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INNOVATION AND IDEALITY IN INDUSTRY 4.0

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Curriculum Development

of Master's Degree Program in

Industrial Engineering for Thailand Sustainable Smart Industry

1. Introduction

- A very important competence of master graduates is the complex „creativity & innovation”.
- Design is one of the basic components of technologic innovation and creativity in product manufacturing.
- Design activities are part of the product development stage.
- An original innovation model, named “The 25 Screen Model”, was created by Visan and Ionescu (2004).

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2. Conceptual bases of model achievement

The global product design process has five phases:

1. Competitive Design;
2. Functional Design;
3. Conceptual Design;
4. Assembly Embodiment Design;
5. Detailed Embodiment Design.

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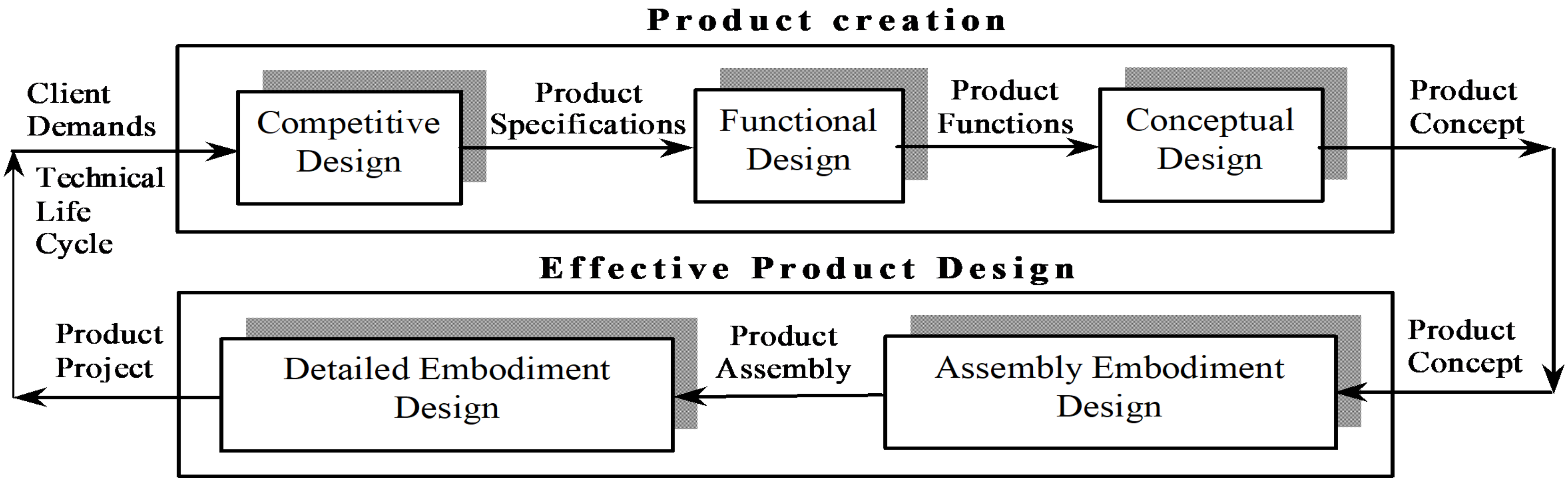
2. Conceptual bases of model achievement



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- **Competitive Design** concept is consisting of the design of product characteristics and its design specifications, based on client demands and product technical life cycle, in accordance with the concept of client demand in the process of product achievement.
- *Method: QFD-Quality Function Deployment, Stage 1 – Product Planning*
- **Functional Design** is the design phase when the product functions design are achieved based on the product’s design specifications.
- *Methods: constructive and functional decomposition methods*

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- **Conceptual Design** is the phase of product concept design based on the functions as determined at the functional design phase.
- *Methods: TRIZ, morphological analysis, etc.*
- *Methods: QFD-Quality Function Deployment, Stage 2 – Planning of the main component parts*
- **Assembly Embodiment Design** means the product preliminary design is achieved, consisting of the design of product assembly and component parts and resulting in a preliminary project.
- *Methods: Failure mode and effect analysis - FMEA, Fault tree analysis - FTA, Analytically Hierarchy Process - AHP, Poka Yoke, etc.*

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- **Detailed Embodiment Design** is the design phase when the final or detail design of the product is prepared both as a complete entity and the component parts, to obtain the complete project of product.

Accordingly, there were defined five **design categories**:

- Competitive Design (A category),
- Functional Design (B category),
- Conceptual Design (C category),
- Assembly Embodiment Design (D type),
- Detailed Embodiment Design (E category).

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There are five levels of innovation solutions and the necessary sources of inspiration determined by Altshuller (Mazur, 2001):

- First Level Design;
- Second Level Design;
- Third Level Design;
- Fourth Level Design;
- Fifth Level Design.

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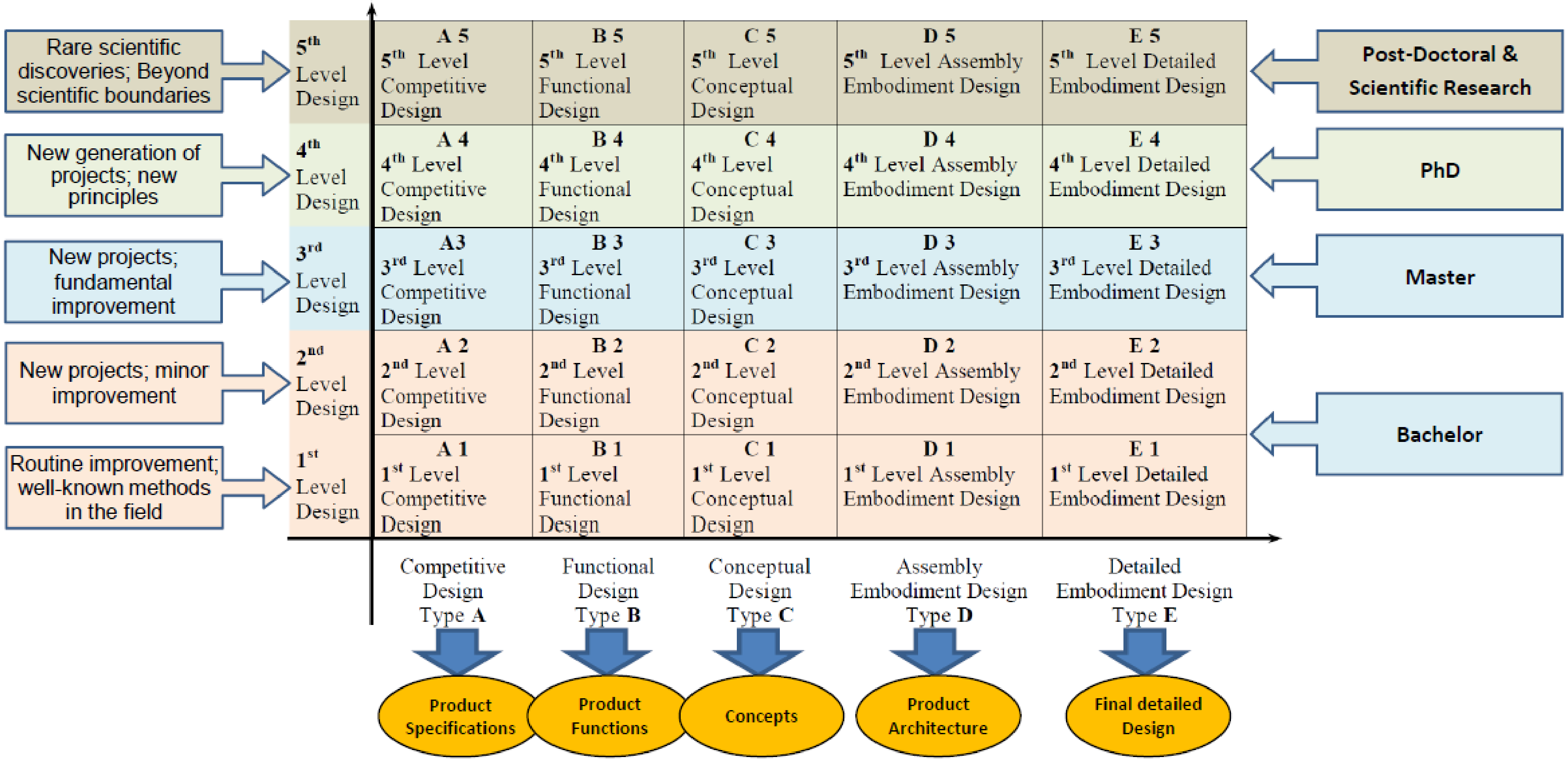
3. The 25 screen model



Rare scientific discoveries; Beyond scientific boundaries	5th Level Design	A 5 5th Level Competitive Design	B 5 5th Level Functional Design	C 5 5th Level Conceptual Design	D 5 5th Level Assembly Embodiment Design	E 5 5th Level Detailed Embodiment Design	**Post-Doctoral & Scientific Research**
New generation of projects; new principles	4th Level Design	A 4 4th Level Competitive Design	B 4 4th Level Functional Design	C 4 4th Level Conceptual Design	D 4 4th Level Assembly Embodiment Design	E 4 4th Level Detailed Embodiment Design	**PhD**
New projects; fundamental improvement	3rd Level Design	A3 3rd Level Competitive Design	B 3 3rd Level Functional Design	C 3 3rd Level Conceptual Design	D 3 3rd Level Assembly Embodiment Design	E 3 3rd Level Detailed Embodiment Design	**Master**
New projects; minor improvement	2nd Level Design	A 2 2nd Level Competitive Design	B 2 2nd Level Functional Design	C 2 2nd Level Conceptual Design	D 2 2nd Level Assembly Embodiment Design	E 2 2nd Level Detailed Embodiment Design	**Bachelor**
Routine improvement; well-known methods in the field	1st Level Design	A 1 1st Level Competitive Design	B 1 1st Level Functional Design	C 1 1st Level Conceptual Design	D 1 1st Level Assembly Embodiment Design	E 1 1st Level Detailed Embodiment Design	
		Competitive Design Type **A**	Functional Design Type **B**	Conceptual Design Type **C**	Assembly Embodiment Design Type **D**	Detailed Embodiment Design Type **E**	
		Product Specifications	**Product Functions**	**Concepts**	**Product Architecture**	**Final detailed Design**	

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The 25 Screen Model of the Product Design allows to define several major aspects of product design, such as:

- to determine the project level of technological innovation, the structure of design according to ‘type’ and ‘level’,
- to perform design staff appointment and payment according to their professional abilities, design activity quantification, design project and designers assessment, etc.

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25 Screen Model can also be used to ***design university curriculum***, especially for Bachelor and Master.

As we move on the vertical axis from level 1 to level 5, the role and importance of the three major pillars of the industry 4.0 concept, i.e. cyber-physical system, big data analytics and cloud computing, is growing.

Thus, the training of graduates' skills, related to industry approach 4.0, must be gradual, from Bachelor to Master and PhD.

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3. Determining the global indicator of the innovation level

The assessment methodology of the product innovation level is based on developing a global indicator, which relies on the weighted sum of three indicators:

- Indicator of client’s satisfaction, I_{SC}, corresponding to the product delightful characteristics of the Kano model;
- Indicator of inventiveness, I_{IN}, associated with the research in the books of Altshuller on the 5 levels of inventiveness;
- Indicator of ideality, I_{ID}, which reflects the ideality degree of a product.

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The global indicator of the level of innovation:

$$I_{NI} = I_{SC} \cdot p_{SC} + I_{IN} \cdot p_{IN} + I_{ID} \cdot p_{ID} = I_{SD} \cdot p_{SC} + I_{IN} \cdot p_{IN} + \left(\sum_{k=1}^{28} i_k \cdot q_k \right) \cdot p_{ID} .$$

where p_{SC}, p_{IN} and p_{ID} represent the weights corresponding to the three indicators; i_1, i_2, …, i_9 are indicators of the ideality level; q_1, q_2 …, q_n are the weights of the indicators of ideality level; 28 is the number of sub-indicators i_k taken into consideration for the calculation of ideality indicator I_{ID}. The sum of weights of each category is equal to 1, that is $p_{SC} + p_{IN} + p_{ID} = 1$ and $q_1 + q_2 + \ldots + q_9 = 1$. Function of the domain in which the methodology is applied and the type of product, some weight values can be null.

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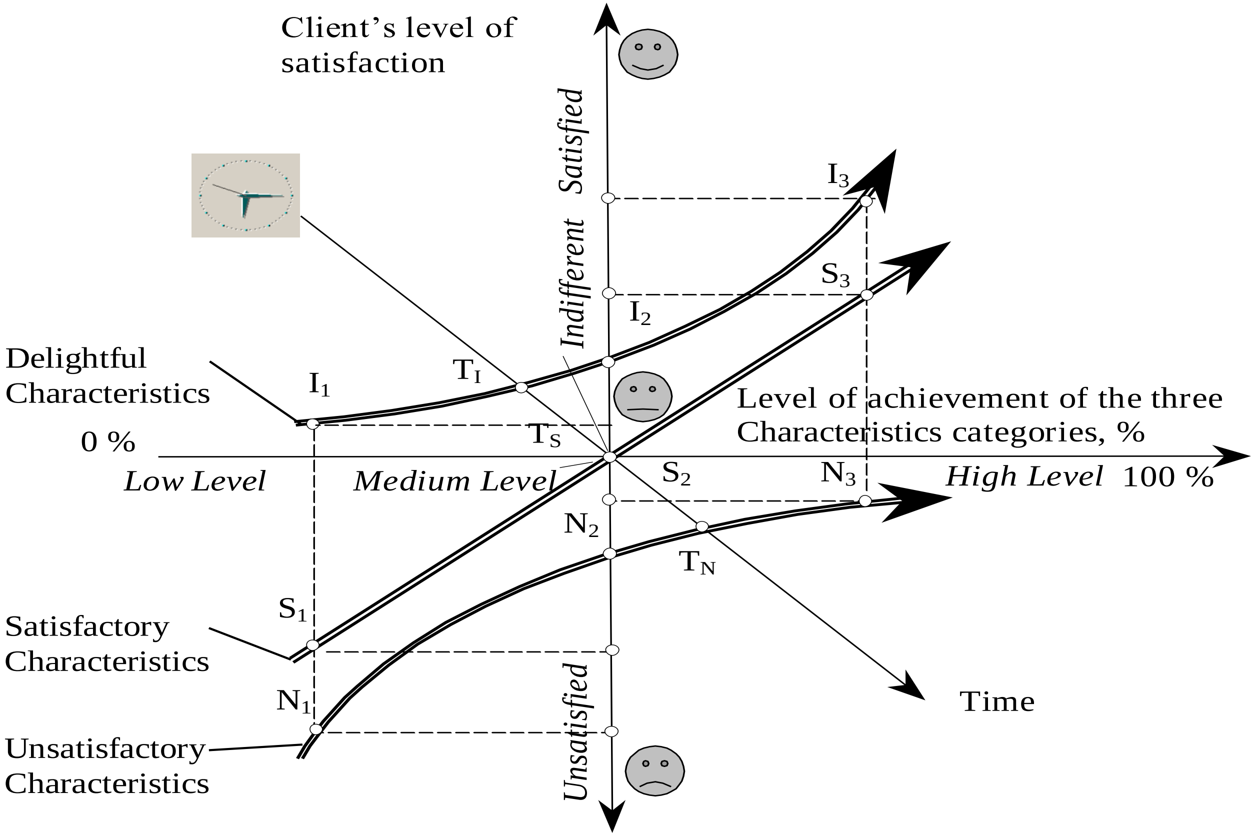
4. Determining the indicator of client satisfaction

The client's satisfaction by type of product characteristics



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5. Determining the indicator of inventiveness

- **Products of first level** – new products achieved through routine improvements brought to the existing products, improvements determined through well-known methods in the domain, whose source of inspiration comes from own knowledge of the design engineers in various domains. No invention is necessary for the achievement of these products.
- **Products of second level** – new products obtained through minor improvements brought to the existing products, established through well-known methods in industry, whose inspiration source is the scientific domain, where the design engineers work and usually are solved by aid of compromise.
- **Products of third level** – new products achieved through fundamental improvements brought to the existing products, through known methods, wherefore the solutions must be sought in related domains or taken over from other domains.

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- **Products of fourth level** – products that are new in principal, or new generation products, wherefore new principles are used, to obtain the principal product functions. At this level, the solutions applied are the result of clarification of several effects and phenomena from domains, such as: physics, chemistry, or geometry less understood until that moment, therefore more specifics to science than technology.
- **Products of fifth level** – products based on rare scientific discoveries, which are essentially new products, with solutions identifiable beyond the known boundaries of science.

Considering this classification, for the indicator of inventiveness, I_{IN}, grades will be assigned correspondingly, on the following scale: grade 2 for a product of level one, grade 4 for a product of level two, grade 6 for a product of level three, grade 8 for a product of level four and grade 10 for a product of level five.

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6. Determining the indicator of ideality

Indicator of ideality, I_{ID}, concerns the product ideality.

Generally, the evolution towards ideality implies:

- substitution of matter by fields;
- evolution in the domain of segmentation mainly of the acting (operating) elements in the system;
- evolution in the sense of increasing the flexibility and controllability;
- decrease of human factor implication.

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It is recommended that quantification of the ideality level of a product should be done through 28 indicators, to which grades are assigned on a scale from 1 to 10, function of the level of achievement.

Each indicator has the weight $q_{k,}$ the value of which depends on the product specific characteristics. Some of these indicators have been conceived by the Visan and Ionescu, and others have been obtained through adapting as indicators, like the developing trends towards ideality from CREAX software.

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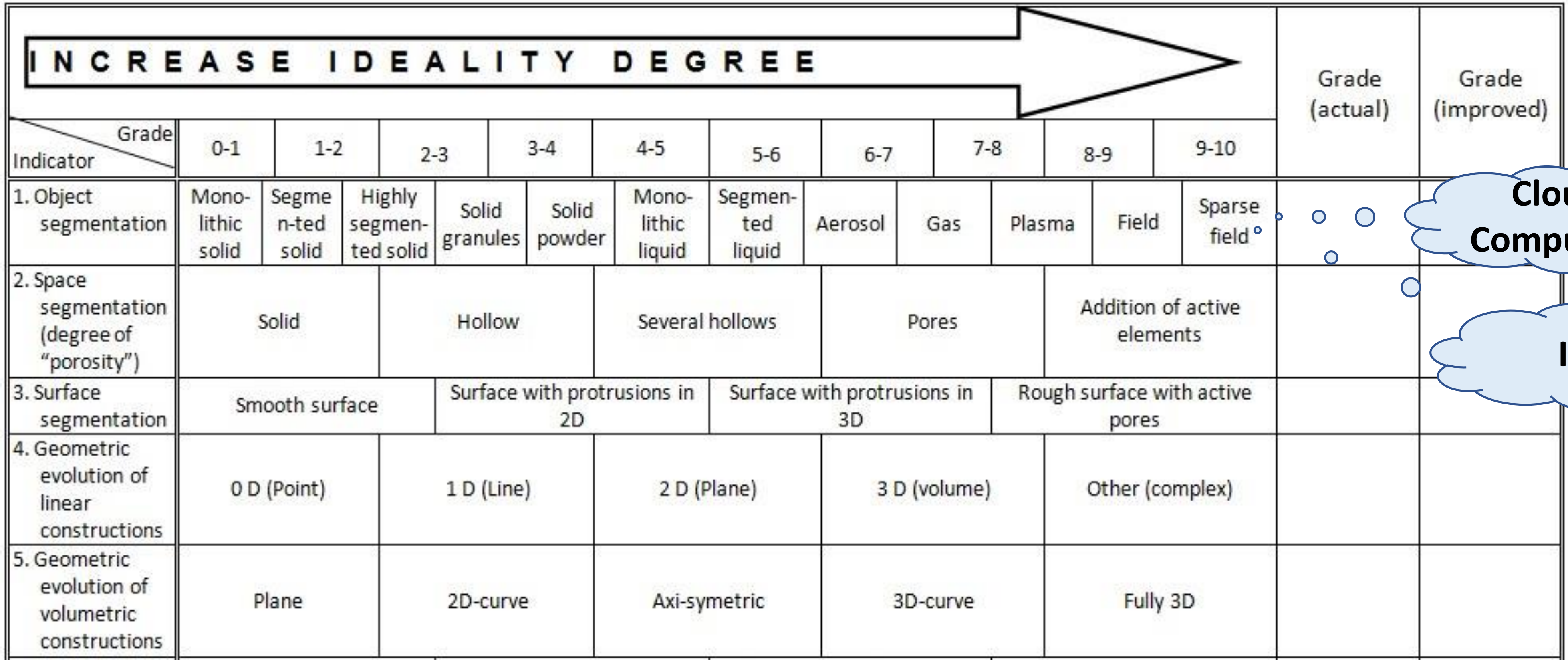

INCREASE IDEALITY DEGREE											Grade (actual)	Grade (improved)
Grade Indicator	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10		
1. Object segmentation	Mono-lithic solid	Segmen-ted solid	Highly segmen-ted solid Solid granules	Solid powder	Mono-lithic liquid	Segmen-ted liquid	Aerosol	Gas Plasma	Field	Sparse field		
2. Space segmentation (degree of "porosity")	Solid		Hollow		Several hollows		Pores		Addition of active elements			
3. Surface segmentation	Smooth surface		Surface with protrusions in 2D			Surface with protrusions in 3D		Rough surface with active pores				
4. Geometric evolution of linear constructions	0 D (Point)		1 D (Line)		2 D (Plane)		3 D (volume)		Other (complex)			
5. Geometric evolution of volumetric constructions	Plane		2D-curve		Axi-symetric		3D-curve		Fully 3D			

Cloud Computing

IoT

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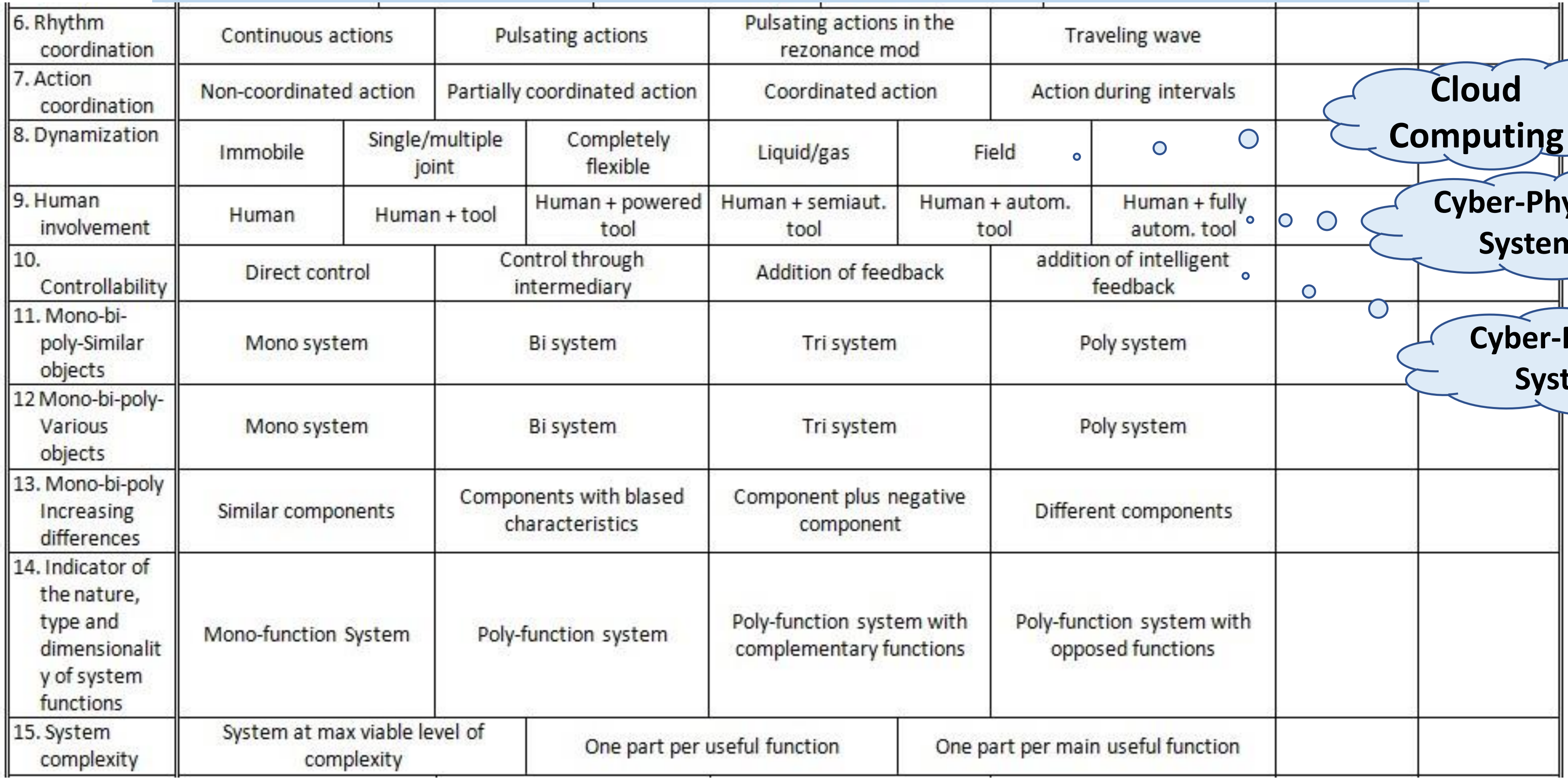

<table>
<tr><td>6. Rhythm coordination</td><td colspan="2">Continuous actions</td><td colspan="2">Pulsating actions</td><td colspan="2">Pulsating actions in the rezonance mod</td><td colspan="2">Traveling wave</td><td></td><td></td></tr>
<tr><td>7. Action coordination</td><td colspan="2">Non-coordinated action</td><td colspan="2">Partially coordinated action</td><td colspan="2">Coordinated action</td><td colspan="2">Action during intervals</td><td></td><td></td></tr>
<tr><td>8. Dynamization</td><td>Immobile</td><td colspan="2">Single/multiple joint</td><td>Completely flexible</td><td>Liquid/gas</td><td colspan="2">Field</td><td></td><td></td><td></td></tr>
<tr><td>9. Human involvement</td><td>Human</td><td colspan="2">Human + tool</td><td>Human + powered tool</td><td>Human + semiaut. tool</td><td colspan="2">Human + autom. tool</td><td>Human + fully autom. tool</td><td></td><td></td></tr>
<tr><td>10. Controllability</td><td colspan="2">Direct control</td><td colspan="2">Control through intermediary</td><td colspan="2">Addition of feedback</td><td colspan="2">addition of intelligent feedback</td><td></td><td></td></tr>
<tr><td>11. Mono-bi-poly-Similar objects</td><td colspan="2">Mono system</td><td colspan="2">Bi system</td><td colspan="2">Tri system</td><td colspan="2">Poly system</td><td></td><td></td></tr>
<tr><td>12 Mono-bi-poly-Various objects</td><td colspan="2">Mono system</td><td colspan="2">Bi system</td><td colspan="2">Tri system</td><td colspan="2">Poly system</td><td></td><td></td></tr>
<tr><td>13. Mono-bi-poly Increasing differences</td><td colspan="2">Similar components</td><td colspan="2">Components with blased characteristics</td><td colspan="2">Component plus negative component</td><td colspan="2">Different components</td><td></td><td></td></tr>
<tr><td>14. Indicator of the nature, type and dimensionality of system functions</td><td colspan="2">Mono-function System</td><td colspan="2">Poly-function system</td><td colspan="2">Poly-function system with complementary functions</td><td colspan="2">Poly-function system with opposed functions</td><td></td><td></td></tr>
<tr><td>15. System complexity</td><td colspan="3">System at max viable level of complexity</td><td colspan="2">One part per useful function</td><td colspan="3">One part per main useful function</td><td></td><td></td></tr>
</table>

Cloud Computing

Cyber-Physical Systems

Cyber-Physical Systems

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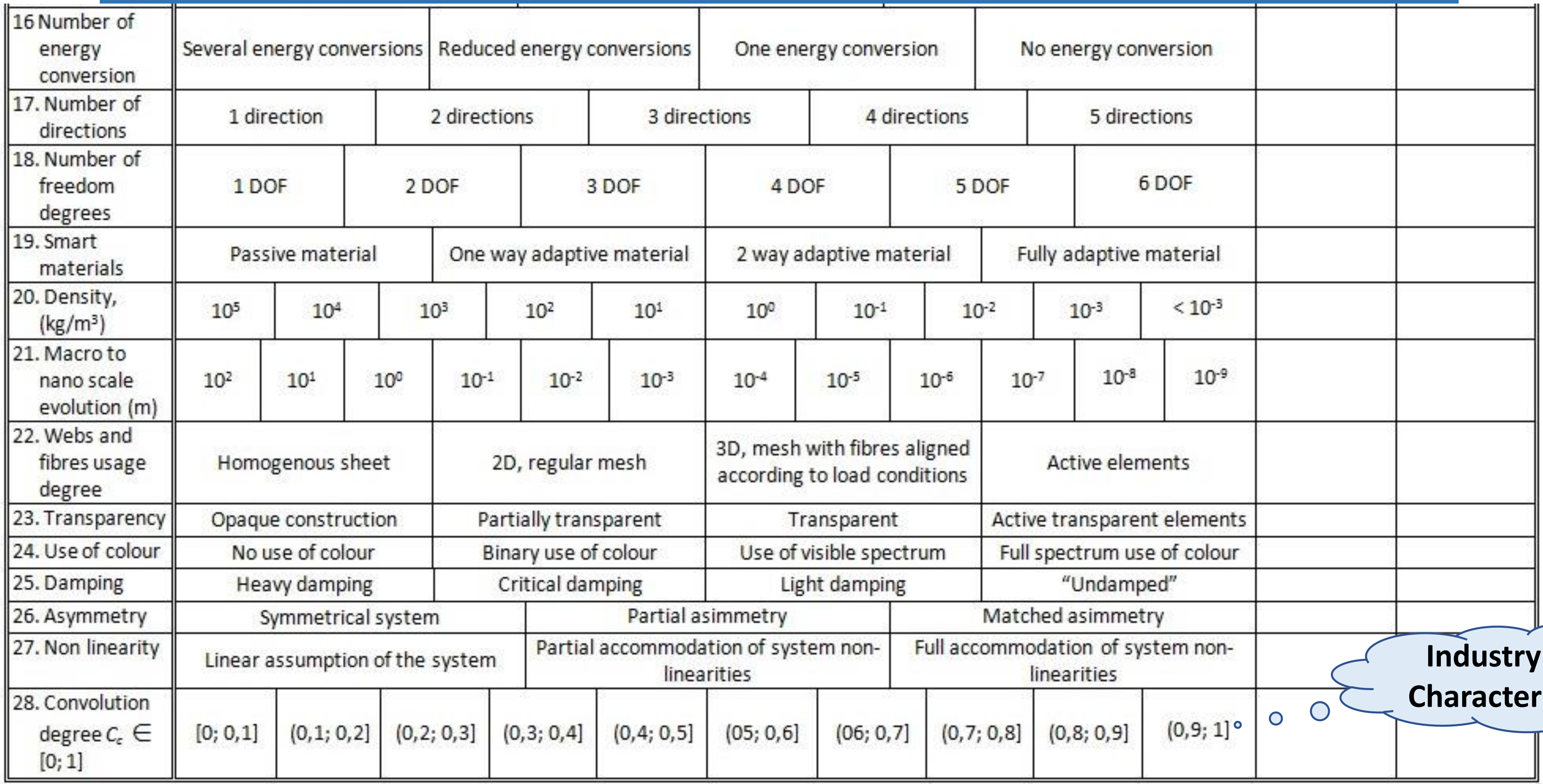

16 Number of energy conversion	Several energy conversions	Reduced energy conversions	One energy conversion	No energy conversion										
17. Number of directions	1 direction	2 directions	3 directions	4 directions	5 directions									
18. Number of freedom degrees	1 DOF	2 DOF	3 DOF	4 DOF	5 DOF	6 DOF								
19. Smart materials	Passive material	One way adaptive material	2 way adaptive material	Fully adaptive material										
20. Density, (kg/m³)	10^5	10^4	10^3	10^2	10^1	10^0	10^{-1}	10^{-2}	10^{-3}	$< 10^{-3}$				
21. Macro to nano scale evolution (m)	10^2	10^1	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}		
22. Webs and fibres usage degree	Homogenous sheet	2D, regular mesh	3D, mesh with fibres aligned according to load conditions	Active elements										
23. Transparency	Opaque construction	Partially transparent	Transparent	Active transparent elements										
24. Use of colour	No use of colour	Binary use of colour	Use of visible spectrum	Full spectrum use of colour										
25. Damping	Heavy damping	Critical damping	Light damping	“Undamped”										
26. Asymmetry	Symmetrical system	Partial asimmetry	Matched asimmetry											
27. Non linearity	Linear assumption of the system	Partial accommodation of system non-linearities	Full accommodation of system non-linearities											
28. Convolution degree $C_c \in$ [0; 1]	[0; 0,1]	(0,1; 0,2]	(0,2; 0,3]	(0,3; 0,4]	(0,4; 0,5]	(05; 0,6]	(06; 0,7]	(0,7; 0,8]	(0,8; 0,9]	(0,9; 1]				

Industry 4.0 Characteristics

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Summarizing, the ideality indicator I_{ID} is calculated with the formula:

$$I_{ID} = \sum_{k=1}^{28} i_k \cdot q_k$$

It is recommended to use the method AHP (Analytically Hierarchy Process) to set the q_k weights.

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7. Conclusions

Major remarks that should be mentioned:

- To perform assessment of design types and their effect on products, the authors have provided two criteria that is design content and technical innovation level.
- The design structuring model based on these two criteria is recommended by the authors as a technological innovation tool termed the 25 Screen Model of the Product Design, and allows for the design and projects classification by five types (A, B, C, D, E, and F) with five levels each (1, 2, 3, 4, 5).
- The model prepared by the authors is used for solving the major issues of product design related activities and technological innovation in a wide range of companies, such as: determining the technological innovation scale of a project, classification of design compartments according to type and level, appointment and payment of designers based on competence, quantification of design activities, assessment of projects and designers. This model can also be used to design university curriculum, especially for Bachelor and Master, to introduce competences in creativity and innovation according Industry 4.0 concept.

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- In the second part this work proposes a methodology for assessing the innovation level of products based on the weighted sum of three indicators: client’s satisfaction indicator, inventiveness indicator and ideality indicator obtained by weighted sum of 28 indicators.
- Because there is a perfect analogy between some of the indicators and the features of the Industry 4.0 concept the indicator of ideality can be used (partially or totally) as a magnitude that quantifies the degree of implementation of the 4.0 industry concept within a system.

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References (selected)

1. Altshuller G. (1997), *40 principles: TRIZ - Keys to Technical Innovation*, Worchester, Massachusetts: Technical Innovation Center.
2. Cross N. (1994), *Engineering Design Methods*, J. Wiley & Sons, New Jersey
3. Mazur G. (2001), *Theory of Inventive Problem Solving (TRIZ)*, http://www-personal.engin.umich.edu/ -gmazur/triz/
4. Pahl, G. and Bietz, W. (1996), *Engineering Design-A Systematic Approach*, Springer
5. Vişan, A. and Ionescu N. (2004), *Tolerances – Basics of product design and precision prescription*, Bucharest, BREN Publishing

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