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THE PROTO-THEORY OF DESIGN: THE METHOD OF ANALYSIS OF THE ANCIENT GEOMETERS

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1. Introduction

In the disciplines related to the design and production of products and services, such as New Product Development, Project Management, Systems Engineering and Design Science, there is no commonly accepted theoretical and methodical basis. In this paper, a new interpretation is provided. It is contended that the ancient method of analysis and synthesis, developed originally by Greek geometers, is able to provide – and has provided - stimulus and ingredients to the methodical aspects of these disciplines. However, the core understanding on this, as well as the historical connections have largely been lost during the modern period.

In order to prove this, the historical development and interpretation of the method of analysis and synthesis is examined. Current understanding of the methods used in design are compared to the method of analysis and synthesis, for pinpointing their similarities. It is argued that this state of affairs is not only an interesting finding in the history of managerial thought, but also, and more importantly, a major opportunity to consolidate and advance the theoretical and methodological basis of these disciplines.

In this paper, *the method of analysis* is used as a short hand, for referring to the whole of analysis and synthesis.

2. The ancient method of analysis and synthesis

The method of analysis and synthesis was developed and widely used by the early Greek geometers, the foremost representative of which is Euclid. However, the only existing wider description of the method is from a later period, around 300 AD, when the Greek geometer Pappus defined analysis and synthesis as follows (as translated by Hintikka and Remes (1974); alternative wordings of the translation, as given by them, are omitted):

> Now analysis is the way from what is sought - as if it were admitted - through its concomitants in order to something admitted in synthesis. For in analysis we suppose that which is sought to be already done, and we inquire from what it results, and again what is the antecedent of the latter, until we on our backward way light upon something already known and being first in order. And we call such a method analysis, as being a solution backwards.
>
> In synthesis, on the other hand, we suppose that which was reached last in analysis to be already done, and arranging in their natural order as consequents the former antecedents and linking them one with another, we in the end arrive at the construction of the thing sought. And this we call synthesis.
>
> Now analysis is of two kinds. One seeks the truth, being called theoretical. The other serves to carry out what was desired to do, and this is called problematical. In the theoretical kind we suppose the thing sought as being and as being true, and then we pass through its concomitants in order, as though they were true and existent by hypothesis, to something admitted; then, if that which is admitted be true, the thing sought is true, too, and the proof will be the reverse of analysis. But if we come upon something false to admit, the thing sought will be false, too. In the problematical kind we suppose the desired

> thing to be known, and then we pass through its concomitants in order, as though they were true, up to something admitted. If the thing admitted is possible or can be done, that is, if it is what the mathematicians call given, the desired thing will also be possible. The proof will again be the reverse of analysis. But if we come upon something impossible to admit, the problem will also be impossible.

Four issues are immediately clear from this description. *Firstly*, the starting and end points of analysis are qualitatively different. Regarding the starting point, the "desired thing", we do not know whether it is possible or can be done, whereas the end point consists of something already known. *Secondly*, there are two directions of inferences needed: backwards for the solution (regressive analysis), and forwards for the proof. This is also called directional analysis (Hintikka & Remes 1974). *Thirdly*, the method of analysis does by no means ensure that a solution can be found: we may be compelled to return to the problem and revise it, and start afresh. Thus, the method leads to an iterative approach. *Fourthly*, there are two types of analysis: theoretical and problematic (Figure 1). Two other features are not immediately clear, but can be deduced from the examples of analysis and synthesis given by Pappus, namely that the analysis consists of at least two other different lines or types of reasoning. Thus, *fifthly*, a configurational (or decompositional) analysis is usually also involved in the method of analysis (Hintikka & Remes 1974). *Sixthly*, it has been put forward that an analysis may also comprise transformational or interpretive aspects, where the original problem is transformed into another for facilitating its solution (Beaney 2003). In the geometric analysis, the use of auxiliary lines is one form of this type of procedure. These six features do not exhaust the ancient understaning of the method of analysis, but provide a suitably concise starting point for our present purposes.

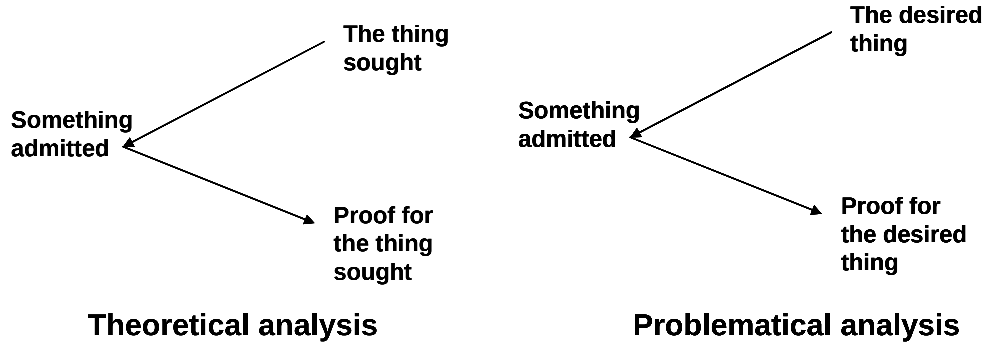

Figure 1. Schematic presentation of theoretical and problematical analysis

3. Reception and use of the method of analysis

The method of analysis was known to medieval scholars through the books by Euclid. However, it was the more systematic treatment of analysis by Pappus, translated into Latin in 1589, that ignited a lively interest in this method among the leading thinkers of the emerging modern movement. Thus, among others, Descartes and Newton subscribed to and applied the method of analysis. Descartes (1637), in his *Discourse on Method,* gives the following account about the rules he was applying – the first two falling into analysis and the last two into synthesis:

> The first was never to accept anything as true if I did not have evident knowledge of its truth: that is, carefully to avoid precipitate conclusions and preconceptions, and to include nothing more in my judgements than what presented itself to my mind so clearly and so distinctly that I had no occasion to doubt it.
>
> The second, to divide each of the difficulties I examined into as many parts as possible and as may be required in order to resolve them better.
>
> The third, to direct my thoughts in an orderly manner, by beginning with the simplest and most easily known objects in the order to ascend little by little, step by step, to knowledge of the most complex, and by supposing some order even among objects that have no natural order of precedence.
>
> And the last, throughout to make enumerations so complete, and reviews so comprehensive, that I could be sure of leaving nothing out.

Newton writes in *Opticks*:

> By this way of Analysis we may proceed from Compounds to Ingredients, from Motions to the Forces producing them; in general, from Effects to their Causes, and from particular Causes to more general ones, till the Argument end in the most general. This is the Method of Analysis; and the Synthesis consists of assuming the causes dicover'd, and establish'd as Principles, and by them explaining the Phaenomena proceeding from them, and proving the Explanations.

It has been suggested that here Newton actually identifies his experimental method with the analytical method (Hintikka & Remes 1974). Another example of using analysis and synthesis as methodological starting points for science is provided by Riemann, the brilliant 19th century mathematician, who, in an unfinished work, analyzed how the mechanism of the ear could be studied (Ritchey 1991). The applications of the method of analysis did not limit to science. As he himself has announced, Edgar Allan Poe used the method of analysis for writing poetry (Niiniluoto 1990).

However, it seems that after the great scientists, who propelled the Enlightenment into speed, the attention of the subsequent generations of scholars turned to imitating the example of them, in the true sense of a paradigm, and the method of analysis was transmitted in a rather superficial and impoverished form, as a generic method. The term analysis itself was "captured" by the mathematics, in the sense of analytical calculus.

Thus, in the 20th century, it seems that even if many features of analysis were routinely applied in a most diverse group of scientific endeavours, the roots and the totality of the method of analysis were not commonly known. For example, in the well-known textbook of Pahl and Beitz (1996) on engineering design, analysis and synthesis are shortly described as part of "general working methodology", but in a shallow manner and without the background. Pugh (1991) suggests a cyclical process of synthesis/analysis/synthesis, but cogently, he provides the definition of synthesis in *The Concise Oxford Dictionary* as a sufficient starting point for understanding this key concept. However, as an exception, the popular "How to solve it" by Polya (2004, first edition in 1945) must be mentioned. He goes as far as identifying heuristics with the ancient analysis, as described by Pappus. For Polya, heuristics is applicable to all kind of problems, even if the book concentrates on mathematics.

4. Applying the method of analysis to design

What is the relevance of the method of analysis to design? We contend that the method of analysis provides a proto-theory of design, which unfortunately has been forgotten as an explicit body of knowledge. In fact, various issues covered by the method of analysis have recently been rediscovered in various design sciences, but without any connection to it.

In the following, we analyze the six features of the method of analysis and discuss the correspondence of the features to recent developments in design theory. The feature "two directions of analysis" is discussed both as such and regarding its one component, solution backwards.

4.1 The starting and end points

4.1.1Analysis

The starting and end points of analysis are qualitatively different. Regarding the starting point of analysis, the "desired thing", we do not know whether it is possible or can be done, whereas the end point consists of something already known. In turn, synthesis provides the definitive proof of that the "desired thing" is possible.

4.1.2 Recent development in design theory

In the C-K theory of design, developed by Hatchuel and Weil (2003), design is defined as a process by which a concept generates other concepts or is transformed into knowledge. A concept (C) is defined as a proposition that has no logical status, i.e., we cannot know whether it is true or false. In turn, propositions in the knowledge space (K) have a logical status, and obviously the most interesting knowledge is what is known to be true. Thus, design is expressly defined by its starting and end points.

4.1.3 Discussion

In spite of different vocabulary, the method of analysis and the recent C-K theory can be viewed as corresponding well, regarding the starting and ending points.

4.2 Two directions of analysis and synthesis

4.2.1 The method of analysis

There are two directions of inferences needed: backwards for the solution, and forwards for the proof. That the inferences towards solution do not as such ensure that they are reversible is an issue requiring justification (that cannot be given here), but this was well-known already to Aristotle (Hintikka & Remes 1974).

4.2.2 Recent development in design theory and methodology

The Vee model, developed in the framework of systems engineering (Stevens & al. 1998) and recently diffused in software engineering, similarly implies two directions. The first found occurrence of the model in the literature is from a paper by Boehm (1979), who indicates a related personal communication from J.B. Munson, System Development Corporation in 1977.

The most explicit embodiment of the Vee model is perhaps the “V-Modell”, a method and standard for software development and project management in general used by the German federal administration (Anon. 2005a). The “V” in this method is described as follows (Anon. 2005b):

> The left tail of the V represents the specification stream where the system specifications are defined. The right tail of the V represents the testing stream where the systems is being tested (against the specifications defined on the left-tail). The bottom of the V where the tails meet, represents the development stream.

4.2.3 Discussion

The idea of two streams of activities, one towards solution and the other towards a proof of the solution, is evident both in the method of analysis and in the recent embodiments of the Vee model.

4.3 Iteration

4.3.1 The method of analysis

The method of analysis does by no means ensure that a solution can be found. Rather, the method leads to an iterative approach: we may be compelled to return to the problem and revise it, and start afresh. Pappus was a practicing mathematician, and it should be justifiable to claim that he knew the two reasons for the lack of a solution: the problem may be impossible or we have just not invented the solution yet.

4.3.2 Recent developments in design theory and methodology

The view that the design process is iterative is now wide-spread. However, this was a new idea in the 1980´s, as evident from the observations of many who reported that in practice, the designers unpredictably move between goals and means, instead of a linear, one-way process. However, a major shift in the project realization methodology was achieved only through the agile methods, originating in software engineering (Schwaber & Beedle 2002).

For example, in the method of SCRUM, the requirements for the software to be developed are explicitly variable, to be adjusted according to new understanding gained on technical possibilities and other issues.

4.3.3 Discussion

The iterative working method is evident both in the ancient method of analysis and the new agile methods.

4.4 Problem to prove and problem to find

4.4.1 The method of analysis

There are two forms of analysis: theoretical and problematical. These are, in Polya's (2004) terms, the problem to *prove* (in geometry, a theorem) and the problem to *find* (a solution to a mathematical problem).

4.4.2 Recent developments in design theory and methodology

The existence of two modes of reasoning has been established in various fields of design. A good starting point is provided by architecture. Aalto says (Wilson 1979):

> In such cases I work – sometimes totally on instinct – in the following manner. For a moment I forget all the maze of problems. After I have developed a feel for the program and its innumerable demands have been engraved in my subconscious, I begin to draw in a manner rather like that of abstract art. Led only by my instincts I draw, not architectural syntheses, but sometimes even childish composition, and via this route I eventually arrive at an abstract basis to the main concept, a kind of universal substance with whose help the numerous quarrelling sub-problems can be brought into harmony.

Here, the process of *finding* a solution is described. The resulting concept became then the starting point of analysis for *proving* this solution, to be carried out by others in the architectural team. This is evidenced by Aalto's frequent prompt to young architects in his office: "Analyse, do not compose!" (Oksala 2005). The important task of composition was reserved for the maestro himself.

Similarly, in the seminal description of systems engineering, Hall (1962) positions systems synthesis before systems analysis, and explains that they are analoguous to theory formation and deduction in pure science.

4.4.3 Discussion

It seems plain that the two objects of analysis, as defined by Pappus, are widely recognized in design methodology and practice.

4.5 Solution backwards

4.5.1 The method of analysis

Pappus says of solution backwards:

> For in analysis we suppose that which is sought to be already done, and we inquire from what it results, and again what is the antecedent of the latter, until we on our backward way light upon something already known and being first in order. And we call such a method analysis, as being a solution backwards.

Without further justification, we contend that this is equal to to the well known means-ends analysis, when starting from the ends.

4.5.2 Recent developments in design theory and methodology

Shewhart wrote in 1931:

> Looked at broadly there are at a given time certain human wants to be fulfilled through the fabrication of raw materials into finished products of different kinds. […] The first step of the engineer in trying to satisfy these wants is therefore that of translating as nearly as possible these wants into the physical characteristics of the thing manufactured to satisfy these wants. In taking this step intuition and judgement play an important role as well as the broad knowledge of the human element involved in the wants of individuals.

The idea of starting from customer wishes, and working then through different stages, to the design of a product fulfilling those wishes, has been the (or one) basis for several recent approaches, such as systems engineering, requirements engineering, and value management.

There is a recent profileration of related methods and tools, such as requirements management software, tools for rationale capture, Quality Function Deployment, Axiomatic Design (Suh 2001) and others. The common feature in these is that they endeavour to provide a systematic approach to decisions on and documentation of the chain of means and ends.

4.5.3 Discussion

Again, the similarities between the ancient and the modern conceptions are plain.

4.6 Decomposition

4.6.1 The method of analysis

Even if not explicitly discussed in Pappus' account, a configurational (or decompositional) analysis is usually also involved in the method of analysis (Hintikka & Remes 1974). In the context of geometry, the question is about investigating from which parts (lines, angles, points, etc.) a figure is made up, and which relations exists between those parts. Actually, it is in this meaning of breaking down that the term analysis is today most often used.

4.6.2 Recent developments in design theory and methodology

The decomposition of a product to be designed into composite parts is a well-known method, called, for example, Product Breakdown Structure (PBS) or bill-of-materials (Bachy & Hameri 1997). In the conventional methodology of project management, the Work Breakdown Structure (WBS) is prepared based on a Product Breakdown Structure. It has been contended that scope management, achieved by means of the WBS, is a foundational idea in project management (Turner 1993).

4.6.3 Discussion

Again, it is not difficult to see the similarity of the ancient and modern views on decomposition. However, there might be one difference: the modern view sees the decomposed parts as independent, whereas the ancient approach also covered the relationships between the decomposed parts.

4.7 Transformation

4.7.1 The method of analysis

The transformative or interpretative reasoning may be the least understood feature of analysis, at least of those discussed here. Beaney (2003) refers to Russell and Frege, who suggested transforming statements to be analyzed first into their correct logical form. Further, the use of auxiliary lines in geometrical analysis (Hintikka & Remes 1974) can be viewed to fall into this type.

However, in contrary to Beaney, all these issues could also be viewed as a process of expanding the knowledge associated to the problem (or theorem). Namely, a transformation of information or knowledge does not destroy the input, as is the case regarding physical transformations. Thus, any transformation or new interpretation leads to expanded knowledge.

4.7.2 Recent developments in design theory and methodology

The view of design as a progressive transformation of the representation of the object to be designed (Dym 1994) can broadly be classified as belonging to this class. Alternatively, from the C-K method we may take the idea of expanding the space of concepts and knowledge (Hatchuel & Weil 2003).

4.7.3 Discussion

Even if this transformation feature of analysis is somewhat vague and disputed, we can pinpoint similarities between the ancient and the modern views.

4.8 Summarizing the discussion

For all the features explicitly, or implicitly, contained by the ancient method of analysis, we can pinpoint modern, corresponding ideas and concepts, many very recently invented, as summarized in Table 1. Consequently, it is justified to hold the method of analysis as the proto-theory of design. Interestingly, almost without exception, the modern concepts and practices have been forwarded by their originators without any reference to the ancient counterparts – obviously, due to ignorance of them.

Table 1. Overview on the method of analysis and corresponding recent developments

	Start / End	Direction of analysis	Iteration	Problem to Prove/Find	Solution backwards	Decomposition	Transformation
Method of Analysis	Starting: we do not know whether it is possible or can be done Ending: something already known	Backwards for the solution; forwards for the proof	The method is iterative: we may be compelled to return to the problem and revise it, and start afresh	Theoretical and problematic form of analysis	"…which is sought to be already done, and we inquire from what it results, and again what is the antecedent of the latter, until we on our backward way light upon something already known and being first in order…"	"In the context of geometry, the question is about investigating from which parts… a figure is made up, and which relations exists between those parts…"	Auxiliary lines in geometrical analysis
Recent Develop-ments	Concepts: no logical status, neither true nor false; Knowledge: it has logical status (**C-K**)	The left tail represents the specification (backwards for the solution); The right tail represents the testing (forwards for the proof) (**V model**);	Iterative methods where requirements are understood as a variable (**Agile**)	Problem to find (a concept) and problem to prove (its feasibility and validity) (**Creative Design Process**);	"…starting from customer wishes, and working then through different stages, to the design of a product fulfilling those wishes…" (**Quality management, requirements engineering**)	"The decomposition of a product to be designed into composite parts…"(**PBS; WBS**);	Design as a progressive transformation of the representation of the object to be designed; expanding the space of concepts and knowledge (**C-K**)

5. Conclusions

It must be concluded that design has suffered from most damaging epistemological dilution, as defined by Papert (2000). As in other cases of epistemological dilution, rather the implications of the original big idea have diffused than the idea itself. The method of analysis has provided a number of various stimulae for further development of various fields, but the method itself has been almost forgotten. This has rendered the various sciences of design hollow. The core theory has been missing, and development has either occurred in the periphery or endeavoured to rediscover the core. This has obviously contributed, first, to fragmentation of the field. Second, development has focused on re-inventing wheels. Thirdly, there has been little accumulation of knowledge regarding design and its management. Namely, the discussion on the method of analysis having been carried out in other domains, such as mathematics, philosophy and history of science, has not been fruitfully used for stimulating and advancing project management, systems engineering and design science.

It seems that further development and unification of design science requires that we return to the proto-theory of design and start to validate, criticize and expand it. The following issues especially invite further research:

- Compilation of a common conceptual and theoretical core for the various design and production sciences, and associated ways of contextualizing it to specific situations.
- Management of the interactions between the different features of analysis.

- Inherent limitations of the method of analysis, for example from the point of view of arguments promoting a holistic approach (Bohm 1980).

In the past, the method of analysis has proved to be extremely stimulating in various fields, and has played a crucial role in the emergence of the modern world-view. Thus, it is justified to hope that the rediscovery of a proto-theory will accelerate the progress of design and production disciplines.

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