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Ideality in Axiomatic Design and beyond

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Abstract

AD helps to conceive controllable and manageable designs, beyond fulfilling initially posed requirements. According to authors' experience and understanding, this eases the evolution of designs towards their future versions. Thus, ideal solutions according to Suh's theory are characterized by a considerable capability of evolving and accelerating technological progress. Conversely, such an aspect is seldom considered in the most diffused definitions of ideality, although it can be easily regarded as a fundamental feature of good designs. In this context, the paper reviews the definitions of ideality dispersed in the literature. A particular attention is dedicated to TRIZ, since ideality represents a pillar of the former USSR-originating theory and many attempts have been performed to combine it with AD. The paper explores the compatibility of the surveyed definitions with AD objectives, revealing theoretical pitfalls, but also pointing out opportunities for increasing ideality in the design practice.

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Keywords: Ideality; Axiomatic Design; Design Theory; TRIZ; Modularity

1. Introduction, objectives and structure of the paper

The literatures documented a large number of theories, methods and tools to support engineering design and the development of new and better concepts in particular. By limiting his efforts to the most significant contributions, Horvàth [1] attempts to organize the plethora of existing methodologies and highlights their different objectives and roles in the design field. The way of thinking behind Axiomatic Design (AD) belongs to the most meaningful theoretical frameworks, although objections are not lacking. Previous authors' work [2] has been addressed at analyzing AD's affinities and incongruence with other design theories, by articulating and critically discussing insights from dispersed literature. A different result-oriented approach is employed in the present paper in order to define constraints of AD application and inherent strengths and weaknesses of design outcomes provided through strict adherence to AD principles.

In other words, the objective of the article is providing major understanding about the peculiarities of the designs AD intends to deliver and compare them with solutions addressed by other theories and methodologies. The paper analyzes first which are the circumstances in which AD displays maximum benefits. Subsequently, the manuscript attempts to point out the peculiar traits of designs developed by means of AD or that, at least, fulfil the axioms. These designs can be considered as ideal targets of AD application. An overview of ideal systems shaped by other theories and methodologies is illustrated in order to point out similarities and different scopes of conceptual design techniques with respect to AD.

The paper is structured as follows. Section 2 provides an overview of AD's domain of application and the kind of solutions that are generally achieved, meant as goals of AD employment. Section 3 describes the concept of ideality as it is interpreted in the Theory of Inventive Problem Solving (TRIZ) and in other contributions from design literature. While Section 4 attempts to draw a comparison between different meanings of ideality, Section 5 concludes the paper by introducing further discussion and outlining future authors' work.

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2. Outreach of Axiomatic Design: applications and solved problems

The articulation of AD foresees a cascade process, through which designers use the Independence Axiom and the Information Axiom sequentially. To this regard, it seems reasonable to assess that the diffusion of the former is widely greater. Many AD beginners are exposed to the one-to-one logic (mostly between Functional Requirements and Design Parameters) that urges to separate function carriers with the aim to avoid tangled interrelations. The classical faucet example is well tailored to demonstrate the applicability and the value of the first Axiom. However, AD's outreach cannot be restricted to the Independence Axiom and to its corresponding principles. Additional information about the impact of the whole AD corpus on design thinking can be achieved through literature sources.

According to authors' knowledge, [3] represents the most recent contribution in which the use of AD has been surveyed and analyzed. Indeed, while [4] just presents a general overview of the industries and application fields in which AD is adopted, [3] allows to understand which AD-oriented practices result the most successful and diffused. In principle, the mentioned study highlights the overwhelming majority of case studies in which just the Independence Axiom is used. More seldom, the Information Axiom is employed as a support for decision-making, but no manuscript actually documents the full procedure prescribed by AD theory.

By delving into product design examples presented in [3], it is possible to assess that the main drivers and targets of AD are constituted by the followings:

- Simplification and decomposition of complex systems;
- Optimization tasks conducted to maximize/minimize certain effects with the recurrent goal of enhancing operability and safety.

These kinds of design tasks are consistent with the scopes of AD theory largely.

The former mirrors the wide application of Independence Axiom and AD capabilities of decomposing problems and/or product architectures. The definition of complexity and its classification are actually undergoing fundamental research, also within AD community, e.g. [5]. A precise and formal definition of complexity falls outside the scopes of the present paper, which will use an intuitive meaning that involves e.g. the number of parameters and components and the existence of tangled interrelations. From this viewpoint, AD supports the creation of functional modules, as in [6]. Besides being quite logic, the link between modular design and AD is acknowledged in the literature [7-9], as independence is fulfilled through the introduction of different specialized sub-systems. It should be noted, however, how modularity and the consequent increase in the number of parts is not the only strategy that allows for the generation of systems that comply with the Independence Axiom. [10] remarks that the search for new Design Parameters that contribute to fulfil Functional Requirements can take place by exploiting features and characteristics of existing components.

With reference to the latter, the term "optimization" is widely employed in the design field, as the process of fine-tuning the functioning of a new product or system in the detailed design phase. The meaning to be intended here diverges from the above concept. Indeed, Axiomatic Design is classically employed in early design stages, mainly conceptual design [11, 12]. Hence, the term "optimization" has to be considered in this context as the process of devising the system in order to achieve functions with expected performances in an easy, controllable and repeatable way. Despite the use of Information Axiom is not widespread, these design objectives mirror its goal at least from a theoretical perspective. Indeed, the second Axiom takes into account the probability of fulfilling the intended functions that are associated with alternative independent systems. Besides, concepts such as "controllability" [13, 14] or "target value" [12, 15], i.e. optimal measures for a given parameter/function, are frequent in the literature that describes AD applications or design objectives.

As a result, it is possible to infer that designed ideal systems, according to AD principles:

- are suitable for achieving the desired target performances;
- are scarcely affected by sensitivity effects, as controllability ranges between the core objectives;
- replace existing ones by diminishing complexity through the separation of function carriers, by benefitting from the indications of the Independence Axiom.

In a graphical format, Fig. 1 describes the expected system transition. In the illustration, FR and DP stand for the overall set of Functional Requirements and Design Parameters, respectively. The recalled example of the faucet is paradigmatic in this sense, as both the target values of flow rate and temperature of water can be achieved in a stable and controllable way thanks to the mixer faucet.

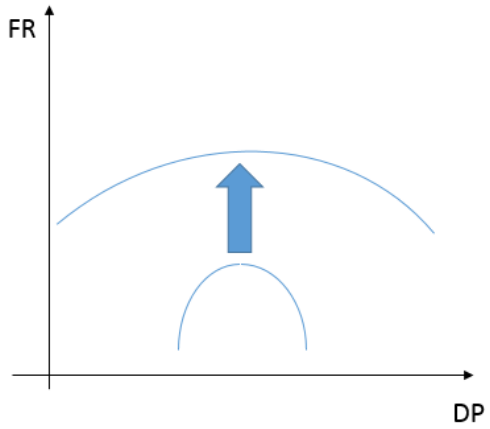

Fig. 1. How interdependences are expected to change when a system is modified based on Axiomatic Design principles.