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REVIEW ARTICLE

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Creative engineering – introducing the progress of science to forestry[1]

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Motto:
The real and legitimate goal of the sciences is the search for truth, and endowment of human life with new inventions and riches.
(Francis Bacon)
The great aim of life is not knowledge but action.
(T.H. Huxley)
That which science and ethics do not forbid the imagination, nature does not forbid man.
(T.J. Wodzicki)

Abstract. Implementing creative engineering, or in other words the progress of science, in forestry practice requires the integration of knowledge from its various branches concerning the impact of human activity on the Earth's ecosystem. In fact, various aspects of development in the forest services are already associated with ecological engineering, which in practice includes biology, economy, sociology as well as technical and mechanical construction. Special attention was given to modelling as the most productive method of promoting progress in forest management. In the case of biological engineering in forest ecology, for example, various possibilities of applying genetic engineering as a potential future method for increasing productivity as well as for the preservation of genetic diversity and environmentalprotection are discussed in more detail. Literature recommendations concerning engineering in forestry accessible to students of the Extramural Doctorate Studies at the Forest Research Institute in Sękocinare also presented.

Keywords: creative engineering, modelling, ecological engineering, biotechnology

[1] Theses for doctoral students (January2020)

1. Creative engineering

Creative engineering is the use of knowledge, that is the products of experience and imagination formulated in scientific theories of the laws of energy conversion and the properties of matter, to design methods and construct the technical means to meet human needs. Science and engineering are thus linked by the result of the creative activity of the human brain.

In the economy, creative engineering is a way of using the results of scientific research to increase the utility value of the environment. That is, not only searching for and testing answers to the question 'How does it happen' and formulating theories or searching and testing methods of knowing (measuring) the reality but also designing and formulating answers to the questions: 'What is the practical value of a specific discovery and how can it be used or improved, bearing in mind human development needs', or looking for answers to

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more specific questions: 'How can this goal be achieved with a different method than the one used so far', 'What is the utility and the threat to natural homeostaticprocesses of a specific product of creative engineering', 'What is the cost-benefit balance of the designed project or the probability of its success'?

Apart from curiosity, creative engineering may be one of the main drivers of scientific development. In this sense, engineering is a way to test experimentally the working hypotheses in research that are finalised with the formulation of scientific theories. However, there is quite a significant difference between the mental processes of both these forms of creativity. The creation of scientific theory involves memory and imagination in the analysis of the causal relationships of facts collected earlier – in the past. On the other hand, creative engineering also includes the design and construction of a system of causal relationships but creates facts in the future. Both forms of creativity entail a search for truth (in the sense given to this notion in science), that is, testing the reliability of the results of creating. The process of creative engineering provides a particular opportunity to use the potential of the resources of the laws of nature known earlier, in order to satisfy the assumed level of human needs. In each case, and thus also in forestry, it concerns the question of changes in the properties of a product of nature's evolution (created by natural selection in successionof generations) and the possibility of progressive changes in the natural environment's resistance potential. It is possible, thanks to the properties of the human mind in its multifaceted association of meaning and the interdependence of collected information, as well as the freedom to choose the criteria of the goal and ways of its implementation in the practice of forestry. This can be, for example, the choice of traditional methods of silviculture or the deliberate in vitro modification of the DNA structure of the meristem, determining the direction of immune processes or the growth correlations of trees. In this way, creative engineering is somewhat a process that creates alternative paths of natural evolution, which can be shaped both to enrich the utility value and to increase the level of protection of the natural structure of the biocenose of ecosystems.

To summarise, human creativity is a multi-level process, consisting of mechanisms of mental activity in the processes of (Al-Khalili, McFadden 2016) taking in the environmental information through a system of senses; (Borecki, Stępień 2015) memory in a system of encoding sensory information; (Brzeziecki 2015) associating the logical sense of sensory information, the so-called intelligence; and (Carroll 2017) imagination, a process whose (archaic, but the closest of many) definition is: the mental depiction of something, in the form of an intangible idea. In scientific creativity, the determining goal is to use sensual information in close reality (experimentally verifiable) to formulate a theory about the properties of the examined system. In creative engineering, it is mainly the involvement of memory and imagination in the construction of a work of social utility. The third form of human creativity is 'science fiction' and artistic creation, in which imagination is decisive, integrating the features of human individuality, reflected in the construction of the content and form of a work of art.

Doctoral studies in the field of forest science give participants the opportunity to pursue both learning objectives simultaneously or alternatively. The creative process in the research constituting the content of the doctoral dissertation may concern mainly cognitive values (improvement of theory) or innovative management methods (breeding, protection, forest use and management or economic principles and management organisation). The problems of creative engineering in the doctoral programme are an element of knowledge about the evolution of human consciousness in the search for truth about the structure of the environment of human existence in the universe as a way of using knowledge for the development of humankind without limiting the creative potential of Earth's biosphere.

The most primitive manifestations of 'creative engineering' can be observed in many animals – usually as a way of securing the existence of the family, for example, when dens are built by mammals, nests by birds, or webs by spiders. The development of the nervous system in the course of phylogeny, and especially of the brain and the creative potential of consciousness, was decisive in the evolution of human civilisation and culture. The key role in this process was improvements in gathering knowledge and communication between the generations, and above all, the evolution of language as a product of the recombination of symbolic sound and graphic signs – factors of memory and education. The most primordial forms of creative engineering were manifested by man already in the processes of splitting stones, shaping spearheads, braiding fibres, tying nets, making vessels as tools for obtaining and preserving food, constructing the means of transport and defence and, finally, striking sparks for fire or constructing and furnishing buildings. The selection and cultivation of plants or animal husbandry, for the same reasons, should be considered as manifestations of the creative human engineering activity. This is how, thanks to the accumulation of knowledge, the creative potential of humans has evolved in the field of improving the ways in which it is used for progressively developing the living conditions of the population in successive generations. In psychology, this process is described as the evolution of high-level intentionality (Trojan 2016). Humans are the only species that travel so far mentally and that are curious and intentionally ready to seek answers to the questions they formulate and then, searching for logical causal relationships, formulate hypotheses and theories and apply them to the economy. Only people are able to use remembered observations, the knowledge and imagination to choose the direction of associating events and facts – to construct hypotheses, theories, planning, modelling, valuing and fantasising– and so they also have the ability to creatively interfere in the processes of natural evolution. Various forms of creative engineering, not only those associated with surveying, construction and mechanics, which have the longest history of development, are used in forest science and management as a means of delimiting forest areas. Examples includenot only activities determining the ownership of woodland or hunting areas and wood reserves but also the ways of regulating water resources, mechanising breeding work and protecting and using or transporting wood, which are generally conducted in accordance with biological engineering and sociology (Rykowski 2006; Szwagrzyk 2015).

2. Ecological engineering in forestry

As the worldfamous ecologist Professor H.T. Odum wrote, ecological engineering is a special branch of creative biology that'...takes advantage of the natural changes occurring in the environment to benefit both man and the environment itself'. It follows that all engineering activities in forestry are elements of the implementation of various tasks in ecological engineering. The methods of ecological engineering in forestry differ significantly (not only in Poland) depending on the choice of forest functions, that is, the structural properties of the ecosystem and the main factors of homeostasis at different stages of its development. Practically, the diversity of creative engineering in forestry starts from the problems of only protecting a forested area (as in the case of strict nature reserves), through the preservation of different variants of use and protection, to the system of complete anthropopressure in plantation breeding (as in agriculture). This means that there is a need to determine the proportions or knowledge of many basic fields of science in order to choose the right ecological engineering strategy– for example, biology, geology, climatology, hydrology, petrography (in silviculture and forest protection engineering, hunting, etc.), physics, chemistry, machine building technology, road construction, amelioration, architecture (in forest use engineering, machine construction, construction and transport in wooded areas, etc.), theories of finance, market analysis and planning methodology (in management engineering, and thus in administration, financial economy), and finally psychology, sociology, pedagogy and history, in particular, the mathematics, geometry and statistics – to solve any problems arising from the progress of management methods in forestry. In developing any programme of creative engineering in forestry, not only the utilitarian purpose but also the ways of securing the process of the ecosystem's homeostasis, and if possible, even increasing its effectiveness,need to be determined (Rykowski 2006; Podgórska, Sierota 2010).

The concept of engineering has its own semantic history. The most commonly understood concept of engineering in forest management is the process of the implementation of tasks planned by the State Forests administration within the scope and methods defined by the current state of knowledge. This article talks about creative engineering as the construction of conceptual programmes of future forms of forestry, taking into account the civilisational development of the human population and using the progress of knowledge resulting from intentionally created research programmes. In this sense, creative engineering concerns proposals for economic activities in the future and, therefore, requires the probability of success to be determined, that is, studies of the complex of factors determining the designed use of knowledge. The Forest Research Institute in Sękocin Stary organises meetings of representatives of the State Forests administration and the scientific community (known as the Winter Forestry School) in order to update basic programmes: planning, management, forest protection and their implementation in practice, thus, the current principles of forest engineering in the first sense of the term. In the publications from these sessions, information, amongst others, on the development of forestry engineering, the progress in scientific creativity as well as the list of pilot projects of the Forest Research Institute in Vienna is provided (e.g. Zimowa Szkoła Leśna [Winter Forestry School] 2013).

3. Modelling

One of the basic methods of scientific research at all stages of learning about nature and creative engineering in the process of planning the development of the economy is modelling – a method of testing the probability level of hypotheses, thus, a mental attempt to learn about the relationship between knowledge and practice (usually in the form of a mathematical model). Generally speaking, it is a method of searching for answers to the question: 'what will happen if', for example, in forestry: 'how will the utility of the forest change if the species structure of the stand changes'. A model is a simplified image of the examined fragment of reality, or in other words, the model simulates a real phenomenon. This simplification consists of eliminating features, elements or other relations, which (at least theoretically) are of little importance. The process of the homeostasis of forest ecosystems is primarily achieved in the system of the trophic associations of autotrophic populations and heterotrophic organisms (also in the form of symbionts and parasites), respectively, to the type and current state of the population size determined by the broadly understood variability of environmental conditions of the existence of the whole biocoenosis – especially soil fertility and moisture, as well as the seasonality of changes in precipitation, temperature and light. This means that although it is usually based on the choice made by the enormous potential of the process of associating knowledge encoded in the memory of the human brain, sometimes the choice of essential elements and those that are to be excluded will not be possible in model studies without conducting preliminary research. This also applies to the choice of the size and type of measurement sample in designing experimental tests of hypotheses and even theories. Building models involves imagination, because it is an attempt to create alternative theories that differ from each other by their physical assumptions and concepts or by the distances and scales of energy in which they are applied. Models make it possible to predict phenomena. Thus, by conducting an experiment, scientists can theoretically confirm or negate the truthfulness of the claims made by the models.

As a method of scientific research, modelling may also be a basic way of learning about the potential of the forest as a factor satisfying the developmental needs of human beings and thus also designing and testing the probability of the effectiveness of planned management principles. This is due not only to the variable dynamics of the complex structure of forest ecosystems but also from the longevity of trees and the longevity of evolutionary changes, as emergent properties of the forest's structure. They are realised through natural succession, in accordance with the variability of environmental conditions of the life of forest ecosystems in the biocoenosis. This means that all attempts in using the test method to learn about an experimentally modified structure of the forest ecosystem, that is, the effects of an intervention in the natural process of succession, can only be finalised after many years of observations and measurements. This also applies to human needs conditioned by changes in the cause and effect interactions of many social processes. And it should be remembered that the credibility of predictions decreases with the distance to the planning horizon. In view of the life expectancy of trees, which exceeds even several times the period of a researcher's creative work, a single measurement barely provides preliminary knowledge about the structure of the same research subjects in subsequent developmental phases of the individual system. This means that predicting the future based on the results of a single measurement of the correlation between selected elements of the structure of the system is limited and sometimes illusory. Given the very high level of interdependence of the biological and economic processes in forest management planning, more effective would be the results of data analysis obtained from many repeated measurements in different phases of the physiological development of the forest, fluctuations in market parameters and even in the state system.

For this reason, predicting the effects of planned activities in forest management is possible,thanks mainly to the modelling method. This applies not only to the theoretical assumptions for experimental tests but also to the analysis of hypothetical coefficients of variability of the forest ecosystem'sstructure. In the latter case, the modelling method means the analysis of the probable effects of including information, being a product of the mental activity of humans, into the order shaped by evolution, which ensures the sustainability of the functional structure of the forest. In this sense, modelling is the first stage of preparing a research project, both as a method of formulating rational questions as well as to construct research tasks in order to find possible rational answers to these questions. However, it should not be forgotten that in the modelling process, the way data are collected or elaborated is less significant, whereas which is important is that the selection of the elements of the studied interactions.

In the case of the 'forest–human' relationship, model analysis gives us a chance to discover hitherto unknown relationships and reserves of potential of the system reinforcing the relationship of both partners. In each case, the basic method of modelling, in the era of computer programs, is mathematical data analysis. The application of mathematical analysis alone is not tantamount to modelling, which always starts a mental process that is the conceptual basis of the experiment checking the conclusions obtained by the modelling method (Socha 2015). In scientific creativity, one should always remember about the complexity and cognitive limitations of the modelling method (Heller 2014, 2016).

An example of experimentally testing a model, created in the imagination based on only scientifically justified conjectures, was the initiation of the stand crop test of *Thuja plicata* Donn ex D. Don and *Pseudotsuga menziezii* (Mirb.) Franco (North American species) in the arboretum of the Warsaw University of Life Sciences (SGGW) in Rogów by Professor Edward Chodzicki from the Jagiellonian University in Kraków. Prof. Chodzicki did not do this in order to create yet another botanical garden in Poland, the role of which is predisposed by forest arboreta today, but to test a model concept of how to increase the functional potential of forests in Poland, analogous to Schwappach's crops.

The methodology of modelling in forestry is currently used by,for example, scientists of the Faculty of Forestry of the Warsaw University of Life Sciences – Bogdan Brzeziecki (2015), Arkadiusz Bruchwald, Tomasz Borecki (2015) – as well as several research teams of the Forest Research Institute (Rykowski 2006). However, although modelling is probably the most useful method in the process of developing progressive management principles in forestry, it is precisely in this case that economic engineering requires special attention because of the extreme difficulty in determining the valuation factor of nature (Żylicz 2014).

4. Biotechnology in forestry – selected applications of genetic engineering

The term 'biotechnology'" was first used by the Hungarian scientist and politician Károly Ereky in 1919. Today, it is a dynamically developing field of science. The UN Convention adopted at the Earth Summit in Rio de Janeiro in 1992 defines biotechnology as '...all manipulations on organisms or their elements that lead to the production of useful products'. The first phase of biotechnology was the birth of agriculture about 10–12,000 years ago – the unconscious genetic modification of plants through selection and cross-breeding (the first grain, wheat and, in America, wild species of the inconspicuous teosinte grass transformed into maize). The second phase of green biotechnology, at the turn of the nineteenth and twentieth centuries, was the development of breeding methods of plant tissues in vitro and induced mutagenesis in the 1950s, which enabled the development of up to 3,000 plant varieties grown today in the world. The third phase is the methods of genetic modification and genetic engineering techniques introduced in the 1970s, allowing genes from other organisms to be inserted (or excluded) into a genome, for example, the transplantation of single genes, often originating from microorganisms. The first transgenic plants (GMOs) appeared in the mid-1990s and now account for 13% of the world's crops (e.g. soybean, maize, cotton and rape). Phases four and five, already in the twenty-first century, are modifications to the expression processes of genes stimulating the development or resistance to selected species of pathogenic organisms. It is also called the Stimulated Gene Flow (SGF) method – the transfer of genotypes of different geographical races of the same species, using the variability of expression of regional population characteristics, for example, *Picea sitchensis* (Bong.) Carrière in Canada: from Alaska to the southern U.S. states.

The use of advances in biotechnology in forest engineering by intervening in the molecular mechanisms controlling the utilitarian potential of forest ecosystems could result in the following improvements, also in Poland (Wodzicki 2014):

I. Resistance of forest trees to selected pathogenic infections.
II. Production of wood mass
   A. effectiveness of the photosynthesis of trees, through
      a) stimulating the growth of the number of leaves or area of the leaf blade,
      b) using a wider spectrum of sunlight.
   B. selection of tree genotypes
      a) fast-growing trees reaching above average height,
      b) with a high activity of the cambium zone,
      c) with an extended period of synthesising wood secondary cell walls,
      d) with a higher than average intensity of cellulose and lignin syntheses.
III. Windfall resistance
   A. Selection of tree genotypes with a high stem growth stress factor (the effect of cambial activity and the radial growth of differentiating cells of xylem):
      a) throughout the entire vegetation period,
      b) in periods when threats most often arise.
IV. Acclimatisation of trees of foreign origin
      a) naturally reaching significant sizes,
      b) producing wood of particular structural value or resistant to destruction.
V. Selection of trees showing particular values of morphological characteristics: landscape or other than those associated with wood production, for example, decorative features, honey yield and nutritional value to game in hunting management.

Commentary on selected concepts, definitions and assumptions of the problem

Science – the intellectual activity of humans whose aim is to determine the relationship amongst the phenomena occurring in the surrounding world that are accessible to the senses.

Nature – has the property enabling it to be studied, that is, it is of an empirical type and one can expect rational answers to rationally posed questions.

'The social world is an extension of the natural one… both can be empirically studied'.

Knowledge – an appropriately substantiated true belief – but the knowledge of each person is their personal property formed in proportion to their education and their own sensory experiences, as well as the level of individual abilities of perceiving the causal relationships of this information. Therefore, each person can determine what he knows and what he does not know, but not what he does not know that he does not know. Attaining knowledge is based on following the progress of knowledge and searching for answers to the ensuing questions. The current level of knowledge of every human being is one of the many characteristics of the variability of an individual human population.

Scientific creativity – a process of constructing a theory explaining the meaning of a set of facts (partial information) obtained by scientific methods, about the structure or mechanisms of the operation of systems constituting the subject of the research.

Scientific theory – an attempt to determine the truth (conformity with reality) about the structure and functioning of a research subject. Creating a theory starts with contact with experimental data, one's own or collected by others, but it is not a summary of the data. A theory is only scientific if the resulting predictions can be subjected to an attempt to overturn (falsify) them; thus, there can be no discussion with a theory that confirms everything – such a theory is unscientific. The task of a theory is not only to explain facts but also to predict them. A theory (or model) is successful if, first, it not only has not been falsified yet but also the experiments performed thus far were shown to be consistent with its predictions and, second, it has entered a network coherent interactions with other theories or models of a given science (Heller 2014).

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