INTEGRATIVE AXIOMATIC APPROACH TO DESIGN

By Jean Le Mee

The present paper builds on the Axiomatic Approach to Design proposed by Nam Suh and Associates at M.I.T. It establishes design within a philosophical framework. Making use of concepts developed by the grammarians of Sanskrit, it brings into view all the factors involved in the design process in a simple and ordered manner. It should prove particularly useful in teaching design at all levels and in conducting studies in the philosophy of Technology.

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1. Introduction

An axiomatic approach to Design has been proposed by Nam Suh and Associates at M.I.T. The present paper builds on this approach and provides a wider framework for its development and applications.

2. Need for a Wider Framework

The evolution of science in the last fifty years has shown that to be able to account for physical phenomena the presence of the observer/experimenter cannot be ignored. Science is a human activity and, as physicists have discovered, cannot exclude the scientist. Even more than Science, perhaps, Engineering Design is a human activity having a social dimension and cannot _a fortiori_ ignore its human origin and purpose. The question is: How can the "human element" be introduced in it? Let us consider the design process.

3. Definition of Design

Many definitions have been proposed for design. In essence, designing is providing a set of prescriptive rules for reorganizing the elements of creation according to some purpose. It begins with an idea and ends up with a product. But note that with the product, planning for distribution, use, retirement and eventual recycling should be included according to Asimov's morphology of design. [1] The product itself may be physical such as an object

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(chair, table, engine etc...) or a process (electrical current, pneumatic pressure, chemical reaction etc...) It may also be another idea or ideas which find embodiment in a procedure, an organization or a system including people, information, machines, all interacting together. In fact, design is a "way of doing things" which is applicable to all purposeful, "thought-out" activities. It is characterized by decision making. A philosophy of design is therefore essentially a philosophy of human action.

In the context of Axiomatic Design, design may be formally defined (Suh) as "the creation of synthesized solution in the form of products, processes or systems that satisfy perceived needs through the mapping between the functional requirements (FRs) in the functional domain and the design parameters (DPs) of the physical domain, through the proper selection of DPs that satisfy FRs". [2]

The design process can therefore be seen as an interaction between three levels of activity: A conceptual level (the functional domain) where desired values, under the form of specifications for the design are elaborated and from which the functional requirements are selected; a physical level (the physical domain) where the design parameters are embodied, and an intermediary level where decision regarding the design, the matching or mapping of the conceptual level unto the physical level takes place. This latter level is normally that of the mental activity of the designer but can also be that of an Artificial Intelligence machine. This matching requires interaction and iteration between these levels until a satisfactory (optimal) match is achieved. Now, there exists a paradigm matching this process exactly.

The Sanskrit philosophers of grammar attribute levels to language which perfectly match the design domains. They distinguish a physical level (Vaikhari) where sounds are produced and heard, where the "design parameters" of the language (e.g., choice of

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words, forms, etc.) are embodied. Next, they consider a conceptual level where the "seeing", the inspiration, the idea, thought or feeling occurs, a "functional domain" so to speak that they call pasyanti (The Seeing One). Linking both is an intermediate stage (called madhyama, the "middle one") where the translation, the mapping of the pasyanti (the functional domain) into the vaikhari (the physical domain) occurs through the rules of the particular language spoken.

In a sense, we are therefore all potential designers, designing sentence after sentence, but rarely, save in exceptional occasions, do we consciously design our utterances. Much the same can be said about technical design. This correspondence between seemingly so diverse fields should not be surprising since language, being the very articulation of thought, is at the core of the design process. The fundamental rules of language must, therefore, be the fundamental rules of design. The creative process is the same essentially in all human activities. That the product of design be a sound time-series, a two-dimensional display of graphical clusters, a three-dimentional object or any kind of system or process is not essentially relevant. <u>In all cases, it is a re-ordering of the elements of creation according to some purpose</u>, as we previously noted; and though the superficial properties of the objects involved, and of th^u^^(^u^s^r^*tionships may differ according to their respective natures, in each case, the "deep structure" of the design-act remains the same as postulate 3 and 4 and their corollaries will establish in what follows.

Suh emphasizes the importance of problem definition (a linguistic act) and therefore of the choice of the functional requirements: "The final design cannot be better than the set of FRs it was created to satisfy." [3]

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The first and primary function of the Designer is, therefore, the selection of FRs": "The choice of FRs depends on the way in which the designer hopes to satisfy a set of needs." [4] This, in turn, implies that s/he is able to adopt a _viewpoint_ from which these FRs can be selected. To select a viewpoint, one needs, of necessity, a clear conception of who and where one is. It is elementary and fundamental. But, because it is generally taken for granted and thus remains unexamined, a great deal of confusion and incoherence results. We must, therefore, begin at the beginning.

4.   Development of the integrative design postulates.

For anyone, including a designer, the beginning is always some form of the Cartesian Cogito. Descartes stated: "I think, therefore I am".   Nevertheless, he was quick to add: "I very clearly see that, to think, one has to be."   And indeed this very simple evidence that "I am" ought to be taken as the very basis of the science of design, or, in fact, of any science or human activity. We therefore begin by:

Postulate 1: I am.
This simple statement is the foundation of the realization of consciousness and of language. It is at the foundation of all the great traditions.

This being the basis of all our experiences, thoughts and actions, it first follows that:

Corollary 1.1. I am a witness.
Thoughts, perceptions, feelings, actions occur within the field of my awareness.

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Therefore,

Lemma 1.1.1. I have a viewpoint.

This viewpoint changes with my level or sphere of awareness
or of understanding and my function. Five such levels can
be recognized, each governed by certain values as shown on
Table 1.

Not only do I perceive, feel and think, but I can act.
Therefore:

Corollary 1.2: I am an agent.

Through communication (speech, writing etc...) and/or direct
action I can influence my total surroundings.
It therefore follows that:

Lemma 1.2.1: I have a standpoint [for action].

This standpoint is defined by my function with respect to
a particular action. It governs the reach of my authority.
This reach, in both time and space (history and geography),
this sphere of action, may extend from instant to millenia
and from myself and my immediate surroundings to the whole
creation and to time constants of the order of the history
of mankind. One need only compare the design of a door
knob for instance and that of a hydrogen bomb or a nuclear
reactor to see the point (see Table 2). Note that Time and
Space - History and Geography - as the "horizontal plane"
where human action (i.e. Design in our case) takes place,
is crossed "vertically," so to speak, by the plane of
"values" which thus confers on time and space physical,
psychological, intellectual, moral and spiritual
dimensions.

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Note also that the function of the agent is, of necessity, exerted within the same hierarchy of values as those determining the viewpoint, though, of course, the particular values allowed by "my" agency may be different from those chosen by me as witness. In other words, the reach of my authority (standpoint) may be quite other than the reach of my viewpoint. This, naturally, gives rise to ethical and moral considerations.

Postulate 2: Action is a process leading to a result.
This apparent statement of the obvious is necessary to clearly distinguish this dual aspect of action.
It is, of course, also essential in linking an action to its consequences and in exploring those consequences at the design stage.

  Corollary 2.1: The result of an action at time t is the state of the process at time t.

    Lemma 2.1.1: The state of a process at a given time is characterized by a list of identifiable parameters (state vector).

  Corollary 2.2: Actions can be embedded within one another (e.g. drafting, calculating, telephoning, are embedded with Designing).

Postulate 3: Any action necessitates the presence of entities called "Factors of the Action" (Karakas).
In terms of axiomatic design, for instance, there must be a designer who carries out the design, a set of functional

requirements (FRs), a set of design parameters (DPs), a set of
constraints, etc...

      Corollary 3.1: The factors of the action can only stand in
six different types of relationships with respect to the
action.

o These relationships are explained by definitions of the factors
of the action to follow.

o The theory of the factors of the action (Karakas) has been
elaborated by the Sanskrit grammarians of the Paninian School.
These factors correspond to what Chomsky [5] considers the "deep
structure relations" of language.

The six factors of the action, which can be viewed to stand in
relation to the action as shown on Fig. 1, are now given with their
Sanskrit names and English equivalents. Their definitions specify
their functions relative to the action [6] [7] [8].

(1) Apadana: This factor of the action is the fixed point in
relation to moving away, the point of departure. At the beginning
of the design process, it is the set of functional requirements
(F.R.s). The functional requirements are the specific requirements
which spell out the design objectives.
     To satisfy these F.R.s, a physical embodiment characterized in
terms of design parameters (D.P.'s) must be created.

(2) Karman: The Object, is the item or the participant in the
action which the agent most seeks to reach. In the context of
Axiomatic Design, it is the set of design parameters (D.P.s). The

design process involves relating the F.R.s of the functional domain to the D.P.'s of the physical domain.

(3) <u>Karana</u> : <u>The Instrument</u>, is the most effective means of accomplishing the action. In the context of Axiomatic Design, it is <u>the</u> <u>mapping</u> <u>process</u> matching the functional requirements onto the design parameters.

(4) <u>Adhikarana</u>, or <u>Locus</u> is the location or substratum delimiting the field of action. In the context of integrative axiomatic design, it is a <u>set of constraints</u>, technical, economic, ecological, political, societal, human, chronological, etc... which come to bear during the life of the design from conception to retirement, disposal and eventual recycling. As we shall see later, they can be formed in three groups:

- o Input constraints which are constraints in design specifications.
- o System constraints which are imposed by the system environment in which the design solution must function (e.g., laws of nature, capacity of machines, etc...).
- o Human constraints pertaining to agent (and recipient) states of knowledge, viewpoints, standpoints, ethics, etc...

(5) <u>Sampradana</u>: is the <u>recipient</u> of the action, the beneficiary (client) of the design. It is formally defined as the item or participant the agent (designer) has in view through the object (F.R.s) of the action. In the above example, it might be the machine shop (or the person in charge of it) who will receive the complete drawings and specifications for the "better shaft".

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Alternatively, it could be the bearing that will support the shaft manufactured out of the piece of forged steel we started with.

(6) Kartr/Hetu: the _agent_ is the participant in an action which, relative to others, is _independent_. In the context of integrative axiomatic design, it is the designer, or ultimately the person or entity sponsoring the designer.

We shall come back to the study of these factors in time.

> Corollary 3-2: In a given action (design) the determination of the factors of the action depends on the viewpoint of the witness.

The viewpoint is governed by the level or sphere of awareness of the witness as indicated in Lemma 1.1.1. It is the ethical and professional responsibility of the witness to establish the appropriate viewpoint for the proposed action (design).

It is important to note that nothing is predetermined to be a particular factor of action but becomes this or that according to the viewpoint in relation to a particular action only. Thus the machine shop manager may be the _recipient_ of the design process as well as the _agent_ of the machining process. A milling machine might be considered the recipient of a transfer process as well as the instrument or even the agent or the locus for a milling process, depending on the viewpoint. The factors of the action are therefore very flexible semantic categories.

> Postulate 4: Among the factors of the action, only one of them is independent with respect to the action considered. This independent factor is called the agent.

Being independent with respect to the action means that the agent carries responsibility (response - ability) for the action (satisfying the recipient by fulfilling the object of the action).

The extent of the agent's responsibility is equal to the reach of his authority and is defined by his sphere of action as indicated in Table 2.

Postulate 4, stating the independence of the agent, implies that the agent is ultimately a conscious being.

In some cases, it may be convenient to consider a machine, program, tool etc... to be an agent with respect to a function performed by that machine, program, tool, etc. (e.g., the automatic pilot is "responsible" for maintaining speed, direction, altitude of the aircraft). However, there is always a person somewhere who is the "true" or "free" agent and is held accountable - (automatic pilots take their stands in courts only as exhibits!)

In the design process that we are considering here, the agent is the designer. Should he use a decision-making machine, that would simply be an instrument (Karana) with respect to the process of design. Should he be working for an agency, a firm or on order from others, he remains the agent, but of an attenuated grade so to speak.

The ancient grammarians of the Paninian School make this distinction clear by having two different names for the agent. In a sense, they consider two grades of agents:

o   When the agent (that we might call the "direct agent") acts alone completely independently and freely with respect to the action, the name Kartr (doer) is used.

o   When the [direct] agent (Kartr) is "incited" to action by another, for that other, that we might call here the Tele-agent, the name hetu (incitator) is used.

e.g. 1- The machinist turns a shaft.

2- The shop-floor manager orders the machinist to turn the shaft.

In 1., _machinist_ is the direct agent (Kartr)

In 2., _shop-floor manager_ is the tele-agent (hetu).

Assuming, therefore, that the primary functional requirements have been established, and following Lemma 1.2.1 and postulate 4, a _standpoint_ must be realized before the agent can proceed with the design. Therefore:

Lemma 4.1.1: Acknowledging himself as the agent, the agent takes his stand with respect to the action (design).

His function is to "most seek to reach" the functional requirements that satisfy the recipient.

The design can then proceed according to Suh's axioms 1 and 2 and the relationships defined by the other factors of the action.

This means that the following imperatives obtain:

Axiom 1: Maintain the independence of the functional requirements. (Suh.)

Axiom 2: Minimize the information content of the Design. (Suh.)

and, from the definitions of the factors of the action given in corollary 3-1, the following additional ones:

Corollary 4.1: Keep the recipient in view through the functional requirements (Sampradana).

<u>Corollary 4.2</u>: Select the most effective Design Parameters to satisfy the functional requirements (Karana).

<u>Corollary 4.3</u>: Respect the constraints. (adhikarana).

Note that Lemma 4.1.1 states, in fact, the step that public officials are asked to take before they assume their function (e.g., the President [Kartr] takes his stand and swears to uphold the Constitution [Karman] for the benefit of the people [Sampradana]). This step is always recognized as very important and is usually set out in some ceremonial (ritual) such as "taking the oath of office", "inauguration" for public servants, or, in business, signing of a contract, accepting a charge or commission, etc.

The choice of the functional requirements (FR's) is the formalized result of the perceived needs. These needs are those of the recipient (client, customer: the sampradana) who is the beneficiary of the design. (In our previous example, the machine shop manager or the bearing.) The perception of these needs is the result of an observation from a certain viewpoint according to Lemma 1.1.1. This viewpoint sets the scope of the design according to corollary 3.2.

When the agent is also the recipient, the action is said by the grammarians to be reflexive (atmanepada, i.e., for self). When the agent and the recipient are distinct, it is said to be transitive or active (parasmaipada, i.e., for the other).

Although Suh's axiom #2 is only concerned with the manufacturing phase, it can be extended through corollary 4.2 to encompass the whole life cycle of the design, from natural resources back to recycling. Design being a reordering of the elements of creation according to some purpose (the Fundamental Requirements spell out that purpose), <u>the most effective Design Parameters will</u>

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be those achieving the purpose (satisfaction of the FR's) with the minimum of reordering along the whole life cycle of the design. Therefore, the Design Parameters chosen will have to be those requiring that the minimum amount of order (information) be put into the design. In accordance with the Second Law of Thermodynamics, which essentially states that increasing order within a system requires decreasing it in the surroundings by an amount even greater, it follows that the most effective Design Parameters will be those which minimize the amount of disorder (entropy) put into the surroundings (environment); in other words, "best design is least design."

Corollary 4-3 is concerned with the constraints imposed on the solution. In the context of axiomatic design, these constraints are of two types (Suh) [10]:

o Input constraints which are constraints in design specifications, in our case, could be constraints on the initial conditions, e.g., using forged steel bar for the shaft rather than stock.

o System constraints which are imposed by the system environments in which the design solution must function, e.g., capacity of manufacturing machines, laws of nature, physical, biological, social environments etc...

Integrative Axiomatic Design brings in explicitly another set of constraints pertaining to the designer (agent). These are of an intellectual, professional, ethical and moral nature and follow from the responsibility the designer carries with regard to the consequences of his actions and decisions.

Naturally, the various constraints are not necessarily independent of one another. They are indeed often related. The imperative is to minimize the unwanted effects on these environments of the design integrated over its projected life cycle.

5. Conclusions

We have sketched out an approach to an integrative axiomatic approach to design. It provides a framework to practice design which brings into view all the factors involved in the process in a particularly simple and ordered manner. By making explicit the concept of viewpoint in the selection of the functional requirements, and that of standpoint in the function of the designer, it allows for the introduction of ethical and moral principles in a natural way. By defining design as a reordering of the elements of creation according to some purpose, it allows for a generalization of Suh's axiom 2 and makes possible the optimization of design within the framework of the Second Law of Thermodynamics. It should prove useful in teaching design at all levels.

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10. N.P. Suh, op. cit. p. 39.

Caption for Tables

Table 1: Levels of Awareness and Their Governing Values

Table 2: Spatio-temporal Spheres

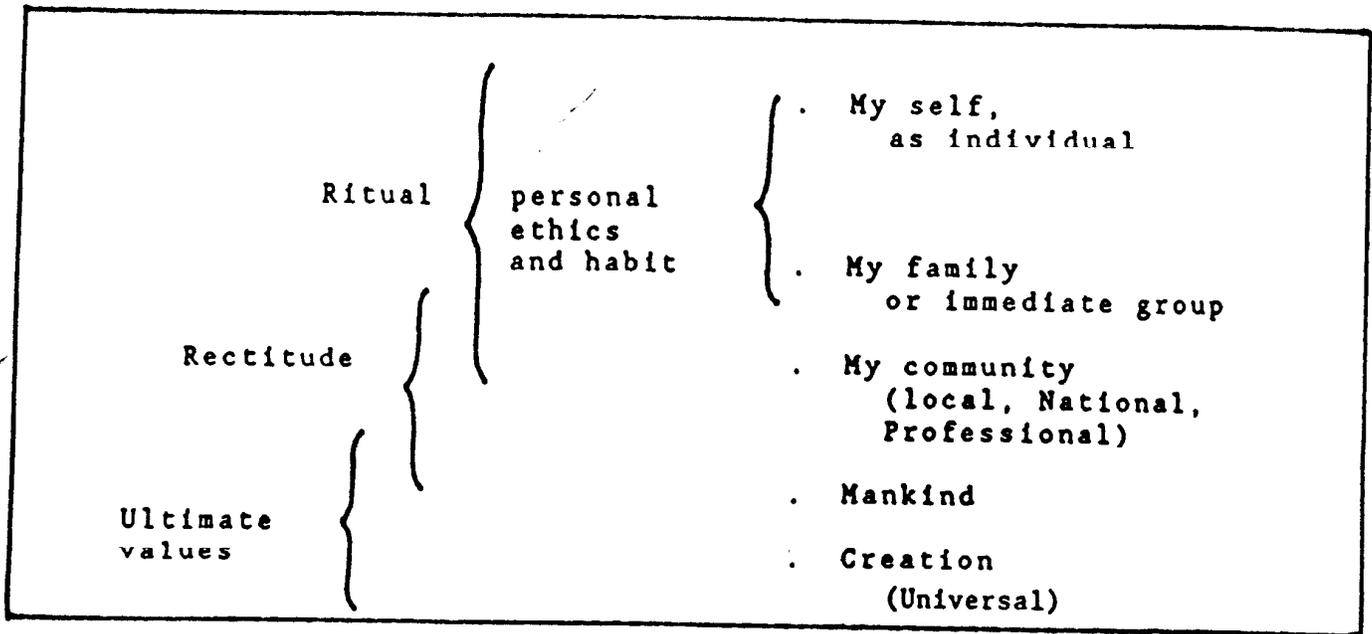Table 1: Levels of awareness and their governing values

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                                          ⌠ ·  My self,
                      ⌠                    |       as individual
            Ritual   ⌠  personal          |
                     |  ethics          ⟨
                     |  and habit         |
                     |                    ⌡ ·  My family
          Rectitude ⟨                          or immediate group
                    |
                    |                       ·  My community
                    |                            (local, National,
         Ultimate  ⟨                               Professional)
         values                             ·  Mankind

                                            ·  Creation
                                                 (Universal)
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Table 2: Spatio-Temporal Spheres

Time Constants (years)	Geographical Radius	Typical Artifact	Typical Values	Governed by
10^{-1}	Local	Disposable items,	Personal Habits	
10^{0}	Regional	Consumer Goods.	Social interactions and habits	Habit
10^{1}	National	Highway Networks, Railroads, Factories, Infrastructure.	Patriotism. National Law, Trade, Culture	Ritual
10^{2}	Continental	Cities, Great Buildings.	Principles of Law and Government Nature of Society	Rectitude
10^{3}	Global	Pyramids, Cathedrals, Nuclear devices.	Great Traditions	Ultimate Values