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DESIGNING HUMAN-MACHINE SYSTEMS: TRANSFORMATION OF A DESIGNER'S THINKING

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ABSTRACT *Industry 4.0 became a powerful impetus for the development of man-machine systems, which, on the one hand, increased their efficiency and reliability and, on the other hand, made them super-complex. As a result, this led to an increase in the complexity of human-machine system management and the manifestation of the human factor. The consequence is that, currently, the main cause of accidents and disasters is the human factor. Thus, the safety of human-machine systems largely depends on the person's psychological and physiological characteristics. The article shows that the study of a person's characteristics is the basis for the development of a human factor management system. The essential element of the human factor management system is the systemic ergonomics thinking of the human-machine systems designer. This type of thinking is formed as a result of training and the gradual acquisition of eco-ergonomic design skills. To explain the importance of the formation of eco-ergonomic thinking in human-machine systems design, eco-ergonomic thinking evolution is presented in the work. Through the analysis of the sequence of the development of ergonomic thought, it is shown how the approach to ensuring the safety of human-machine systems has changed from the middle of the 20th century to the present. The next stage of the work was the analysis of eco-ergonomic, human-oriented, risk-oriented, and strategic thinking. Based on the analysis results, a hierarchy of thinking types is built, and their role in the formation of systemic ergonomics thinking in human-machine systems designing is shown. The main feature of the designer's systemic ergonomics thinking is the priority of finding a solution to the problem in the system operation through research and analysis of human-machine interaction. Based on the obtained results, the importance of the formation and development of systemic ergonomics thinking is substantiated. It is shown how to implement the formation of a designer's systemic ergonomics thinking of human-machine systems through the training system.*
Keywords: *human-machine system; systemic ergonomic thinking; safety; eco-ergonomic designing.*

ПРОЕКТУВАННЯ ЛЮДИНО-МАШИННИХ СИСТЕМ: ТРАНСФОРМАЦІЯ МИСЛЕННЯ ПРОЕКТУВАЛЬНИКА

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АНОТАЦІЯ *Індустрія 4.0 стала потужним поштовхом для розвитку людино-машинних систем, що, з одного боку, підвищило їх ефективність і надійність, а з іншого – розробила їх надскладними. У підсумку, це призвело до підвищення складності управління людино-машинною системою і підвищення прояву людського фактора. Наслідком цього є те, що на поточний момент основна причина виникнення аварій і катастроф це людський фактор. Таким чином, безпека людино-машинних систем значною мірою залежить від індивідуальних психологічних і фізіологічних особливостей людини. У статті показано, що дослідження індивідуальних особливостей людини є підґрунтям для розроблення системи управління людським фактором. Ключовим елементом такої системи є системне ергономічне мислення проектувальника людино-машинних систем. Такий тип мислення формується у результаті навчання і поступового набуття навичок еко-ергономічного проектування. Для пояснення важливості формування еко-ергономічного мислення у проектувальника людино-машинних систем у роботі представлена еволюція еко-ергономічної думки. Через аналіз послідовності розвитку ергономічної думки показано, як змінювався підхід до забезпечення безпеки людино-машинних систем із середини XX століття до теперішнього часу. Наступним етапом роботи став аналіз еко-ергономічного, людино-орієнтовного, ризик-орієнтовного, стратегічного мислень. На підставі результатів аналізу побудована ієрархія типів мислення, показана їх роль у формуванні системного ергономічного мислення у проектувальника людино-машинних систем. Головною особливістю системного ергономічного мислення проектувальника є пріоритетність пошуку розв'язання проблеми у роботі системи через дослідження й аналіз взаємодії людини і машини. На підставі одержаних результатів обґрунтовано важливість формування і розвитку системного ергономічного мислення. Показано, як реалізувати формування системного ергономічного мислення у проектувальників людино-машинних систем через систему навчання.*
Ключові слова: *людино-машинна система; системне ергономічне мислення; безпека; еко-ергономічне проектування.*

Introduction

The development of modern design in the conditions of worldview orientation in the formation of the spatial-subject environment of human activity in the system of new technologies, revolutionary technological changes, and a radical revision of civilizational strategies for the benefit of society's sustainable development is accompanied at this

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stage by the creative activity of designers in building new values and norms of material and spiritual life.

It has become legitimate to consider modern civilization as informational. Therefore, information is getting more and more expansive. All intellectual work, production, culture, art, and design are built on it. The design's informational aspect is related to human perception of the environment and the designer's creative attitude. Awareness of the formation, transmission, perception and memorization of messages, design's informational properties and process allow for increasing the information expressiveness and meaningfulness of the spatial-subject environment, and its communicative contact with a person.

Today, design is a scientific and practical discipline for creating a balanced spatial-object environment, the organization of human life, and the content and structure formation of objects of material and spiritual culture. It is interpreted as a subject of scientific research and project activity in the "human-environment" system. In the philosophical sense, design is a type of thinking that creates ideas in the direction of the maximum organization of human life according to its needs, ethical and aesthetic norms and socio-cultural center [1,2].

Society's sustainable development is the concept of human activity in harmony with nature, ensuring people's quality of life and protecting the interests of future generations. Awareness of the continuum of space, the sociosphere as a self-organized, self-regulated planetary system with environmental components, complex connections and mutual influences, the limitations of natural resources, as well as the affirmation of the anthropocentric orientation of design as a comprehensive goal of project activities to form a balanced spatially-material environment lead to the creation and use in design of new systems and structures, new technologies with the priority ecological, ergonomic and human factors principles. The design's eco-component of the socio-systemic environment and approaches to solving this problem are determined by the ideology of environmentalism and design. Environmentalism is a worldview fundamental position of the designer, which can be embodied in various objects of material culture. The implementation of the principles of sustainable development, which ensures the creation and maintenance of the triad "ecologization-digitalization-safety", helps ergonomics. Therefore, they must fit modern requirements for eco-protection and safety. At the same time, ergonomics itself should apply new approaches such as ergoecology, green ergonomics, digital ergonomics, ergonomics of information technologies, etc. [3-10]. It will allow designers of human-machine systems to form a new type of design thinking – eco-ergonomic, which will become the basis for eco-ergonomic design development.

Materials and Results

Designing the environment is a complex organizational and creative process that involves a worldview-oriented awareness of the design object as a structural component of the social system and its intended use, as well as the implementation of routine operations for its development. Therefore, the main feature of designing the environment is a careful analysis of each creative solution for compliance with the concept of sustainable development, natural, social, informational, ergonomic and ecological requirements, functional and technological processes, technical and economic indicators, a holistic artistic model and the image of the person for whom it is designed [11-13]. Formation and implementation of information technologies, the theory of human activity and the human factor, the theory of ecological conceptual thinking and the psychology of the ecological relationship to the environment, and the ideas of modern aesthetics and engineering psychology must be the base of this approach [2]. The emergence of Industry 4.0 and Industry 5.0, the emergence of digital eco-systems and digital jobs, cobots and AI have marked the appearance of a new problem of training specialists, engineers, and designers of the future. In this regard, the work aims to analyze the transformation of the "designer's thinking". The task is to form principles included in the modern designer's thinking – ecological, ergonomics, systemic, interdisciplinary. Therefore, it is need to pay attention to the problem of the formation of systemic ergonomics thinking among designers of human-machine systems.

1. The design of the environmental and product life cycle. The design of the environment is usually considered in the broad sociocultural context of integral sociocultural situations - the harmonious structuring of the subject and procedural aspects of the "human-item-environment" system and programs for such systems organization [2]. The design of the environment today is considered within the framework of a more complex system - the activity of a human or a group of people in a spatial-item environment, considering its spatio-temporal properties and environmental protection conditions. Market experts say that what is sold is not the consumer properties of the product but its benefits and potential uses. The item content general structure includes the communication ability of the subject, its form, construction, material, and technology.

It is known, that engineering gives the technical logic of the item, design – its human harmony, the system of human relations with the environment. Design forms cultural and consumer properties that materialize as an item in the production process and develop in the use process. In the sociocultural aspect, design forms systems of information and communication in the broadest sense.

Modern science about complex systems formation and the organization of the human life environment widely uses the concept of the life cycle structure. The product's life cycle, as defined by its ISO 14035 standard, is a set of processes performed from identifying the needs of society in a specific product to the moment of satisfying these needs and disposal of the product.

The general structure of the product life cycle is presented in Fig. 1. As a rule, the spatial-item environment formation includes areas such as planning, design, production, operation and intended use.

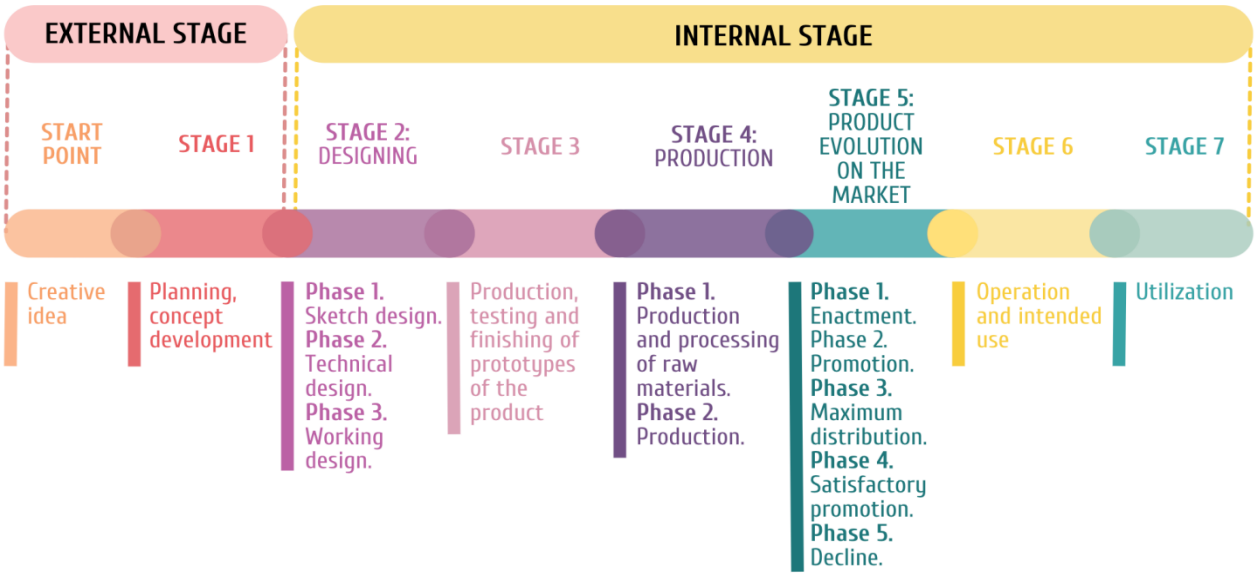

Fig. 1 – Product's life cycle structure

The life cycle of a product design also includes the following stages: product evolution on the market (trade) and disposal. The environmental aspect of the life cycle is the "superstructure", the upper level of the product's existence, and the ergonomics are a mandatory component of the planning, concept development and design stages. The product's competitiveness and the economic side of the products life on the market directly depend on these aspects.

External design is a creative idea and the first stage of development. The first stage should address issues related to identifying the needs of user subjects and defining the design object with clarification and assessment of the environment, goals, and objectives for which the product is being created. At this stage, the social order and the content of the future development, the market situation and the possibilities of promoting the product on the market are clarified, and the matrices of the parameters of the consumer, the techno-world, and the environment are laid down. The result is the planning and development of the concept, the drawing up of technical specifications for the design, which contains the formulation of the purpose and tasks of the design, the identification of needs, the formation of the concept and its details, the main requirements for the subject of development and its interaction with the consumer and the environment, which would ensure the solution of the tasks.

Let's emphasize that ecological and ergonomics issues, the designer's eco-ergonomics awareness and worldview play an essential role even at the first stage. Internal design - the second stage of the design cycle with sketch, technical and working design following the developed concept includes product design, preparation of working documentation for the manufacture and testing of prototypes, and the third – manufacture, testing and proofing of prototypes.

Note that the human factor manifests itself at all stages of the life cycle, namely in the processes of designing systems and technologies, selection and measurement of informative parameters, choosing and processing of relevant information, its analysis and generalization based on previously set or formed evaluation criteria, decision-making based on informational and visual-conceptual model; execution of the decision made using a specific sequence of actions. Therefore, modern design of the human environment takes training a new designer who understands the importance of eco-knowledge and ergonomic principles and applies them in activity.

2. The problem of eco-friendliness in designing.

Eco-friendliness. Each item being designed, in the process of its development, must be subjected to multiple checks for environmental friendliness. Verification is provided when choosing a design object and understanding its concept; searching for resource-saving technologies; assessing detailed solutions for the production of the item; making decisions about the effective use of materials and energy resources; forms and means of production; shaping, transportation and storage of items. Tests are conducted in the following areas: compliance with functional requirements, operational, static strength, reliability, and durability. In manufacturing test samples, clarifications and some structural changes are possible. After testing and proving the prototypes, a decision is made about the feasibility of manufacturing a new product.

The problem of eco-friendliness plays an essential role when choosing eco-friendly technologies for production (stage 4), operation (stage 6) and disposal of the product (stage 7). Environmental concepts must consider decisions crucial for ensuring the efficiency of production and consumption of the item and what consequences the designer's activity may have not

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immediately but in the distant future. A special place is occupied by social measures aimed at lowering the product price, increasing the length of its service life, ease of maintenance, and, in general, at the organization of human life, harmonizing relations with the surrounding world [14,15]. Stage 5 describes the evolution of the elements of the subject environment in the market with the stages through which the new product passes: market introduction, promotion, maximum distribution, satisfactory promotion, and decline in demand for the product. These stages of product sales require different strategies and separate marketing plans. But even here, the dependence of economic profit on the product's eco-quality and considering the economic features of design formation are evident [9,16-19]. Thus, there is a tendency to reflect the product's life cycle with the priority of "economy, energy-efficiency, eco-friendliness" directions (Fig. 2).

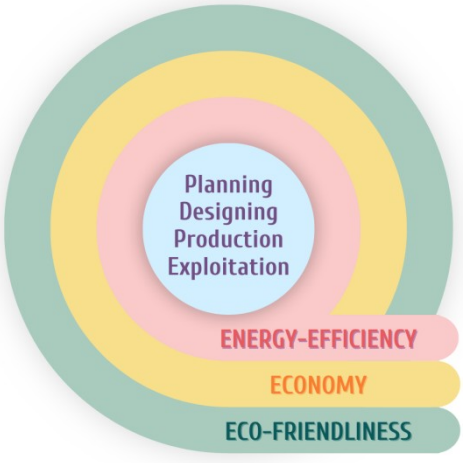

Fig. 2 – The product's life cycle with considering economy, energy-efficiency and eco-friendliness

Interestingly, today, eco-thinking is closely related to a type of thinking and life organization known as healthy thinking. Namely, healthy thinking determines a person as an element of society. Such thinking consists of positive thinking, feeling good, physical exercises, and quality eating. All components of healthy thinking have an ecological part. Healthy thinking is an eco-friendliness in all elements of human life. It is an understanding of the importance of an eco-approach to all spheres of life. It is an awareness of the necessity of eco-knowledge.

A systematic approach to eco-design. The practical implementation of such a system approach requires the designer to significantly expand his worldview to collaborate with specialists in other fields of knowledge. A person's participation in the system makes it self-learning and self-developing, and the actions of each factor in different periods are ambiguous. Increased attention is given to uncertainty factors, their evaluation and consideration when choosing the most predominant solutions and possible alternatives. A balanced environment with a systemic approach should take into account the dynamics of a complex system at small time intervals within its systemic environment with minimal resource consumption and minimal uncertainty. The starting point of such an approach is the designer's creative attitude. The peculiarities of the designer's creative inclination and his experience make it possible to process the accumulated and purposefully used information material, which leads to the setting of a creative task and attitude.

The informational nature of design implies [2]:

1) a system of language signs – the formalized language of design and communications;

2) the subject matter and sensory-figurative meaning of linguistic semantic units;

3) symbolic relations in the system "source – symbolic message – coded system – decoder";

4) designative (informing) and appreciative (evaluating) meaning of design signs;

5) communicative and expressive function of design language.

A systematic approach to design should also include new ideas about the perception of the environment, which are based on the laws of human cognitive processes as the dominant psychophysiological process of human cognition. The basis of the sensory image that arises when perceiving the environment is tactile-kinesthetic and tactile sensations. Visual and auditory sensations do not have an independent meaning because they are formed based on tactile and kinesthetic sensations. At the same time, perception is not the sum of separate perceptions but a qualitatively new level of sensory cognition. Therefore, it is indisputable that visualization and identification of the environment is one of the main components in creating a harmonious, balanced environment for human life support.

Methods considering the ecological factor occupy a special place in the design. Among them:

1) effective use of materials with the possibility of multiple processing and forming during design, production of the product and its operation;

2) the use of natural materials and natural raw materials;

3) designing objects based on natural analogues;

4) design of items with effective material content;

5) design of items with low-energy consumption;

6) designing objects with long-term of the life cycle;

7) multi-touch design.

Solving eco-aspects in the complex design of the item environment directly affects the physical, psychological and social health of both person and society. The theoretical provisions of visual ecology make a valuable contribution to a harmonious environment and are decisive for the appearance of new ecological thinking [20,21].

3. Transformation of the thinking of the human-machine systems designer.

It is interesting that the activity of outstanding engineers, scientists and developers is based on particular thinking and the ability to identify and resolve

contradictions hidden in technical problems. One of the foundations of implementing the Japanese economic miracle was the workers' continuous training from the lowest level to managers in order to create in them specific thinking and to stimulate this thinking through rewards for ideas (suggestion boxes at factories).

The founders of Japan's economic breakthrough proved that leadership, coaching, motivation and continuous learning are the basis of success in creating viable and efficient production systems. Interestingly, many scientists who researched and implemented the theory of quality were ergonomists with ecologically oriented thinking. Due to this thinking, such well-known quality strategies as Just in Time, Kaiser, and Lean production were born. So, for instance, the estimate method of service quality, which has been known for half a century, has many items from the ecology area and was proposed by well-known ergonomists. Thus, ergonomics ideas are closely intertwined with theories from other areas, especially environmental ones.

Therefore, the professional training of human-machine systems designers requires special attention to engineering thinking development, which ensures compliance with the above principles of engineering activity. The human-machine systems designer must assess the problem systemically, avoid the standard solutions, generate unconventional ideas, and master the skills of multivariate solving problems and objective assessment. Systemic thinking is necessary because it is characterized by a holistic perception of objects and phenomena and their connection. Along with this, engineering thinking is specific, professional thinking aimed at the development, creation and operation of new high-performance, reliable and safe equipment (Fig. 3).

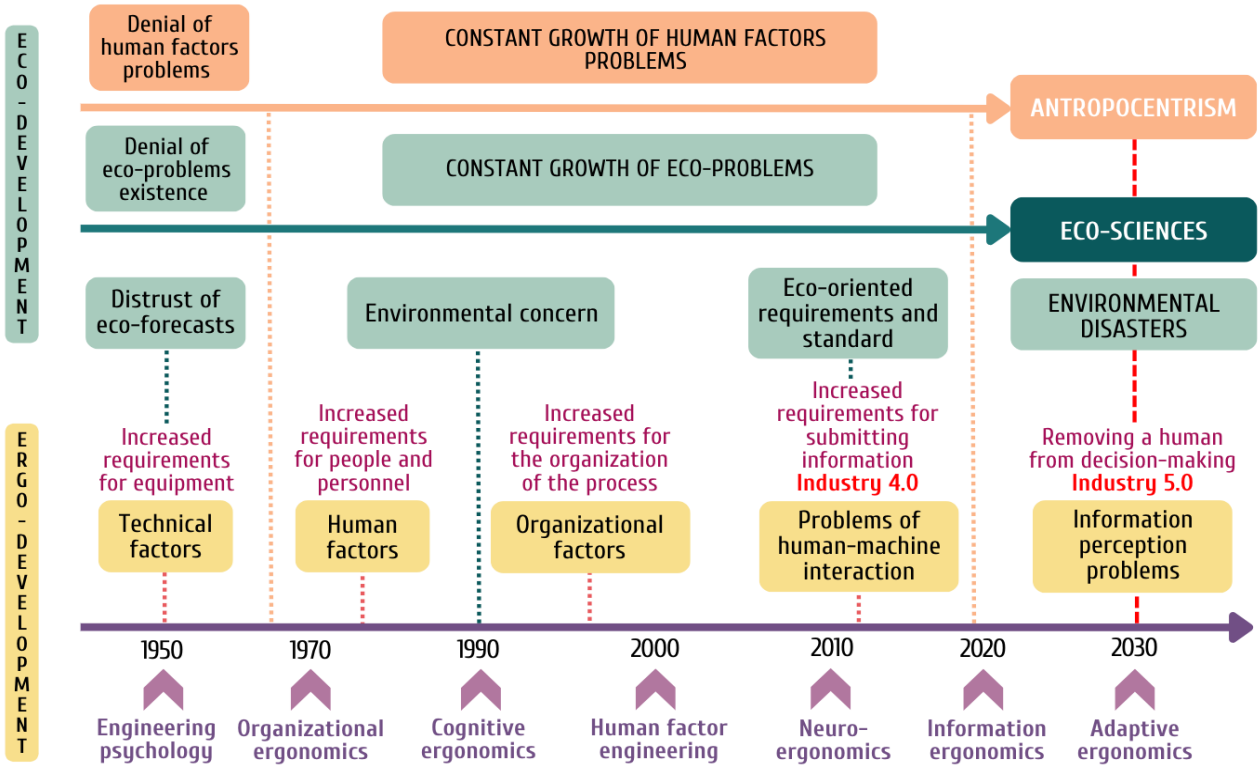

Fig. 3 – The development of eco-ergonomic thought for designing human-machine systems

4. Transformation of eco-thinking into eco-ergonomic thinking.

The thinking problem of a modern specialist. The knowledge, skills and abilities of a modern human designer of human-machine systems are often insufficient. Thus, there is a need for engineering thinking development, which is the most essential component of engineering activity. An engineer has to transform the human environment. It is how smart homes and cities, eco-friendly offices and technologies appeared. Crucial elements of engineering thinking are the ability to see contradictions (logical, technical, physical) and a broad scientific outlook, i.e. having interdisciplinary knowledge. They allow evolutionary innovations (gradual development) and revolutionary innovations. The emergence of Industry 4.0. and 5.0, the emergence of digital eco-systems and digital jobs, cobots and AI marked the emergence of an acute new problem of training specialists, engineers, and designers of the future.

At the current stage, science and society have two essential features: the digitalization of working processes and the promotion of sustainable development principles through people's eco-attitudes toward the environment. In

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these conditions, the design of man-machine systems considering the demands of an eco-digital society is a complex task that involves a comprehensive analysis of each stage of design for its compliance with the principles of sustainable development. To solve this problem, when designing man-machine systems, it is necessary to apply information and digital technologies, concepts of ecological and ergonomic thinking, principles of eco-attitude to the environment, and principles of creating the safest working environment. It will minimize the negative impact of the human-machine system on the environment and increase human safety. At the same time, the importance of training designers to implement such an approach becomes apparent.

Designer's eco-ergonomic thinking of the human-machine systems. For now, eco-ergonomic thinking is a part of systemic thinking, which focuses on solving problems of human-machine interaction. For a designer, such thinking means high reliability and qualification. Eco-ergonomic thinking focuses on the priority of eco-problems and human-machine interaction problems. That is why emphasis must be drawn to the eco-ergonomic thinking development in designers of human-machine systems because it allows understanding of the human-machine interaction processes, forecasting risks and developing the systems with preliminary consideration of these risks. The final result of the development of an eco-ergonomic approach to designing human-machine systems is the promotion of the development of an eco-digital society creating a balance in the development of an ecological attitude to the environment, digitization of activities and ensuring human safety [22,23].

Design thinking. Today, more and more people are talking about design thinking. Design thinking is based on the designer's cognitive, predictive and practical knowledge and skills. Design thinking is a methodology for solving different types of problems using a creative approach [5,6].

The design thinking process includes the following stages: empathy, definition, ideation, prototype, and testing or verification. Such a cyclical process is the key to solving complex problems, the key to creative and innovative activity based on the essential principles of bionics [24] and creative thinking, which manifested in:

1) science in finding similarities between different things;

2) the art of finding differences between things that are similar;

3) design when creating a possible whole from impossible parts.

Since the design activity forms the spatial-item environment, it is a crucial tool for innovation and competition, growth and development, which is essential for the effective revival of Ukraine and its prosperity. Therefore, it is crucially for design education to:

1) formation of hybrid design-thinking in the learning process (disciplines - history of design, bionics, fractals in nature);

2) expansion of worldview (metaphysics, metaergonomics, topology);

3) mastering the principles of risk forecasting (human factors engineering, viability theory, life safety).

Design thinking is a promising technology trend for 2016, writes the German IT business magazine CIO. This innovative method was developed by University of Stanford Professors David Kelley, Larry Leifer and Terry Winograd and brought to Europe by SAP co-founder Hasso Plattner [25,26]. Since the 1990s, human-centered design (HCD) has emphasized the need to remain user-centered.

Healthy thinking. It is interesting that today, there is another interesting, generalizing type of thinking - healthy thinking. Healthy thinking means perceiving the environment realistically, without "pink glasses", aware of the entire range of problems – positive, negative and neutral, based on this data, making a decision or conclusion. Schneider proposed three characteristics of healthy thinking: constancy, organization and continuity. Disorders of thinking under the general name "formal thinking disorders" include confusion, messiness, backwardness, neologism, poverty of language content and persistence.

Human centered thinking. Ergonomic thinking is inseparably connected with human-centered thinking. Human-centered thinking is a way of solving problems that puts a person at the center of the design process to create products and services specifically to meet the person's needs.

Risk-based thinking. Risk-oriented thinking will ensure stability and security. In the ISO 9001 standard, risk-based thinking is defined as "the systematic application of information, knowledge and action to address uncertainty and potential opportunities" [27]. Thus, risk-based thinking is a proactive approach to problems or opportunities. This type of thinking aims to incorporate preventive action.

Strategic thinking and vision. Thinking is a strategic prediction, so it is the basis for solving future problems, designing systems and human activity. This way of thinking is based on the search for all possible scenarios of the development of events and preparation for them, regardless of their probability. It is a technology that creates competitiveness and guarantees the capacity, safety, reliability and viability of systems and environments. Strategic thinking is connected with a vision of the desired future and predicting the consequences of forecasts (Fig. 4).

Systemic Ergonomics Thinking. Types of thinking could be united into a systemic ergonomics thinking. Brown described design thinking as "a human-centered approach to innovation that draws on the designer's toolkit to integrate the needs of people, the capabilities of technology, and the requirements for business success" [26]. Design thinking combines human desires with feasible technologies and the need for business success, or in other words: "Desirability (human aspect), viability (business aspect) and feasibility

(technical aspect).” As shown in Fig. 5, within the spectrum of these three main components lie eco-principles (existence in an ecosystem), ergonomic principles (human activities in the ecosystem) and human factors principles (human errors and decision-making).

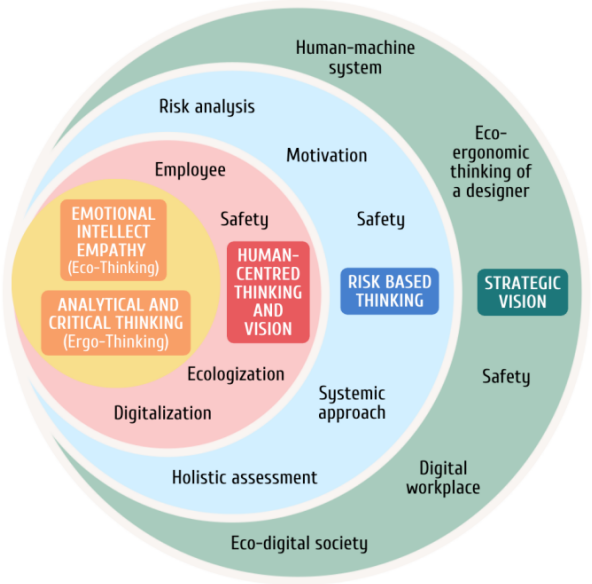

Fig. 4 – Thinking types hierarchy.

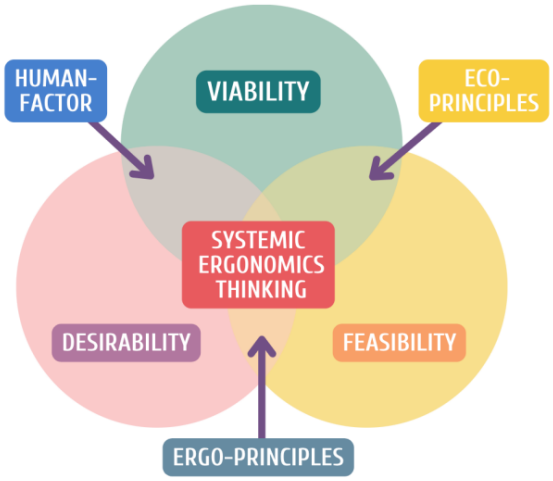

Fig. 5 – Structure of a systemic ergonomics thinking

Conclusions

Today, a whole block of humanitarian, socio-economic, scientific and technical disciplines has been formed. They have an orientation towards the objectification of artificially created complex systems for the organization of human life. The design process has an iterative nature, because, during its implementation, it is necessary to consistently clarify the decisions made at the earliest stages of the design based on the analysis of the received concrete decisions. In turn, the iterative nature of design requires multivariate design solutions. An essential role in the design of the human environment is played by the system of restrictions, which are determined not only by state and international standards, scarcity of materials, constructive solutions, and existing manufacturing technologies but also by the need for a modern look at the design of the environment through the prism of the triad of principles: ecological, ergonomic and human factors.

Applying a systematic approach to environment design, the problem of the creative process, revealing the designer's thinking in the creative process, is crucial. The hierarchical nature of the design procedure itself should also be taken into account. The designer initially makes rather general decisions characterized by a low level of specification. In the course of the design, the commonality of the decisions being made decreases, while the level of specification increases. In the meantime, the designer is obliged to go through several decision process levels – from the development of concepts to the design of the decision. The centuries-old experience of human development confirms that none of the methods chosen by the designer to solve creative problems can be considered unbreakable and untouchable because everything can be improved.

Currently, the priority issue for any society is the implementation of sustainable development principles, which ensures the creation and maintenance of the triad “environmentalism-digitalization-safety”. Ergonomics helps to optimize society’s activity in this direction. Consequently, they should fit current environmental and safety requirements. At the same time, ergonomics should apply new approaches such as ergoecology, green ergonomics, digital ergonomics, ergonomics of information technologies, etc. It will allow designers of human-machine systems to form a new type of design thinking - eco-ergonomic, which will become the basis for eco-ergonomic design development.

Therefore, to live in new conditions, it is necessary to develop design thinking and new tools to learn to think, live and act following the conditions of the time. After all, the beginning of the XXI century was marked by a change in paradigmatic attitudes in education, which are characterized by a reorientation from technology to humans.

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