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Development of a classification and generation approach for innovative technologies

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Abstract

This paper considers the state of the art and analyses five existing classification principles for technological and manufacturing processes aiming at the part and product formation. The proposed energetic-information model describes the generation of technological schemes and processes, based on the system description for structural conversion, transfer and interaction of material, energy and information. Classification principles for technological processes and their structural description generate classes, types and procedures (methods). A generation procedure and mechanism for innovative technological processes is developed. Approved classification of manufacturing processes for DIN8580, NISTIR 7913, according to Todd, Paul De Garmo, by Ashby are particular cases of the proposed classification approach. The proposed approach and process classification system is forming an image of DIN8580. The classification, generation and analysis approach for manufacturing technologies applies for the creation of innovative procedures, manufacturing equipment and systems.

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Keywords: methods, manufacturing processes, technology, classification

"First of all learn the exact name for everything - that's the primary and most important science of all sciences." [Pythagoras von Samos]

1. Introduction

The term "progress" relates to a system consisting of elements, links, connections and interactions both between elements and with the environment in order to identify their properties and characteristics. Processes are caused by

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changes in properties and states and result from elements and external interactions. These characterize the system performance, setting changes in state and in space - time related properties. Most important cognition tools for the state, evolution and trend are minds, terms and their content, the system structure and equivalent model, which describe those properties and characteristics. Currently we apply a variety of manufacturing techniques for the part and product formation and different technological processes and manufacturing equipment for their implementation. The state of the art in classification principles for technological processes and manufacturing techniques [1,2,3,4,5,9] is systematically structured and presented in table 1.

Table 1. Classification principles for technological processes and manufacturing techniques

Classification by	Classification principles	Classification criteria	Advantages
National Institute of Standards and Technology NISTIR 7913 (USA) [1]	5 physical process clusters: 1 – change in mass 2 – material state changes 3 – structural changes 4 – shape changes 5 – joining	Physical state change	Use of research information
R.H. Todd et al. (USA) [2]	6 shape change clusters: 1 – mass reduction 2 – thermal mass reduction 3 – chemical mass reduction 4 – keeping mass 5 – linking 6 – joining 4 manufacturing process clusters: 1 – hardening 2 – tempering 3 – surface preparation 4 – surface coating	Shape change, without shape change	Easy of use
Standard DIN 8580:2003-09 (Germany) [3]	6 manufacturing process clusters: 1 – Primary shaping, 2 – Forming, 3 – Separating, 4 – Joining, 5 – Coating, 6 – Modification of material properties	Shape change, Material property change	Used by CIRP group CO2PE! for defining the specifications of machining processes
E. Paul De Garmo (USA) [4]	7 manufacturing process clusters: 1 – casting or forming 2 – shape change or cutting 3 – machining, ablation 4 – thermal processes 5 – finishing 6 – assembling 7 – check	Casting, Shape and material property changes	Easy to understand
M.F.Ashby (GB) [5]	4 manufacturing process clusters: 1 – primary shaping 2 – secondary shaping 3 – joining 4 – finishing	Primary and secondary processes	Easy to understand

Progressive trends in technological techniques, acting at the manufacturing item, require the generation of innovative system analysis and evaluation approaches. This system analysis targets more efficient and sustainable technological and manufacturing processes, new materials, innovative techniques and technologies.

Thus, technological processes are still based on the system structure description of physical changes in elements without considering element connections. Furthermore they are based on internal links and connections types, which keep constant, destroy, increase or change internal connected material properties. Publications [6,7] refer to the energy-information model of technological processes aiming at the part and product formation. Following this model, links and connections between interacting elements (material, energy and information) cause and define a physical process. Structure of space-time transformations in the physical process is set in position, in motion and in state. Established energy-information model of technological processes and the analysis of their system properties will support different evaluation methods in order to characterize technological process efficiency, manufacturing equipment effectiveness and will define trends for their improvement, development and the creation of innovative types.

2. New model of technological processes

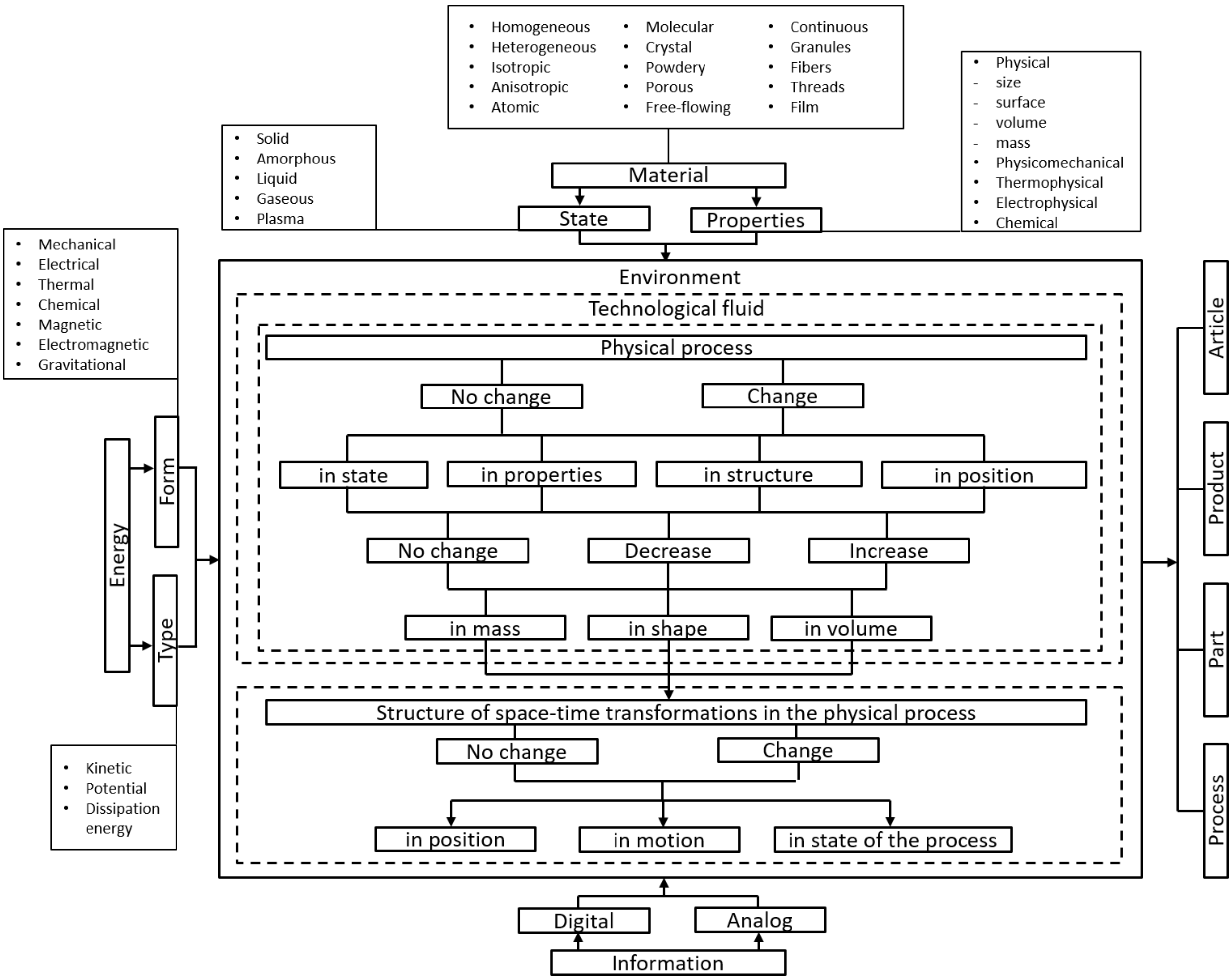

Fig. 1. General energy-information model of technological processes.

Figure 1 shows a **general energy-information model structure** of technological processes aiming at the part and product formation. **Types of energy** are kinetic, potential, dissipation etc. **Forms of energy** are mechanical, electrical, thermal, chemical, magnetic, electromagnetic, and gravitational, so each energy form bases on the motion of energy potions (electron, ion, gas or liquid molecule). Usually energy forms in engineering practice are mechanical, electrical, electromagnetic, thermal, chemical, atom energy. The last three forms are internal energy forms, caused by potential energy type of interaction between material particles. Energy type realized in a physical process is the most important characteristic setting the interactive principle between related work piece and tool materials.

Interactive principle regularly describes a manufacturing method realizing a special technological process. A physical manufacturing process for items (part, product) is the result and type of interaction between materials (solid bodies), material and his state (liquid, gas, plasma), material and physical fields (electrical, magnetic, gravitational), and combinations of them. Consequently, a plurality of physical processes, phenomena and existing forms is creating.

Material – as a system element in fig. 1 – is defined by two elements: state and properties. Known **material states** are solid (constant shape and volume), amorphous, liquid (constant volume), gaseous (changing shape and volume), low or high temperature plasma (changing shape and volume). **Material types** differ in relation to shape and volume stability: homogenous, heterogeneous, isotropic, anisotropic, atomic, molecular, crystal, powdery, porous, granules, fibers, threads, film, free flowing, continuous. **Material properties** reflect the physical (size, surface, volume, mass), physico-mechanical, thermos-physical, electro-physical chemical parameters and characteristics. Mass is a general property, derived from volume and volume derived from surface area and size.

Information – as a system element in fig. 1 – consists of data from the item (part, product, article), process and process control. Information types are **analog** (point, line, surface, volume), symbolic, graphical and **digital**. Information transformation and time flow is either synchronous or asynchronous with material and/or energy transformation. Information amount in an ideal system is constant for the whole process, same for energy. In a real system, we find a lack of information.

This classification approach proposes a common system structure, classification principles and the structure formation. This generalized description of technological processes forms the basis for the main conceptual role to enable the cognition, analysis, creation development, improvement and trend prognostics. The proposed models support the previous mentioned tasks by a not yet finished, comprehensive and detailed approach. Nevertheless, each considered conceptual system more or less reflects generalized features and a common system structure.

Resuming the system elements for the general model in figure 1, let us propose the following classes of technological processes in table 2, which builds the top level of classification principles. [7]

Table 2. Classes of technological processes.

№	Energy		Material		Information		Class	Processes
	Type	Form	State	Properties	Analog	Numerical		
1	0	1	0	1	1	0	T1	TP, form 1
2	1	0	0	1	1	0	T2	TP, type 1
3	0	1	1	0	0	1	T3	TP, form 2
4	1	0	1	0	0	1	T4	TP, type 2
5	0	1	1	0	1	0	T5	TP, form 3
6	1	0	1	0	1	0	T6	TP, type 3
7	0	1	0	1	0	1	T7	TP, form 4
8	1	0	0	1	0	1	T8	TP, type 4

Type and form plurality in the interaction of material, energy and information cause, define and create a plurality in technological processes. Table 3 shows an example for a more detailed classification of possible technological processes in class T1.

Table 3. An example of components in technological processes TP, form 1.

№	Energy		Material		Information		Class	Processes
	Type	Form	State	Properties	Analog	Numerical		
1	0	mechanical	0	physical	Model	0	T1	TP, form 1
				physical	-size -surface -volume -mass			
		electrical		physico-mechanical	-shape			
		thermal		thermo-physical	-cam			
		chemical		electro-physical				
		magnetic		chemical				
		electro-magnetic		-				
		gravitational		-				

The quantity of processes defined by the system elements in fig. 1 is equal to the number of combinations C_n^k over k elements from n overall. Depending on the element set and possible combinations (targeted, considered) a plurality of processes and systems (groups, types, classes, etc.) may be established, which effect their behavior and system state change, performing the target solution – create process, product, part, article. The number of elements in the considered system, depending on detailed structure, may be equal n = 6;12;18;24;30;36;42;48 and more. Consequently the number of created system combinations based on material, energy and information transformations with k =3 for $n=6$ is equal to the number of combinations $\mathrm{C}_6^3 = 20$. If the requested condition for creating a technological process is the combination for one element of each group (material, energy, information), the number of classes is equal to $C = 2 \times 2 \times 2 = 8$, as shown in fig. 2. Consequently, the number of technological processes in the first class "TP, form 1" is equal to $C_{30}^3 = 4060$. Therefore, in order to evaluate, recommend and analyze the effectiveness of one from 4060 possible technological processes, there arises a demand in efficiency evaluation procedures for the innovative one in comparison to established technological processes.

Fig. 1 proposes the energy – information model structure of technological processes as a general procedure for the *efficiency evaluation* of technological processes, manufacturing equipment and systems, where types and forms of energy, material and information are transforming.

For this evaluation procedure, the term **effectiveness** is equal to the overall relative effectiveness of all included transforming element types. Then **Efficiency** is the extent of the use of any resource. **Productivity** is the rate of change of properties, conditions, structure of material. **Accuracy** of processes, equipment and productions determined by the level of compliance or degree of approximation of the amount of information about the real properties, parameters and characteristics of the product (object, product or part) to the nominal amount of information, or given ideal.

The relation of output values E_j (energy, power, information, time etc.) to input values E_i *i*s equal to the effectiveness criteria $E_{ээ}$, where the output part E_j characterizes the useful, theoretically maximal possible resource value. This value E_j is caused by physical process, equipment or system phenomena. The input part E_i is equal to the real (true) resource consumption by the process, equipment or manufacturing system. Therefore, a process, equipment or manufacturing system comparison is performing based on their relation $U_e = E_e^1 / E_e^2$. Thus the comparative effectiveness evaluation criteria assessing two technological processes can be calculated as follows, see formula (1) [2]:

$$U_e = \frac{\left(E_e^m E_e^e E_e^{in}\right)^1}{\left(E_e^m E_e^e E_e^{in}\right)^2} == (U_{pr}^f \cdot U_{pr}^{fh} \cdot U_r^{fh})^m \cdot (U_{pr}^f \cdot U_{pr}^{fh} \cdot U_r^{fh})^e \cdot (U_{pr}^f \cdot U_{pr}^{fh} \cdot U_r^{fh})^{in} \qquad (1)$$

where E_e^m – indicator productivity; E_e^e – indicator energy efficiency; E_e^{in} – indicator accuracy, U_{pr}^f - useful degree of resource / process potential, U_{pr}^{fh} - useful degree of equipment potential, U_r^{fh} - real (true) equipment resource use.

3. Application example

Fig. 2 and fig. 3 present the general energy-information model of technological processes applied for partial classification cases, referring to table 1. Examples of innovative technological processes are proposed for technological processes with mass change (fig. 2) and technological processes for modifications of material properties (fig. 3).

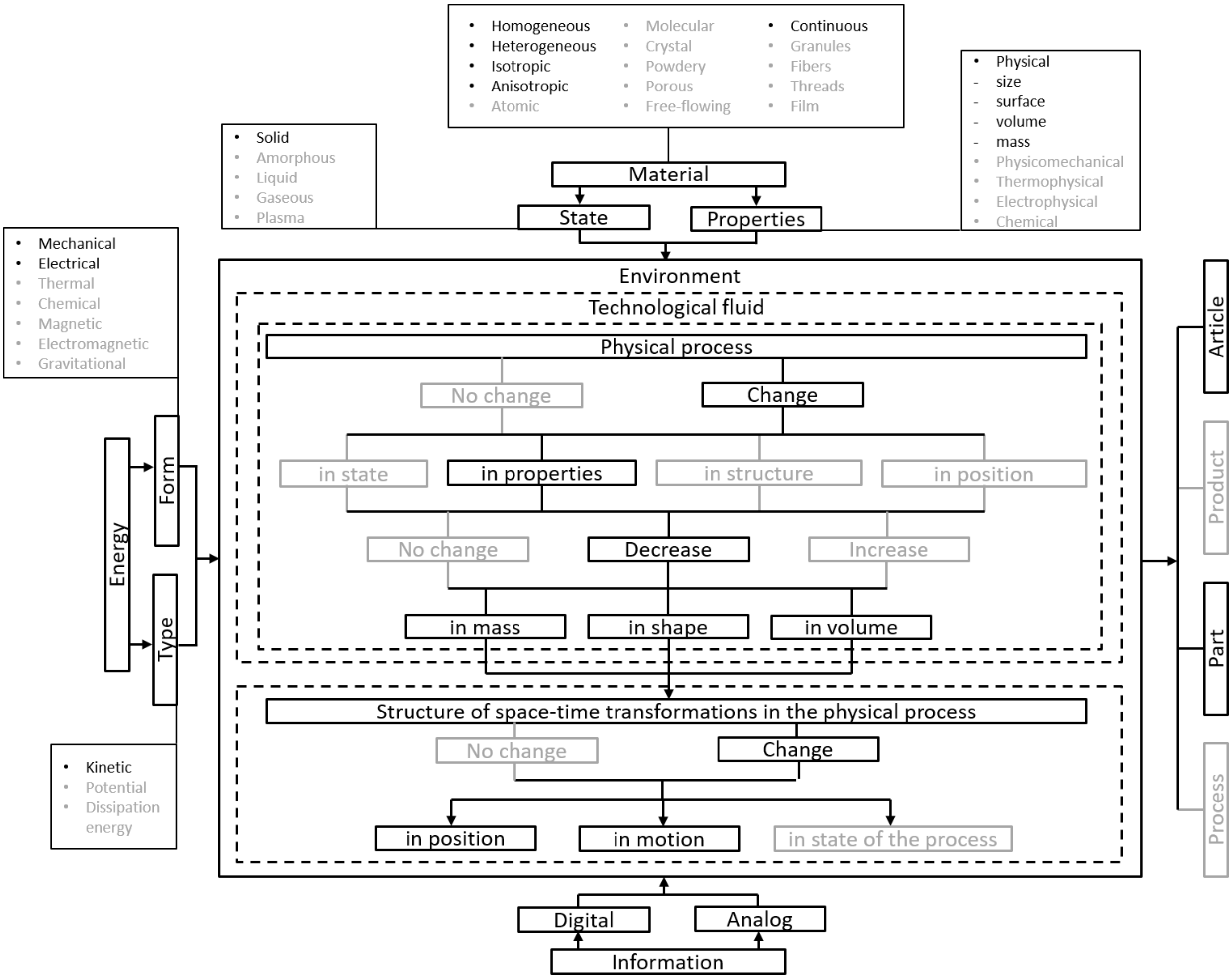

Fig. 2 Technological processes with mass change following NIST (USA)

The comparative effectiveness evaluation criterion of two technological processes is given in formula (1). An example for the comparative effectiveness of two technological diverse processes for the part manufacturing based on equation (1) is presented in [8], where manufacturing types are:

- *Basic technological process* type based on mass reduction model in the physical process of plastic deformations and targeting shape / form parameters through cutting operations following fig. 1,
- *Innovative technological process* type based on mass increase in the physical process of melting and targeting shape / form parameters through additive process following fig. 1.

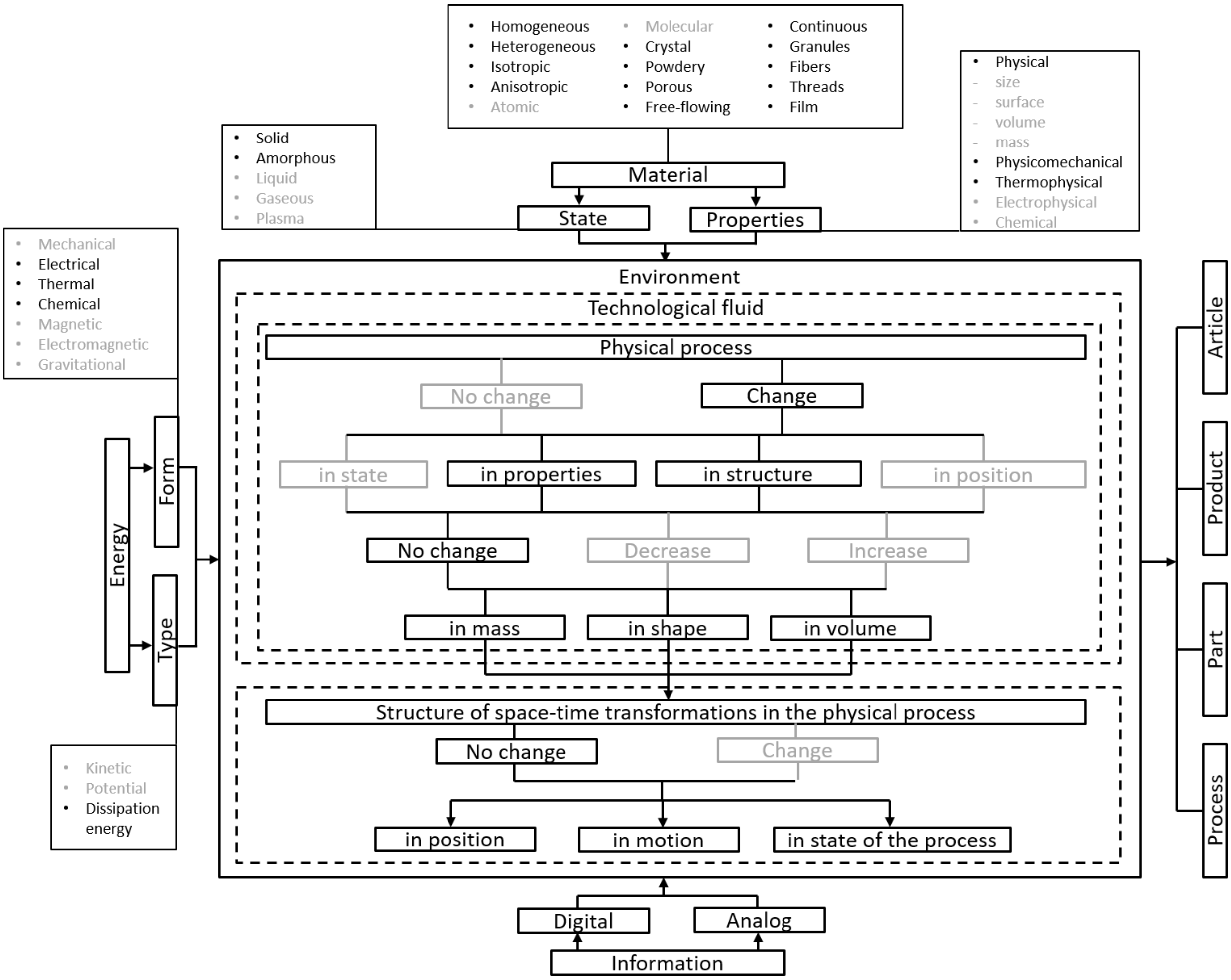

Fig. 3 Technological processes for modifications of material properties following DIN 8580:2003-09 (Germany)

4. Summary

Proven classification methods of manufacturing processes according to DIN8580, NISTIR 7913, to Todd, Paul De Garmo, by Ashby in chapter 1 are particular cases of the proposed classification approach. The effectiveness is equal to the overall relative effectiveness of all included transforming element types.

The proposed general energy-information model of manufacturing processes and new classification will initiate progressive research and development activities on manufacturing processes and associated technologies. Furthermore it will contribute to the evaluation of increased technological competitiveness, the strategic trend forecasting, the optimization of manufacturing processes and their applications. Figure 4 shows the creation of an innovative technological process based on the proposed general energy-information model of technological processes. The proposed classification of manufacturing processes is invariant to the kind of material. The material properties are important only for physical processes. Therefore, the structure of manufacturing processes is shown in regular groups, where operations are transformed or in a sequence of the physical process, the technological process class and the technological process type. Forthcoming research is needed for a comparison methodology of the resource consumption applied to classified manufacturing processes on different technical systems.

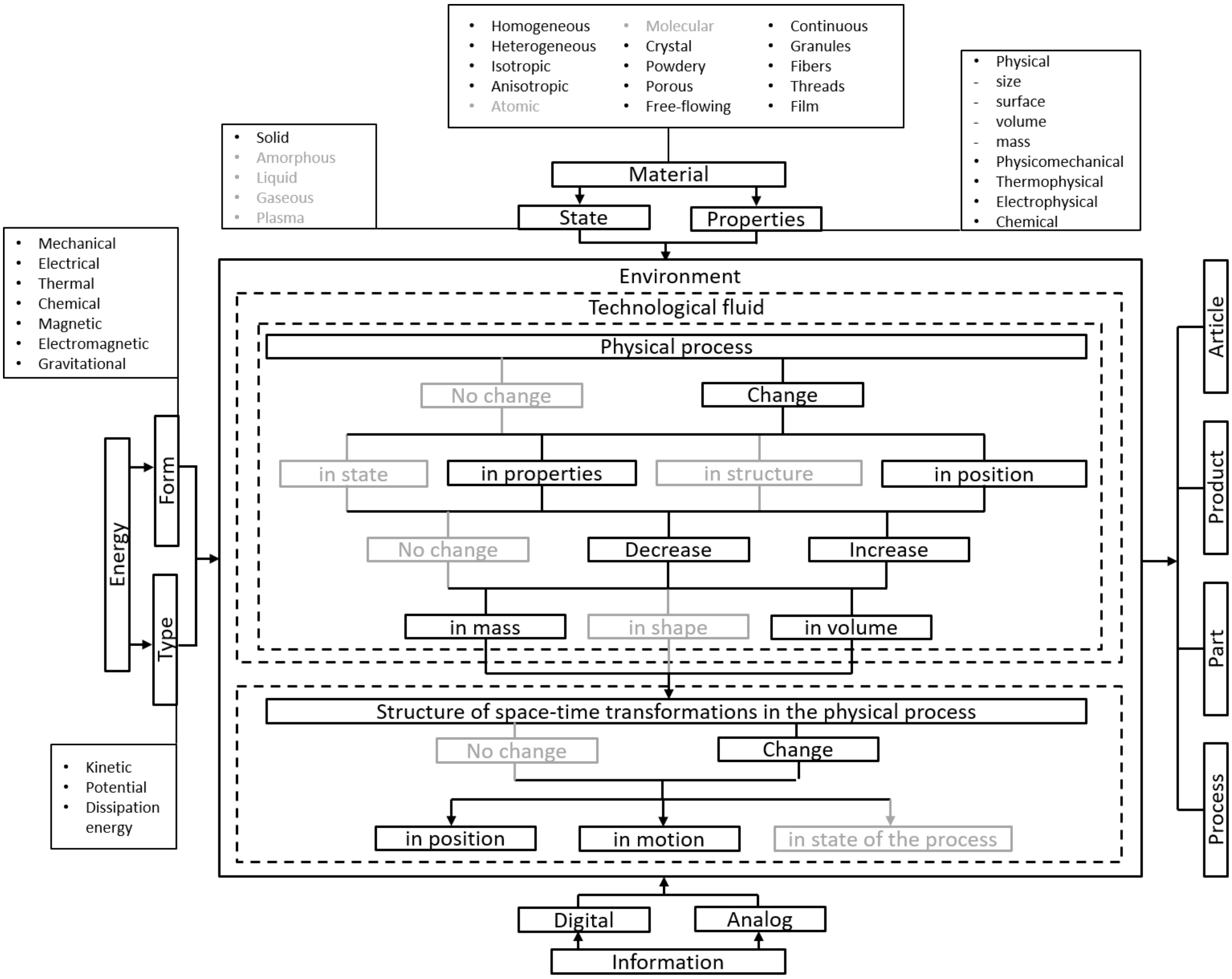

Fig. 4 Innovative technological process for "vibration compression" manufacturing

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