INSIGHTS INTO INDUSTRIAL ERGONOMICS

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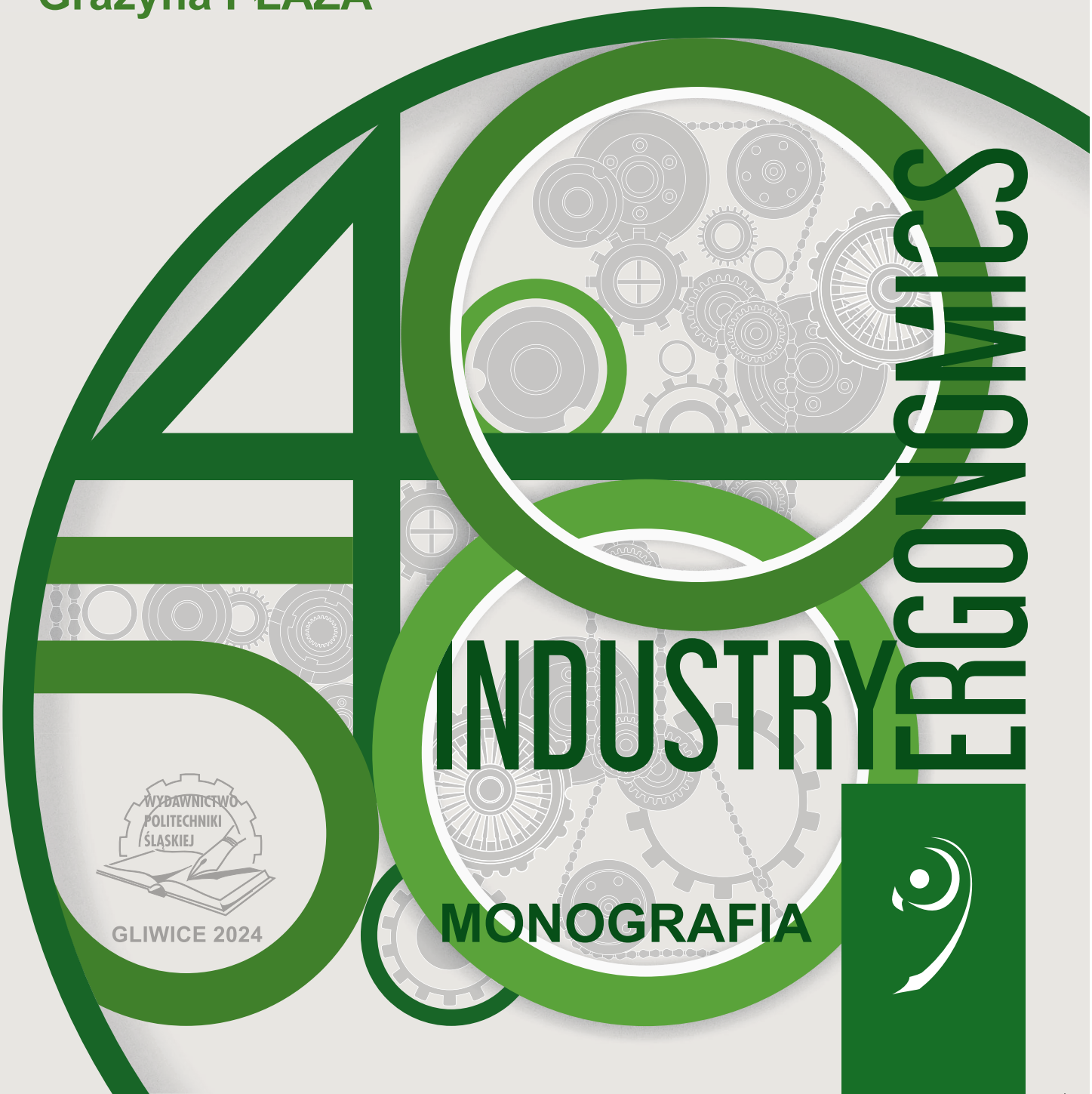

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3. ECO-ERGONOMIC THINKING UNDER HUMAN-MACHINE SYSTEM DESIGN

3.1. Introduction

The current stage of society's development has two key characteristics. The first is the application of digital technologies in all spheres of human activity. The second is the promotion of the principles of sustainable development of society through the formation of people's ecological attitude to the environment. In 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 design stage for its compliance with the principles of sustainable development. To solve this problem in the human-machine system design, it is necessary to apply information and digital technologies, the concepts of ecological and ergonomic thinking, ecological attitude principles to the environment, and principles of creating the safest possible 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.

Formulation of the problem. Today, human activity is the search, use, exchange, creation and organization of information in the digital environment. However, the employee is constantly under the information load, the fast pace of work and lack of time, multitasking, responsibility for the decisions and implemented actions, and an unregulated regime. In addition, currently, the working environment is a complex of

factors of natural and artificial origin, which has a constant physical, chemical, biological and psychophysiological influence on a person. Over time, this can lead to adverse changes in the employee's health. Collectively, the problems of organizing human activity in the digital environment and ensuring the eco-friendliness of the working environment are currently the central issues of ergonomics [1, 3–6, 10, 17–19]. After all, the employee's comfort, productivity, and physical and mental health can be ensured if working conditions, materials, equipment and software are designed to his psychological, physiological and social needs and characteristics. Therefore, the goal of the current stage of ergonomics development is to achieve a proper match between the working environment and the employee's capabilities. It, in turn, determines the relevance of forming eco-ergonomic thinking in the designer of human-machine systems. Forming such thinking is connected with learning and phased acquiring knowledge and skills.

However, there is **a scientific problem** consisting of the lack of a general concept that would combine the ecological directions of research in ergonomics and the study of digital ecosystems into a single system of theoretical knowledge and practical methods increasing the human-machine system's safety and efficiency.

The purpose is to analyse the concept of "eco-ergonomic thinking". **The main task** is the formation of a set of principles of eco-ergonomic thinking. **The motivation** is to draw attention to the problem of developing eco-ergonomic thinking among designers of human-machine systems. In this regard, the focus of the work is on:

1. Analysis of the evolution of ergonomic thought in the design of human-machine systems.
2. Consideration of the idea and components of the "eco-ergonomic thinking" concept.
3. Consideration of the essential principles of eco-ergonomic design of human-machine systems.

3.2. Literature review

Historical foundations of the intersection of ecological and ergonomic issues. In the mid-1950s, Tahiti Ono (the founder of the Toyota Production System) implemented the "lean production" concept. Lean production is an approach to managing the organisation based on increasing the quality of products while

simultaneously reducing costs. At the same time, the basis of this concept is the maximum focus on the person – worker, manager, or consumer. Moreover, lean production is impossible without a lean culture, in which the analysis and estimation of the impact of human activity on the environment play an essential role.

Additionally, it is known Kaizen concept, which focuses on the continuous improvement of production processes. It is interesting that the main components of Kaizen are ergonomic characteristics of human-machine systems that serve to improve quality: interaction and teamwork, discipline and standards in activities, the psychological climate in the team, leadership and intelligence. Also, among the seven main types of losses that should be minimized (and preferably avoided) were the ergonomic shortcomings of human-machine systems, namely:

1. Disadvantages associated with poor planning are waiting, unnecessary transportation and movement (which leads not only to economic losses but to negative environmental consequences), useless stages of processing, and uneven execution of the operation.
2. Disadvantages related to people are the production of defective products, the unrealized creative potential of employees, and the overloading of workers and equipment (which has both economic and environmental consequences).

One of the lean production tools is the 5S tool, a workplace streamlining system based on five elements of workplace organization to ensure visual control and lean production. These five elements are Sort, Straighten, Shine, Standardize, and Sustain. The main goal of this system is to reduce problems in production caused by improper organization of the workplace. The 5S system's purpose corresponds to the aim of the eco-ergonomic approach to human-machine systems: increasing safety (reducing the number of accidents), creating a comfortable psychological climate and motivation, increasing labour productivity, increasing the level of product quality (reducing the number of defects).

Thus, even half a century ago, eco-ergonomic principles were used little by little to analyse the performance of human-machine systems.

Ecological studies in ergonomics. In recent years, new areas such as ergoecology [4, 5] and green ergonomics [10, 17] have appeared in ergonomics. Their essential principles are research and analysis of the interaction of the human-machine system with the environment. Both directions appeared as a result of the objective need to change the approach to the issue of workplace safety [10, 18].

Ergoecology emerged at the end of the 90s of the 20th century. There were two reasons for this. First, humanity realised the problem of limited natural resources, which stimulated the transition from the paradigm of a "consumer society" to a "sustainable society". Secondly, this period is associated with the beginning of mass computerisation of production, which fundamentally changed the conditions of human activity. As a result, it became impossible to apply traditional ergonomic approaches to create safe working conditions, so a new direction – ergoecology – emerged. Ergoecology is a product of the interaction between an ergonomic system, physical space and the environment of systems (political-legal, economic, financial, socio-cultural, techno-scientific and ecological-geographical factors) [4, 5, 10]. Ergoecology principles are:

1. Anthropocentric approach considering the impact on the ecosphere.
2. Orientation to the principles of sustainable development of society.
3. Consistency in designing, analysing and estimating ergonomic systems.

Ten years later, another direction in ergonomics emerged named "green ergonomics" [17, 18]. From the point of view of green ergonomics, it is currently impossible to achieve sustainable human well-being in conditions of constant environmental deterioration; therefore, this direction emphasises the preservation of natural ecosystems and their restoration. According to this, green ergonomics works in three directions. These are the development of low-resource systems and products, the design of green workplaces, and the development of employee orientation systems for "green" behaviour. Green ergonomics principles are:

1. Eco-efficiency and eco-productivity.
2. Environmental sustainability.
3. Orientation to the study of natural systems.

Undoubtedly, ergoecology and green ergonomics have a common goal. However, a principal difference lies in the levels of assessment of the problem of interaction of human-machine systems with the environment and ways of solving them [10].

Ergoecology is the basis for the development of such approaches as green ergonomics and eco-ergonomic design [13, 15], as well as for the study of other macro--ergonomic approaches related to the research and analysis of ecological aspects of human-machine systems [21, 22]. Thus, ergoecology is focused on the derivation of concepts and systems to create practical solutions, which are engaged in green ergonomics and eco-ergonomic design (Fig. 1).

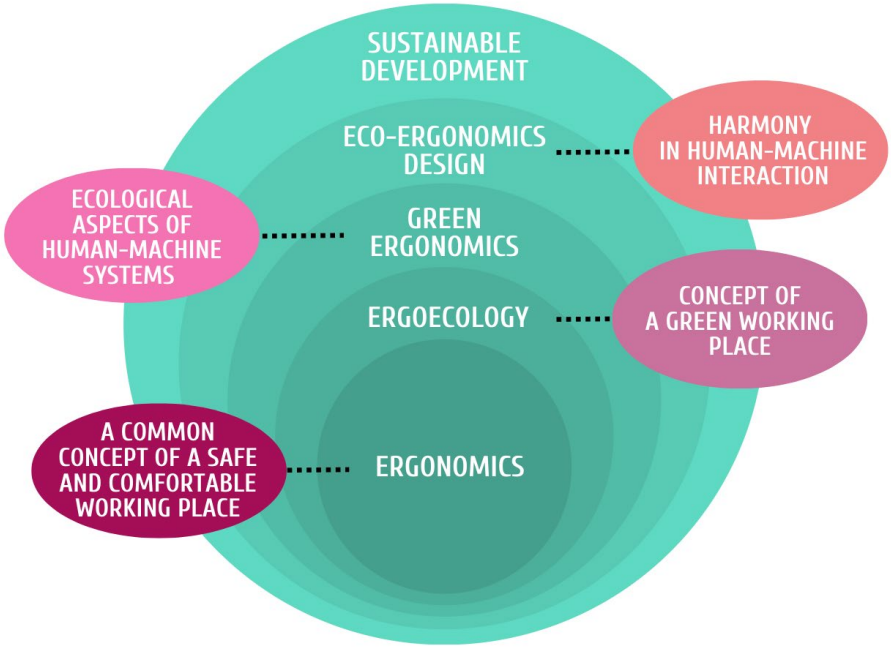

Fig. 1. The value of ecology in ergonomic research

Research of the digital environment in ergonomics. Digitalization of work operations affects the issue of occupational safety. Enterprises are interested in programs allowing them to find effective digital solutions to reduce the risk of hazards and injury rates. At the same time, digital technologies have changed the approach to work and the requirements for its safety. As a result, it led to the emergence of a new concept of "Work 4.0" [8, 9, 12, 20].

Work 4.0 is a concept that discusses the future of work in the EU. It describes what changes in the work organization will take place in the coming years in connection with the implementation of Industry 4.0 and digitalization. "Work 4.0" is based on the maximum use of digital technologies and the creation of flexible working conditions. The essential provisions of the concept are [20]:

1. Digital transformation of economic sectors and activities.
2. New forms of work through digital platforms.
3. Reliable data protection system.
4. Balance of human-machine interaction.
5. Flexible working conditions.
6. Changes in organizational structures, etc.

The creation of the "Work 4.0" concept became the impetus for the transition of ergonomics to a new stage of development. The key trend of this stage is a comprehensive study of the problems of human-machine interaction in the digital

environment. As a result, several areas of research and analysis of human-machine interaction in the digital environment have been created within the framework of ergonomics (Fig. 2).

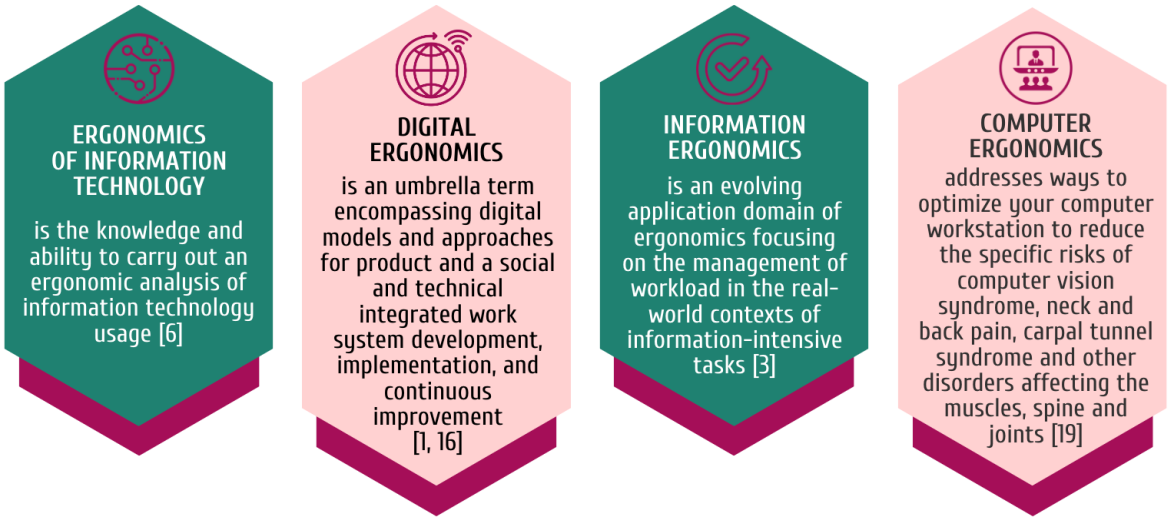

Fig. 2. Ergonomics directions on researching of digital environment

These directions study human-machine interaction in the digital environment but from different positions. Digital ergonomics focuses on digital models of human interaction and information systems. Its purpose is to streamline the human-machine system operation by a previously developed virtual model of this system. Based on this, digital ergonomics forecasts the emergence of probable problems and shortcomings in system operation. Thus, digital ergonomics detects system flaws at an early stage. As a result, digital ergonomics minimizes the negative consequences of their influence due to virtual simulation.

Computer ergonomics focuses on practical training of users of information and communication technologies in the rules of their operation. After all, it is essential not only to ensure the appropriate technological level of workplace equipment but also to teach the user the rules of work, which contributes to the user's health.

The primary goal of information ergonomics is to manage the workload of the user of information and communication technologies in the conditions of performing information-intensive tasks. Today, the performance of work tasks increasingly depends on the creation, search, use, exchange and organization of information. At the same time, the employee works in a multi-channel and information-rich working environment. Thus, the management of the information load has become one of the essential issues in ensuring the efficient operation of the human-machine system, which gave an impetus to the development of information ergonomics optimizing information flows in the human-machine system.

And one more direction is the ergonomics of information technology. It aims to develop the principles of creating ergonomic digital products. Among other things, UX/UI design uses principles of the ergonomics of information technology.

Thus, in recent years, new directions have appeared in ergonomics that study human--machine interaction in a digital environment and develop measures and tools for optimizing this interaction.

The above can be presented as a diagram of the evolution of ergonomic thought in the human-machine system's design (Fig. 3).

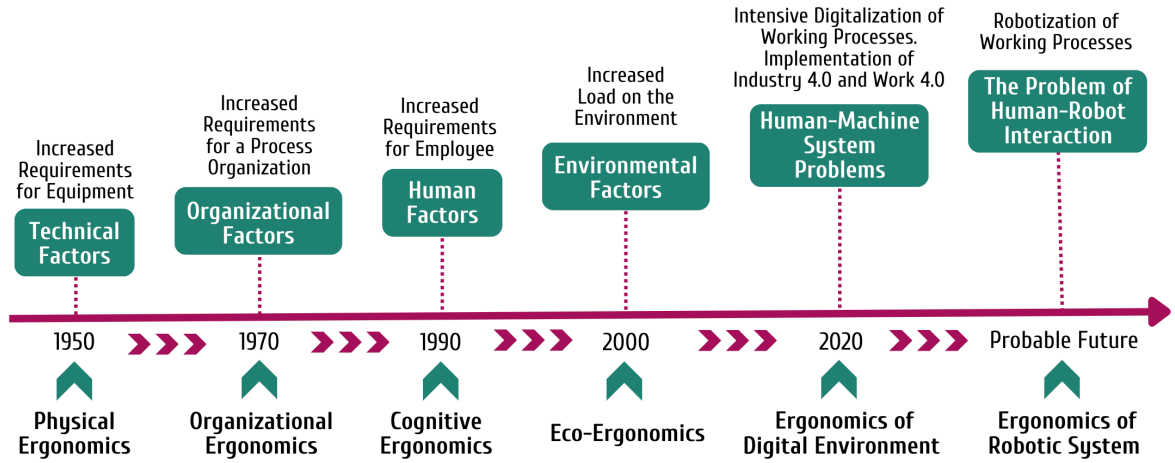

Fig. 3. Evolution of ergonomic thought in human-machine system's design

3.3. Results and discussion

Transformation of the labour paradigm. Today, there is a rethinking of approaches to ensuring the safety of human-machine systems. The prerequisites for this are:

1. Increasing requirements for safety in the workplace by employees.
2. The need for the development of an organizational safety culture.
3. Development of innovations in production and industrial technologies in the era of Industry 4.0: modern IT technologies; the digital transformation of management and production processes; changes in the professional capabilities and competencies of employees put forward new requirements for safety at the workplace [8, 9].

Thus, the global processes and technologies of Industry 4.0 fundamentally change the world of work, the parameters of the labour market, and safety requirements. As a result, it led to the emergence of the paradigm "Work 4.0" (Fig. 4).

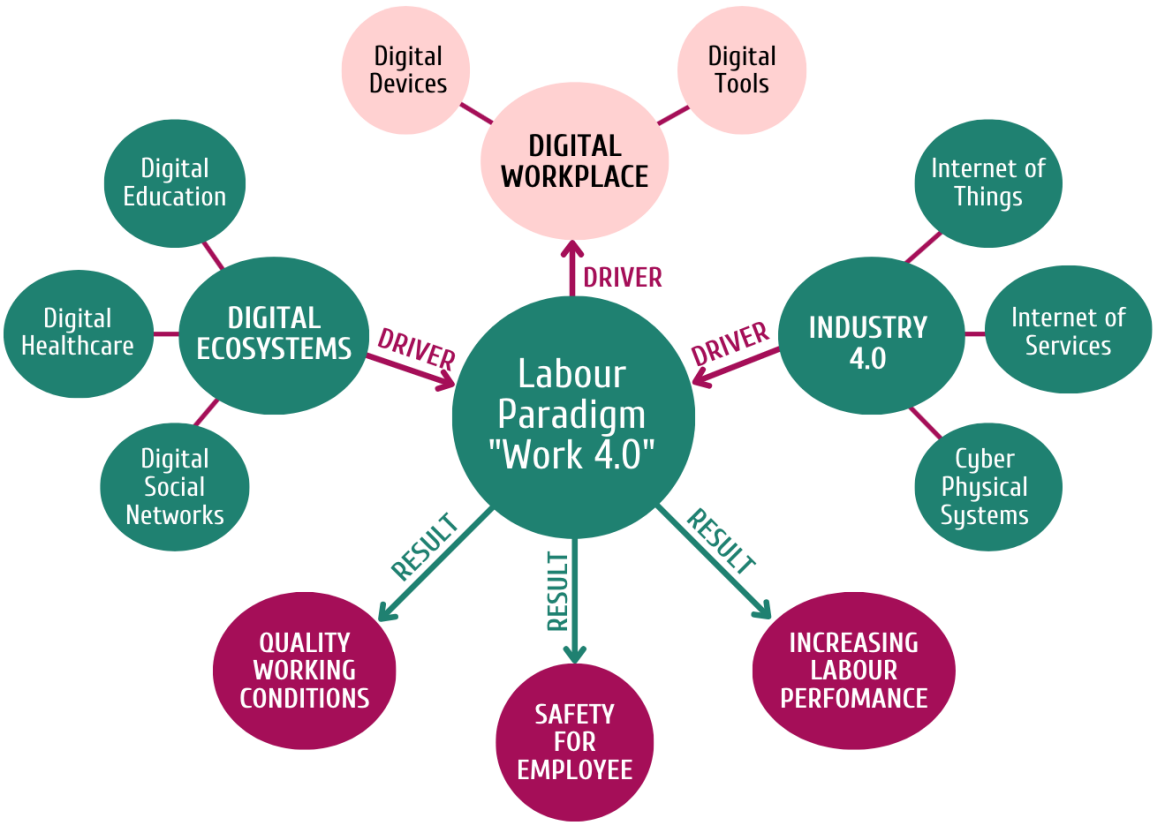

Fig. 4. Model of the labour paradigm “Work 4.0”

Thus, “Work 4.0” is a new social and labour reality of the beginning of the 21st century forming under the influence of current realities.

Transformation of the workplace. Work 4.0 is the driver of the revision of the concept of “workplace”. In the digital environment, workplaces cease to be tied to physical locations. Workplaces become mobile [8, 9]. It allows the employee to create his work mode considering individual capabilities and needs. The trend in digital workplaces is spreading quickly, and employees perceive them positively.

Digital workplace designing includes the following points:

1. When developing a digital workplace, the comfort and safety of the employee have the highest priority because they determine his productivity.
2. Technological advances are driving changes in the digital workplace, which is why technology is a part of workplace design.
3. Designing a digital workplace means an organic combination of technology, the work environment and the needs and capabilities of the employee.

Thus, the digital workplace makes it possible to increase the efficiency of employees due to the use of technologies and a working environment that are as close as possible to individual needs. Eventually, creating a digital workplace provides the following benefits:

1. The employee changes routine and repetitive operations to dynamic ones.
2. The employee uses new types of internal and external communication. For example, they use social networks, messengers, specialized sites, etc.
3. The worker uses new forms of work such as crowdsourcing, job sharing and micro--tasking.

Programs to increase the level of digital skills and competencies of employees, the need for individualization of the work process, and motivation for personal development contribute to the spread of digital workplaces.

3.4. Development of ergonomic thinking

Thinking problem. The main problem with the development of ergonomic thinking today is the differentiation of knowledge. Then how the convergence of knowledge and the use of interdisciplinary approaches are essential to ensure the safety of the human--machine system [2, 7, 11, 14]. In this regard, an obstacle in designing safe and effective human-machine systems for modern specialists is ignorance of the ergonomic laws of human-machine interaction.

In this context, it is necessary to pay significant attention to the development of ergonomic thinking among future engineers because:

1. It forms a system of views of a specialist on human-machine systems.
2. It provides an understanding of the complex processes of human-machine interaction.
3. It develops the ability to predict risks in human-machine systems and to design systems with prior consideration of risks.

The lack of ergonomic thinking leads to the lack of predictive risk control, which increases the frequency of their realisation and even the severity of the consequences. That is, there is a problem: the dis-proportionality of the knowledge of a designer and an operator under the continuous increase in the complexity of human-machine systems and the level of threats from them.

Design problems. The design of reliable human-machine systems is possible if the designer uses a system approach. The basic principle is to predict the worst consequences and be ready for them at all stages of the human-machine system life cycle. Protection, barriers and safeguards are central to a systemic approach enabling proactive rather than retrospective risk management.

The creation of a reliable human-machine system can go in three ways in line with the Shell model and Reason's model [11]:

1. Designing of risk-resistant systems for which the realisation of risks is not critical (for example, alarms, physical barriers, automatic shut-down, etc.).
2. Designing human activity in a human-machine system, when the bet is on an individual approach and professional selection, professional training, and intelligent decision support systems play the core role (this especially applies to activities with a high degree of uncertainty, for example, pilots, dispatchers, etc.).
3. The safety culture formation is based on procedures, administrative controls and overall management (i.e. controlling the risks associated with systematic errors).

The transformation of the designer's thinking is based on the understanding of these three ways.

Transformation of the thinking of human-machine systems designer. Analysis of the activities of outstanding engineers (I. Vyshnegradsky, A. Eiffel, E. Paton, G. Ford, F. Porsche, O. Shargei, etc.) allows asserting that the success of their activities is based on a specific type of thinking characterized by a particular multifaceted vision of a technical problem, the ability to identify and resolve technical contradictions and the physical contradictions hidden in them, purposefully generating paradoxical ideas. After all, even one of the basis of the Japanese economic miracle was the uninterrupted training of workers from the lowest level to managers to create a unique way of thinking and to stimulate this thinking through rewards for ideas. Therefore, even at that time, it was obvious that an employee could generate ideas in his professional field, and the effectiveness of this process directly depended on his involvement in the process. The founders of Japan's economic miracle showed that leadership, coaching, motivation and uninterrupted learning are the basis of success in creating viable and efficient production systems. Interestingly, many scientists who researched and implemented quality theory were ergonomists. So, for example, one of the methods of assessing the quality of services, which has been known for half a century, was proposed by well--known ergonomists. That is, ergonomic ideas are closely intertwined with theories from other fields.

The professional training of human-machine systems designers requires special attention to the formation of engineering thinking in them. Such thinking must ensure compliance with the mentioned principles of engineering activity. The human-machine systems designer (in addition to acquiring the necessary professional knowledge) must learn to think systematically, overcome the inertia of thinking, identify and resolve technical contradictions, generate non-standard technical ideas, and master the skills of multivariate problem-solving and objective assessment.

Systems thinking is thinking characterised by a holistic perception of objects and phenomena considering their connection with each other. Systems thinking should be cyclical: identifying structure, establishing links, setting goals, searching for and choosing alternatives, implementing, and again in a circle.

Engineering thinking is professional thinking aimed at the development, creation and operation of new high-performance, reliable and safe equipment, the development and implementation of advanced technologies, and improving the quality of products and the level of production organization.

Note that the given definitions consist of concepts that form the purpose and tasks of ergonomics. And in our opinion, creating a modern competitive product and highly efficient fault-tolerant systems with the help of engineering thinking is impossible without the parallel growth of eco-ergonomic consciousness and the transformation of the ergonomic thinking of the human-machine systems designer.

Eco-ergonomic thinking of the human-machine systems designer. Today, eco--ergonomic thinking for an engineer is a sign of education and a guarantee of the high qualification of a specialist. A necessary feature of eco-ergonomic thinking is the recognition of the exceptional priority of problems of human-machine interaction among human activity problems. In our view, the model of the employee's eco--ergonomic thinking structure looks like this (Fig. 5).

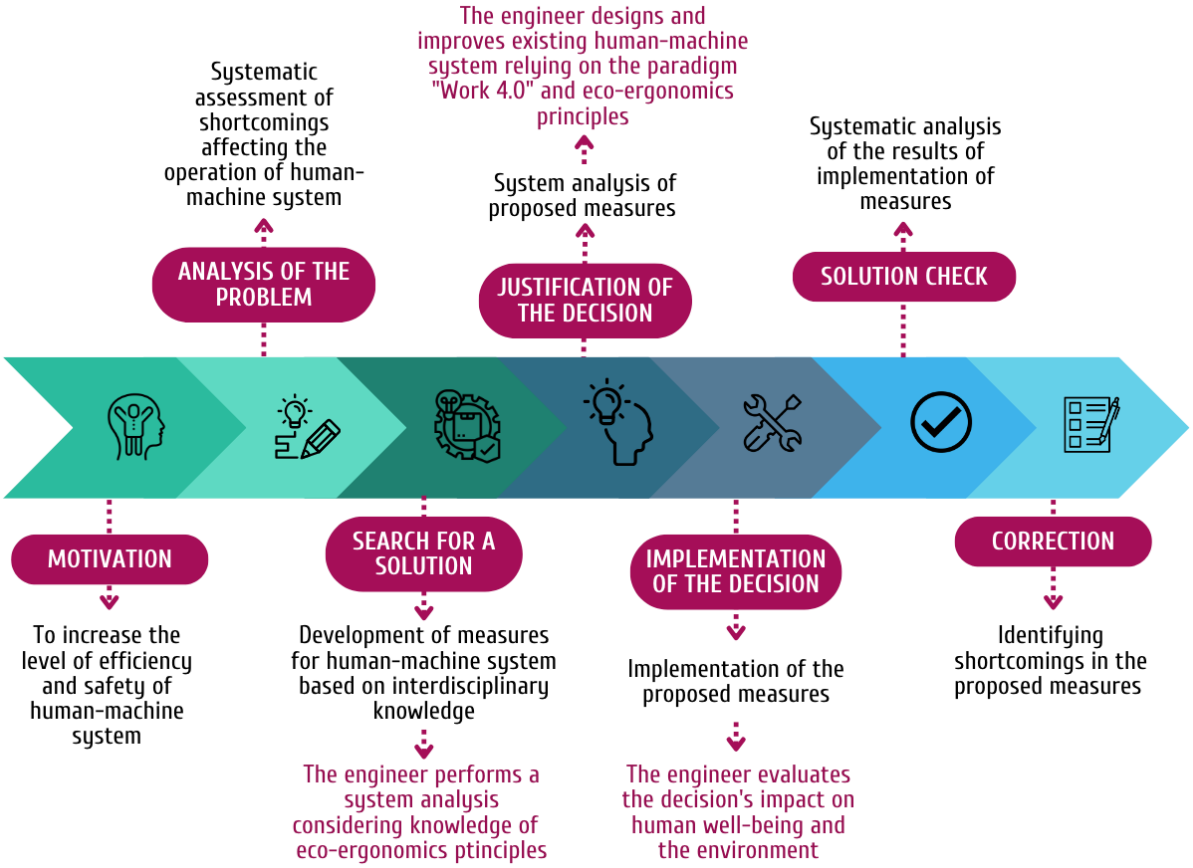

Fig. 5. A model of the structure of eco-ergonomic thinking of a human-machine system designer

Today, eco-ergonomic thinking is one of the forms of system thinking and recognition of the exceptional priority of human-machine interaction problems. Currently, ergonomics is associated with a shift of emphasis from an adaptation of humans to technology or technology to humans to the formation of a “human-machine” symbiosis. That is why attention should be paid to the development of eco-ergonomic thinking among designers of human-machine systems because it allows:

1. To understand the processes of human-machine interaction.
2. To be able to predict risks in these systems.
3. To plan the development of systems with a preliminary consideration of risks.

The final result of the development of an eco-ergonomic approach to the design of human-machine systems is the promotion of the development of an eco-digital society, the goal of which is to create a balance in the development of an ecological attitude to the environment, digitalization of activities and ensuring human safety (Fig. 6).

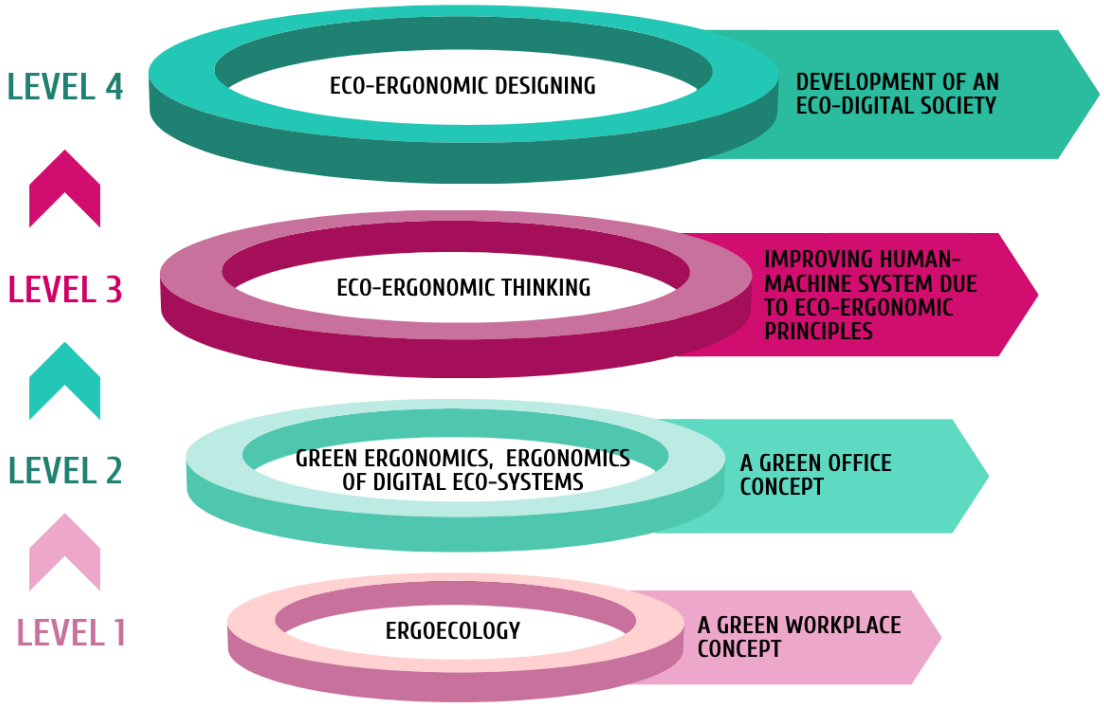

Fig. 6. Development of an eco-digital society through the prism of an eco-ergonomic approach to working place designing

3.5. Conclusions

Currently, the priority issue for any society is the implementation of the principles of sustainable development, which ensures the creation and maintenance of the triad "eco-friendliness-digitalization-safety". Ergonomics helps to optimize society's activities in this direction since human-machine systems constitute a significant part of human life; therefore, they must meet modern ecological 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 human-machine systems designers to form a new type of eco-ergonomic thinking, which become the basis for eco-ergonomic design development.

Analysis of the ergonomic thinking evolution in the design of human-machine systems and consideration of the concepts of "eco-ergonomic thinking" and "eco-ergonomic design" allowed to substantiate the importance of the formation of eco-ergonomic thinking among designers of human-machine systems; to propose a model of the employee's ergonomic thinking structure; to show how the training system ensures the formation of eco-ergonomic thinking in the human-machine systems designers.

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