Axiomatic Design And TRIZ: Compatibilities and Contradictions, Part 1

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Introduction

TRIZ offers a wide-ranging series of tools and methods to help designers and inventors to solve problems in creative and powerful ways. For the most part these methods have evolved independent and separate from many of the design strategies developed outside Russia.

TRIZ-based research work taking place at the University of Bath includes activities to compare and contrast TRIZ with some of these non-TRIZ methodologies. Our aim is to produce tools and techniques which will coherently combine the best features of each method.

This article focuses on Nam Suh's Axiomatic Design (AD) ideas and their possible relationship with TRIZ; firstly from the perspective of how TRIZ might benefit designers more accustomed to AD methods, and then looking more closely at how Axiomatic Design might be usefully applied within a TRIZ context.

An Introduction To Axiomatic Design

Professor Nam Suh at MIT has published widely on the subject of design. Probably his seminal work remains 'The Principles of Design' (Reference 1), published in 1990. The bulk of that textbook discusses his Axiomatic design approach. The approach is primarily concerned with the establishment and deployment of means of determining whether a solution to a given design problem is 'good' or 'bad'.

The approach is built around two axioms:-

Axiom 1 - 'The Independence Axiom' - In which it is stated that 'good' design occurs when the Functional Requirements (FRs) of the design are independent of each other.

Axiom 2 - 'The Information Axiom' - In which 'good' design is defined by achievement of a minimum 'information' content (or. to grossly over-simplify the Axiom, good design corresponds to minimum complexity).

In essence, the two axioms are analytical in nature. Suh uses a feedback control loop analogy in describing the design process (Figure 1). Given a set of input conditions, 'societal needs', and a desired output - the product, prototype or process - the analogy indicates the presence of a black box 'ideate and create' synthesis capability - through which a designer somehow generates a candidate design solution based on the inputs. The two Axioms are then used as analytical tests (i.e. the feedback part of the analogy) of how 'good' the synthesised solution is.

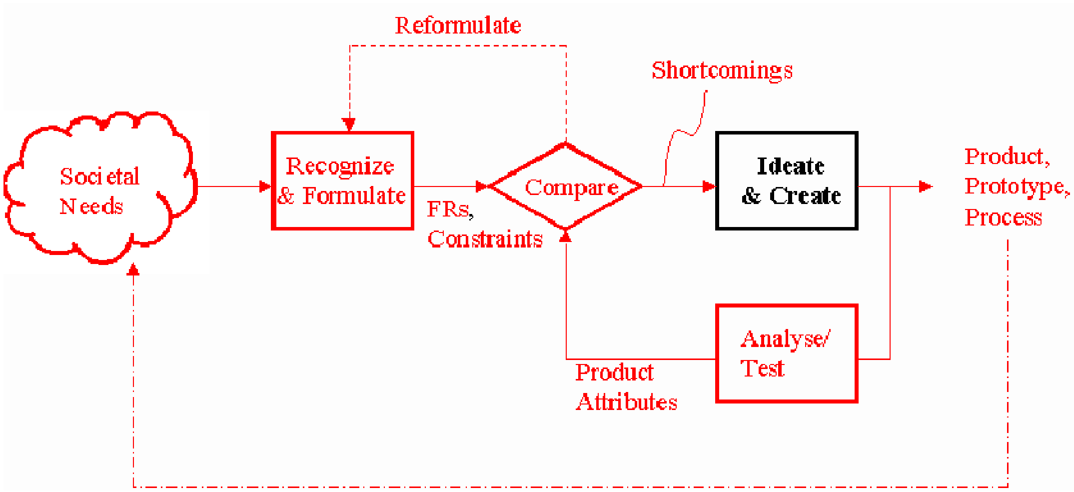

Figure 1: Schematic of Design Process (based on (1), Fig 3.10)

The following sections explore some of the compatibilities and contradictions between Suh's **analytical** design Axioms and the powerful design solution-**generating** capabilities of TRIZ using design examples from The Principles of Design.

A Simple Example - Reduction of Materials Cost

Suh discusses the case of a major US instrument maker looking to reduce the cost of the impact-grade polystyrene it used each year (Reference 1, pp30-31). Seeing that material cost for the parts under consideration constituted 75% of the manufacturing cost, Suh describes how the R&D team at the company was asked to devise a means of reducing cost of materials by 20% without sacrificing the mechanical properties of the part.

As in the large majority of other approaches, Suh also sees problem definition as the key to achievement of successful design (see also freezer design example later in this article). In Suh's terms, problem definition is an iterative process centred on the definition and optimisation of the Functional Requirements of a design.

In the case in question, Suh derives two FRs:-

FR1 = reduce the material cost by 20%
(i.e. reduce the material usage by 20%)

FR2 = toughness of the plastic part to equal or exceed that of the original part.

In terms of synthesising possible solutions to the problem, Suh offers little in his book to detail how the ‘ideate and create’ black box derived viable solutions other than by stating that the designers tried a few different ideas (e.g. 'insert fillers', insert very small fillers') and eventually came up with the idea of 'microvoids'. The description in the book very much implies that the 'process' of discovering the solution was a somewhat nebulous and protracted affair.

At this point, then, it is very interesting to introduce how TRIZ might have been usefully deployed in reaching such a design solution:-

Contradictions - the problem of how to reduce the amount of material being used, while maintaining strength should hopefully immediately suggest a design contradiction and hence the use of the Contradiction Matrix. The Matrix suggests 'Parameter Change', 'Curvature Increase' and 'Preliminary Action' as means used by others to inventively solve this QUANTITY OF SUBSTANCE versus STRENGTH technical contradiction. The first two suggestions in particular point immediately to a void-based solution (e.g. 'curvature increase should suggest the idea of making 'bubbles'/voids in the material smaller).

Evolutionary Trends - even more encouraging is the 'space segmentation' evolution trend spotted by Altshuller and his team - Figure 2 - i.e. a trend in which voids are introduced into a structure in ever smaller fashion:

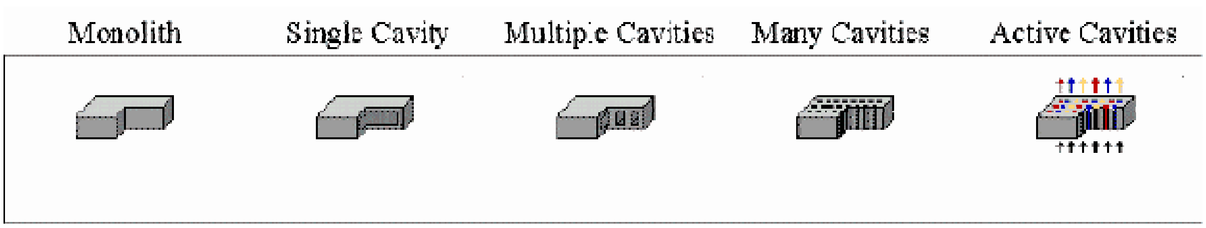

Figure 2: Altshuller's 'Space Segmentation' Evolution Trend
(figure based on TechOptimizer output)

In both instances, TRIZ has vividly replaced the somewhat nebulous ideation stage in the Suh description with a systematic solution synthesis.

Once derived, Suh demonstrates (albeit extremely briefly) how the Axioms may be used to determine that the microvoids solution is a good one and, perhaps more importantly (in Chapter 6) how the axiomatic approach may be used to quantitatively establish the most appropriate size and volume fraction of microvoids for the detailed, final solution. In this way, Suh's approach may be seen to be complementary to TRIZ: TRIZ equals synthesis tool, Axiomatic design equals analytical tool.

The Wright Brothers and Freezer Doors

Problem definition is everything. According to Suh, the key to successful problem definition is the formulation and minimisation of Functional Requirements. He cites birds' wings as an example. Birds' wings have to satisfy many FRs; vertical take-off, horizontal take-off, climb, dive, cruise, hover, pitch, yaw, roll, retract, provide thermal insulation, etc. Initial human attempts at flight looked to mimic the bird wing design. They failed to recognise that not all of the bird wing FRs were required to achieve flight and hence they failed to fly. Suh suggests that the genius of the Wright brothers was in minimising the number of FRs to only those necessary for near-horizontal take-off, slow cruise speed and limited need for change in direction.

In many senses, this minimization of FRs is a solid test of 'good' design. It is however not the whole story. It is not the whole story for two important reasons:-

1) It fails to recognise evolutionary trend towards increasing 'value' or 'ideality' (Miles, Reference 2); minimising the number of FRs might be the only way to achieve *any* form of solution – as was the case with the Wright brothers - but as capability increases, so we will seek to introduce more FRs in order to increase customer 'value'. For example, sticking with the case of wing design, think of the evolution from the Wright brothers effectively fixed wing (i.e. their use of 'wing-warp' was (understandably) crude), to simple flaps, to complex multi-flap designs, to swing wing aircraft, to smart structures, etc (NB note also the 'Dynamisation' evolution trend – Figure 3.)

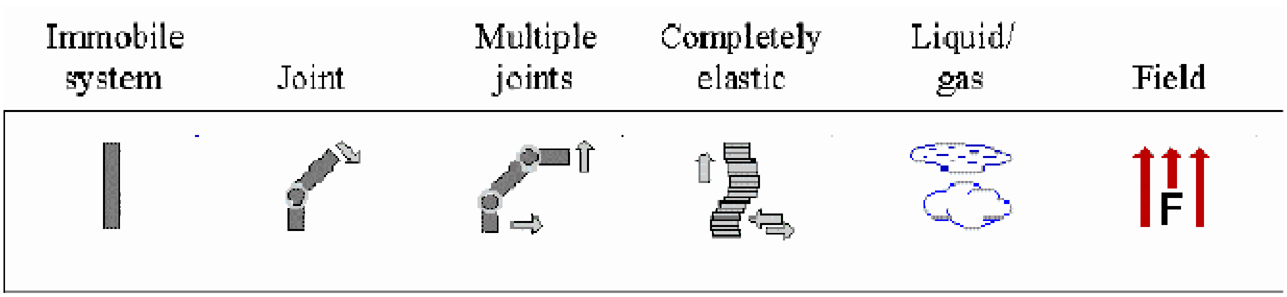

Figure 3: Altshuller's 'Dynamisation' Evolution Trend
(figure based on TechOptimizer output)

2) It fails to recognise the 'delight' aspects when a customer buys a product to do

one thing and later finds out it can also do something else as well.

When we reduce the FRs to a minimum (or simply define them inappropriately) - as in Suh's example of freezer door design; where the Requirements are reduced to 1) minimise energy (cold air) loss, and, 2) provide good access - we may well actually be shutting ourselves off from a significant sector of the actual customer base.

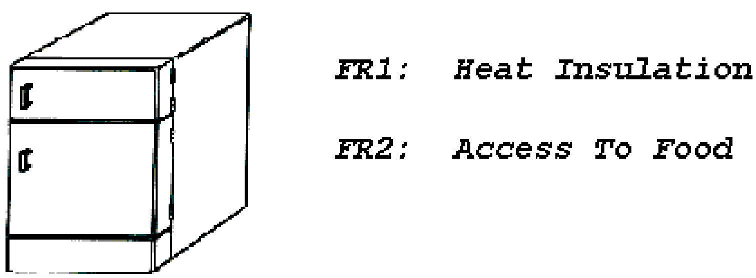

Figure 4: Nam Suh's 'Bad Design' Freezer

Of course, the freezer design case cited by Suh is merely used as a convenient demonstration of his idea of Functional Requirements. In the real world of very high levels of competition and consumer choice, however, when he describes the vertical hinged door as 'bad design' because it does not meet his FRs, he is failing to recognise that they actually might well not be the most important requirements. Or that a very large proportion of freezers sold are of the vertically hinged variety.

The 'customer delight' aspect is also interesting. "Good design is about giving customers what they want. Great design is about giving customers what they didn't expect" to quote Tom Peters (3). A great example of a product which turned out to offer customers something they did not expect is the AV-8B (Harrier) vertical take-off and landing (VTOL) aircraft. The Harrier was –and, thirty years later, still is – a great aircraft. At least a small part of its longevity is due to the realisation some considerable time into it's service life that if pilots used the swivelling nozzles during flight (as well as for the initially designed vertical-to-horizontal flight transition functional requirement), they were able to produce manoeuvres capable of defeating just about any kind of enemy threat: 'Vectoring In Flight' – VIFing – an unexpected additional functional capability.

Problem definition continues to be the single greatest challenge facing designers. The TRIZ 'Ideal Final Result' philosophy (References 4 and 5) is perhaps one of the more effective and practical methods available, although, as we shall see later, the appropriate definition of FRs can offer new problem solving insights in certain regards.

Wheel-Covers

The Suh book contains many examples of use of the Axiomatic design analysis approach. While the main purpose of the examples is to demonstrate the underlying principles of the AD methods, they, unfortunately, do not always demonstrate his stated belief in the importance of effective problem definition. The example of the wheel-cover design (pp289-93) is one such case. More interesting than simply providing a demonstration of how the axiomatic approach may be used to find a good ('right') answer to the wrong question, however, is the role it might help to play in highlighting both the power inherent in the TRIZ methodology and the future potential for integration between the two approaches.

The example comes from work done at General Motors. Back in the early 80s, the book records, the designers at GM had a problem with wheel covers. GM wheel covers at the time were held on by simple spring clips. The problem the designers faced was that, if spring force was too small, the wheel covers fell off, and, if the spring force was too high, vehicle owners found it difficult to remove the cover when a wheel change was required. Suh's book describes the high degree of scientific rigour and customer focus employed by the GM designers during the search for a problem solution: They conducted a series of sophisticated customer trials using wheel covers with different spring forces and systematically measured how satisfied the customers were with each of the different cases. The results are summarised in Figure 5. Very simply, they found that 100% of customers were satisfied from the perspective of ease of cover removal if the force required to remove the cover was 30N or less, and that 100% of customers were happy that their wheel-covers wouldn't fall off if the retention force was 35N or more.

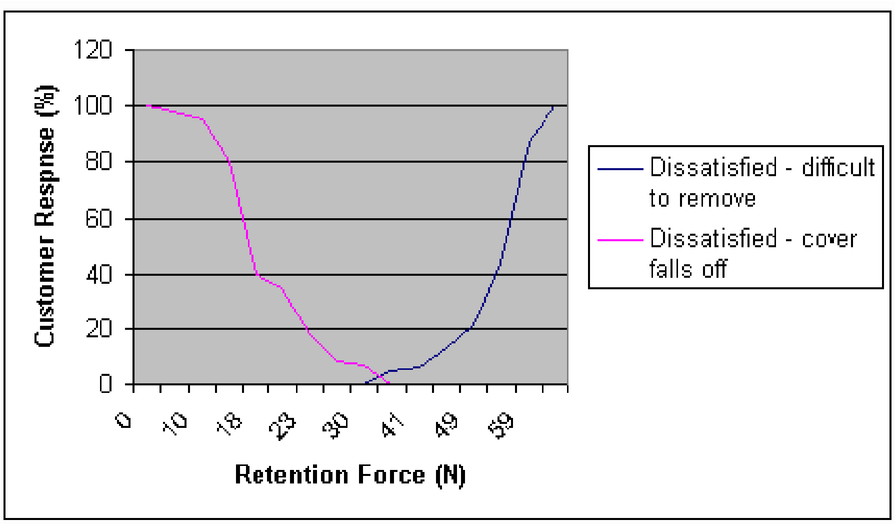

Figure 5: Wheel Cover Retention Force Design Point Selection

As well as being customer focused scientists, the GM designers are also shown in the book to be very much cast in the non-TRIZ 'design is a trade-off' mind-set. Given the customer data, the 'design-is-a-trade-off' mindset says that the 'optimum' spring retention force needed to be somewhere between 30 and 35N. Being scientists, they also recognised that mass-production would mean some statistical variation in the achievable spring force. The Functional Requirement for the wheel cover spring design, therefore, became '*Provide a retention force of 34±4N*'.

In non-TRIZ terms, they had done the best they could. In effect they had come up with a solution which was 'optimum' because it dis-satisfied the minimum number of customers. In fact, their data had shown that a 34±4N solution would dis-satisfy somewhere between 2 and 6% of their customers. Or, put another way, probably somewhere around 100,000 per year.

Suh's analysis of the problem is subsequently somewhat complex, but nevertheless shows how the axiomatic approach was able to best tune the design variables to achieve the defined Functional Requirements.

TRIZ, on the other hand, would immediately identify the GM wheelcover problem as a design contradiction. The TRIZ approach is built on a 'design without compromise' philosophy. It is about eliminating contradictions rather than accommodating them. The contradiction present in the wheelcover case is a Physical Contradiction. It is a physical contradiction because the wheelcover retention force is required to be be HIGH (to retain the cover) AND LOW (to make it easy to remove). Altshuller and his team's analysis of the patent database has allowed us to see how inventors across all industries and specialities have successfully eliminated such contradictions. A very good summary of principles for eliminating Physical Contradictions may be found in Reference 6 (page 176). The wheelcover example quickly reveals itself to be a physical contradiction in which we might seek to separate the contradictory requirements in TIME – i.e. we would like the retention force to be HIGH when the car is in motion, and LOW when the car is stationary. Specific TRIZ Inventive Principles, then, recommended to solve problems of the wheelcover 'separation in time' type, include:-

- 'Preliminary Action' (e.g. push-and-twist type wheel covers)
- 'Taking Out'/'Combination' (e.g. eliminate the spring and use some other means of holding the wheelcover – e.g. Peugeot sometimes use the wheel-nuts to hold the cover as well as the wheel - or eliminate the spring altogether – e.g. alloy wheels (the wheel is the wheel-cover))

In other words, the GM designers were using Suh to optimise the wrong design. The 'right' design – according to TRIZ – is the one which eliminates the trade-offs rather than seeking to balance between them. The 'Contradictions' parts of TRIZ provide designers with a systematic approach to finding means of eliminating those contradictions.

The Axiomatic approach may have some use in **analysing and optimising** the conceptual solutions derived from TRIZ in some cases. In a simple case like the wheelcover, it is perhaps difficult to see what additional benefits the Axioms might bring. Moving along to look at the AD/TRIZ connection story from the perspective of how Axiomatic Design might be usefully applied to help produce a 'better' TRIZ solution, however, we can see that this need not always be the case.

Pizza Box

US patent 5,472,139 is a commonly cited example amongst TRIZ users of the 'geometric evolution of linear constructions' technology evolution trend. The patent uses the trend as the basis for contouring the base of a pizza box in order to introduce thermally insulating air-gaps between the pizza and the base of the box – i.e. a harmful planar contact surface will evolve towards a line-based contact (and ultimately towards a point-based contact). A sketch of the pizza box design is illustrated in Figure 6.

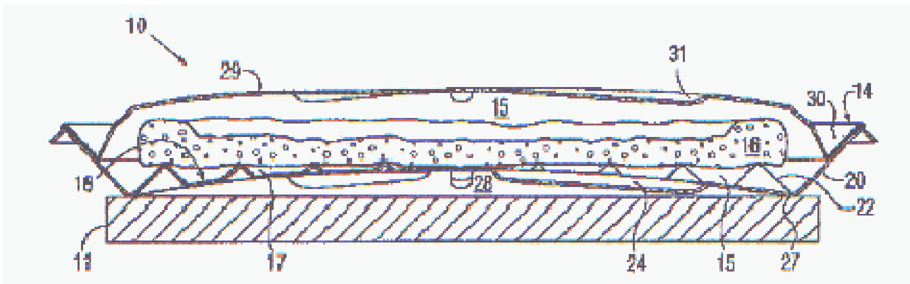

Figure 6: US Patent 5,472,139 Pizza Box

The basic idea of the patent is to improve the heat retaining properties of the box such that the pizza stays hotter for longer.

In terms of Axiomatic Design, the invention sees the introduction of a Functional Requirement 'improve heat insulation' to the basic pizza box FR of 'protect pizza'.

A more complete functional analysis of the pizza-box using Suh's approach, however, might well also register the presence of a Functional Requirement to be able to slice and serve the pizza direct from the box. The 5,472,139 invention has not been conceived with this requirement fully in mind (NB despite the fact that the invention is an upgrade of a previous patent by the same inventors incorporating changes specifically to try to improve 'slice and serve' performance). The simple fact is that the contoured base of the box is not amenable in a sufficiently practical sense to the use of a cutter to slice *in situ* pizza.

The pizza box example demonstrates the importance of identifying all the necessary FRs to be achieved in a given design. Suh's Axiomatic Design methods, while not always able to help identify what 'all' means – Suh in fact recommends QFD for this task – can be very usefully employed to ensure the chosen FRs are independent and thus consistent with good design practice. Alternatively, perhaps it is sufficient that AD forces designers to give the matter of Functional Requirement definition due consideration.

More Complex Designs

In more complex cases, there is not yet a substantial enough database of examples to enable any firm conclusions about the benefits AD might bring to a TRIZ-based design approach to be made. Preliminary evidence, however, suggests that Suh's analytical methods do complement the synthesising capabilities of TRIZ in at least three significant areas:-

1. a very important philosophical aspect of AD is that there exists a necessary process of iteration between FRs and physical design attributes. In other words, it is not sufficient to simply define a set of Functional Requirements and then set about the process of translating them into Design Parameters. The method says that if we are to achieve 'good design' – i.e. design satisfying the two Axioms – the Design Parameters must be allowed to influence the form and content of the Functional Requirements.

2. Perhaps the most significant difference between AD and TRIZ becomes apparent when considering the hierarchical nature of design problems. Aspects of this difference may be seen in a previous discussion regarding the design of a helicopter particle separator (Reference 7). Basically, meanwhile, AD places careful emphasis on the importance of recognising the hierarchical nature of design, and particularly to ensuring that the process of iteration between Function Requirements in the Functional Domain and selection of Design Parameters in the Physical Domain (shown as the green arrows in the following figure) is carried out in a systematic manner.

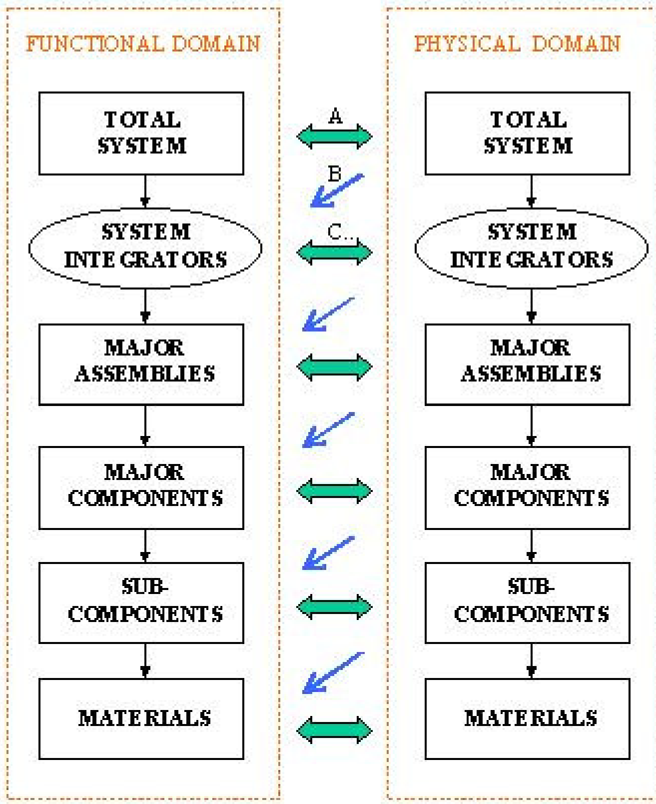

Figure 7: Hierarchical Nature of Functional Domain – Physical Domain Mapping

As may be seen in Figure 7, this systemisation occurs through an essentially top-down approach; definition of System Level FRs permits derivation and iteration of System Level DPs (green arrow 'A') and then – most importantly – definition of the System Level DPs is necessary before FRs at the next level down in the hierarchy (blue arrow 'B') may occur; and so on right through each level of the hierarchy. In effect, AD suggests that finalisation of top level FRs can only really be achieved after each layer of the problem hierarchy has been given due consideration and iterated accordingly.

3. As well as recognising the relationship between Functional Domain and Physical Domain, Suh further extends the AD model to include what he describes the Process Domain (Reference 1, Section 4.10). In other words, AD demands that manufacturability issues are given appropriate consideration **during** the process of iterating to achieve the most appropriate form of the design Functional Requirements (i.e. we might add a third 'Process Domain' column to Figure 7 above).

It would appear that Axiomatic Design has much to offer TRIZ in terms of providing a better understanding of both the hierarchical nature of design **and** the need to pay due attention to the inter-connections which exist between successive hierarchical layers. A future article will examine how such a process can be made to work for a real design problem.

Conclusions

1. From an Axiomatic Design perspective, TRIZ fits very elegantly into the 'Ideate and Create' element of Nam Suh's map of the design process.
2. From a TRIZ perspective, Axiomatic Design offers the potential for improving the problem definition and problem solving processes through Axioms offering means of assessing the effectiveness of a design concept, and new perspectives on the specification of functional requirements and the handling of multi-layered problems.

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