Artificial Intelligence in Engineering Design, Analysis and Manufacture* (1996).

Gero and Kazakov note that problem solving based on analogy in design is used when a routine design cannot result in a satisfactory solution.[35] They consider the analogy-based process in three stages, according to an FBS framework as follows:

1. The matching and retrieval stage. During this stage the analogy of archived designs are evaluated with a target design, and the target design state space is retrieved.

2. The mapping and transformation stage. During this stage design variables are mapped from the source state space to the target design space. The result of these operations transforms to the revised design space.

3. Knowledge construction stage. Knowledge is passed from the target design state space to the revised state space.

As previously mentioned, the generalised design knowledge helps to prepare a summary of individual design experiences, and it covers a range of successes and properties which are constructed according to the relationship of function, behaviour and structure variables. The main idea is that, by analogy, multiple mappings are perceived which flow into FBS routes. Until this point, analogy is limited to the structure state space in order to create the capacity to produce creative designs. The FBS framework gives potential power for a design to become creative, not only in the structure space, but also in the behaviour space.

Behaviours can also develop in the same way within structure space, and these new behaviours can be result of new structural configuration or the introduction of new structural variables. The new criteria (behavioural components) have the potential to be expressed using the variables of the required structure. However, knowledge is needed in order to describe these new behaviours. Therefore, only behaviour space changes, and structure space remains the same. In some cases, new behaviours cannot be expressed based on the variables of the required structure space because there needs to be a revision of structure space. [36]

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35 Gero and Kazakov (1999)

36 The generalised design knowledge involved in analogy-based design is a form of causal and heuristic knowledge, which is impossible to achieve without creating analogies of the available case. Maher and Gazra highlight the models that can be used to represent generalised design knowledge, as follows: Casual Models, Stage Interactions, Heuristic models, Heuristic rules and Geometric constraints.
Mary Lou Maher and Andres Gomez de Silva Garza 'Case-Based Reasoning' in *Design* (1997) pp.34-41

Therefore, behaviour can be seen as a set of device states and transitions, which connect states to each other. These behaviours explain how device structural elements gain their function, and this causal knowledge can also be used to explain malfunction.

One important aspect of creative design is the emergence concept, but its mechanism is not well understood, and it can be limited to the domain of shapes. However, this fault can be compensated for by considering an emergent 'behaviour' concept. Poon & Maher talk about emergent behaviour as part of a co-evolutionary model of design.[37] This co-evolutionary approach can create an internal space (structure space) in response to a problem space (behaviour space), and Poon and Maher attempt to show how behaviour can emerge in a co-evolutionary process. Shape emergence is briefly discussed earlier in this thesis, but by examining the theories of Poon and Maher in more detail is it possible to generalise emergence in design beyond emergent shapes.

Emergence and the process which leads to it is highly unspecified and unknown, but the common thing which links various definitions of emergence to each other is that the general behaviour of a system appears as the result of interaction between the units and elements of lower-level systems. In evolutionary genetic language, behaviour emerges in phenotypes, where organisms exist in the biological world, and solution space exists in a design process. However, the interaction of lower-levels occurs in genotypes where information and properties are coded in order produce an end product. The gene as a biological unit for inheritance can copy itself on a sequence of genotypes. This is considered as a design variable in a design system, and emergence can be considered as the side effect of gene interaction inside the genotype. Further, design is an ordering process that starts from a problem formulation and moves towards a solution combination. In other words, there is a repetitive process of mutual interaction between problem space and solution production.

The first repetitive stages of design only exist in the designer's mind. By publishing the primary results, the final solutions may be considered as a dramatic and salient solution that puts the focus on the design description, or its product, rather than on the acquisition process of such results. It could be argued that the design process is just a process of selection, refinement, revision and the combination of available design and objects (in terms of constraints and operation requirements).

37 Josiah Poon and Mary Lou Maher 'Emergent Behaviour in Co-Evolutionary Design in *Artificial Intelligence in Design* (1996)

However, it could also be argued that the design process can be seen in the evolutionary procedure of repetition. In design, an evolutionary process exists, where any creative and innovative design is the result of the retrieval stages of evolution and production based on pre-existed solutions.[38] As previously mentioned, Type 2 reformulation (s→B'e) occurs when new behaviour variables in the available design are introduced from outside and change the behaviour state space, and this may affect the structure variables in a structure state space.

The structure space determines the solutions' space, and expected behaviours are related to the structure space, where current structural variables can produce behaviours or needs that serve to create new variables in the state space. This mutual action comprises structure and behaviour space, and one calculative model in design. FBS framework is the result of the interaction of three different worlds, which connect to reach each other by three classes of processes. Gero & Kannengiesser[39] expand these eight stages to twenty stages in the context of interaction between the three worlds, and based on the interaction of agents with the external world. They visualise these three worlds as and external world, an interpreted world and an expected world, as shown below:

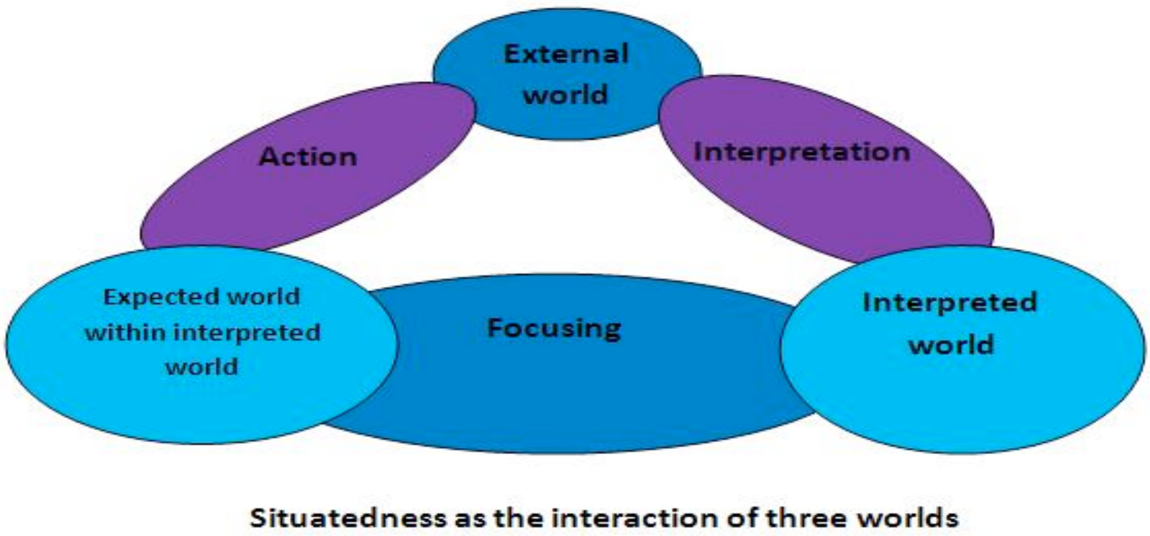

Figure 10: Situatedness as the interaction of three worlds[40]

38 L. Qian and J.S. Gero 'Function-Behaviour-Structure Paths and Their Role in Analogy-Based Design' in *Artificial Intelligence in Engineering Design, Analysis and Manufacture* (1996).

39 Gero and Kannengiesser (2004)

40 Ibid - The expected world is a sub-set of the interpreted world.

The external world refers to an external environment and agents, the interpreted world refers to sensory experiences, perceptions and concepts of design agents, and the expected world is the world in which designer's imagined actions are produced. These three worlds connect to each other by three processes:

1. The interpretation process. This transfers the variables received from the external world such as sensory experience, perceptions and concepts, which are the constructive elements of the interpreted world.

2. Focusing process. This focuses on an aspect of the interpreted world in order to offer them as targets in the expected world.

3. Action process. The action performed in the external world should lead to producing the states that support the targets. The result of an action is an effect that is created in the external world according to the targets of the expected world.

The interaction of these various environments constructs a situation dynamic that is the basis for evolutionary movement in the FBS framework. Previously, it was noted that constructive memory is an interpretation process which works according to a push process (a data acquisition process) and a pull process (where the interpretation results).[41] This model allows a new understanding of the evolutionary procedure that is constructed based on prototype. In fact, it shows how eight main design processes develop in interaction with different worlds, and due to the distinction between these different worlds, the FBS framework can show the possibility of a set of processes that can produce a design state space based on F, B and S. The main framework links the process of function (F) to expected behaviour (B_e) due to the lack of distinction between the different worlds, and this is only a part of the formulation process. This idea is visualised as shown below:

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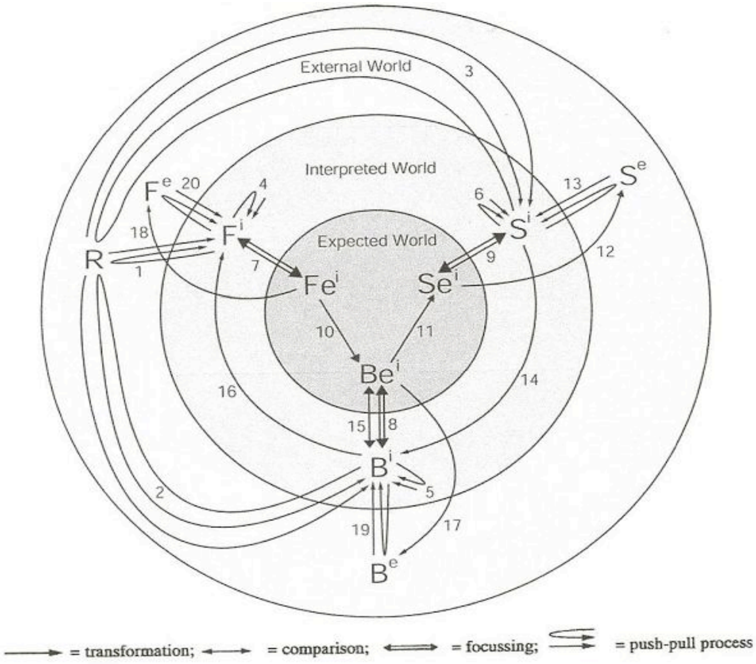
41 The push-pull process is used introduce the interaction of an agent with its external world (by interpretation) and its internal world (by constructive memory).



The situated FBS framework

Figure 11: The Situated FBS Framework

Fei, Sei, Bei variables belong to expected world.

Fi, Si, Bi variables belong to interpreted world.

Fe, Se, Be variables belong to external world.

The twenty processes involved in this revised FBS model show the capacity of this framework. Stages 1 to 10 are the formulation stage. Stages 1 to 3 describe the design demands and requirements (the problem) which produce function, structure and behaviour variables in the expected world by using a push-pull idea, which is, to a high extent, based on a designer's experiences and perception of design conditions. Stages 4 to 6 are used to optimise the mentioned variables in the interpreted world using constructive memory. Stages 7 to 10 are used as focusing processes between the interpreted and expected worlds in order to prepare a primary state space for design. Stages 11 and 12 stages are combination stages (octal processes).[42] Stages 13 and 14 are concerned with analysis. In stage 13 a push-pull order shows that using S_e based on expected targets, S^i is obtained.[43] Stage 15, which is the evaluation stage, is exactly the same as the primary

42 In the FBS primary model, there is no Sie, and the expected behaviour transfers directly to the structure of external world in a combination process.

43 In the primary FBS model, Stage 13 is not mentioned.

framework.[44]

The documentation in the prototype of this process is represented by s → D.[45] Stages 12, 17 and 18 prepare the expected world variables for the external world in order to produce and construct the artefact. In the primary model, the reformulation of structure introduces new variables in the structure state space, but it cannot specify whether the available structure is internal or external, in relation to the design agent. Stage 9 operates as a stimulus for structure formulation. Stage 6 represents the action of constructive memory as used in the interpreted world, whilst Stage 13 proceeds to interpret the external world using a push-pull model. In this way a new S^i from S^e is created, and the function and behaviour of re-formulation works as a result of these related processes.

This situatedness approach in design models tries to reconstruct the environment as a determining element in the evolutionary methodology of design. However, by removing environment in the design model, the design process cannot be described completely. This methodology uses a standard evolutionary algorithm, where design requirements are evaluated based on the fitness function of the design description. Design descriptions as genotypes consist of combinations of state genotypes can proceed to be developed into successful gene combinations. Combinations that create phenotypic effects or behaviours with higher fitness can develop in the gene treasury of future generation. The embedded processes in this model can generate a flow of introducing new variables into the design state space. In addition, adaptation in these new spaces operates in the same way as optimising does in design cases. Therefore, solutions are considered as genotypes, and operations are measured by fitness function.

As previously mentioned, emergence is the result of the interaction of lower level units, and an evolutionary structure or behaviour variable can consist of emergent variables. Of course, the emergent behaviour should be goal-based in order to be able to evaluate emergent behaviours.[46] Emergent behaviours result from the evolution of behaviour phenotypes that are placed into the best current structures, and these evolutionary behaviours in their own turn can be used to find design solutions within the new design context. Therefore, it could be argued that evolutionary behaviour

44 In the situated framework, the evaluation is between Be'↔Be - In the primary model it is Be ↔Bs.
45 Today, the most used design descriptions are maps and graphs.
46 Although it does not necessarily represent a causal relationship

can affect structure space.

3.4 Critical Approaches to the FBS Model

Design starts from functional requirements and leads to structural descriptions. In other words, the intentions and goals in a design process decrease according to structure space.[47] The FBS model tries to infer an artefact's function from actual behaviour. This actual behaviour is assessed based on physics/qualitative reasoning gained from an analysis of the structure space. The actual behaviour set is a subset of expected behaviour that prepares the function, and subsequently, teleological reasoning suggests that function connects to expected behaviour. Therefore, the behaviour of an artefact can be inferred from the acquired causal analysis of behaviour and structural components. According to a teleological analysis of function, behaviour is acquired as a result of causal analysis, and by examining the dependence network of structural elements.

Dorst & Vermaas are the main critics of the above-described model.[48] They see a problem in the absence of a fixed definition of the function variable in both the main and revised FBS model. They look at transference between intentional descriptions (function and purpose) to structural descriptions in the design process, and they raise questions about the transference of intentional descriptions to structural descriptions.[49] The second problem they see relates to the question of to what extent can the FBS model be considered as a normative and descriptive model. The dual model as a descriptive model, the goal of which is describing the design process, and as a normative model, the goal of which is optimising design. In such a way, we should consider theories of function, structure and behaviour as progressing in three stages:

1. The main FBS approach noted by Gero in 1990.
2. A revised approach suggested in 1998.
3. The 2002 approach that somehow goes back to the viewpoints of the main model.

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47 Structural variables consist of: structural elements, attributes (which explain the elements' specifications) and communications (which generate communication between elements).

48 Kees Dorst and Pieter E. Vermaas 'John Gero's Function-Behaviour-Structure model of designing: a critical analysis' in Research in Engineering Design (2005) 16:17-26 and 'The Problem of the Design Problem' in Cross, N.G. Edmonds, E.(eds), Expertise in Design- Design Thinking Research Symposium 6, Creativity and Cognition Studies Process Sydney (2007)

49 They show two different viewpoints of the FBS model.

In his 1990 article, Gero notes eight main stages in the FBS model. These stages are formulation, synthesis, analysis, evaluation, documentation, and reformulation of structure, behaviour and function. The first criticism raised is the instability of the conceptual framework of this model. The concept of function changes over time. The instability of this concept results in changes to the $F \rightarrow B_e$ formulation stage. Vermaas and Dorst[50] focus on design prototypes, where the design's primary stages are performed, and where knowledge is needed for design.[51] Therefore, the prototype's content consists of a description about function, behaviour, structure[52] and internal procedure and external effects. One of problems with the FBS model is the dual descriptive and normative state of design methodologies. By placing these states in a separate part of the model, it is suggested that we can prepare a solution for coherence in the design process, and, consequently, the prototype allows for a rational reconstruction of how stages are performed by the designer. The design prototype is a set of design experiences that show the relationship between behaviours and functions. Function is related to the purpose for which the product is produced. Vermaas and Dorst[53] talk about four processes of eight primary design processes that result in design prototypes, as follows:

i) The retrieval process. Retrieving all prototypes that have the F function possibly justifies all structural and behavioural requirements. During this stage information about structure and behaviour is related to accessing the required function.

ii) Selection process. Selecting the related prototype prepares the selected prototype for the receipt of relational knowledge in connection with expected behaviour B_e which realises function and provides tools to perform formulation ($F \rightarrow B_e$). Furthermore, the selected prototype provides

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50 Vermaas and Dorst (2007)

51 As mentioned by Gero and others this knowledge consists of: relational knowledge (the link between function and the expected behaviour of structural elements), qualitative knowledge (the manner of the effect of structural elements on the actual behaviour of Bs) contextual knowledge (related to design materials) calculative knowledge (this specifies the mathematical relationship between behaviours, structure and contextual parameters). Qian and Gero (1996) talk about qualitative causal knowledge and develop the design prototype idea in relation to dynamic structures. Therefore, not only is the dependence relationship determined between structure and behaviour, but also structure is related to external effects, and based on this a comprehensive explanation of design is prepared.

52 The distinction between state and structure is historical. The structural variable, which changes in a relatively short time, is called state. Behaviour can be considered as the successive change of states and method and result of these changes can be explained using qualitative physics.

53 Vermaas and Dorst (2007)

information about the synthesis stage ($B_e \rightarrow S$). Therefore, focus proceeds to design state space that is related to design duties.

iii) Instantation process. During this stage examples of design prototypes are created by assigning borders and re-considering design space. This information may convert into a more detailed division. Actual behaviour or structure is determined by formulation ($F \rightarrow B_e$) and synthesis ($B_e \rightarrow S$), retrieval, selection and instantation of the prototypes of structural elements.

iv) Refinement process. This determines actual behaviour or structure by analysis ($S \rightarrow B_e$) and estimation of the results through the evaluation stage $B_s \leftrightarrow B_e$. If the results are satisfactory, the sample goes through to the documentation process, and if they are not satisfactory, they are used for refinement in the reformulation stages ($S \rightarrow S'$, $S \rightarrow B_e'$, $S \rightarrow F'$).

Different definitions of function can affect the FBS model, and our perception of the formulation stage $F \rightarrow B_e$ acts as a suppressor of the definition of behaviour and function variables. The intentionality concept is challenged in the design methodology. The link between intentional descriptions and structural-physical descriptions should be considered in different FBS models.[54] According to Gero (1990) functions are design intentions or purposes. Behaviours are thought of as the manner of acquiring function from an artefact's structure, and structure is the constructive components and the relationships of structural design space. Therefore, the transference of intentional description to structural description occurs at ($F \rightarrow B_e$) formulation and at ($B_e \rightarrow S$) analysis stage. However, in 1998 Rosenman and Gero begin to take a new approach to concept of function. They suggest that functions are the result of artefact behaviour, and that behaviours are the processes and actions demonstrated by artefacts in certain conditions, and in an environment. Structure is thought of as a material arrangement of components based on homogeneous relationships. This definition results in change, specifically where purpose is transferred to function and vice versa.

The formulation stage develops to $P \rightarrow F_e \rightarrow B_e$ and the "P" purpose is transferred to "F_e" the expected function, and then subsequently transferred to "B_e" expected behaviour.

54 Intentional description consists of mind states (purposes and demands) which meet needs. These needs can be placed in the different categories of aesthetic, terrestrial, etc. It should be noted that the directionality of these states towards needs distinguishes them from mere mind states like 'pain' and 'happiness'.

The analysis stage is also developed to $S \rightarrow B_s \rightarrow F_s$ which is based on actual function and behaviour of the structure selected in synthesis stage.

Eventually the $F_s \rightarrow P_s$ relationship stage is added which shows the P_s actual purpose that determines the design description. Therefore, the intention in formulation stage is not imported into a structural description and the behaviour of the artefact is determined by examining the artefact's reaction in an environment.[55] The result of this reaction produces function.[56] In this interpretation function is distinguished from intention and purpose, and intentions are linked to behaviour as a result of expected function. Therefore, defining behaviour is not exclusively limited to expected behaviour (the 1990 interpretation) but it concerns actual behaviour. Consequently, only logic is needed to infer actual functions from actual behaviours, because artefact functions are the result of behaviours, and function is obtained by focusing on the behaviour results. This theory does not take the behaviour element out of structure, but causal reasoning is bound by the inference of expected behaviour and structure, and actual behaviour from structure. In their third interpretation Gero and Kannengiesser in (2002) look back to definitions similar to the 1990 interpretation.[57] Purposes are placed in the realm of function again, and behaviour is related to an artefact's structure. Based on this idea, functions become the purpose of design, i.e. its teleology. Behaviours are taken or are thought of as expected properties, which result from structure, and, therefore, are the structure, elements and relationships of a design.

Taking all this into account, it seems that it is, therefore, necessary to think about a theory relating not only to a function's concept in relation to the design methodology, but also a theory of the artefact. The next chapter will investigate concepts and definitions of function, and place emphasis

55 Such descriptions of behaviour comprise a combination of structural and intentional elements. For example, it can be shown that 'Construction Costs' have this combination (as a behaviour description). This is the cost of an intentional concept that refers to a value that people allocate to objects and actions. If behaviour is static, it does not change with time, and structure connects to behaviour based on a qualitative causal relationship. If behaviour is dynamic, the change of the qualitative state of the structure specifies behaviour mechanisms.

56 The function of an artefact is inferred by the teleological reasoning of expected behaviour. In the 1998 interpretation, this reasoning is involved in $P \rightarrow Fe$, $Fe \rightarrow Be$ stages.

57 Vermaas and Dorst (2005)

on a theory that can work with the intellectual framework of the FBS model.[58] Terminologies will be considered that describe the behaviour and structure of components in relation to an artefact's function as a whole. It should be noted that according to the 'no-function-in-structure' principle, function should be considered according to the relationship and dependence network of components. Therefore, any design theory should consider a perception of what a design is or should be.[59] A realistic interpretation of the model would look at the expressions that refer to behaviour, function and structure, and consider the consistency of elements that converge prior to artefact construction.

It is possible to construct descriptions that do not exist ontologically, and from this viewpoint a design description could be independent of the related artefact, because functions and behaviours are physical dispositions that can be considered as properties. By looking at realistic solutions, it can be seen that function and behaviour can exist as qualities in themselves. However, in the FBS model structure cannot be assumed to be independent of the artefact. The material elements that form to construct structure and their geographical relationships cannot be described as independent of the material. Therefore, design reasoning can be understood based on the knowledge acquired about structure and behaviour, and consequently this knowledge is placed among experimental knowledge of a coherent world. The FBS model shows how required function is transferred to structure, and there is no one to one correspondence between function and behaviour. Behavioural variables perform certain functions in specific environmental conditions. Additionally, an evolutionary theory of the artefact cannot be prepared without considering the theory of function ascription. The next chapter will look at this idea and will investigate theories such as:

1. An overview of evolutionary computation - Spears et al.

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58 Vermaas & Dorst (2007) considered function as a physical disposition that co-operates with purpose, and is based on the analysis of a use-plan in formulation stage. Therefore, they connect intentions to physical structure because the use-plan is a rational reconstruction. The formulation stage is divided into two stages: 1. Design a use-plan that links the purpose to action. 2. Determining physical dispositions that the artefact should have for effective usage. Designers act using their experimental knowledge (at the formulation stage) which can be shown by a use-plan. The concept of a use-plan will be analysed in the next chapter when a theory of function is investigated.

59 Galle places emphasis on an ontological reasoning of the FBS model, and tries to increase its clarity and logical coherence. this article Galle discusses his meta-theoretical reasoning of design, and explains that results do not have direct function in the design procedure. Per Galle 'The ontology of Gero's FBS model of designing' in Design Studies, 30 (4), (2009) pp.321-339 In

2. An introduction to simulated evolutionary optimization – Fogel
3. A survey of evolution strategies - Bäck et al.
4. Function, behaviour, and structure - Umeda et al.

Chapter Four

The Theory of Technical Functions

In order to present an interpretation of function, this chapter will review the advantages and disadvantages of various basic theories about function, such as intentional function theory, system function (or causal-role theory) and etiological evolutionary function theory. The question of whether single theory is adequate in order to interpret and explain different functional aspects and meet proposed criteria (such as the distinction between proper function and accidental function or malfunctioning etc.). It could be argued that conjunctive and disjunctive combination theories present an interpretation of function, and are designed to overcome the problems of essential criteria. In addition, other theories that take into account function analysis, such as a use plan and the action-oriented activities involved in production, designing and use will be considered. This chapter will provide an interpretation of function that can be used to facilitate an evolutionary model of technology, in the context of deliberative history, in order to present a forward-looking view in terms of the epistemic knowledge of agents.

4.1 Functional Knowledge: Proper - Accidental Function, Normativity and Malfunction.

As discussed in previous chapters, any theory of the artefact should consider the idea of *intentionality* and *normativity*, the idea that directedness and purposefulness play important roles in the creation of intentional states. The idea of normativity can be understood in terms of how the mind is directed towards an artefact, and in the context of design, mental states are sometimes called intentional objects.[1] If a mental state is directed towards a subject, this is called the intentional state.[2]

Intentional states are the source of normative statements, which are statements that determine the difference between artefacts and objects. The practical actions involved in the designing, manufacturing and using of artefacts are not only based on theoretical reasoning and physical-chemical characteristics, but on practical reasoning. It is this kind of reasoning that considers the instrumental value of artefacts for achieving goals. Practical rationality is based on knowledge found in an *instruction manual,* knowledge based on *skills and techniques,* and an analysis of the outstanding role of the agents, who are seeking function. [3] The idea of 'know-how' can be expressed in terms of when the agent recognises the necessary skills needed in order to run the procedure, but such know-how and knowledge do not provide enough evidence to draw conclusions about proper function. Artefacts may be malformed and unable to perform function. Indeed, when we recognise a malfunctioning artefact, normative states and engineering norms are used to formulate an ‘ought to be’ idea. However, the absence of such a deliberate thought process in natural objects means that the concept of malfunction seems to lose all its meaning.

Engineering norms and standards play a crucial rule in describing normativity, and normative statements and judgments are based on such norms and normative reasoning. Options and choices are based on rational reactions of agents, and they use normative reasons for meeting demands. This type of selection is undertaken by a rational agent in order to create favourable conditions. Desirability is graded, is context dependent, and may be dependent on mental states. Norms are not only used in the engineering process, but also are present in the artefacts produced by this process.

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1 An intentional state is not a specific class with its own content and nature, but only the state in which human agents are directed at them.

2

3 To carry out a sequence of actions in a use plan may need specific knowledge and skills, but one of the advantages of an instruction manual is that it includes a standard rationality.

Evaluative judgments about artefacts are part of an understanding of normativity. In normative judgment action-oriented theory of artifact using, designing and manufacturing can involve in normative judgments. This means that the artefact can be judged as a 'good' or 'bad' one. A description of both function and malfunction includes normative facts. Function-oriented theories of the artefact are usually based on the phenomenology of an artefact, whereby function is classed as the inherent essence of the artefact, and when proper function is undeniable. If the malfunction relates to the product, a lack of user skills, or unfavorable conditions, then normative facts that translate into engineering norms do not apply to the artefact. In addition, the accidental functions of natural objects cannot be considered in terms of normative norms. [4]

Ascribing function relies on normative stance and whether such ascription is based on the actions of the designers or users, and normativity draws a line between proper and accidental function. Houkes and Vermaas focus on an action centred approach when looking at design and use; they look at the actions involved in designing an artefact.[5] In order to distinguish between proper function and accidental function, we should distinguish standard and non-standard, rational and irrational use.[6] Proper function is achieved through the standard use of an artefact, and accidental functions are included in an alternative use category.[7] The use plan has instrumental value in respect of the achieving of goals. This must be evaluated as a whole, because the sub-actions included in the pattern may not be helpful for achieving general goal independently, and a plan can only be useful when taken as a whole as part of a modular system. A standard use plan is the result of the

4 In the next section, I will examine a variety of functional theories and examine the advantages and disadvantages of them.

5 E. Vermaas and Wybo Houkes 'Technical functions: a drawbridge between the intentional and structural natures of technical artefacts' Stud. Hist. Phil. Sci. 37 (2006) pp.5-18

6 Standard and non-standard use is not necessarily equivalent to rational or irrational use. According to an action centered approach, the standard use of an artefact is designed based on use plan or has traditionally evolved. However, users may also use trial and error in order to develop alternatives, and these innovations can be efficient, effective, rewarding, and rational, for example, using a flat headed screwdriver to open a paint-can. Conversely, the standard use may be irrational. In addition, designers may fail to develop a use pattern that has adequate intellectual conditions, and the designed use pattern does not lead to the desired results. Thus, the distinction between rational/irrational and standard/non-standard use is independent conceptually.

7 These alternative uses may be confirmed by a community of users and change into standard use, or they may not be useful and fail. In any case, alternative and standard uses cannot describe the terms of accidental and proper function, and must be considered with reference to analysis of use and design.

use of an instruction manual and deliberative historical use. A manual presenting the order of actions is needed for achieving operation of technical systems (which draws on the privileged knowledge of the designers). Alternatively a use plan may be accepted by users based on the historical function of predecessors, or based on a process of trial and error. For example, although aspirin was made for alleviating pain, over time it has acquired the function of preventing blood clots.[8] Thus, by means of an action-centred approach, an artefact's function is analysed based on use plan, and this requires a new metaphysic for malfunction. In other words, function and malfunction contribute towards the idea of intentionality in artefacts, and normative facts are nowhere more apparent than in an artefact's behaviour. Therefore, the notion of function without a consideration of malfunction is meaningless.

Rudder-Baker refers to concepts that are not mental, but have no application without the mind (such as function and certification) as *intention-dependent*.[9] Most economic, social and political concepts can be classed as intention-dependent. Thus, all artefacts and their properties, including function and malfunction, need to be evaluated in these terms. Malfunction can be caused by faulty materials, design, structure and technique of use and operation. It might be that each of these elements may not have been selected properly to achieve proper function. In addition, it should be noted that the status of malfunction can still be applied to an artefact when the performance of an artefact's function is possible physically, and when the necessary skills are available. However, the main point to be obtained from the above discussion is that normativity is a central aspect of intentionality. This relates to the usability value of artefacts when the context of practical rationality provides a reason for artefact use. Use refers to the performing of activities in a sequence that is specified in an instruction manual.

Designers can use scientific and technical knowledge in order to design artefacts, and they write down technological explanations based on this knowledge in a manual.[10] Knowledge contained in a manual contributes towards an artefact gaining a normative stance in terms of explanatory power. The connection between function and design in our daily use of artefacts can easily be seen. Designing involves capturing intentional elements, but, as Kitcher notes, design cannot always be

8 The non-standard use can communicate to a community of users over the course of time and change into standard use - based on the teological elements that appear in the theory.

9 Lynne Rudder-Baker 'The Metaphysics of Malfunction' in *Techne* (2009)

10 The epistemology of proper function privileges the designer who knows the rational use plan.

understood in terms of design background.[11] In technology, design is based on the designer's intention, but in the world of biology the action of natural selection performs as the source (except in the case of genetic engineering). The relationship between intention and function is not always direct or clear, for example, if a screw is accidentally fitted into a machine but serves to make a necessary functional connection, although the connection was never anticipated, in the form of a direct intention, the accidental placing of the screw performs a useful connecting function.[12] Here, the idea of function is the contribution the screw has in the system operation as a whole, and, as a result, a link is established between the designer and the function.[13] However, the question remains of how the intentional aspect of function ascription can be interpreted. To what extent can function theories contribute towards an understanding of the presence of normative facts in engineering procedures, and normativity in artefacts? When talking about proper function or malfunction, it is important to address the concept of intentionality. McLaughlin believes that the three mainstream theoretical interpretations of function lack the ability to explain and interpret normative facts. McLaughlin articulates these ideas of function as follows:

1. Intentional functions. This idea interprets function based on the tendencies of the intelligent agent. The designer, or person with epistemic merit, justifies subjective norms according to opinion. However, questions remain about the role desires play, and the extent to which desires contribute, in the creation of norms. The desire to achieve a goal or a state does not serve to establish norms.

2. Causal-role functions. Function is interpreted in terms of the causal-role played by an item in the performing of an imposed action in a system. The problem here is that if the item loses its share contribution in the system, it is no longer functioning. Thus, the concept of malfunction is not comprehensible, and this would obscure normative criteria.

3. Etiological functions. This perspective is concerned with the date of the selection of descriptive running normativity. However, what remains uncertain is how etiology can assure the future of a normative item.[14]

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11 Philip Kitcher 'Function and Design' Midwest Studies In Philosophy, Volume 18, Issue 1, (1993) pp.379–397

12 Pieter Kroes and Larry Wright used this example to distinguish between proper and accidental function in their theories.

13 Ibid

14 Peter McLaughlin 'Functions and Norms' in Functions in Biological and Artificial Worlds Comparative Philosophical Perspectives edited by Ulrich Krohs and Peter Kroes, (2009) pp.93-102

In response to these problems and questions surrounding normativity, McLaughlin discusses three ideas, as follows:

1. Means-ends relationships. Each part of a system participates in the operation of that system and is considered as the means for reaching an effect (effects are referred to as 'ultimates'). Each link in the etiological chain can be a link for the next means. Therefore, when we talk about the function of something, we are considering the means to serve a purpose. From this perspective, functions are nothing more than the effects in a means-end relationship. These means-end relationships can be seen in nature too. It is possible to look at natural objects not only in the context of a cause and effect relationship, but in terms of a means-end relationship, and in this context, a pre-hypothesis is made about why something exists. It can be supposed that the means facilitates the achievement of goals, which are resources for normativity.

2. Part-Whole relationships. A series of cause-effects and means-end relationships could be considered as a chain process. However, to a certain extent, in a system that has a hierarchical structure, the means-end relation is repeatable. The components of an artefact possess function in that they are part of a system (a containing system that is organised hierarchically) and the system itself has a function for something or someone. However, in organisms, components and organs (or their properties) have functions that are independent, and the question arises of whether an organism serves a function for something or someone other than itself.

3. Type-tokens relationships. Function is given to special types of items. Tokens of one type can comprise a set (members of a special class). However, the members of a set cannot be judged in an evaluative manner, because, to an extent, members can possess the properties of the containing set. Further, tokens can possess the properties of their type in different degrees. This raises the question of to what extent a type token can function in the context of normative facts? This idea considers the notion that the type-token relationship is not an essential relationship for ascription function, and, therefore, a 'weak' normativity is introduced in this context. [15]

In contrast to type-token relationships and part-whole relationships, a means-end relationship contributes to a more in-depth analysis of engineering rational norms. Practical rationality is

15 Ibid

different from a scientist's scientific rationality. When we look at the actions of an engineer, it is possible for an engineer to consider different and additional hypotheses for rationality to those that would be considered by a scientist. It could be argued that ‘true’ and ‘false’ as scientific statements change to ‘optimality’ and ‘efficiency’ in engineering science, and the question of normativity can be considered in terms of practical rationality.

4.2 Functional Theories

It could be argued that Larry Wright (who specialises in etiological function theory)[16] and Robert Cummins (who specialises in functional causal-role theory)[17] were the first to begin the debate about biological and artificial function. Since then, theorists have attempted to design a theory of function that meets function of organs (in biology) and function of artifact (in technology). However, this task has yet to be accomplished, and it still remains to be seen whether a single theory of function can be found which articulates both function in biology and technology. Function theories should distinguish proper functions from accidental ones, and ascribe proper functions to malfunctioning artifacts, and innovative artefacts.[18] Of course, theories should address proper function in terms of physical-chemical properties.[19] Theories of function need to incorporate a descriptive phenomenology of artefact production and use, in order to prepare an adequate and necessary condition for the theory, to ascribe function to capacity in the containing system performance, and for the consideration of distributing proper and accidental function.

The three main interpretations of function theory (evolutionary theory, intentional theory and causal-role theory) can be measured using the above criteria. However, the inability of these

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16 Larry Wright 'Functions' in *The Philosophical Review*, Vol. 82, No.2 (1973) pp. 139-168

17 Robert Cummins 'Functional Analysis' in *The Journal of Philosophy,* Vol. 72, No. 20 (Nov. 20, 1975), pp. 741-765

18 A theory of function must distinguish between the accidental functions and the proper functions of an artefact. Proper functions can be understood as functions that are specified to the artefact in a standard way, whilst accidental functions are only used accidentally.

19 Preston suggests that these criteria are incompatible with each other, and argues that either one of the proper-accidental or innovative criteria must be deleted. He suggests deleting the later in favour of former because being able to distinguish between proper and accidental function in the phenomenology of production and use is crucial. Beth Preston 'Of Marigold Beer: A Reply to Vermaas and Houkes' Brit. J. Phil. Sci. 54 (2003) pp. 601-612

theories to account for all functional requirements has encouraged academics to combine theories, which have been created using a combination of the different components of the basic theories. Etiological theory is based on the history of selection, and causal-role theories are based on the contribution of components in the containing system in order to distinguish proper function from accidental function. The intentions of different agents may have different characteristics and special knowledge, and in this regard, it is possible to set designer intention apart from user desire, because some users may decide to use an artefact for alternative functions. A designer's intent is that the designed artefact must have a proper function. The user's intent might be to use the artefact in another way, or it might acquire an accidental function.

However, if an artefact's function is only dependent on intentions and the expectations of competent agents, who have privileged knowledge of the artefact, then there may never be such a thing as malfunction. The intentions of competent agents (designers and users) cannot explain proper-accidental function alone, and we need also to look at reproduction history and containing systems to be able distinguish proper-accidental function. Although intention may explain innovative and physical-chemical properties, function is also based on an agent's knowledge. On the other hand, the production history of technical systems always refers to the intention of agents.

The challenge for academics is whether a single theory of function can be formulated to link successfully the idea of function in the field of biology and in the field of technology. Ontologically an artefact's function is subjective, whilst an organism's function is objective.[20] Technical functions are ascribed by agents in terms of their mental states, and biological functions are context related.[21] Further, technical and biological functions have different ontological status. Therefore, is it possible to establish a single theory to link function in both fields?

20 Something is subjectively ontological if it exists in a state dependent of the subjective state of the agent (like a painting) and something is objectively ontological if it exists in a state independent of the subjective state of the agent (like a car).

21 Use and design create relationships between subjective states (intentions and goals) of user-designer and function.

4.2.1 Existing Functional Theories

Vermaas and Houkes focus on the classification and measurement of various functional theories, and this thesis will remain committed to these classifications in the progress of the development of its overall argument.[22]

Reaction to criticisms about proposed various theories of function have resulted in the correction of these theories using existing theories. One of ways in which academics have responded to criticisms of function theory is to attempt to combine the main interpretations of evolutionary/etiological, causal-role, and intentional theories in different disjunctive and conjunctive styles, and some academics try to resolve problems by presenting pluralistic theories.

4.2.2 Etiological Theories[23]

In 1973 Wright was one of the first theorists to distinguish between proper and accidental function using an etiological interpretation of function.[24] Wright reviews the theories of Morton Becker (1959) and John Canfield (1964) and notes their inability to distinguish between proper and accidental functions. This is a common criticism of theories that are constructed based on the role and contribution of a capacity in a containing system, or of those that consider a determinant role for a user's intention. Wright uses simple two-statement logic to explain the single concept of function in technology and in biology, as follows:

The function of X is that Z means:

- A) There is an X because it does Z.
- B) Z is a consequence (result) of X's existence.[25]

Based on this logic, 'a' explains the etiological form of function ascription in both the technological and biological worlds. Function is seen as the reason for the existence of things, whether this is as a result of natural selection or conscious selection. This establishes a close relationship between

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22 Houkes, Wybo and Vermaas, Pieter E. 'Technical Functions: On the Use and Design of Artefacts', Springer, Jan 1, 2010 - *Technology & Engineering*

23 From this point on the following abbreviations will be used: Intentional theory - 'I-theory', evolutionary theory - 'E-theory', and causal role - 'C-theory'.

24 Larry Wright (1973) pp.139-168 He uses 'Functioning As' to refer to accidental function.

25 Ibid

design and function, and shows how function can participate in an evolutionary interpretation. However, the problem of thinking about design in biology is fundamentally a problem that encompasses the question of the history of natural selection.[26] When the term 'design' is used for human activities, a different approach is taken, in that ideas about design attempt to explore the formation of an object and its behaviour in the light of specific goals. However, etiological theories look at long-term history in biology, whilst conceptual artefacts with (one-shot) selection are linked to agent desires. Etiological evolutionary theories that consider function take into account the long-term selection history. Using this approach Millikan proposes an etiological theory for function. Millikan describes proper function as it operates in the two fields of biology and technology as follows:

1. Direct proper function theory (direct proper function).
2. Derived proper function theory. [27]

Based on this, an item has direct proper function as a member of a special kind family known as the *reproductively established family*. In this family, similar things form reproductively, and the mean functions of members of this family are the same. Millikan distinguishes two kinds of these families, as outlined below:

- ➢ Reproductively established families - first order.
- ➢ Reproductively established families - higher order.[28]

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26 Lauder notes that the past history of an organism plays a role in the formation of their modern features. Lauder interprets design as biological structure in relation to function, and talks about a historical analysis based on three principles of transmission, as described below:
1. There must be an explanation for the general properties of a structure or functional set, not for single features.
2. A phylogenetic hypothesis of a relationship that is nested the hierarchy of structural features, (in their historical order) is necessary for analysing historical patterns.
3. Historical hypotheses are tested by checking related proportions.
George V. Lauder 'Historical Biology and the Problem of Design' J. theor Biol. (1982) 97, pp. 57-67
In evolutionary theories, focus is placed on production history. Allen interprets natural design in the following way: T (trait) is designed naturally to do X, if and only if: a) X is a biological function of T
b) T is the result of a process of changing the structure that is due to a natural selection.
Colin Allen and Marc Bekoff 'Biological Function, Adaptation and Natural Design' Philosophy of Science, Vol. 62, No. 4 (1995), pp. 609-622

27 Ruth Garrett Millikan (1986) Metaphysical Anti-Realism In *Mind 95* (380) pp.417-431
28 Millikan (1984) p.19

Members of the family type one are copies of each other, and the proper function of a family type two is only determined by referring to type one.[29] However, most items are not a direct reproduction of each other. Mass production lines can produce an artefact indirectly. Thus, only members of first-order families are reproduced from each other.[30] The direct proper function of a member of a reproductively established family refers back to the selection history of those items where ancestors performed a function. However, having proper function refers to a selection history, and the item does not necessarily have to carry out its function (in the case of malfunction). It is important to note that the proper function of item may not be able to be traced using ancient history.

Apandis' historical relationship pattern examines the idea of function in relation to the distant past. By using the idea of derived proper function, it can be shown how innovations acquire proper function. However, intentional elements enter into this theory, and this suggests that an agent's desired elements have a role to play in proper function, because proper and accidental function is determined with reference to designer and user desires. Proper function is determined by the producer's intentions and demands rather than according to use patterns. Proper function is the result of a reproductive relationship because the normative states of functions can be linked to past performance.[31] Artefacts can incorporate chemical - physical criteria and malfunction, and this is why we need to establish a normative stance for function in terms of past performance, even when we are incapable of describing innovative artefact function. Neander argues that the proper function of a trait is that which it is selected for, and he explains that structures and organic processes are the result of natural selection. In this way, biological proper function incorporates etiological elements. For example, if we assume that the unit of natural selection is a genotype, Neander[32] explains proper function as:

'*the/a proper function of an item (X) of an organism (O) to do that which items of X's type did to contribute to the inclusive fitness of O's ancestors, and which caused the genotype, of which X is*

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29 Reproduction is more similar to a copy. Viruses, genes and artefacts are created based on imitation reproduction behaviours, and not based on a single design.

30 Millikan identifies higher order families. It is not necessary that the members of first order families are all produced in the same way rather there are a variety of ways of producing artefacts.

31 Millikan (1993) extends proper function to the use plan, but after Preston's critique (Preston, 1998) which takes away a distinction between proper and accidental function, Millikan (1999) revises her theory.

32 Karen Neander 'Function as Selected Effects: The Conceptual Analyst's Defence' in *Philosophy of Science,* Vol. 58, No. 2, (1991) pp. 168-184.

the phenotypic expression, to be selected by natural selection.'

In another article, Neander argues that taking an evolutionary approach is not adequate to explain proper function.[33] In addition, she attributes proper function to innovative artefacts, even those with malfunction, by suggesting that, even if an artefact does not work, the designer's desire gives derived proper function to an exquisite artefact.[34] Therefore, direct proper function based on natural selection date must refer to previous examples of successful performance, but derivative proper function, regardless of successful performance, does not have to refer to a selection date.[35]

4.2.3 Intentional Theory

Intentional theory is based on the intentions, beliefs and demands of the designer and user. The designer uses physical-chemical capacities to design an artefact for a purpose, in order to contribute towards a goal related function. The idea of conscious selection provides a theory of design that can be explained regardless of past effects, and whereby selection is only based on hope and the belief of achieving a favourable impact in the present or future. Although this kind of theory can incorporate malfunction criteria, and the design of innovative artefacts, it cannot meet the support criterion, because of proliferation of function, especially when the user's intentions are determinant.

4.2.4 A Combination of Basic Theories

Each one of the basic theories (I, E, and C theories) does not demonstrate an ability to meet the required criteria to facilitate an evolutionary model of technology. For this reason, many theorists attempt to present theories that are the result of the combination of ideas taken from all the basic theories.[36] Two main strategies have been used by theorists in order to create this effect as outlined below:

1. Disjunction combination theory. Disjunction combination theory can include all functional ascriptions of the basic theories in combination. The advantage of this strategy is that the theory does not suffer from basic theories limitation.

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33 Karen Neander (2006) 'Moths and Metaphors: Review Essay on Organisms and Artefacts: Design in Nature and Elsewhere by Tim Lewens' in *Biology and Philosophy 21* (4) pp. 591-602.

34 Karen Neander (1995). Explaining Complex Adaptations: A Reply to Sober's 'Reply to Neander'. *British Journal for the Philosophy of Science* 46 (4) pp.583-587

35 It could be said we can ascribe proper function to innovative items and novelty in use.

36 I and E theories can justify malfunction diseratum. Also C and I theories can justify innovative artefacts.

2. Conjunction combination theory. In this combination the only function ascriptions that are accepted are those stated in the basic theories. One merit of this theory is that it incorporates the whole merits of its constructive.[37]

Disjunction theories can be introduced in two forms: theories that are based on intra-domain pluralism and theories that are categorised based on inter-domain pluralism. Inter-domain pluralism refers to different functions in the fields of biology and technology, while intra-domain pluralism refers to only one function for items in both fields.

4.2.5 Causal-Role Basic Theory

In causal-role theory, function is interpreted by examining contribution in the containing system. Cummins determines function ascription exclusively based on the contribution of structure components or system capacities.[38] Thus, function is related to the capacities of the artefact constructor and the capacities that comprise the containing system, and is viewed in relation to the causal role.[39] Cummins talks about two explanatory strategies (the sub-sumption strategy and the analytical strategy) as follows:

'*X functions as a Φ in S (or: the function of X in S is to Q) relative to an analytical account A of S's capacity to Ψ just in case X is capable of Q-ing in S and A appropriately and adequately accounts for S's capacity to Ψ by, in part, appealing to the capacity of X to Q in S.*'[40]

This functional analysis theory needs an (A) analytical interpretation to explain properly capacity, and general rules dominate on system behaviour. However, although the C-theories justify physical-chemical properties criteria and innovative artefacts, they do not cater for malfunction ascription. As with intentional theory, this theory suffers from the problem of proliferation of function. Artefacts can play different roles within an inscribed system, and all these roles are performed according to function. This is true in the condition whereby an A-analytical interpretation for a

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37 Wybo Houkes, Pieter E. Vermaas Technical Functions: On the Use and Design of Artefacts, Springer, Jan 1, 2010 - *Technology & Engineering*

38 Robert Cummins 'Philosophy of Science Association' in *Philosophy of Science,* Vol. 44, No. 2 (Jun. 1977) pp.269-287

39 Preston names such type of function as System Function. Beth Preston (1998). Why is a Wing like a Spoon? A Pluralist Theory of Function. Journal of Philosophy 95 (5) pp.215-254

40 Cummins, Robert 'Functional Analysis' in The Journal of Philosophy, Vol. 72, No. 20. (Nov. 20, 1975)

system is available.[41]

4.3 Forward-Looking Propensity Theory and Function as Disposition

As mentioned previously, for Cummins, function ascription is evaluated based on the interpretation of its role in a containing system. Then, a functional analysis is considered as an analysis of properties, when the property is considered as a capacity or physical disposition. Based on this, function is linked to physical disposition. Kroes suggests that the idea of functions as physical dispositions is important in nature, because ascribing a physical disposition to an object is equal to the claim that the behaviour of an object under certain conditions shows lawful order. [42]

Although the contribution of item capacity in a system can be considered as function, it does not provide the necessary and adequate conditions for achieving desired function. As can be noted, etiological theories have a backward looking character and use prior reasoning to ascribe function. From the viewpoint of Bigelow and Pargetter, the function of an item at the time of 't' refers to its performance at the time of 't'.[43] The describing of an item's function does not only refer to certain effects in the current system. Some functions are available even when the current effects of character do not exist.

In order to grant explanatory power to function, Bigelow and Pargetter propose forward-looking propensity theory in order to explain function ascription to items.[44] Based on such a view, an item has a function when it demonstrates tendency for selection (due to the related effects). This idea interprets tendency according to physical disposition, and is inspired by the evolutionary concept of fitness (fitness is a state that determines the survival or the replication of an organism in an especial environment in nature). Physical disposition increases the survival probability tendency of being selected in the selection process. The granting of these tendencies is what comprises function. Fitness gives tendency for survival to organisms in a proper habitat, even if they don't survive or have never been in their habitat. However, the question is raised about whether this theory can be related to artefacts too? In response to this question, looking at the idea of disjunction theory

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41 Cummins considers pumping blood as a function of the heart based on the biological cycling system of blood

42 Peter Kroes 'Technical Functions as Dispositions: A Critical Assessment' *Techne* 5:3 (Spring 2001)

43 John Bigelow and Robert Pargetter 'Functions' in *The Journal of Philosophy,* Vol. 84, No. 4 (Apr. 1987) pp.181-196

44 Ibid

applied in the field of technology might be a valuable approach. Propensity refers to the capacities that give tendency because they are selected by agents, although the effects of these capacities are not necessarily needed in pre-determined blueprints.[45]

In order to illustrate this theory of function, we can use the example of the sound of a heartbeat. The monitoring of the sound of the heartbeat can play a role in achieving a medical diagnosis, which increases chances of survival, and, therefore, this can be considered a function. However, in etiological theory, the lack of an evolutionary history would mean that this sound does not have any function. Therefore, it would seem that this theory omits the boundaries of proper and accidental function, and in respect of innovative artefacts, together with malfunction, it lacks explanation.

4.4 Robert Cummins and Neo-Teleology

In response to critics of *Functional Analys*is, and in contrast to those who believe that the existence of traits and organs is not describable in terms of their function, Cummins proposes a neo-teleology conjunction theory of function.[46] An etiological interpretation of function tries to explain the existence of biological traits, structure and behaviour with regard to function. In other words, it attempts to answer the question *why something is there* by answering the question *what is there.* This kind of analysis tries to explain system capacities, and deals with the question of *how does it work?* By applying this line of questioning, the mechanism of function and system design can be understood. Neo-teleology theory is composed of two hypotheses, as outlined below:

1. We have hearts because of what hearts are for.
2. Traits are spread through populations because of their function.[47]

In this way, we can explain why an organism has a trait or structure in terms of a function. For example, if *we have hearts because of what hearts are for,* then hearts perform the function of blood circulation, and not the production of heart sounds. Therefore, in contrast to classical etiological theory, in neo-teleology theory, current effects and their function act as clues to discovering an object's existence. In this theory, properties are selected according to function, and

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45 In their 1987 paper, John Bigelow and Robert Pargetter talk about the similarities between their theory and etiological theory, but indicate two crucial differences.

46 Robert Cummins 'Neo-Teleology Functions: New Essay' in *The Philosophy of Psychology and Biology* edited by André Ariew, Robert Cummins, Mark Perlman, Oxford University Press, (2002) pp.157-173

47 Ibid

their presence in the organism is because of the effects and functions they have. In this kind of selectionist approach functional properties are considered in terms of etiological concepts, and Cummins foregrounds the designer and constructor roles in artefactual production.[48] This theory acknowledges that the process that produces properties is not sensitive to function, because these properties are acquired after the production of function. However, the processes that maintain and reproduce them are sensitive to function.

In this theory, adaptiveness concepts are used for explaining function. In other words, properties are selected due to their function, only if the function is considered as an adaptive variation in the population. Adaptiveness can be used to evaluate the level of the vehicle's success in survival and reproduction, which is the basis of selection, but adaptiveness should be distinguished from adaptive concepts and function. Sometimes an organ that has better adaptive qualities performs its function better, but it may function in the same way as a lower adapting item. Therefore, functional analysis occurs prior to and independent of adaptation, although there is a link between function and adaptation, because if the level of adaptation is higher, it may result in an increase in function.

It could be argued that Cummins presents a 'weak' interpretation of theory in order to evade one basic problem of etiological theory, which is that properties do not develop because of their function.[49] In contrast to a strong account, in which traits are to be selected because of performing their function, neo-teleology account argues that natural selection do not pick up proper function but supplies the relationship between the existence of traits and function. This deals with the introduction of functional invention, and this idea provides for an interpretation of functional innovative vehicles after the act of selection. However, on the whole, this theory does not pay substantial attention to the field of artefactual design.

4.5 Beth Preston

Preston formulates a disjunctive theory' of function which is inspired by Millikan, and which tries to address the shortcomings of the theories of Cummins and Wright.[50] For Preston, only a pluralistic theory that incorporates the distinct ideas of etiological and causal-role theory can work to provide a

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48 Selection can be natural selection or intellectual selection.
49 Ibid
50 Beth Preston *The Functions of Things: A Philosophical Perspective on Material Culture* (2000) pp.22-49

general theory for use in both the fields of biology and technology. In pluralistic theory, the basic theories of C and E play a complementary role. As mentioned previously, Wright considers two elements of functional ascription in order to distinguish operations that form a proper function, and those that result in additional or accidental function.[51] Firstly, operations that create functions should be connected to reasons causally in order to establish why something is there. In this way, capacities and capabilities under certain conditions are created. Secondly, it is necessary to refer to the history of the discussed capacities that justify their existence. However, one of the problems with this interpretation is that the current capacity of an item is often unrelated, or might even be in contrast, to the reasons for its being; there are cases in which the current use of an item's being has no relation to historical performance. For example, insect wings were used for the regulation of body temperature rather than for flying. Preston notes that referring to past performance or use in order to assign function ascription is criticised by Cummins.[52] However, based on this theory, function is the capacity of an item to perform an especial role in the context of a system.[53]

As mentioned in earlier sections of this thesis, referring to the natural selection history imports a normative element into the functional explanation, whereby proper function is distinguished from accidental function. Thus, wherever function lacks a selection history, accidental function is interpreted. For Cummins, the boundary between accidental and proper function is dependent on the containing system. He uses the example of a belt buckle, which is used to prevent a bullet entering the body.[54] This is a system not usually imagined based on the traditional function of a belt buckle, thus in this alternative operation, an alternative function has been devised which might be 'accidental'. When Preston evaluates Millikan's functional theory in relation to Cummins and Wrights' theories and put forward the following example to exemplify this problem, as follows:

If someone is born blind then:

1. Based on Cummins' theory, the eyes don't have any capacity, and, subsequently, any function in the containing system.

2. Based on Wright's theory, because it cannot be said that X is there because it does Y, then this

51 Wright (1973)
52 Cummins, Robert 'Functional Analysis' in The Journal of Philosophy, Vol. 72, No. 20. (Nov. 20, 1975)
53 Preston (2000) - These capacities are sub-functions of a system as a whole.
54 Cummins (2002)

theory results in a similar outcome to 1.

3. Based on Millikan's theory the eyes have function, but they have malfunction in a sensory system. [55]

In 3 Preston presents a pluralistic theory of function that refers to Millikan's idea of directed proper function. In 1 and 2 Preston shows that different concepts of function are two different aspects of functional explanation, and are complementary. However, the point, which needs consideration, is how function can be achieved dynamically? In other words, can items obtain or lose proper function in their dynamic process? Using an evolutionary approach, artefacts achieve their proper function, and if an innovative artefact or the innovative use of an existing artefact is successful, it is produced based on this capacity, and the proper function of the artefact is achieved. Capacities that do not obtain productive success are still referred to as system functions. In cases where an item is produced for a system function gradually, it would be the proper function of its own generation. The function of a first example of a certain type must be considered as a system function, and then, when it is reproduced based on successful performance for that purpose, it achieves proper function.

For Preston, system function is similar to Millikan's derived proper function.[56] This kind of function refers to artefacts and innovative items that lack a selection history. What derives proper function out of system function is production history, which provides function with normative elements. For Millikan, proper function is normative and this means that an assumed item has a function even if it is a malfunction.[57] Even if a vast majority of items of a generation have malfunction, then proper function can still be ascribed to them. In other words, normativity of proper function is irreducible to the statistical average.

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55 Beth Preston (May 1998) pp.215-25455 Preston agrees with Cummins in that capacities and selection history do not necessarily follow each other. Wright also agrees with this. Preston (1998) suggests that selection history can be likened to the function of prototype (in the case of artefacts) and ancestors (in the case of organisms). Indeed, what items have been in the past contributes to the selection history that accounts for the existence of the item.

56 Preston (2000) Proper function comes from system function.

57 Ruth Garrett Millikan *Language, Thought, and Other Biological Categories: New Foundations for Realism* MIT Press, 1984 - Psychology

4.6 'Weak' interpretation of functional etiological theory, based on the role of design and adaptability in modern theory

In a 1993 article, Kitcher attempts to create unification between function ascription and design thought.[58] This theory serves to inspire a new interpretation of etiological theory by theorists, including Griffiths in 1993[59] and later in 1998 by Buller[60] who design theories that are thought of as a 'weak' version of etiological theory. Kitcher establishes a connection between function and design. In the biological world an organism's function is chosen based on the organism's response to selection pressures, and the main components' function are determined based on their contribution in overall performance. Thus, for Kitcher, the selection pressures that determine the function of complex organisms can be defined based on a mechanistic analysis of the complex organisms, which shows how components participate in the overall performance.

In this argument, entities have a function when they are designed to do something, and design is rooted in intelligent agent intentions (technology) or in selection (design source in biology). The link between function and design source may be direct, for example in instances where agents expect an artefact to perform an especial task, or it may be indirect, for example when the agent desires a complex system to perform an especial task and the components create a causal contribution in the overall operation. A 'strong' etiological concept of function is based on a direct link between function and the related source of design (which takes place in selection biology), and thus an evolutionary explanation can be assigned to the presence of an item.[61] In a 'weak' etiological interpretation, the selection role in function ascription is not clear, and selection for the presence of an entity is not a necessary condition.

Kitcher's attempt to unite functional accounts (E-theory and C-theory) (whenever functional analysis in terms of C-theory is considered, then the resources of design would be available) has been criticised by theorists such as Godfrey-Smith.[62] The analyses of Cummins and Wright cite

58 Philip Kitcher (1993) pp.379–397

59 Paul E. Griffiths, 'Functional Analysis and Proper Functions' Brit. J. Phil. Sci. 44 (1993) pp.409- 422

60 David J. Buller 'Etiological Theories of Function: A Geographical Survey' in *Biology and Philosophy* 13 (1998) pp.505-527

61 Kitcher (1993) this theory may apply in both technology and biology. In technology Kitcher considers intentional elements (intention is a source of design) to establish his pluralistic disjunctive IC-theory.

62 Peter Godfrey-Smith 'Functions: Consensus Without Unity' Pacific Philosophical Quarterly 74 (1993) pp.196-208

functional ascription to distinct explanatory states, and argue that uniting a single interpretation is not appropriate.[63] Godfrey-Smith proposes a theory of function (conjunctive EC-theory), which refers to etiological concepts based on (current) modern history. He argues that functions are states or forces that describe the current presence of a property in the selecting context, based on its related past. Godfrey-Smith attempts to express a final formula of function using an adaptive concept, as follows:

The function of M is to F if:

(i) M is a member of T family.
(ii) Members of T family are components of biologically real systems of type S.
(ii) Among the properties copied between members of T is property cluster C, which can do F.
(iv) One reason members of T such as M exist now is due to the fact that past members of T were successful under selection in the recent past, by positively contributing to the fitness of S.
(v) Members of T were selected because they did F, through having C. [64]

This formulation attempts to solve the inability of etiological theories to establish a distinction between functional and evolutionary explanations.[65] Natural selection picks up proper function by showing which operations are used for survival and reproduction. In other words, variations that have the most survival value and the most productivity are maintained by natural selection.[66] However, in complex systems, each component makes a different contribution in adaptation. In contrast to Millikan's and Smith's (strong) etiological theory which places emphasis on natural selection, Buller suggests a (weak) version of etiological theory which undermines reliance on natural selection as the decisive criterion for achieving proper function.[67] A 'strong' theory asserts that a property must be inheritable, and that variations and adaptation can happen in a similar environment. In contrast, 'weak' theory only insists that a property in the current containing adaptation makes a contribution, and based on this contribution, it has survival value.

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63 This view is historical – this is why ascribing function refers to related history (the current past).
64 Peter Godfrey-Smith 'A Modern History Theory of Functions' Nous 28 (1994) pp.344-362
65 Referring to ancient history, the function of flight cannot be ascribed to wings of insect and is for regulating temperature body of insect.
66 This 'strong view' considers selected traits in terms of their contribution to the fitness of the containing system.
67 Buller (1998) p.507

For Buller, a 'weak' etiological theory is interpreted as follows:

'A current token of a trait T in an organism O has the function of production of an effect of type E, just in case past tokens of T contributed producing an effect of type E, just in case past tokens of T contributed to the fitness of O's ancestors by producing E, and there by causally contributing to the reproduction of T's in O's lineage'.[68]

However, focusing on fitness in a weak version of etiological theory shows that weak theory has some advantages over the 'strong' one, in that it shows why the selection process may not have a strong and necessary role in achieving functional properties (and thus it cannot have a significant role in an interpretation of a functional theory). Traits that are produced by genetic drift may account for functional analysis; this theory considers the function of all functional components in an overall system, where components contribute to fitness, even if they were left unchangeable in evolutionary history.

Following on from 'weak' etiological theory, Griffiths presents a conjunctive combing theory (EC-theory) by referring to the historical time period for evolution.[69] This theory considers that proper function is determined based on the causal-role traits of the past (contribution in fitness), as involved in the selection process. Griffiths interprets this theory (a new etiological theory) as follows:

*'Where I is a trait of system of type S, a proper function of I in IN S's is F if a selective explanation of the current non-zero proportion of S's with I must cite F as a component in the fitness conferred by i'*70

Theories about proper function must be able to distinguish functional properties from vestigial properties. Vestigial properties are functional properties that may change or lose their function (like the appendix in the human body).[71] In industrial systems, some components in artefacts may not have a proper function, because they do not make an intelligible contribution in the whole system.

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68 Ibid
69 Griffiths (1993)
70 Ibid
71 It is important to note that vestigial traits can be distinguished from malfunctioning traits. This is why vestigial traits do not contribute to the fitness of organisms in their evolutionary history.

In artefacts that are constructed as part of a process of trial and fail, the contribution of functional components may be unknowledgeable for makers. However, the function of each part is its intended contribution in overall use. This understanding of function in biology can be used for artefacts, because conscious selection almost plays the same role as natural selection. Fitness in artefacts can be described as their tendency for production, and not their efficiency in performing the demanded function.

In technology, some ancient artefacts have not only lost their main function, but are now used for another function (for example, for ornamental decoration) at present. In this regard, the artefact's function is its intended use, because its ability for performing an intended use gives it the tendency for being produced. The overall capacity in which the proper functions of an artefact contribute is the capacity for being produced. For example, a broken tool with malfunction still has a functional explanation, even though proper function is not ascribed to the properties of an artefact that contributes an intended use accidentally.

Griffith's theory still struggles with function ascription to innovative artefacts that have malfunction. Utility and the positive contribution of survival value are tied to biological concepts of adaptation, and saying that an item has adapted with the environment means that natural selection has undergone selection of this item for performing a function. The concept of utility and benefits in adaptation is the result of fitness, and a property is beneficial for an item if it contributes towards fitness positively. Historical functional theories place emphasis on properties that have grown under natural selection in the past. However, utility may change over time according to environment. Adaptation is not an innate property; it is a scaled and relative property (which takes into account environmental factors). When considering the distinction between proper and accidental function, function and malfunction shows that function is not an innate property, but it is a relational property that is determined due to the contribution that a property makes in the adaptation process, and in relation to the environment.

In contrast, Walsh attempts to design a relational functional theory by incorporating historical and non-historical approaches to function in biology, and by using the concept of adaptation.[72] Walsh discusses that the function a property contributes in adaptation and adaptation is only determined in

72 D. M. Walsh 'Fitness and Function' in *The Brit. J. Phil. Sci.,* Vol. 47, No. 4 (Dec. 1996) pp.553-574

a selective regime (the function is relative to the selective regime). Walsh interprets biological relational function as follows:

'(RF): The/a function of a token of type X with respect to selective regime R is to M if X's doing M positively (and significantly) contributes to the average fitness of individuals possessing X with respect to R.'73

Relational function is the contribution an item makes to the average fitness in the selective regime.[74] However, the contribution an item makes in adaptation is not equivalent in different environments. Thus, a normal environment must be distinguished for determining the level of adaptation. In other words, the positive contribution of an item to fitness in a specific context, and the method which the item contributes to fitness on average (in a specific regime), provides the conditions for which the distinction between proper and accidental function, and function and malfunction, can be determined.[75] Therefore, any function ascribed in etiological theory has function in relational theory.

Walsh attempts to provide conditions for a combining theory based on functional explanation; the proper function is cited (in the field of biology), but the question remains as to whether it is possible to use these concepts in the field of technology.[76] As noted, natural selection needs different (variation) fitness, and this fitness indicates ability difference in survival and reproduction. In technological design, prototypes are refined in the mind of the designer, and then some are removed in the process of preliminary testing. These preliminary variations are subject to conscious selection, but there are other criteria for selection, such as aesthetic, economical, civil, or political elements, all of which can affect productive success and artefact adaptation. Thus, the variations that are produced in artefacts and prototypes can activate the selection process in a similar way to the process that occurs in biology. However, the criterion that determines adaptation in artefacts may be different to what it is seen in biology.

Buller suggests that fitness includes the following components*: viability, fertility, fecundity and the*

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73 Ibid p.564
74 The fitness of components can be separated, and not all have a role in entities.
75 Here function means something that items can do in context.
76 Ibid

ability to find mates.[77] In other words, these four basic components provide the propensity for survival, and production in biology. Buller questions whether these concepts are usable in the field of technology or not, and he concludes that potential viability is an adaptive fundamental component in organisms, because they must reach puberty in order to potentially achieve viability, fertility, fecundity, and ability to find mates. For artefacts there is no such life producing cycle; artefacts are constructed to be used for a while, then they depreciate. However, some artefacts experience a kind of puberty (for example, a fermentation process), but this process is not exactly equivalent to sexual maturity because it is not related to production and reproduction. Instead it is related to the performance of other functions. Therefore, in technology, reproduction is not dependent for survival on an item's puberty, whilst in biology if organisms do not reach puberty, their lineage becomes extinct. Artefacts do not have the ability to find mates, but some prototypes are produced and others are released. However, some types do not achieve intended success due to social, economic and technical differences. On the other hand, there are different rates of production in artefacts. Due to differences, some artefacts may have more presence in society.[78] Sometimes the greater efficiency and economy of an artefact leads to its extension.

In technology the above concepts are indirectly related to the cycle of artefact production. In addition, in technology, the rate of an artefact's presence in a user's society might not necessarily be due to the above factors, because social and commercial reasons etc. affect adaptive properties. As noted, a 'weak' etiological theory ascribes function only in relation to the hereditary properties that contribute in fitness, while a 'strong' version of the theory seeks a selection date for items. The 'weak' etiological theory only distinguishes the positive historical contribution of ancestors in the fitness, and is not sensitive to an item's proper function.

Artefactual design, construction and distribution uses techniques and resources that may be insensitive to final product function during the long process of selection, development and use.[79] There is no exact equivalent to fitness in the technological world, and successful performance does not justify an artefact's proper function. It would seem that proper functions in artefacts are determined to the extent they effect reproduction. This method of selecting proper function does not

77 Buller, David J 'Etiological Theories of Function: A Geographical Survey' in Biology and Philosophy 13 (1998)
78 The artefact has the same function in the competing design, but because of efficiency, it is spread out.
79 Basic engineering technologies for producing artefacts usually grow independent of the design and manufacturing of the artefact. In modular systems, modules develop separately.

provide an explanation or description of novel prototype functions, which do not have a reproduction history. The criterion of ascribing proper function for innovative artefacts is not applied, because these kinds of artefacts are not ascribed a production or production history, even though they might be involved in system function.[80]

Davies presents a conjunctive combing EC-theory by referring to natural norms.[81] He attempts to answer the question of whether these two basic theories are in competition, or are complementary, or can be unified in a more general theory. Davies presents an alternative approach and suggests that E theory is an interpretation of C theory in different systems. For Wright, the question of why an item is there is equivalent to the question of function, and, thus, function ascription is equivalent to an item's existence.[82] Based on C-theory, function ascription is explanatory. It describes the contribution of capacities in a certain system, based on a capacity analysis and the tasks of the components. These theories are different in terms of explanatory powers and explanatory strategies. As previously mentioned, the purpose of E-theory is to describe the presence of a property in a certain time, while C-theory describes how the capacity of an item in a containing system is applied. E-theory is described by referring to natural selection mechanism, whilst C-theory is described by referring to constructor components, the capacity of a system and the methods by which these components contribute in the containing system.[83]

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80 In 1996, Vermaas and Houkes and Houkes established the use plan approach in terms of the basic theories of C, I and E and later in (2010), they developed ICE theory.

81 Paul Sheldon Davies 'The Natural Norms: Why Selected Functions Are Systemic Capacity Functions' Nous, Vol. 34, No. 1 (Mar. 2000) pp.85-107

82 Larry Wright (1973)

83 When Davies talks about C-theory, he expands the definition of the theory from a consideration of organisms to an analysis of population capacity. Davies suggests that a population might have capacities similar to a system (with a natural selection date) which allows change inside of itself. Thus, a population is a system that is formed from components, and it has a morphological function. However, the systematic properties of a population are different from those of organisms in that they capture different kinds of structural forms, which create differences in their C-functions. Davies notes that evolution in populations can occur under the influence of mechanisms such as drift, rather than selection. He believes that by distinguishing related systems in populations it is possible to construct an analysis of systematic capacity, and of genotype and phenotype redistribution as created by drift, and, thus, cites C-functions to components. Therefore, each E-function is nothing more than an especial kind of C-function and C-function refers to all cases that determine E-function. The main points of Davies' theory are listed as follows: 1. C-functions are basic. From an ontological and epistemological point of view, E-function is nothing more than the C-function that is kept in the selection process, and is set in a larger system. In fact, selection operates on C-functions and, from an epistemological view, C-function cognition occurs prior to E-function cognition, and without this cognition, historical evidence is needed for item selection. In fact, E-function is only identifiable after C-function. 2

4.7 Overall Design in Krohs Thought

Krohs proposes a concept of design that can be applied in two basic theories, whilst Davies omits one of these theories (E-theory) in favour of the other one.[84] Alternatively, Krohs attempts to present a concept of design based on ontogenetics. This theory is a combining conjunctive IC-theory, which argues that function can be determined without referring to the design history. In the field of technology, C-theory includes I elements, and designing the blueprint determines structural properties by referring to intentions. However, in the field of biology, non-intentional thought is classed as *type fixation*. Krohs aims to show that functional description in both fields can be united according to usage in technical-social systems.

Krohs looks at design in the context of ontogeny rather than by examining evolutionary dates, and he does not connect the adaptive process to design. Krohs suggests that design separates a creature from the process from which the design is created, and this means that biological design can be seen as a kind of intentional design. Accordingly, intentional design comprises something more than mere intentionality. Design merely fixes the type of constructor components in an assembly. Thus, type fixation works alongside intentionality in intentional design. However, a physical-chemical system lacks type fixation, and type identities are determined based on component properties. In the process of intentional design, the designer fixes the types for the constructor components. Thus, Krohs proposes a concept of design that refers to function in which the functional norms do not refer to their evolutionary source.

Theoretical unification. Davies aims to achieve theoretical unification between two basic theories. Kitcher attempts to do this also, but for Kitcher, function is something that is designed: in technology by design resources and in natural selection by desire. Therefore, Kitcher is committed to the theory that evolution creates design by natural selection, and, therefore, this poses the question is it necessary to explain why something is designed in the domain of biology? In addition, why does such a process occur? In addition, Kitcher suggests that design concepts in the field of technology have no equivalent in biology. However, Davies believes that an analysis of natural system capacities may result the classification of C-function, which can be presented in a flowchart or diagram, but all system capacities do not belong to system design, and, therefore, an analysis of all capacities does not indicate systematic design. 3. The preservation of distinctions. Davies' theory preserves the distinction between evolutionary explanation (historical reasons) and functional explanation (systematic reasons), which is a difference in explanation strategy..

84 Krohs Ulrich (2009) 'Functions as based on a concept of general design' Synthese 166, pp.69-89

For Krohs, the contribution of the functions of type-fixed components is designed according to system capacity, as follows:

'To Φ is a function of a component X of a complex entity S with design D with respect to a capacity Ψ of S if F to Φ is a contribution of X in S to Ψ and X is type-fixed in D.'[85]

This definition of function is applicable in both the fields of biology and technology. The possibility of part of a designed system having different functions, or similar functions which run differently by fixed types, is considered. Krohs emphasises the role of the designer's desires in association with type fixing; the designer assumes that a selected type runs a function, and, thereby, the type is linked to examples in the structure design implementation. It should be noted that in this approach, function refers to the constructor components, parts and properties of a system. However, if we want to ascribe function to artefacts as a whole, they must be considered as a part of a designed system (like social-technical systems).

4.8 Sperber and Teleo-function

Sperber 86 poses ontological and epistemological questions in respect of artefactual design, in order to present a combining approach to function theory to explain the presence of intentionality in functions and in artificial selection. In relation to disjunctive IE-theory, Sperber considers functions as *selected effects* in biology, and as *intended effects* in technology. Teleo-functions are broader categories that include biological and social functions. Biological teleo-functions are *phenotypical features* of organisms that relate to the reproduction propensity of a property. Cultural teleo-functions can comprise two types, as follows:

1. Mental representations that are constructed among agents using mental processes.

2. Public products, including behaviour (speech) and its sequences (like manuscripts) which can be received as mental processes input.

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85 Krohs Ulrich (2009) 'Functions as based on a concept of general design' Synthese 166, pp.69-89

86 Dan Sperber 'Seedless Grapes: Nature and Culture in Margolis, Eric and Laurence, Stephen, (eds.) *Creations of the Mind: Theories of Artefacts and their Representations* (2007) pp.124-137

Teleo-function is the effect that explains why an item is reproduced and propagated[87]. Mental representations trigger a desire for cultural production, and the effects that an item had in the past leads to expectations and demands for the reproduction of that item.[88] Thus, Sperber links desires, and the mental presentations that stimulate these desires, to past effects. Sperber defines teleo-functions as follows:

'An effect of type F is a teleo-function of items of type A just in case the fact that items have produced F effects helps explain the fact that A items propagate.'

4.9 Boorse and Goal-Directed Patterns

Boorse argues that theories that are based on a designer's intention do not shed light on the necessary and sufficient conditions of function.[89] Boorse believes that structural components may have a function which is unknown to their designer, and that the intention of the function is independent of manufacturing it, and that if intention was enough to determine function then this means that the artefact could never malfunction.[90] A describes his idea of function by what he refers to as an *Operational Explanation*, which determines function in terms of contribution in a system.[91] The examination of aims provides a more appropriate explanatory method of function, although it should be noted that this analysis should not be limited to an especial goal, such as usefulness. Every goal, which is followed up by a purposeful system, can produce functional statements. Organisms are oriented towards purposes such as survival and reproduction, and, in contrast, artefacts can be goal-directed in automatic systems, or they can be used in a purposeful containing system. For example, the chair has a function because it contributes in a goal-oriented activity (sitting), but the weak point of this analysis is that function is viewed in terms of it being a contribution to a goal, and the contribution may not be fully understood.

Dennet interprets organism design in evolutionary biology in the context of adaptation, and artefact function in the context of hermeneutics.[92] In hermeneutics, a reader's interpretation of a context

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87 Sperber uses words like re-production and propagation to show that produced items may not inherit all traits of their ancestors.

88 Vermass & Houkes (2010) use E-theory to show cultural functions, and I-theory to show technical functions.

89 Christopher Boorse 'Wright on Functions' in *The Philosophical Review,* Vol. 85, No. 1, (Jan. 1976) pp.70-86

90 Makers of ancient artefacts may not have had knowledge about all physical-chemical properties.

91 Ibid

92 Daniel C. Dennett 'The Interpretation of Texts, People and Other Artefacts' in *Philosophy and*

may be independent from its author's intention. Thus, the real interpretation of a context is not based on an author's personal opinion. The artefactual hermeneutic is a hermeneutic which is used in a wider domain. In this context, artefacts are open to different interpretations (use), and the common use of an artefact may be different at any given time. The inventor and the designer act as one reference point for functional ascription by means of having privileged knowledge of the designer. Therefore, functional theories that consider the use pattern of artefacts can be inspired using this hermeneutic approach. For example ICE-theory as presented by Vermaas and Houkes looks at use pattern.[93]

The arguments presented in this chapter can be expanded by reading the work of the following academics: Robert Cummins (1977), Robert N. Brandon[94] (1981), Goslow Efal[95] (1986), Ron Amundson[96] (1994), Larry Wright (1972) and Philip Kitcher (1981).

Phenomenological Research, Vol. 50, Supplement (Autumn 1990) pp.177-194

93 Vermaas and Houkes (1996)

94 Brandon believes that an historical ascription of function is ambiguous and biology limits the application of the evolutionary concept.

95 Efal uses C-theory to examine artefacts and accounts for the function of organisms without reference to selection.

96 Amundson agrees that an etiological view of function applies to evolutionary biology and the function of an organ is its evolutionary goal.

Chapter Five
Modularity and Modular Systems

When trying to find an evolutionary theory for technology, a dynamic process is needed which can link the past to the future events. Modularity can perform this role as a conceptual tool, because it can be explored as an inheritable process. It is important to explore evolutionary mechanisms that act on the 'unit' of selection. Baldwin and Clark consider six modular operators within the evolutionary path of complex systems.[1] Design Evolution occurs when designers make value-seeking changes to a design. In this chapter I will examine a set of operations based on the theories of Baldwin and Clark. If a design is modular then ***six operators across modular architecture*** *and* ***two operators within modules*** *work to create a system. This idea explores splitting a design and its tasks into modules, substituting one module design for another, augmenting and adding a new module into a system, inverting to create new design rules, porting a module to another system, modifying the components of modules, and combining modules. In this analysis, the mentifact (which can, in some sense, be thought of as the module) will be the unit of selection.*

1 Carliss Y. Baldwin and Kim B. Clark Design Rules: Vol. 1, the Power of Modularity (2000)

5.1 Emergence in Technical Systems

The mechanism of natural selection used by evolution in biology requires variation, and changes of pattern in biology always relate to the degree of fitness of the selected variations. Although, there may be some uncertainties about the value of applying evolutionary models in technology, it is becoming increasingly important to consider change patterns for economical-political outcomes. Industrial development has been traditionally regarded as a process rooted in engineering procedures, standards, and social-economical constraints etc. In light of the rapid changes taking place in technological advancement, one question now frequently raised is how is the technological world is related to the biological one?[2] With advances taking place in genetic engineering, in computer technologies, and in other technological fields, it is valuable to explore Darwinian patterns in biology with a view to explaining their relationship with the artificial world.

Artefacts are designed to be used in a means-end context. In contrast, organisms are the result of the selection of genetic variations that occur in the inheritance process aimlessly. It could be argued that the theoretical differences between the artefactual and natural worlds is very extensive and diverse, but that artificial processes such as genetic engineering are linked to both the world of nature and organisms, and the world of technology. It could be suggested that the idea of intentionality in artefactual theory automatically negates and destroys any viable link between the concepts of evolutionary theory in biology and technology. However, by referring to evolutionary design (especially in electronics) and evolutionary archaeology, it could be argued that concepts and models working in both fields are problem-driven and open-ended, and that there is no explicit boundary between selection theory and intention-oriented theory.

By applying a methodology of evolutionary design, designers of electrical circuits and computer science have managed to discover procedures and algorithms that operate free from human interference. These procedures and algorithms are able to engage in evaluating and controlling a system, or take an action to search inside a design area in order to find optimum solutions, or to spread out the design area. Although, nature manages to find solutions for design problems far more efficiently and complexly than evolutionary algorithms do, the evolutionary algorithm uses similar

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2 Houkes believes that if we want to develop evolutionary concepts and models for the artefactual world, we must show (prove) that there is an interaction between the intentionalist description of artefacts and the selectionist view based on principles of evolutionary theory. Wybo Houkes 'The Open Border: Two Cases of Concept Transfer from Organism to Artefacts' in Functions in *Biological and Artificial Worlds:Comparative Philosophical Perspectives,* edited by: Ulrich Krohs and Peter Kroes (2009)

mechanisms in order to solve problems. Artificial design (phenotypes) have been used to change configurations using genetic codes (genotypes), and this process is an imitation of the methods used naturally by organisms when they interact with other living things in the environment.

From a selectionist point of view, technological innovations may satisfy environmental needs and reinforce a well-adapted system. By considering the criteria and necessities in design requirements, designers are often able to create different variations in the design space. In the selection process of the first phase, they eliminate ideas that they believe to be inappropriate.[3] Using evolutionary theory to examine innovations in technology merely gives greater explanatory value to an expanded range of selection and variation factors.[4] For variation, these factors can include: know-how, technical quality, the nature of a suitable design procedure, and the material sources that create the artefact, and all of these determine what alternatives are available for selection. For selection, these factors include: examining the competitive environment, which contains a technology, and the user's requirements of the artefact. However, since these requirements take many various forms, this has resulted in the inability of academics to decide on a comprehensive theory, and an inability to determine the factors of an artefact's success.

We cannot always expect that it is the best, the cheapest and the most useful artefact that survives. The survival of existing artefacts is dependent on market demands, and these demands do not always refer back to the common properties of token artefacts. Therefore, the presence or lack of presence of an artefact is important.

Technical artefacts differ from social artefacts (such as money etc.) in that fulfillment of a function depends on physical structure. Therefore, an appropriate interpretation of 'generation' is crucial for understanding the nature of artefacts. Artefacts are physically produced in an engineering environment, which is an environment in which physical objects are designed and made. Many artefacts are produced in relation to a concept or an idea that possesses humanistic intentionality, and, in this environment, physical objects acquire directionality and become artefacts. Therefore, it could be said that artefacts are produced as *a physical concept* and as an *intentional concept*.

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3 Manufacturers and designers take out the elements that do not meet the design criteria because this might make the cost of production uneconomic. Users also may ignore goods because of price or quality etc.

4 Lewens believes that we must not expect too much from trying to apply evolutionary theory to the world of designing artefacts.
Tim Lewens 'Innovation and Population' in *Functions in the Biological and Artificial Worlds: Comparative Philosophical Perspectives* Edited by: Ulrich Krohs and Peter Kroes (2009)

Some artefacts and complex technical systems may comprise emergent properties, behaviours or qualities that are not created within an intentional context. These emergent properties or behaviours emerge suddenly and unexpectedly as by-products of complexity, and they go beyond the properties and qualities of the components of the system. Emergence shows us many examples both in biology and in technology, such as consciousness in the brain, turbulence in hydrodynamic systems, and resistance in the electrical circuits of complex technical systems. Emergent properties may produce destructive effects, such as the emergence of resistance in a power transmission network, or they can produce beneficial effects, such as adaptable systems. Kroes suggests that emergence should be considered with reference to the following points:

1. The causal power of emergent properties. This causal power is often called epiphenomena. Emergent properties without this causal power cannot prepare new opportunities to influence (causatively) in the physical environment.

2. Emergence and functional decomposition. In order to solve design problems, engineers apply functional decomposition strategy, whereby the function of the whole system is divided into sub functions run by the components of the system. This strategy cannot be used for systems containing emergent properties, because emergent properties cannot be understood in terms of component properties.

3. The unpredictability or unexpectedness of emergence. The nature of unpredictability means that design can be meaningless, and trying to control emergent properties in an engineering system would be challenging.[5]

Emergence is innovative and different from the other components of a system. Therefore, a system or a design cannot be reduced to its components, or the predictable or expected relationships that take place within this system. From an ontological perspective, and with regard to the physical structure of an artefact, it is valid to ask whether function is considered to be emergent property or not? Function supplies the first conditions of emergence, in that function cannot be reduced to the operation of a system's components. However, function does not fulfil the condition that stipulates that a system must demonstrate a new qualitative causal power beyond its components. Consequently, it could be argued that functions are not emergent properties from an ontological

5 Peter Kroes 'Technical Artefacts, Engineering Practice and Emergence' in *Functions in the Biological and Artificial Worlds: Comparative Philosophical Perspectives* Edited by Ulrich Krohs and Peter Kroes (2009)

perspective.

From an epistemological viewpoint, we need two cognitive tools to explore the paradigm of engineering control: *non-predictability* and *non-explainability.*[6] In a 'strong' interpretation of epistemic theory, emergence occurs when the quality of a system is neither predictable nor explainable in principle. Therefore, if we want to define an artefact's function as an epistemic emergence, we must distinguish between the artefact’s function, and its behaviour or capacity. Physical behaviour is not an emergent property because it is predictable and explainable based on physical-chemical properties and the arrangement of components.[7] However, technical knowledge, and recognition of the intention and goals of the user, manufacturer, and designer etc. is required to discover artefact function. From an epistemic perspective, various functional theories can play a crucial role in determining emergent properties. Theories that consider use patterns can be used to explore function in relation to emergent properties, because the function can be ascribed according to the intention of the user (which may be unpredictable).

Theories that look at the intention of the designer may facilitate an exploration of emergent properties in relation to the designer's technical knowledge of components. A 'weak' interpretation of emergence can be examined by exploring time-scales in relation to the design and creation of an artefact. Artefacts may be non-predictable and non-explainable at the time of analysis, and sometimes after the acquisition of required knowledge, an emergent quality may disappear. Hence, engineering history is usually understood in terms of a continued effort to change emergent phenomena into explainable ones.

Emergent phenomena can play a role similar to the role played by 'drift' in evolutionary theory. Using the idea of drift, the emergence of semi-complex systems can be considered as having function. However, although emergent properties may be challenging to the engineering control process, they may be selected in some cases (such as for innovative use), and be placed in an

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6 Peter Kroes 'Technical Artefacts, Engineering Practice and Emergence' in Functions in the Biological and Artificial Worlds: Comparative Philosophical Perspectives Edited by Ulrich Krohs and Peter Kroes (2009)

7 It can be possible to divide a whole function into sub-functions based on a lack of energy, material, and signs noted in the system. For simple artefacts, emergence is not straight forward. This means that function is not a property can be ascribed to components.

adaptive system over a long period of time. Consequently, this results in the fitness of the artefact.[8] As mentioned in previous chapters, in biology drift usually occurs in small populations rather than in large ones. However, in technology, in rare cases emergent phenomena may occur in complex systems as a product of complexity in specific types of technical systems.

5.2 Modularity and Modular Systems

In order to present an evolutionary theory, a dynamic process is needed to connect the past to future events. Modularity exists in both biology and in technology, especially in complex systems, where the components of a system, or the modules, have limits relationally and interactively, and interaction is limited based on hierarchical structure.[9]

In modular design, modules are independent (and possess their own design rules) but they work together under the general rules of the system's design, so the options increase and the structure of design changes from an integrated structure into a hierarchical one. In modular systems, functional units are distinguishable, but these functional structures are compatible with the other structures in the system. Therefore, a modular system supplies a desired technical and specific solution. Modular systems are used when different functional variations are required in a product, and the modularity concept is frequently used in design, manufacturing and operation. It is expected that these designs have a positive impact on evolve-ability. Indeed, in order to perform adaptation mechanisms, complex systems must be evolve-able (whether in organisms or in artefacts). In other words, these systems must have the ability to make random variations that sometimes lead to improvement. In fact, in these systems the adaptation process only can proceed to the extent that desired mutation occurs. This depends on evolve-ability that is the manner of the writing of the genotype variation in the phenotype variation.

Wagner and Altenberg separate modularity into two processes as follows:

1. Parcellation: A process that generates modularity from an integrated whole.

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8 In memetics, fitness refers to technique, ideas or even artefacts, and it corresponds to growth rate in society. Lewens (2009) argues that the psychology of a population is one of the key factors for determining fitness.

9 This section will proceed to outline an evolutionary theory of technology inspired by Baldwin and Clark's 'Design Rules: The Power of Modularity' Baldwin and Clark *'Design Rules: The Power of Modularity'* MIT Press, 2000 - Business & Economics (2000)

2. Integration: The result of the integration of separate functional units.[10]

In technology, the modules in modular systems are designed and produced independently as functional structures, and are included in a system under the rules governing that system. However, individual modules have limited interaction, but can be consistent with other modules. In an evolutionary process, modules can evolve independently. Individual designers (who may not be the designers of the entire system) can make modules more efficient and effective. Therefore, by examining and categorising different types of modules and functional structures, it is possible to engage in the evolutionary procedures of technical systems, and to clarify the possible impact of evolution on modules in the evolutionary procedure of complex technical systems. Pahl et al. divide modules into *function modules* and *production modules*.[11] Function modules that work independently or in combination together play a role in the performance of a system's function, whereas production modules are designed independently of their function, and use based on production considerations.[12] They categorise modules as follows:

Distinguishing Features	**Classifying Criteria**
Function modules, Basic function modules, Auxiliary function modules, Special function modules Adaptive function modules, Non-modules	Types of module
Essential/possible modules	Importance of modules
Large/small modules	Complexity of modules
Similar modules only, Different modules only Similar and different modules, Modules and non – modules	Combination of modules
Number of parts per modular Number of units and their possible combinations	Resolution of modules
Software/paper modules only, Mix of hardware and software modules, Hardware only	Computerisation of modules
Closed system with combinatorial plan Open system with specimen plan	Appropriation of modules

Table 5: Pahl et al. - Functional and Production Modules[13]

10 Guenter P. Wagner and Lee Altenberg *Complex Adaptations and the Evolution of Evolve-ability* (1996)
11 G. Pahl, W. Beitz and J. Feldhusen *Engineering Design: A Systematic Approach* (1996) p.498
12 Function modules refer to equipment and spare parts etc.
13 G. Pahl, W. Beitz and J. Feldhusen (1996) p.498

Basic functional structures are fundamental to a system. They can run the function of one system individually or in combination with other functional modules. Basic functional structures are identified as essential. *Special functional structures* are complementary structures with special sub-functions. They are special modules that are attached to basic modules, and can be named as possible modules. *Adaptive functional structures* are essential in order to adapt the system to other systems according to boundary conditions. They are run by adaptive modules, and since their dimensions are not pre-determined, they are suitable for unpredictable conditions. *Customer-specific functional structures* are not used as part of a standard modular system. They are designed individually for special tasks, and their application is based on a combination of modular and non-modular systems. It must be noted that a combination of different modules, and modules that are consistent with customer-specific modules, often results in the creation of complex systems that are designed to satisfy market demand. In fact, market demand and functional requirements often determine the different combinations of modules in modular systems, and the type of participating modules. However, there are limitations to the techniques and combinations available.

Creating functional structures in modular systems involves dividing functions into sub-functions. This is important because identified sub-functions can be placed in order within modules. In other words, general functions can be divided to less complex sub-functions in order to be placed in the functional structures individually or together in consistent combinations. These functional structures in a modular system are of special importance. The process of evolution that can be traced in these systems derives from the running of evolutionary operators within these fixed structures. In technology, functional modules are adapted into structural units. This inconsistency between functional and structural decomposition in biology and in technology has led to the idea that, in biological systems only a structural approach can be considered when examining function.[14]

Modularity is scaled both in biology and in technology, and contains dynamic dimension. However,

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[14] Krohs suggests that animal organs can be viewed as structures with strong interior interaction ability, but with weak outside interaction ability However, morphological criteria are not always applicable to the modules' decomposition when a complex system is decomposed. Modules such as temperature and enzyme metabolism can be distributed between cells. However, these networks are divided into modules according to structural and functional criteria. Ulrich Krohs 'The Cost of Modularity' in *Functions in Biological and Artificial Worlds: Comparative Philosophical Perspectives,* edited by: Ulrich Krohs and Peter Kroes (2009)

modular systems can evolve from different onset spots and with changes in different directions.[15] Since modularity creates evolutionary plasticity, it makes selection more possible, and artefacts having a modular design can evolve through the substitution and reconstruction of modules. Therefore, modular systems that experience gradual revision and improvement evolve easier than integrated systems, since in integrated systems the whole design must be revised.

In engineering, modular systems are able to complete rapid revisions in line with the general rules of design, but, in the long term, the evolvability of the system may decrease. In addition, a modular design that includes an integrated design may be less able to accept changes; modules may show different applications in different systems, and this might result in limitations in the acceptance of changes, since the changes must be consistent with the running of the different functions. Therefore, it could be argued that modularity does not increase evolve-ability. Hence, modules are functional structures in which interior structural elements are strongly interdependent and are independent of other functional structures. In addition, they are able to integrate functions.

5.3 Design and Modular Operators

The architects of modular systems must identify working principles in order to create a modular design. These principles identify the functional role of modules within the system, and are designed to take into account the most economical efficient arrangement of modules.[16] Baldwin and Clark explain that for a modular design to function properly, design parameters must be distinguished according to their visible and hidden information.[17] This information tells the designer which parameters interact outside their modules, and how potential interactions can occur between modules. Indeed, the system is modularised by hiding some information of systems. They present a hierarchical vision of modular design that shows the categories of information involved in the modular design as follows:

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15 Integration and parcellation mechanisms are able to bring about modularity separately or together.

16 Interdependences leave room for creative design space, and innovative modules can bring about evolutionary effects in modular systems.

17 Baldwin and Clark (2000)

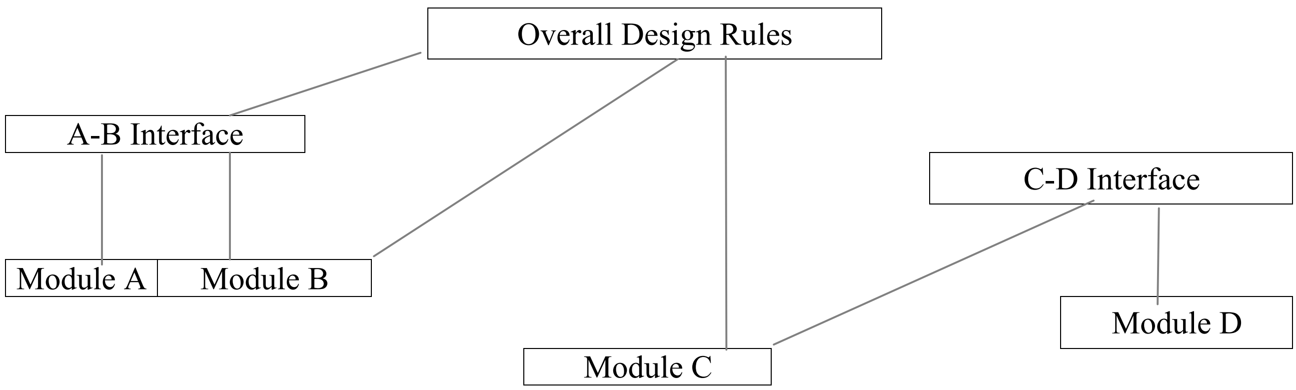

Figure 12: Baldwin and Clark's Hierarchical Structure of Design[18]

The design comprises four types of module, A, B, C, and D. The general rules of design are visible for modules B and C directly (and for modules A and D indirectly). This means that designers of modules C and B must be familiar with the general rules of the design, the A-B and C-D interfaces.[19] In this hierarchical design, the designers of hidden modules act independently of the overall design rules.[20] However, they must be aware of rules that are placed higher than their own in the hierarchy. Therefore, any change to visible information must be compatible with changes to the components of that level.

Designers determine the architecture of a system in terms of design rules, working principles, dependent networks and the operation of modules. Designers consider the functional requirements, cost of production and create desired assemblies based on optimal solutions. Placing modules without considering interaction between modules would not result in a modular design. Modular layouts rely on the relationship and interaction between modules, and they are designed to optimize opportunities in order to access desired goals.

Modularity might not be restricted only in an artefact's design. The production process can be divided into separate and independent processes. For example, different production units are created

18 Baldwin and Clark (2000) p.75

19 Interfaces are pieces of visible information in the hierarchy of modular design, and express interaction between modules.

20 Hidden modules relate to when design decisions do not have an affect on decisions made for other modules. Visible means the design rules and the designers of hidden modules must follow these rules.

in a steel production factory all of which can produce a given product independently. Pelletizing units can prepare the required pellets for iron making, which is used in steel making plants. Then, steel can be used in cold rolling units, or used on galvanizing and colour coating production lines. Although these units use each other's products sequentially, they are not interdependent. However, a steel making process in the plant can occur without the presence of pelletizing unit in the plant complex, or in some cases, plants just contain steel making and rolling lines. The products produced on each line can be used as raw materials for other plants. On the other hand, modularity may take place in use, when a part of a product (for example, part of a piece of furniture) is used. Then, the use can be a function of the modularity condition.

Each design is made by determining functional requirements and essential issues through the design rules of functional structures and the mechanisms of a system's function. The design space is achieved based on the layout (configuration) of the working structure. There is more flexibility in modular design in complex systems, and the number of sub-functions in the running phase decreases. When the revised modules are placed into a larger system, the system starts to change and evolve gradually. Therefore, it must be noted that changes made to modules in the containing system will be the result of the module operation actions. This process can be seen when changes in the modular design are the result of the operation of (one or a combination of several) modules. These conceptual tools can be defined as follows:

1. Splitting: dividing one design or system (and its tasks) into modules.
2. Substituting: substituting a module with another module.
3. Augmenting: adding a new module to the system.
4. Excluding: removing a module from the system.
5. Inverting: to create new design rules.
6. Porting: the process of adapting a module in another system, and done using common modules.[21]

In addition to six operators across modular architecture presented by Baldwin and Clark, I propose two operators within modules as follows:

21 Baldwin and Clark *'Design Rules: The Power of Modularity'* MIT Press, 2000 - Business & Economics (2000). P123

1. Modifying the components of modules. Hidden modules can be revised and improved more economically and easily. The evolutionary paths of the hidden modules are attained by means of operator activity in the system, and invention surrounding these modules may subsequently affect the containing system.

2. Combining modules. The design rules of hidden modules and the function of modules in the same level can be shared.

The above operators articulate the dynamic process that can result in evolutionary changes within genetic modular systems.[22] These operators affect technical functions and design layout directly, and production methods indirectly.[23] However these operators act on available structures, and new architectures result from the new relationships these structures form. This forms part of evolutionary theory as it works in complex technical systems. Therefore, assessing the role and function of these operators is off crucial importance. An evaluation of these operators is outlined below:

1. Splitting: This is the only operator used to create function structures and modules in a system, and to establish the initial mechanism of evolution. Therefore it is the first and the most fundamental operator used in integrated systems. This operator separates most of the modules that leads to the creation of a hierarchical design in a modular system.

2. Substitution: This operator is used in both modular and integrated systems. The functions of the previous operators create opportunities to facilitate the function of this operator. The substitution of modules creates a basis for economic competition. After the separation of modules, the designer can substitute a module for another in the framework of the design rules. Thus, alternative designs can compete together. An evaluation of these designs depends on economic and social conditions.

3. Augmenting and excluding: These operators are used only for modular systems. They add or remove modules from the system in order. A module is added to the system to provide a new function, and another is removed when there is no need for it any more. In expanded systems, the

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22 Two first and last two operators apply for integrated systems, and the others apply for modular systems only.

23 In their appropriation of 'operators' Baldwin and Clark were inspired by Holland (1992). For Holland, the actions of these operators (or structural modifiers) can create new structures that are embedded and adapted to their environments.

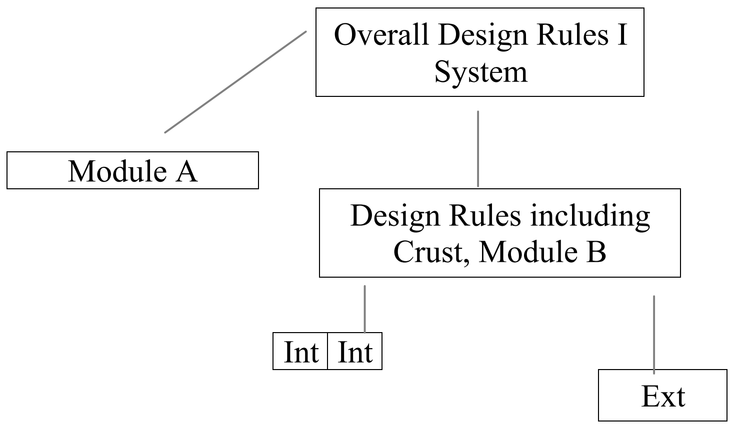
user may exclude a group of modules that are not required. Systems that let the user select according to their needs are called configurable systems. Configuration is a form of modularity in designing. These systems can place the user in the designer's role.[24] The designers of a system may use operators to determine the design rules for a flexible system that contains a large collection of modules. In such a situation, designers may implement a basic minimum system and then add other modules to it gradually, depending on market conditions. This allows users to complete the system according to their economic situation. However, the adding and removing of modules may lead to some differences in the function of the system.

4. Inversion: This operator improves modules in the higher layers of the hierarchy of modular design. Thus, a common carrier with widespread use is placed in an upper level of the modular system, and increases the number of layers in the hierarchy of modular design.

5. Porting: This operator occurs as the last, when a hidden module is able to act upon a different collection of designing rules, and it can be used in more than one system. Like the previous operator, this module enables a hidden module to move upward in the design hierarchy. However, because that module is hidden, it means that the designers and architects of other modules may be unaware of the function of this operator. For a module to be transmittable, the designers should split their design into parts that are influenced by the environmental system, and those that are not. A shell cannot be created for the uninfluenced parts that are the interior parts affected by the environment nor have any influence on it. Thus, they can change without significantly changing the larger system, or they can emigrate to another system. Exterior parts should transmit information from the exterior system to the interior parts and vice versa. The design rules of an environmental system and portal module should be both equally clear for these translator modules.[25] Additionally, if the above-mentioned actions - definition of shell, separation and the design of translator modules- occurs, then a module would be able to act in two or more inconsistent systems.

24 The system may be modular in respect of use, but not be modular in relation to design and vice-versa.

25 Translator modules are a kind of hidden module that transmit data and information from one system to another compatibly



Note the phase when module B is transformed to Π system. The system connects to another system via hidden transmitter modules.

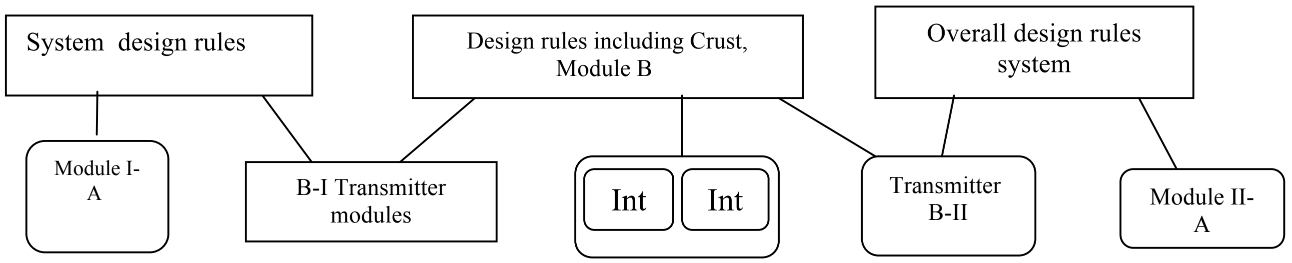


Figure 13: The Internal-External Phase of Modularization[26]

Thus, through the operation of these six elements, a modular system can adapt itself to environmental changes. As mentioned, the first two operations are not able to establish modularity alone; they cannot create new functions or connect to other systems. Modules can be used in a system individually or together. Further, the authors of these theories have relied mostly on the theory of descent rather than replication, because the performance of these operators in available systems has meaning. Therefore, the existence of previous generations has particular importance for current modular systems.

26 Baldwin and Clark (2000) p.133-35

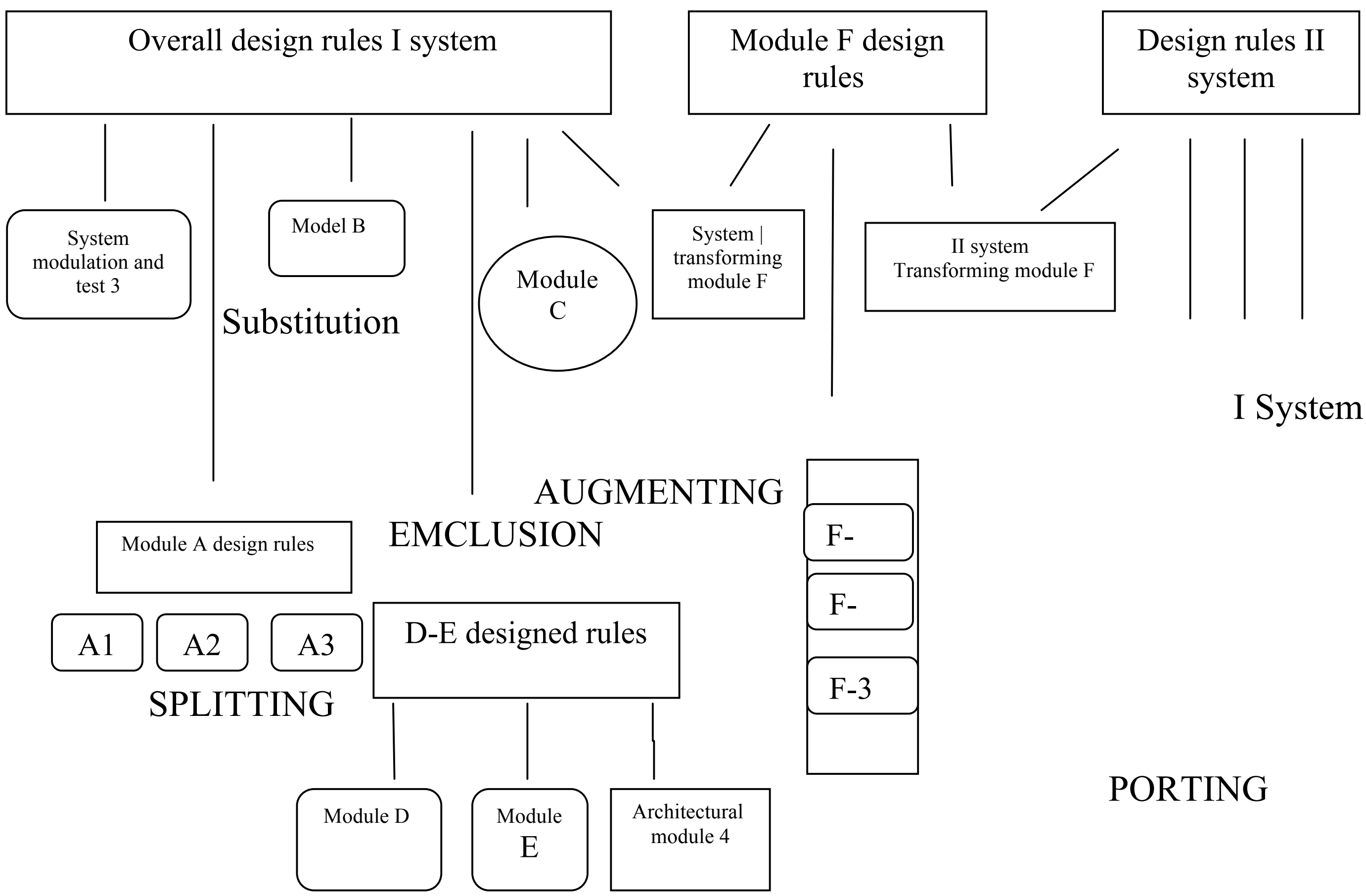


Figure 14: Activity of the Six Operators[27]

Model A is separated into three sub-modules, and the various substitutions that occur in module B and module C are removed. The common elements of D and E are delivered into the sub-system design rules so that an architectural module can be developed for this delivery.[28] Then, Module F is transformed.[29] Accordingly, the final system has three levels, with two modular systems that perform the functions of A, D and E modules in the old system, together with a standard hidden module and three special modules (system integration & testing, architectural, and transformer modules). The evolution of technical systems participates in a value seeking process that achieves value or fitness for adaptation to the environment.

27 Ibid p,140
28 These modules integrate hidden modules in architecture of systems.
29 It is separated, first and then the internal modules are placed in shell, and then the finally transformed modules will be developed.

To find an evolutionary pattern in technological development, we need to establish the unit of selection, the variation resources, mechanisms, and criteria for selection (theories about the 'unit' of selection are discussed in other chapters).[30] In technology, the processes of production, and the purchase and use of artefacts, are considered as mechanisms working within the act of selection, and capital market value provides the criteria for such selection. However, in technology, the adaptation of a system is viewed as a whole. In fact, adaptation is assigned to a system, which is going to be adapted to the environment. Hence, it is possible that parts of a system are separately inefficient and lack technical-economical justifications, but they achieve the necessary value for survival in an efficient system. In biology, this is also so. For example, the appendix (in the human body) lacks necessary function, but its presence is still preserved within the body. However, functional structures may also be efficient and competent in an abandoned and failed system, but they vanish in the containing system. In biology, the quality of an organism is measured by the metric called 'fitness'.

In economics, the concept most similar to adaptation is called IRR (the internal rate of return) or the ERR (economic rate of return). In engineering economy, one of the standard ways to evaluate economical proposals is called IRR. Investors measure profitability of their capital based on the rate of return. The IRR provides a criterion for technological evaluation. Thus, new forms of design, flow sheets and processes that can achieve the necessary value are adapted into the social-economical environment, and as noted, novel examples in modular systems are the result of foregoing operational acts, and provide resources for variation in modular design upon which selection operates.

The willingness and awareness of the designers and users of an artefact is derived from variation and selection. However, modularity is a conscious manner as part of the evolutionary dynamic in technology, which designers predict the value of the designed product using technical knowledge. However, issues of design are not completely predictable, and this process is often dominated by a degree of uncertainty. Moreover, the value of modularity links the different parts of a design, and the parts can be evaluated separately as independent units of selection[31]. This means that a system's

30 Hidden modules, architect modules, and even whole systems can be considered as units of selection.

31 In previous chapters, we have already discussed the memetic evolutionary process. By referring to this theory, Baldwin and Clark (2000, P 242) note two important differences between design evolution theory and memetic evolution theory, as outlined below: 1. In evolution, memes act as agents of removal for blind replicators. Therefore, their function as mental units in societies is a side effect of their success, which is

evolutionary process accelerates in relation to systems integration. Modules are not completely independent from others, and so designers must consider the visible information in a system, and obey the overall rules. Further, modularity includes a cost, and a pattern for investment is provided which is related to an evolutionary framework. Modular system architecture, and establishing design rules and testing needs investment, and the results must be tested and combined to obtain the final design. Therefore, investment is needed to perform testing at module level.

A generation of modular systems begins with design rules, and tests are done at system level to highlight variation resources based on value-seeking behaviour in the evolutionary process. These tests enable designers to be more aware of the relationships between modules in a system, and they provide new opportunities for operators. The evolution pattern of system's overall configuration is independent from its modular evolution, and this evolutionary pattern appears as a co-evolution of the selection mechanism and the unit of selection. When the design of an artefact is modular, the system components are divided into hidden and visible modules. The evolutionary paths of the hidden modules are attained by means of operator activity in the system, and invention surrounding these modules may subsequently affect the containing system. The hidden modules may bring about unpredictable effects on system, which modular design can tolerance of uncertainty so far modules obey overall design rules. Therefore, modular designs can suggest alternatives which non-modular designs cannot.

Finally, modularity provides options, which, when put under selection, an evolutionary path for the modular system will be created. Worthwhile options encourage investors in respect of following and implementing innovations. Based on this, invention would (in most cases) increase change in the hidden module design (but the changes are not sudden) in a way that produce technical and economical value.

This chapter could be enriched by referring to the following work:

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measured by the number of copies of a meme in society. In contrast, designers create designs for special goals, and so the success rate of a design is measured by how well the designed artefact runs its function, and how and what this function is important for.

2. Design evolution is to destroy to memes. When human endeavour tries to improve designs, it destroys the previous pattern and replaces it (the available memes) with new and better designs.31However, although there are differences in these two approaches, they coexist in human society and fulfil each other, because one design may consciously produce memes that will replicate themselves (such as advertising slogans, etc.).

Gunter et al. (2001) attempt to present an explanation of modularity and an evaluation of modules and their roles from the perspective of different academics

Deguet et al. (2005) discuss the idea of visibility and present five definitions of this concept. They claim that visibility is an idea that was first discussed in the field of philosophy and then was used in the field of complex technological systems as a key element.

Also: Peter Kroes et al. Al (2006) and (1991), Parent and Spaccapictro (2009), Heylighen (1992), Blackmore (2001), Buchi and Santini (2005), Vincent and Mann (2002) and Tversky and Kahneman (1974) contribute to this debate.

Conclusion

When the evolutionary biologist Theodosius Dobzhansky first published '*Nothing in Biology Makes Sense Except in the Light of Evolution'* in 1973, he probably did not think that the application of the biological principles of evolutionary theory in the field of technology and engineering design would become so important in the 21st century. Now, it is apparent that evolutionary theory can be used for theoretical planning in relation to the growth and development of technical-social systems. The basic principles of Darwin's theory of evolution notes that each system (which can), under a selective regime, achieves properties including variation, reproduction and heritability, in order that the system can evolve. Simondon is one of the first academics to use the conceptual tools of Darwin in order to consider a 'concretization' process for the evolutionary goal of technical complex systems.[32] Other academics studying the growth and development of technology in the context of an evolutionary-historical process use the idea of genetic transfer for inspiration. Simondon also interprets this technical transfer from the level of basic elements (or the system's constructional elements) to its phenotypic surface.

The presence of intentionality in engineering design, and the conscious selection mechanism (in accordance with market demands and functional requirements) grants directionality to engineering procedures in technology in terms of non-linear developmental patterns. To understand non-linear evolutionary theory, an accurate cognition of the artificial environment, and the physical structure and functional nature of artefacts is crucial. Certain structures interacting in different milieu find different adaptive properties based on the actions of evolutionary operators. Although using evolutionary strategy is promising for shaping developmental patterns in technology, scientific progress and in economic theory, the distinctions between biological systems and technical-social systems highlights the importance of the preparation of a distinct conceptual framework for this kind of model. In this respect, the most important idea to consider is the presence of human desire and intention in the production of artefacts, and the idea that purposeful design is at the centre of such consciousness. Purposeful design is the intentional sensitivity of technological innovation toward human needs, social conditions and aesthetic aspects.

Chapter One of this thesis explored the basic conceptual and theoretical elements of the artificial and evolutionary worlds. In this kind of exploration, it is important to consider the role of the

32 Gilbert Simondon, 'On the Mode of Existence of Technical Objects' Jérôme Millon (2005)

selection 'unit', and to examine the unit of selection in the context of its role as replicator and interactor. This approach helps to resolve ambiguity at the level of selection. In the past few decades, much debate has taken place among evolutionary biologists about the level and unit of selection. Selection is the result of replicator and interactor operation. An item is considered to be a replicator if it transfers its structure intact to the next generation following reproduction. Dawkins believes that longevity, fecundity and fidelity are the three properties of a replicator.[33] In evolution, these properties are capable of participating in the process of reproduction, and can be transferred to next generations. The main principle of Darwin's theory of evolution is the idea of natural selection and survival of the fittest, and this can be used to inform the contribution made by phenotypic effects in fitness. Using an historical-etiological approach it can be seen that adaptation occurs in the process of creating artefacts and systems that are used optimally in context (which have fitness). This adaptive process (in recursive practice) can be related to optimality in technical-social systems.

Change and progress in technology is the result of different factors of operation. Technique and technical knowledge, engineering procedures, designing sets, aesthetic aspects, and commercial and economic aspects can have an effect on what is understood as the *unit of selection,* and some parts of technological culture could be referred to memetic. In this approach, a mentifact is considered to be a *unit of selection.* This idea views the cohesive whole as including the artefact and all activities involved in its production, use, maintenance, and developmental patterns (like design methodology, engineering procedures, etc.) which act to achieve the stable reproduction of the technical systems. Stable reproduction ability emerges when conditions and resources change in the context of the means-end process. Chapter 1 assessed the different units of selection, as identified and interpreted by different academics, and the different frameworks within which innovation and variation in technical-social systems occurs.

An understanding of how evolutionary theory works in technology is crucial in order to discover how these two worlds (artefactual and natural) interact with each other. Chapter Two looked at whether it is possible to distinguish artefactual kinds from natural kinds, and whether the artefactual world is determinable ontologically and epistemologically. A theory of the artefact should be able to establish coherence of physical-chemical and intentional-tendency aspects. However, examining artefactual theory is not merely an analysis of structural properties. Intentionality plays a central role in human artefactual design, construction and use. Metaphysical studies show that an analysis

33 Dawkins, Richard *The Selfish Gene* (1976) New York City: Oxford University Press.

of function cannot provide the necessary and sufficient conditions to determine artefactual membership. Identity criteria links to artefactual kinds and the theory of Fregean cardinality and relativism can contribute towards showing whether an artefact can be examined in a sortal context or not.

Chapter Three discussed why technical systems are considered the product of a design process. An understanding of evolutionary mechanisms as they work in the design space is a pre-condition of an evolutionary theory of technology. Design methodology is involved with the improvement of the design process. John S. Gero talks about activities such as formulation, synthesis, analysis, evaluation, re-formulation and the production of a design description.[34] According to how these procedures perform, function, structure and behaviour are bonded together. An exploration of state space initiates the spread of the design space, and new elements emerge based on additional or substitutional patterns, and as a result of relational knowledge. Design is a re-formulation process, based on the behaviour of structure, and function in different environments. This means that design activity can be thought of in terms of the idea of 'situatedness' as an evolutionary recursive. One important aspect of creative designing is the emergence effect. As a result of interactions among units and low-level elements, overall system behaviour emerges. An analysis of 'situatedness' in design attempts to examine the status of the environment as a determinative element in the evolutionary methodology of design.

Chapter Four looked at different fundamental theories about function, such as intentional function theory, system function or causal-role theory, and etiological-evolutionary theory. By presenting existing theories of function, it is possible to consider whether the 'unit' theory of function can be used to answer all questions about how function works. The chapter considers the distinction between proper function, accidental function, and malfunction. In order to overcome theoretical obstacles, conjunction and disjunction combination theories are frequently used by academics in order to try to present a comprehensive interpretation of function. Some of these theories look at functional analysis from the perspective of the use plan or the action-oriented activities involved in production, design and use. In addition, this chapter presents a discussion about how an interpretation of function can be used in an evolutionary model of technology, and in evolutionary design methodology.

34 John S. Gero 'Creativity, emergence and evolution in design' in *Knowledge-Based Systems* 9 (1996) pp.435-448

Planning a dynamic evolutionary theory for technology means that a method is needed in order to link the past to the future. It could be argued that, in technology modularity plays the same role as heritability does in the world of nature. Additionally, evolutionary mechanisms that act on the unit of selection are a requirement for evolution. Baldwin and Clark look at the dynamic possibilities of modular operators in complex systems, such as splitting a design and its tasks into modules, substituting one module design for another, augmenting and adding a new module to the system, inverting to create new design rules, and porting a module to another system.[35] Thus, the mentifact (which can also be thought of as the module) can be thought of as the unit of selection, and this idea of fitness encapsulates the idea of a selection criterion and emergent properties that are part of the source of variation, as well as the creativity of intellectual agents.

35 Baldwin and Clark (2000)

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