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~~Cutting Edge Influence on Machining Titanium Alloy~~

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Synonyms

Combination; Creation; Integration

Definition

Generally speaking, synthesis can be defined as the composition or combination of parts – building blocks, elements – to create a new whole product, artifact, technology, machine, or graphic, whose ruling behavior emerges from the interaction of its constituents parts. In the context of design, synthesis follows different definitions (Chakrabarti 2002). The two mostrelevant to this work are "synthesis as designing" and "synthesis as solution generation." In the first definition, synthesis is defined as an iterative process of solution generation and solution evaluation. The second definition narrows its scope to that of generation solutions.

Theory and Application

A synthesis process comprehends a complex combination of cognitive and mathematical mechanism (e.g., random generation, backward reasoning, abduction, case-based reasoning, and constraint-solving). Although no unified theory exists for explaining the nature of the synthesis process, the generally accepted FBS family of frameworks allows for making some concrete statements on the nature of synthesis.

The FBS Model

FBS models a design artifact by distinguishing the following levels of object representation: function, behavior/state, and structure, as shown in Fig. 1. The basis of the FBS model is that the transition from function to structure is performed via the synthesis of physical behaviors. Therefore, behaviors allow characterizing the implementation of a function. As many different views of the FBS model have been developed and researched, the FBPSS model presented by Zhang et al (2005) serves as a unifying framework for the different FBS schools of thought. This model is based on the analysis and generalization of the Japanese (Umeda and Tomiyama 1995), (Umeda and Tomiyama 1997), European (Pahl et al. 2007), American (Chandrasekaran et al. 1993), and Australian (Gero and Kannengiesser 2004) schools of design theory and methodology.

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The FBPSS model uses the following definitions:

- Structure: Is a set of entities and relations among entities connected in a meaningful way. Entities are perceived in the form of their attributes when the system is in operation. For example, in Fig. 1 the structure is represented by an electric motor and a crank mechanism. Here, the two possible entities (structures) are the lengths of the bars L_1 and L_2.
- States: Are quantities (numerical or categorical) of the behavioral domain (e.g., heat transfer, fluid dynamics, psychology). States change with respect to time, implying the dynamics of the system. For example, in Fig. 1, the states of the structure are represented by the distance L_0 between the electric motor and the piston, the torque T of the electric motor, or the displacement of the pistons.
- Principle: Is the fundamental law that allows the development of a quantitative relation of the state variables. It governs behavior as the relationships among a set of state variables. For example, in Fig. 1, two possible principles are electromagnetism ruling the operation of the electric motor and solid mechanics ruling the function of the crank mechanism.
- Behavior: Represents the response of the structure when it receives stimuli. Since the structure is represented by state and structure variables, behaviors are quantified by the values of these variables. In the case presented in Fig. 1, the two behaviors are *Generate torque* and *Convert torque into force*.
- Function: It is about the usefulness of a system. For example, in Fig. 1, one possible function of this system is to compress gas.

Figure 2 shows how these definitions are related. The relationship between state and structure is a one-to-many relation. The behavior is produced as the combination of state sets underlined by a given set of principles to the structure. Behavior and function have a many-to-many relation, which depends on the context and usefulness of the structure.

Classification of Design According to Its Synthesis Process

Within this framework, one can classify top-down steps aiming at determining the structure of an artifact given a functional representation as synthesis processes, while their back reasoning counterpart of determining function characteristics given a known structure as analysis processes.

From this perspective, synthesis processes are classified into three groups according to the type of representations:

- Routine design: One in which the space of functions, behaviors, and structures are known, and the problem consists of instantiating structure variables.
- Innovative design: One in which the functions and behaviors are known, and the design consists of generating new structures that satisfy them.
- Creative design: One in which the functions are known, and the problem consists in determining the structures and behaviors required to satisfy them.

Furthermore, as nature encompasses a vast variety of behaviors (physical, chemical, human, etc), synthesis processes can also be classified according to the types of behaviors being targeted:

- Engineering design: Behaviors are characterized by principles stated in the laws of physics. Depending on the discipline of study, engineering design can be further classified into mechanical, electrical, chemical, geological, etc.
- Human-centered design: Behaviors are characterized by physiological, psychological, and emotional human reactions. Two examples are architectural design and industrial design.

Information Flow in Synthesis

Figure 3 shows a well-accepted model of the design process (Schotborgh and van Houten 2012). According to this model, a candidate solution is generated in a synthesis process. This candidate solution is then analyzed to calculate its performance. Finally, the evaluation process assesses whether the solution is to be adjusted

Au2 (path 1), rejected (path 2), or accepted (path 3). If necessary during the adjustment process, modifications (small) are made to the candidate solution, i.e., without changing the solution principle.

The flow of information through these processes can be classified into three types of information (Webber ; McMahon 1994): embodiment, scenario, and performance. Embodiment regards the information that describes the product being designed (e.g., its topology, size, and shape). Scenario regards the information that describes the flow of energy, mass, and signals the embodiment is exposed to. Finally, performance regards the information that determines how the embodiment behaves under a given scenario.

The relation between these three types of information varies according to the four processes of the design process model. In the synthesis process, embodiment information is generated (i.e., embodiment parameters are chosen and a candidate solution is formed) such that it meets certain performance parameters for a given scenario, as shown in Fig. 4b. Conversely, in the analysis process performance parameters are quantified or qualified for an embodiment undergoing a given scenario, as shown in Fig. 4a. In the evaluation subprocess, the generated performance parameters are used to determine what follow-up action should be taken (paths 1–3). Finally, in the adjustment subprocess small changes to some embodiment parameters can be made in order to improve the performance of the candidate solution.

Cross-References

- ▶ Design
- ▶ Design Methodology
- ▶ Model
- ▶ Process
- ▶ Product

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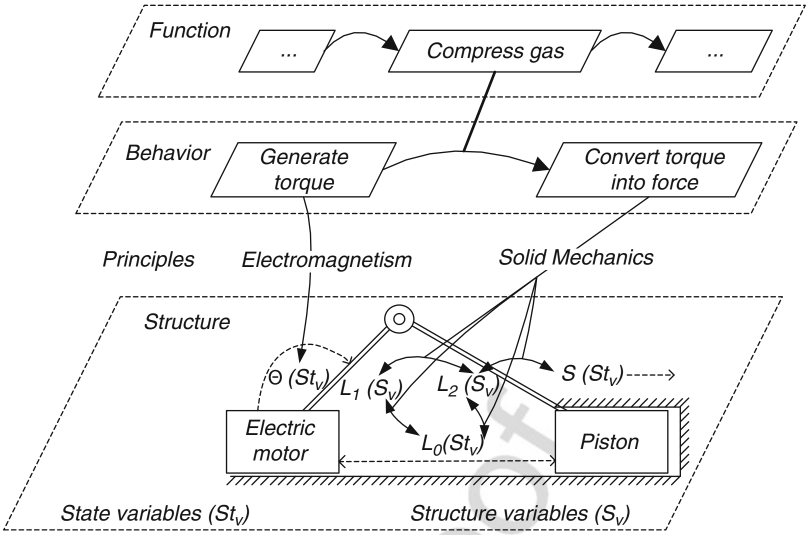
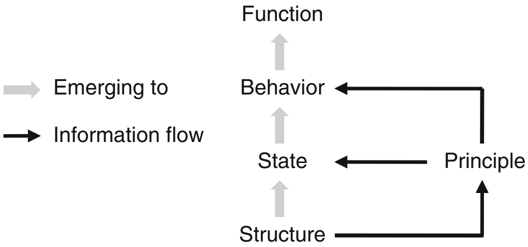
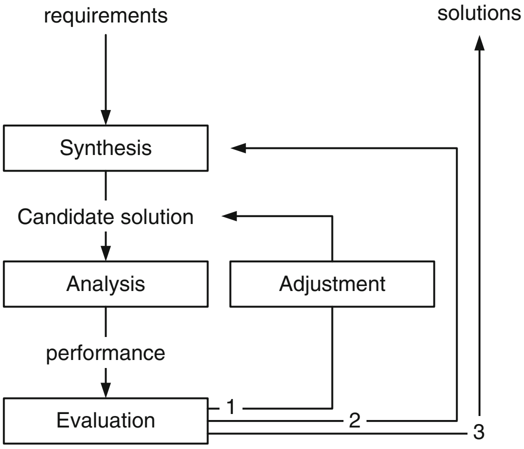


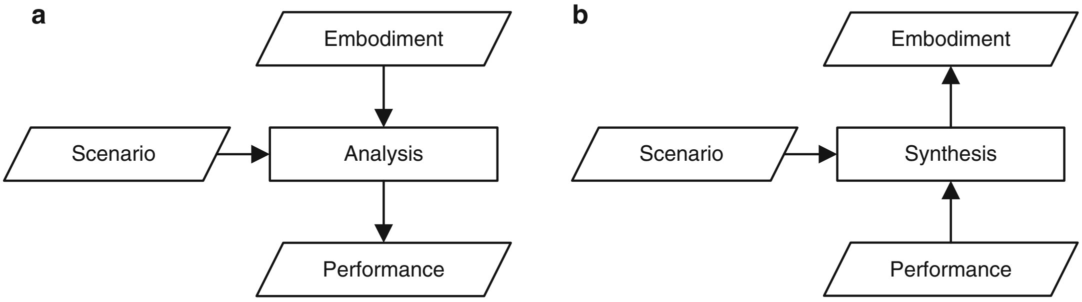
Cutting Edge Influence on Machining Titanium Alloy, Fig. 1 FBS of a crank compression mechanism



Cutting Edge Influence on Machining Titanium Alloy, Fig. 2 Relation between function-behavior-principle-state-structure (Zhang et al. 2005)



Cutting Edge Influence on Machining Titanium Alloy, Fig. 3 Generic model of the design process (Tomiyama et al. 2009)



Cutting Edge Influence on Machining Titanium Alloy, Fig. 4 Information flow of analysis technique and synthesis process. (**a**) Analysis. (**b**) Synthesis

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