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Formulating the Causal Logic of Design Management in the Production Process Based on Aristotle's Philosophical Framework

Ali Faregh*

Department of Architecture, Jundishapur University of Technology, Dezful, Iran; faregh@jsu.ac.ir.

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Abstract

Design for production can be examined in contrast to conceptual or abstract design. Within this distinction, design oriented toward manufacturing is more closely associated with the requirements and constraints of the production process. This distinction extends beyond differences in design objectives and also influences the nature, logic, and criteria governing its various stages. In fact, industrial design, as a deliberate process aimed at creating functional and meaningful artifacts, follows a set of logical principles and requirements that are directly related to their manufacturability and production feasibility. Accordingly, this study seeks to answer the following question: can fundamental philosophical concepts serve as an explanatory framework for developing a prescriptive model to guide the ideation process in Design For Manufacturing (DFM)? To address this question, the study aims to investigate the theoretical potential of Aristotle's Four Causes as a basis for establishing a systematic model for classifying and organizing the stages of ideation in manufacturing-oriented design. The findings indicate that conceptual correspondences and potential alignments exist between the principles of Aristotle's Four Causes and the fundamental components of the design-for-manufacturing process. Accordingly, four principal indicators can be identified to guide and structure the ideation process in DFM: the intended functions and objectives of the artifact, corresponding to the final cause; manufacturing methods and production processes, corresponding to the efficient cause; the materials and substances constituting the artifact, corresponding to the material cause; and the structure, form, and overall appearance of the artifact, corresponding to the formal cause. This framework can provide a logical foundation for classifying and directing the ideation process in production-oriented design.

Keywords: Aristotle's four causes, Design for manufacturing, Ideation process, Design management, Production process.

1 | Introduction

Although experts in the field of design (such as Cross [1], Boothroyd et al. [2], and Kuo et al. [3]) collectively regard designerly ways of thinking, the professional practice of "Design For Manufacturing (DFM)" stands as a purely operational domain, positioned at the opposite end of the spectrum, which means conceptual

Corresponding Author: faregh@jsu.ac.ir

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design. When the design process is geared toward actual construction (rather than being limited to mere conceptual and abstract ideation and design), certain constraints inevitably arise that if these constraints are considered more thoroughly and clearly during the initial stages of design, it facilitates the process and enhances the productivity of the final design outcome. To achieve this objective, design methods were developed. The first reported research on design methodology was conducted by Cross [4]; since then, design theories and methods have been the subject of extensive attention and study. Each design method is a model through which the precise manner of designing is presented in a logical and classified way, thereby facilitating the design process for the production or development of a product. For this logical process to be feasible and capable of being prescribed, it must be founded upon fundamental studies. Accordingly, the research question addressed here is whether it is possible to utilize fundamental philosophical concepts (conceived as irrefutable rational acts) as a descriptive foundation for developing a prescriptive model within the ideation process for DFM? The objective of this research is to examine the feasibility of a logical prescriptive model grounded in the philosophical principles of Aristotelianism (Aristotle's Four Causes) to introduce a rational classification in the ideation stages within the context of DFM. Such a sensible classification, if available, is significant from two perspectives: 1) it paves the way for utilizing philosophical principles (serving as foundational sources) as a strategy for classifying the stages of design, and 2) it facilitates the ideation process within the context of design for construction. It means that design in the context of construction or for the purpose of construction has its own specific characteristics that are linked to the manufacturing process.

2 | Research Background

Ranjan et al. [5] believe that design and manufacturing are two fundamental and essential stages in product development. Shukor and Axinte [6] explain that DFM consists of a set of methods and patterns that designers employ to adapt their designs, with the aim of reducing production difficulties and minimizing manufacturing and assembly costs.

Boschetto and Bottini [7] argue that the concept of DFM should be grounded in the designer's understanding of production constraints, with the aim of finding the optimal solution to align the whole product with available manufacturing capabilities. Ranjan et al. [5] state that DFM concepts, as well as the notion of "design for assembly," were developed to ensure manufacturability from the early stages of design.

Poli et al. [8] believe that DFM is a philosophy or mindset in which production details are incorporated into the early stages of design to enhance ease of manufacturing and reduce costs.

Chu et al. [9] explain that, nowadays, reducing the time required to produce new products is a main issue in the manufacturing process, and eliminating the gap between designers and manufacturers is considered one of the primary objectives of the production system.

Therefore, based on the background research for this article, some of which has been referenced, it appears that facilitating the ideation process within the context of DFM is both important and essential. Given the significance of this subject and the relative scarcity of research in this area, as well as the critical importance of streamlining manufacturing processes across various production indicators, the study and analysis of this topic appear both important and necessary; this subject, in itself, clearly underscores the significance and necessity of the present research.

3 | Research Methodology

In this research, with the aim of identifying potential connections between fundamental philosophical concepts as a strategy for the sequential explication of concepts within design models for DFM, the logic underlying Arastoo's theory of the four causes is first examined. Subsequently, the components relevant to DFM are examined, and to achieve the research objective, the insights derived from Arastoo's four causes, along with key concepts within the DFM process, are synthesized to establish a logical sequence for the ideation stages. Finally, by applying these synthesized findings to existing terminology in the field of design,

the results of this research are obtained. The research methodology employed in this study is descriptive, and the examination of the issues, the significance and necessity of the research topic, was conducted through the collection of information from library sources and reputable articles.

4 | A Conceptual Examination of Arastoo's Four Causes

In his philosophical work Metaphysics, Aristotle identifies four fundamental causes through which the existence, nature, development, and transformation of phenomena can be explained. These causes constitute four distinct but interrelated principles of explanation, which Aristotle considers sufficient for understanding why a particular thing exists and how it comes into being. No additional fundamental cause is required beyond these four categories, since each addresses a different dimension of the existence and constitution of things. In classical Aristotelian philosophy, these four causes are identified as the formal cause, the material cause, the efficient cause, and the final cause. Collectively, they provide a comprehensive explanatory framework through which the nature of both natural phenomena and human-made artifacts can be investigated.

Aristotle's theory of causation differs from the contemporary understanding of causality, which is often primarily associated with the direct relationship between an action and its resulting effect. Rather than limiting causal explanation to the immediate agent responsible for producing an outcome, Aristotle considers several complementary dimensions that contribute to the existence of a phenomenon. Accordingly, understanding an object requires more than identifying the materials from which it is made or the process through which it was produced. It also requires an examination of its defining structure, the agent or mechanism responsible for its formation, and the purpose or function for which it exists. These dimensions establish a broader understanding of causation in which the identity, composition, origin, and purpose of an object are considered together.

To introduce these four causes, Aristotle employs different philosophical concepts and expressions. The formal cause is associated with substance, form, and whatness (essence), referring to what makes a thing the particular thing that it is. The material cause concerns matter and the underlying subject upon which change occurs. The efficient cause is explained through the expression "that from which the change or rest first begins," identifying the origin or agent responsible for bringing about a transformation. Finally, the final cause is associated with the expression "that for the sake of which," referring to the purpose, end, or objective toward which a process or phenomenon is directed. Although these causes address different aspects of existence, they should not be understood as isolated explanations. Rather, they operate together to provide a more complete account of how something is constituted and why it exists in a particular way.

The formal cause (causa formalis) refers to the defining structure, organization, essence, or configuration through which a thing becomes identifiable as a particular entity. It concerns what a thing is, rather than merely what it is made of. In Aristotelian philosophy, form is not limited to the external appearance or visible outline of an object; instead, it represents the organizing principle that gives matter its identity and establishes the unity of the whole. Through form, the constituent elements of an object are organized into a coherent entity rather than remaining a collection of unrelated materials. Consequently, formal cause can be understood as the principle that determines the essential characteristics, arrangement, and organization of a phenomenon. In the case of human-made artifacts, this cause may be interpreted in relation to their overall configuration, geometry, structural organization, component relationships, and defining characteristics. It therefore addresses both the internal organization and the external manifestation of an object.

The material cause (causa materialis) concerns the substance or matter from which a particular thing is constituted. It represents the underlying physical basis that makes the existence of a material object possible and provides the potential for it to assume a particular form. According to Aristotle, matter is not necessarily understood as a completely passive or independently defined substance; rather, it is considered in relation to the form that determines its actual constitution. Matter provides the underlying subject upon which change and transformation occur. For example, wood, stone, metal, and other substances can serve as the material causes of different artifacts, while their physical and mechanical properties influence the ways in which they

can be shaped, assembled, and utilized. The significance of material cause therefore extends beyond identifying the substance of an object. It also concerns the characteristics and potentialities of that substance, including its capacity to receive a particular form and participate in the formation of a complete entity.

The efficient cause (causa efficiens) refers to the agent, source, or process through which a phenomenon is brought into existence or a change is initiated. It addresses the question of how something comes into being and identifies the factors responsible for the transition from one state to another. In natural phenomena, the efficient cause may be an agent or process that produces a particular change, whereas in human-made objects it may involve the designer, craftsman, manufacturing equipment, production techniques, and fabrication processes. Importantly, efficient causation is not necessarily limited to a single individual or immediate action. It may encompass a sequence of operations, interactions, and technical procedures through which materials are transformed and organized into a finished artifact. From this perspective, the efficient cause provides an explanation of the mechanisms and means through which the potential of matter is realized in a specific form. It therefore establishes a connection between the material composition of an object and the processes responsible for its physical realization.

The final cause (causa finalis) concerns the ultimate purpose, objective, or function for which something exists, or an action is performed. It addresses the fundamental question of why a phenomenon comes into existence and what it is intended to accomplish. In Aristotle's philosophy, the final cause is not simply an outcome that occurs after a process has been completed; rather, it represents the purpose toward which the process is directed. This concept is particularly significant because it introduces intentionality and functional direction into the explanation of phenomena. In the context of human-made artifacts, the final cause can be associated with the intended function of a product, the needs it is designed to satisfy, the activities it is expected to support, and the objectives that determine its development. For instance, the purpose of a structural element may be to transfer loads, provide stability, or span a particular distance, while the purpose of a manufactured product may be related to its practical function, user requirements, or operational performance. Accordingly, the final cause establishes the conceptual and functional basis upon which the other causes can be interpreted.

Although each of these causes provides a distinct explanation, their significance becomes more apparent when they are considered collectively. A material substance, by itself, does not fully explain the identity of an object; it must be organized according to a particular form. Similarly, the existence of a form does not explain how that form is physically realized, making it necessary to identify the agent or process responsible for its production. Furthermore, neither the material composition nor the manufacturing process alone provides a complete explanation of an artifact without considering the purpose that determines why it has been created. Thus, the four causes establish a complementary relationship in which matter provides the physical basis, form determines the organization and identity, efficient causation explains the process of realization, and final causation establishes the intended purpose.

This interrelationship also demonstrates that Aristotle's theory can be used as an analytical framework for examining both naturally occurring phenomena and intentionally created objects. In the analysis of natural entities, the four causes help explain their constitution, development, and characteristic functions. In the analysis of human-made artifacts, the same framework can be employed to investigate the relationship between design intention, material selection, production processes, and final configuration. The distinction between these two contexts is particularly important because human-made objects are generally developed through deliberate decisions and purposeful interventions. Their existence is therefore closely associated with the intentions of their creators, the characteristics of the materials employed, the technologies available for their production, and the forms through which their functions are expressed.

From the perspective of design and manufacturing, Aristotle's four causes offer a theoretical foundation for understanding the different dimensions involved in the creation of an artifact. The formal cause can be related to the structural and geometric organization of the designed object; the material cause corresponds to the substances and constituent materials used in its construction; the efficient cause can be interpreted through

the manufacturing methods, production technologies, and processes employed to transform those materials; and the final cause relates to the intended functions and objectives of the artifact. Such an interpretation makes it possible to establish a conceptual connection between classical philosophical reasoning and contemporary design methodologies.

Furthermore, the four causes provide a useful basis for distinguishing between the examination of an existing artifact and the conceptualization of a new one. When an existing object is analyzed, the observer can investigate its visible form, identify its constituent materials, examine the processes through which it was produced, and determine the purpose it serves. However, when a designer intends to create a new artifact, these dimensions can be approached from a generative perspective. The designer must establish the intended purpose, consider the means through which it can be achieved, identify suitable materials, and develop an appropriate form. This distinction highlights the potential relevance of Aristotle's theory to design thinking, particularly when the objective is to establish a systematic relationship between conceptual intentions and the practical conditions of production.

Ultimately, Aristotle's Four Causes should be understood not merely as four separate categories of explanation but as an integrated philosophical framework for investigating the existence and constitution of things. Their continued conceptual relevance lies in their ability to address four fundamental questions: What is a thing? What is it made of? Through what agent or process does it come into existence? And for what purpose does it exist? These questions provide a comprehensive basis for examining the relationship between form, matter, production, and function. Accordingly, the Four Causes offer an appropriate theoretical starting point for further investigating how philosophical principles can be translated into practical indicators within contemporary design processes, particularly DFM.

5 | Conceptual Investigation of the Design for Manufacturing Process

The historical evolution of production methods has been shaped in alignment with shifts in social, economic, and technological limitations and needs of human society. From a design perspective, one of the oldest topics within DFM (established with the aim of reducing production costs) has concerned the manufacturing of parts via industrial forging processes.

DFM has been a key design approach over the last three decades; broadly, this method is defined by the constraints inherent in the manufacturing and production process. It can be stated that the production process encompasses various stages, including product design, material selection, material processing, manufacturing, and packaging. Although design guidelines are generally formulated specifically for the production process, manufacturability still depends on several other factors, such as geometric dimensions and the raw material. Assembly, geometric dimensions, and constituent materials have a profound impact on production operations; understanding these aspects is economically crucial for reducing the gap between the designer and the product, facilitating quality improvements, reducing production costs, and enhancing the efficiency of the manufacturing process, and appears to be a key factor.

6 | Discussion and Conclusion

As previously mentioned, Arrastoo's Four Causes consist of formal causes, material causes, efficient causes, and finally, final causes. Accordingly, when philosophers approach existing phenomena to explain their nature, they first examine and interpret the phenomenon's form (its shape and appearance, or any factor upon which that shape and appearance depend) and subsequently examine and interpret the substance or materials from which the phenomenon is composed. Next, the efficient causes, which elucidate the factors through which the composition of a phenomenon takes place, or in other words, the means by which the phenomenon is brought into existence, will be examined and interpreted. Finally, the ultimate purpose behind the existence of the phenomenon is examined. Since the outcomes of the DFM process typically result in concepts that actually exist, it follows that provided Arasato's four causes are valid, these causes should also be applicable

to the results of this process. Concepts representing key components in the DFM process are presented in the previous section through the following statements: design, material selection, material processing, manufacturing, geometric dimensioning, raw materials, and constituent materials; they were identified by experts as significant and influential factors in the DFM process. Of course, it should be noted that the role of philosophers in examining these causes is that of an observer.

In the event that the design process is considered, the designer's position in relation to these causes is that of a creator. This shift in perspective results in a reordering of the four causes in reverse sequence; specifically, the final causes, which represent the end, goals, or ultimate functions, must be examined first. These objectives can be categorized in terms of the ultimate and primary functions of the phenomenon, from the perspective of product design or even service. Efficient causes, which explain how changes are brought about in the substance and constituent material of a phenomenon, can be interpreted as the production method (such as the constraints inherent in the manufacturing process), while material causes can be understood in relation to the substance and constituent material of the phenomenon itself. Ultimately, formal causes, which relate to the overall appearance and shape of an artifact, are closely linked to the technical parameters governing its physical construction, such as the structural system and the nature of the connections, viewed from an internal perspective, as well as its aesthetic elements (form, color, texture, and surface) viewed from an external and outward perspective.

The results of this investigation indicate that the concepts articulated within Arastoo's four causes can be mapped onto the concepts inherent in the DFM process (these factors may be termed the four indicators of conceptualization in DFM). These indicators consist of the following:

I. First indicator: the ultimate functions of the artifact (final causes).

II. Second indicator: the method of production (efficient causes).

III. Third indicator: the materials used in the artifact (material causes).

IV. Fourth indicator: the overall shape and appearance of the artifact (formal causes).

Accordingly, in order to employ this design approach specifically when conceptualizing for DFM, the designer must first consider the fundamental final functions expected of the product or service. The implementation of this section is possible through descriptive ideation (describing the ultimate goals and functions of the phenomenon). Next, the limitations inherent in production methods (for instance, those related to products or the manufacturing process within an industrial unit) will be examined from various perspectives. Subsequently, the limitations inherent in the materials selected for the product's fabrication should be categorized and identified, and finally, a visual ideation process should be undertaken to give form to the ultimate objectives for the use of the product to be manufactured via a specific production process using defined materials.

Authors' Contributions

All aspects of the research and manuscript preparation were carried out by the author. The author has read and approved the final version of the manuscript.

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The author declares that they do not have any conflict of interest.

Consent for Publication

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Ethics Approval and Consent to Participate

This article does not contain any studies with human participants performed by the author.

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