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PREFACE

We are delighted to welcome you to the new issue of the journal on the history of science and technology! This issue is unique as it explores diverse aspects of the development of science and technology in various countries and historical periods.

We invite you on an exciting journey through the pages of this issue, where you will find works by distinguished scientists such as Maryna Gutnyk, Florian Nürnberger, Tetiana Karmadonova, Natalya Pasichnyk, Renat Rizhniak, Hanna Deforzh, Liudmyla Zhuravlova, and many others. Their research covers various facets of history and technology.

The collaborative work by Maryna Gutnyk and Florian Nürnberger presents a comprehensive exploration of the evolution of the Fe-C diagram, tracing its historical development through the lenses of various scientific contributions over time. Their analysis underscores the rich history behind this diagram, highlighting the foundational studies dating back to the early 19th century, marking crucial milestones in understanding the carbon content in steel and its implications for industrial applications. The authors' meticulous use of comparative analysis, synthesis, and chronological examination sheds light on the gradual refinement and evolution of the

Fe-C diagram. From the initial recognition of graphite as pure carbon to the establishment of phase diagrams through collaborative efforts at international congresses, the Fe-C diagram's progression intertwines with the advancements of the industrial revolution.

Tetiana Karmadonova's work on the migration trends of Ukrainian researchers from 1991 to 2023 provides a comprehensive analysis of the multifaceted factors driving the migration of scientists from Ukraine to various destination countries, particularly against the backdrop of recent events in the country. The study delves into the intricate landscape of migration among Ukrainian researchers across different historical periods.

Natalya Pasichnyk, Renat Rizhniak, and Hanna Deforzh's meticulous study on the publications in the "Bulletin of Experimental Physics and Elementary Mathematics" from 1886 to 1917 offers invaluable insights into the organization, proceedings, and outcomes of domestic and international congresses of mathematicians and natural scientists during that period. Their research, focused on a comprehensive and quantitative analysis of these journal publications, sheds light on the pivotal role of these gatherings in the scientific and pedagogical realms

Liudmyla Zhuravlova's research on the evolution of techno-nationalism and the pivotal role of space in this phenomenon from the 1980s to the 2020s offers a compelling exploration into the intricate dynamics of technological advancements and their influence on international relations and national strategies. The article delves deeply into the theoretical comprehension of techno-nationalism, particularly examining its relationship with space policy and its relevance within the context of US-China relations. Employing an interdisciplinary approach, drawing from historical, economic, political sciences, and international relations theory, the research unravels the dichotomous evolution of techno-nationalism juxtaposed against techno-globalism. Zhuravlova's work accentuates the ongoing power struggle between the US and China within the space industry, amplifying the techno-nationalist dimensions within innovation systems.

Artemii Bernatskyi and Mykola Sokolovskyi's research presents a comprehensive review of the evolution of additive manufacturing (AM) processes within the realm of metallurgy, spanning from the foundational theories of layer-by-layer manufacturing to the contemporary landscape of AM technologies. This work illuminates the rapid advancements within the AM sector, capturing the profound interest of the scientific community. It underscores the dual significance of AM technologies - not only as an alternative manufacturing method for existing structures but also as a gateway to crafting new, intricately complex structures unattainable through traditional methodologies. Through meticulous analysis and classification of prior studies focusing on technological advancements and implementations, the research establishes a structured approach towards comprehensively mapping the development of additive manufacturing technologies in various trajectories. As a result, the research proposes a systematic approach to formulate a comprehensive scheme for AM technology development, thereby offering a framework that navigates the intricate landscape of technological advancements in various directions.

Mykhailo Klymenko's meticulous study offers a comprehensive evaluation of Professor Tomasz Nikodem Ścibor-Rylski's pioneering contributions to the development of agricultural machinery testing during the latter half of the 19th century. This research sheds new light on Rylski's scientific endeavors and their significant impact on the evolution of agricultural equipment testing. Employing principles of historicism, scientific rigor, and objectivity, Klymenko utilizes historical-scientific methodologies, archival analysis, and generalization to present a nuanced understanding of Rylski's work. For the first time, archival documents are introduced, unveiling insights into the scientist's activities in advancing the field of agricultural machinery testing.

Mohamad Khairul Anuar Mohd Rosli, Ahmad Kamal Ariffin Mohd Rus, and Suffian Mansor's insightful study delves into the overlooked yet pivotal role of electricity, specifically facilitated by the Perak River Hydro-Electric Power Company (PRHEPC), in the tin-mining industry within Kinta Valley during the period of 1927 to 1940. The research illuminates the historical emergence of electricity as a dominant power source in the tin-mining industry of Colonial Malaya, a topic that has received minimal attention in Malaysian historiography.

Sana Simou, Khadija Baba, and Abderrahman Nounah's research represents a profound call to action amidst the urgent need to safeguard Morocco's cultural heritage, notably exemplified by the Marinid Madrasa within the Chellah archaeological site in Rabat. This research intricately weaves advanced technologies with a profound appreciation for the historical, social, and cultural significance of these sites. It charts a course that not only conserves architectural brilliance but also honors the profound stories encapsulated across epochs. Ultimately, it emerges as a blueprint for harmonizing the past with the present, ensuring the preservation of cultural heritage while embracing the imperatives of progress.

In his article, Oleh Strelko shows that the history of bridge construction is an important part of historical knowledge. Developments in bridge construction technology reflect not only engineering advances, but also social, economic and cultural aspects of society. Engineers and scientists faced unique challenges when designing and building bridges depending on the technological level of the era, available materials and the needs of society. This process may reflect technological progress, changes in transportation needs, and cultural and social changes. The purpose of this article is to briefly review key moments and stages in the history of metal bridge construction using welding technology in the 20th century.

We invite you on this exciting journey with our authors exploring the history of science, technology, and cultural heritage. May this issue broaden your knowledge and inspire new research endeavors!

HISTORY OF SCIENCE

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The Fe-C diagram – History of its evolution

Abstract. *The evolution of concepts and methods of physical and chemical science that contributed to the formation of the Fe-C diagram during the previous centuries is considered. Despite the classical knowledge, there are still differences in the representation of the Fe-C diagram by scientists from different countries, in particular, the data of scientists from Germany, Poland, Ukraine, the USA, and Australia are somewhat mismatched. The authors tried to understand the reasons for this discrepancy. To conduct the research, general scientific methods of cognition were used: comparative analysis and synthesis, as well as a chronological one. It is claimed that the first studies of carbon content in steel were carried out in 1802. Further research development began in 1827–1829 when it was established that graphite is pure carbon. It is emphasized that further studies of carbon content in steel and cast iron are connected with attempts to create the first graphs of dependence on content and temperature. This, in turn, contributed to the development of the industrial revolution. It is believed that the first complete diagram was presented in 1897 by Roberts-Austen. Later, with the use of X-ray methods and microscopy, the Fe-C diagram gradually took on a new form. At the beginning of the 20th century, scientists actively proposed their phase diagrams. Studies conducted by scientists of different countries during 1909–1911 gained a consolidation, which was produced at the 6th Congress of the International Association for testing materials meeting into the unification of the names of phase transformations. Further research until the beginning of the Second World War was aimed at the creation of "pure" steel, that is, without* *harmful impurities, and clarifying the transformation temperatures. The period of the Great Depression in the USA and the war in Europe did not contribute to scientific research. At the same time, for the mass production of steel and cast iron, errors in critical points of a few degrees did not have a significant impact, that is, refining the temperatures of phase transformations were not considered appropriate. Today's trend in scientific research is aimed at solving environmental problems caused by the industrial revolution.*

Keywords: *Fe-C diagram; unification of transformation modes in Fe-C binary alloys; consolidation of science; material science*

Introduction.

The development of a post-industrial society could not have been achieved without the application of structural materials, the main of which remain steel and cast iron. The dominant components of these alloys are iron and carbon. The type of alloy that can be obtained in the final result depends on the percentage content of the component, the temperature, as well as the emergence of carbon e.g. in the form of graphite and in a certain morphology. While working on a joint study (Nürnberger, Frolov, Grydin, Gutnyk, & Blank, 2022), the authors saw a discrepancy between the diagrams in the percentage of graphite included in the composition of the steel. If Ukrainian scientists take 2.14 % as the maximum content (Timofeeva & Komarova, 2013, p. 50; Bobrova, 2016, p. 18), Polish scientists – 2.11 % (Hucińska, 1995, p. 86; Pawłowski, 2012, p. 2; Pawłowski, 2017, p. 146), then in Germany in general – 2.03% or 2.06% (Eckstein, 1969, p. 53; Horstmann, 1985, p. 117; Läpple, 2022, p. 56). Moreover, the carbon content in cast iron is the same in all countries. It turns out that each country has its own knowledge, of the apparently "classic" Fe-C diagram. The most complete publication that today gives the history of iron-carbon alloy research is the monograph of Eugeniusz Tyrkiel (Tyrkiel, 1963), although it is limited to data up to 1955 and unfortunately does not reveal the development of research including modern knowledge.

The purpose of the article: is to trace the origins of knowledge in materials science, namely the creation of the main "points" on the Iron-Carbon diagram. To reveal which knowledge preceded the study of the physical state of steel and cast iron at different percentage ratios and different melting temperatures. To evaluate from the point of view of modern knowledge of materials science, the development of knowledge about the percentage ratio of iron and carbon.

Methods: general scientific methods of cognition were used: comparative analysis and synthesis, as well as a chronological one. This made it possible to carry out a comprehensive study of the stated topic, to present how the concept about the percentage of carbon and iron were formed during the melting of steel and cast iron, to follow how knowledge and discoveries in the field of physics and chemistry contributed to the formation of the equilibrium system in the Fe-C diagram and transformation of temperatures.

Results and Discussions.

The first attempts to establish mass production of steel and cast iron in the 19th century contributed to the accelerated development of research in this direction. Among the harmful impurities in the production of the mentioned alloys, sulfur, and phosphorus were the most difficult to eliminate. Though in laboratory conditions the steel turned out to be of good quality, the finished castings suffered from redness due to the industrial scale of its smelting and cold brittleness. On the one hand this is caused by sulfur forming a chemical compound FeS with iron, which with iron in steels forms a eutectic with a melting temperature of 985 °C. This eutectic melts at certain comparatively low temperatures and as a result the connection between the grains is lost and cracks are formed. In addition, sulfur reduces the plasticity and strength of the steel, its resistance to abrasion and its corrosion resistance. A fragility at low temperatures on the other hand is a result by the fact that phosphorus causes strong internal crystal liquefaction (Fedirko et al., 2017, p. 74).

Back in 1802, the Englishman David Mushet (Mushet, 1802) conducted a large-scale study to determine the carbon content in certain types of iron-carbon alloys. Starting with Swedish iron and varying amounts of charcoal, he prepared alloys in both open and tightly closed melting pots. By carefully weighing the materials used to cast the alloy and the final products (iron or steel and other carbon), he tried to determine the amount of carbon in % corresponding to different types of alloys. And so, for example, he obtained values from about 0.8 % (soft) to 2 % (very hard) for steel, about 4 % for white cast iron and 5 % for cast iron ingot, and for gray iron more than 6 %. Robert Forester, David Muschet's son, performed more than ten thousand experiments on the influence of impurities on the quality of steel. It was he who invented a method with the addition of manganese to avoid sulfur in the melt (Gutnyk, 2012, p. 254). Significant discoveries and successes in chemistry in the first decades of the 19th century greatly influenced the further development of views on iron-carbon alloys. In particular, one of the main laws of chemistry – the law of constancy of the composition of chemical compounds ("the law of constant ratios") was formulated by the French chemist Joseph Louis Proust. The German scientist Jeremias Benjamin Richter initiated the study of the quantitative side of chemical reactions and founded a new branch of chemistry – stoichiometry.

The Englishman John Dalton established the law of simple and multiple ratios and created the modern atomic theory. Swedish chemist Jöns Jakob Berzelius introduced chemical symbols and formulas, and determined the atomic mass of many elements (Mourelo, 1916; Ostwald, 1974; Rocke, 2005; Berzelius, 1841).

In 1816, the German metallurgist Carl Johann Bernhard Karsten published a handbook on metal structures (Karsten, 1816). The scientist devoted his extensive research to determine the form which carbon can acquire in alloys with iron. Extensive studies of the essence of graphite conducted by the Swedish chemist Nils Gabriel Sefström during 1827–1829 (Sefström, 1828; Sefström, 1829), confirmed Karsten's thesis that graphite is pure carbon. Karsten's works represent to some extent a turning point in the development of views on iron-carbon alloys.

The use of a scientific approach in the development of research on mass steel production became the impetus for the presentation of the first graphs of the dependence of the concentration of carbon and iron. For example, Reinhard Mannesmann, was one of the 4 brothers who ran one of the first steel company in Germany – the Mannesmann company. Most of the commercially successful projects in the development of the company are related to him. The Mannesmann company also produced crucible steel, which was new at the time and had good quality indicators. Mannesmann products received the highest awards at all world exhibitions in the 19th century. The jury of the 1867 exhibition in Paris also suggested awarding Reinhard Mannesmann with the Legion of Honor. Emperor Napoleon III ordered that naval arsenals should be primarily equipped with Mannesmann products. In 1879, the entrepreneur presented the first graph of the dependence of the concentration of carbon and iron depending on the temperature. This graph was quite primitive and far from modern ideas about critical points because at that time it was not possible to measure the temperature physically accurately in the melt (Wessel, 2009).

In 1886, Floris Osmond published the publication "On the phenomena that occur during the heating and cooling of molten steel" where he listed several critical melting points of steel, and also in 1906 on the crystallography of iron (Osmond, 1886; Osmond & Cartaud, 1906).

In 1897, William Chandler Roberts-Austen presented the first complete temperature-concentration diagram (Fig. 1) for the iron-carbon system (Roberts-Austen, 1897), which the Dutchman Hendrik Willem Bakhuis Roozeboom converted into his phase diagram (Fig. 2) (Wisniak, 2003, p. 429). The face-centered cubic form of iron, *Austenite*, is named after Roberts-Austen (Kayser & Patterson, 1998). *Austenite* denotes the soft non-magnetic part of the alloy in which iron takes the form of an allotropic gamma modification, stable at high temperatures. As for other names of different chemical states in iron-carbon compounds, *martensite* should not be overlooked. It should be noted that this name was proposed by Floris Osmond in honor of the German metallurgist Adolf Martens (1850–1914). This is a needle-like structure characteristic for quench-hardened iron-carbon steels (the hard magnetic part of the alloy). It is noteworthy that these assumptions were confirmed only after the application of X-ray diffraction methods. A. Martens was one of the founders of materials testing research in Germany. He was one of the pioneers in using the light microscope as a tool for analyzing metal structures. For many years, the scientist headed the metallographic laboratory. During 1880–1882, A. Martens determined the three main structural components of cast iron: *graphite*, *free iron*, and *bound iron* and he showed that these components (today the latter are called *ferrite* and secondary *cementite*) are easy to recognize when etched with chemical reagents. In 1899, he published a textbook on materials science, which was highly evaluated at the time (Pfender, 1990).

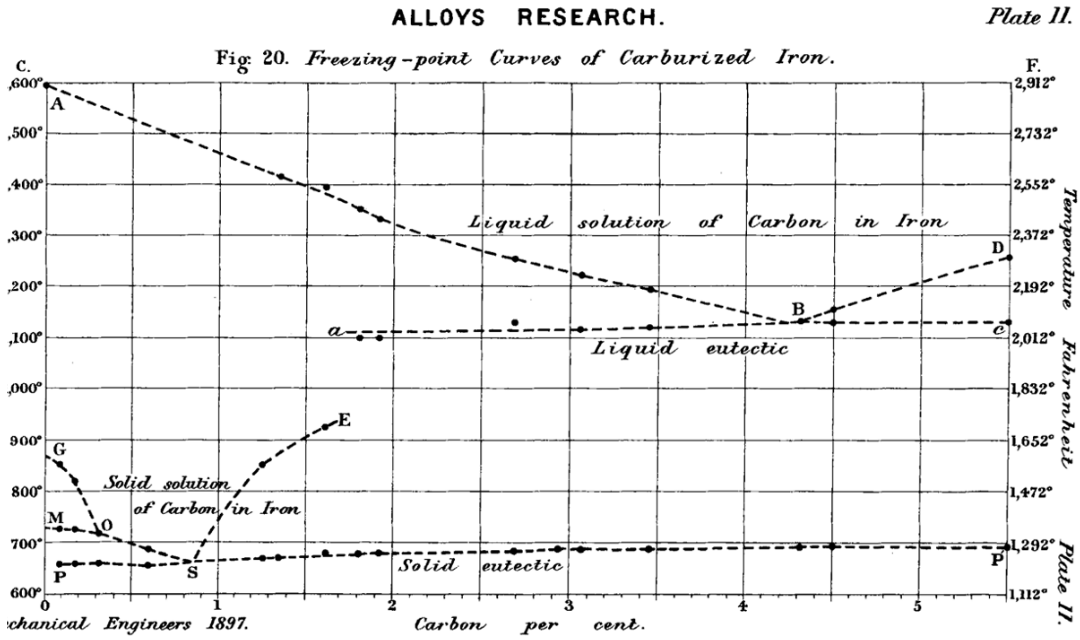


Figure 1. The Fe-C diagram by W. Roberts-Austen (Roberts-Austen, 1897).

To create his diagram, W. Roberts-Austen used a rhodium thermocouple developed by Henri Louis Le Chatelier, which he connected to a self-designed device that recorded the temperature as a function of time. Thus, this diagram is the first for the iron-carbon system.

The work by H. Roozeboom was based on the previous studies of Josiah Willard Gibbs and the diagram was built following the J. Gibbs' phase rule. The diagram already featured closed fields to which certain phases or complexes of phases correspond; all boundary lines create a continuous grid; the solidus temperature of eutectic aBC and the solid eutectic line PSK (eutectoid) do not depend on the carbon content and are horizontal lines; the solidus line showing the carbon content in *austenite* was presented. Since graphite is a more stable modification of carbon than carbides, and its solubility in iron is lower than in the form of carbides, the difference between these two Fe–C systems was also presented: stable (iron–graphite) and unstable (iron–iron carbide) (Wisniak, 2003, p. 428).

In 1888, A. Ledebur, professor of metallurgy at the Berg-Academy in Freiberg, Saxony, proposed to use four forms of carbon and to recognize technical iron. He distinguished between *bound carbon*, *free carbon*, *hardened carbon*, and *graphite* (Ledebur, 1888). This classification became generally accepted in Germany and in a significant part of foreign special literature. It remained valid for about 20 years until it was given a new designation.

According to the state of scientific research at that time, A. Ledebour's views were based on the knowledge of the formation of *hardened carbon* and *carbon carbide* as follows: *bound carbon* in iron-carbon alloys at normal temperatures is usually found in the form of *iron carbide* (*cementite*); this chemical compound with the chemical composition Fe_3C contains 93.33 % of iron and 6.66 % of carbon. When heated above 700 °C, *iron carbide* begins to partially dissolve in the iron-carbon alloy, but its state remains solid. This so-called solid solution contains *solid carbon* (Ledebur, 1906).

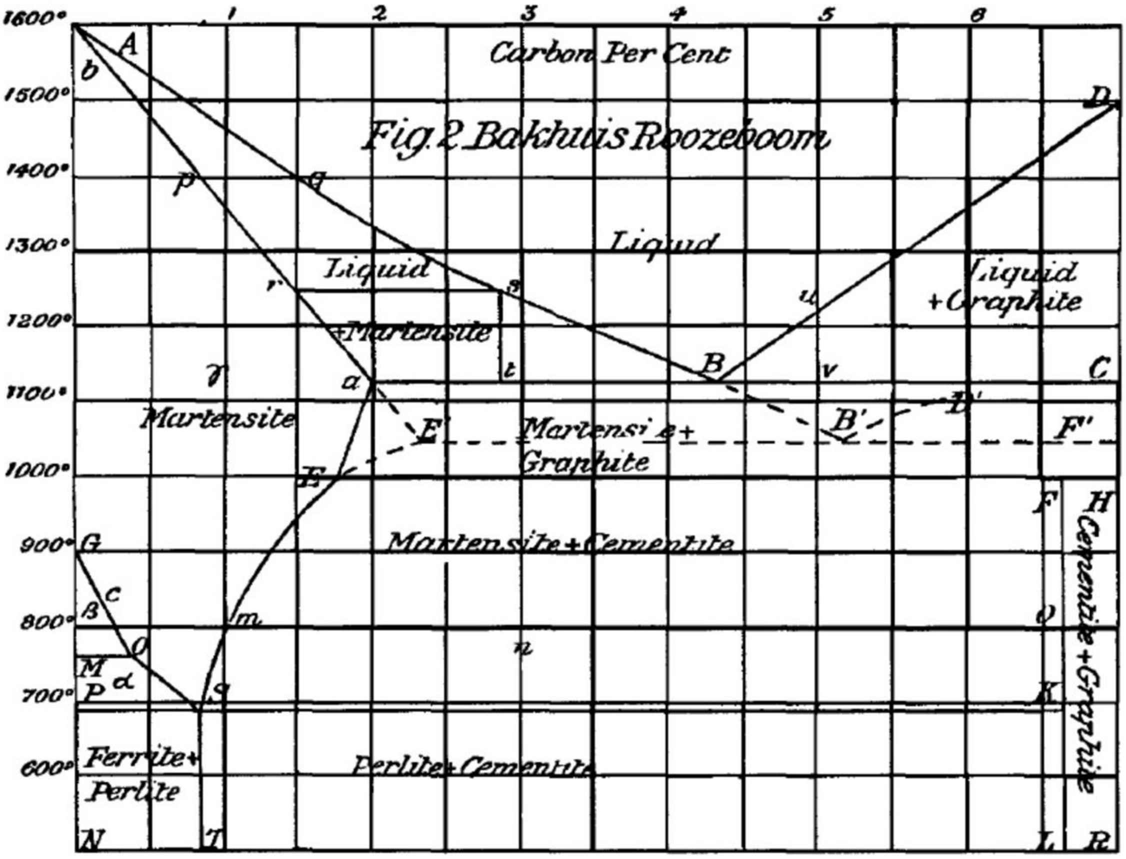


Figure 2. The diagram by H. Roozeboom, 1900 (Wisniak, 2003, p. 429).

As *Dr.-Ing.* Carl Geiger noted, carbon influenced the properties of industrial cast iron to such an extent that cast iron types were divided into two big groups based on the carbon content: high-carbon cast iron and low-carbon forgeable cast iron. He also assumed that the lower limit of carbon content in cast iron is approximately 2 %. At the same time, the professor indicated that the alloy, which contained approximately 1.5 to 2.5 % carbon in the presence of moderate amounts of other particles, was badly forged and cast. And, “such types of cast iron” (although this content today is attributed to steel) are used only in special cases. It is not possible to change the shape of cast iron in a cold or heated but unmolten state by pressure or tension. This can only be achieved by casting after melting. If cast iron (with a composition close to the eutectic point) is heated to the melting temperature (1100–1300 °C), it suddenly changes from a solid state to a liquid state without previously becoming pasty (Geiger, 1925, p. 1–2).

The rapid development of metallurgy at the end of the 19th century, especially in England and France, was based on an organized form of the scientific study of metals and the introduction of microscopic analysis. Thus, in England in 1889, the Society of Mechanical Engineers (Institution of Mechanical Engineers) formed the Alloys Research Committee; soon a similar research center (Commission des Alliages) was organized in France by the Society for the Encouragement of Domestic Industry (Société d’Encouragement pour l’Industrie Nationale). These centers, which had significant material resources, began an extensive study of metals and alloys, primarily the study of the influence of alloying elements on the properties of metals. Among the activities of such centers was extensive research of alloys by methods of thermal and microscopic analysis, due to which in the last decade of the XIX century numerous phase diagrams considering temperature and chemical composition of binary and even ternary alloys appeared. In the following years, studies of the Fe-C diagram were mainly concerned with clarifying the position of individual lines (peritectic part, solubility of carbon in iron, graphite eutectoid).

At the beginning of the new century, European scientific studies of metals and alloys spread to America. Thus, in September 1912, the 6th Congress of the International Association for Testing Materials was held in New York, USA, which was the first congress of this Association to be held in America. The work of the 6th congress may be concisely summarized by the high number of publications of 153, roughly twice as much as the preceding congress and in the results of the work of technical committees it was at least equal to any of the previous congresses. The first official act of the congress was to elect Acting President Henry M. Howe as the president of the association, an act which was beyond the constitutional power of the governing council, after the death of the regularly elected president Dr. C. B. Dudley. The congress accepted the invitation of the Tsar of Russia to hold the next congress in 1915 at St. Petersburg and elected Dr. Nikolai Belelubskyi, St. Petersburg, president of the association for the next three years. Professor H. M. Howe was made a life member of the council. The secretary of the association was Ernst Reitler, Vienna, Austria (The engineering and mining journal, 1912, p. 484).

Among the landmark reports at this congress, it is necessary to note the proposal of the president of the association H. M. Howe, and professor of metallurgy Albert Sauveur on the definition of the names of microscopic substances and structures of steel (Howe & Sauveur, 1912) (Fig. 3). Thus, the names of the structures in the iron-carbon system were defined:

> *"…Graphite*, definite metaral (now we use the word "metal"). *Definition:* the free elemental carbon which occurs in iron and steel. *Composition:* probably pure carbon, identical to native graphite. *Genesis:* derived in large part, from the decomposition of solid *cementite*. Others hold that its formation as kish may be from solution in the molten metal, and that part of the formation of temper graphite may be from elemental carbon dissolved in *austenite*. It is the stable form of carbon in all parts of the diagram. *Occurrence:* 1. as kish, flakes which rise to the surface of molten cast iron and usually escape thence; 2. as thin plates, usually curved, e. g. in gray cast iron, representing carbon which has separated during great mobility, i.e., near the melting range; 3. as temper graphite pulverulent carbon which separates from *cementite* and *austenite*, especially in the annealing process for making malleablized castings.
>
> *Austenite* (up to the year 1900 often called martensite, and wrongly sometimes still called so). The metal of variable composition. *Definition:* the iron-carbon solid solution as it exists above the transformation range or as preserved with but moderate transformation at lower temperatures, e.g., by rapid cooling, or

by the presence of retarding elements, (Mn, Ni, etc.), as in 12 % manganese steel and 25 % nickel steel.

Martensite, metal. Its nature is in dispute. *Definition:* the early stage in the transformation of austenite characterized by needle structure and great hardness, as in hardened high-carbon steel.

Ferrite, definite metal. *Definition:* free alpha-iron. *Composition*: nearly pure iron. It may contain a little phosphorus and silicon, but its carbon content if any is always small, at the most not more than 0.05 %, and perhaps never as much as 0.02 %.

Pearlite. Definition: the iron-carbon eutectoid, consisting of alternate masses of ferrite and cementite. Constitution and Composition. A conglomerate of about 6 parts of ferrite to 1 of cementite.

Ferronite (today ferrite), hypothetical definite metal. Definition: solid solution of about 0.27% of carbon in beta iron.

Hardenite. Definition: Collective name for austenite and martensite of eutectoid composition.

Troostite. Definition: in the transformation of austenite, the stage following martensite and preceding sorbite (and Osmondite if this stage is recognized).

Sorbite. Definition: in the transformation of austenite, the stage following Troostite and Osmondite, if this stage is recognized, and preceding pearlite…"

In addition, definitions for *Ferrous Sulphide, Cementite, and Osmondite*…" were given (Howe & Sauveur, 1912).

Among the reports, the analysis conducted by Professor E. Heyn was also quite interesting. The scientist presented an iron-carbon diagram with different critical points of states proposed by various researchers, including William Chandler Roberts-Austen, Heinrich Hanemann, Nikolai V. Gutovskyi et al. (Fig. 4).

Thus, in the late 1910s, there was still a difference of opinion about the positions of the critical points, and also about the use of the term "steel". In everyday life, the term "steel" was used for any higher-quality material, without understanding that it is an alloy and how it differs from pure iron. Later, the following definition of the term was given: "steel is an alloy of iron that is hardened during hardening." But such a definition remained vague, since there was no clear hardenability limit, and the methods of determining hardness also differed for different alloys. The carbon content started at 0.5 %, but it was not yet possible to calculate extraneous impurities that affected the hardening of steel and, accordingly, its hardness at that time. At the time in European shipbuilding, unhardened ductile iron was almost always called as steel. The Prussian Railway Administration used tensile strength in 1889 and determined that all materials with a strength greater than 50 kg/mm^2 could be described as steel. Regarding tensile strength as a distinguishing feature, professor A. Ledebur has already emphasized that the same wrought iron can show quite different strengths, depending on whether it is tested on thin or thick pieces, or whether it has previously undergone more or less intensive processing. Nevertheless, in 1905 the committee of the German Association for the Testing of Materials in Technology (*Deutscher Verbund für die Materialprüfungen der Technik*) proposed to define the difference between steel and iron as subdivisions of liquid processed iron such as by the Thomas or Bessemer process ("Flusseisen"), on the one hand, and weld metal, on the other hand, that iron is called steel, regardless of its composition and regardless of whether it can be hardened and which has a hardness subsequent to the liquid state after annealing of 50 kg or more per square millimeter, and in a pasty state after puddling of 42 kg or more per square millimeter (Industrienormen Deutsche, 1922, p. 19).

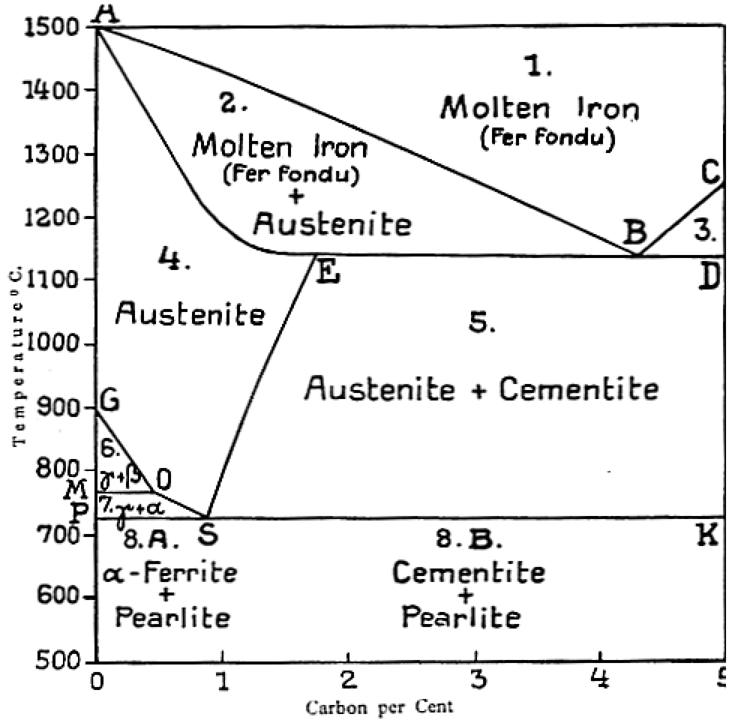
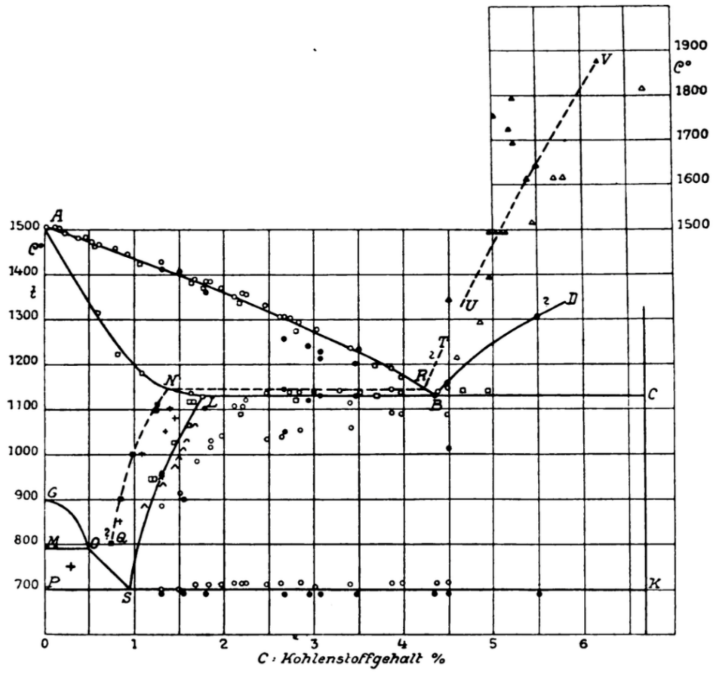


Figure 3. The diagram of different states in the iron-carbon system: the line PSK was often called "A1". The Line GOS is often called "A3", and this name was sometimes applied to the line SE (Howe & Sauveur, 1912).

Finally, in 1919, the German Industrial Standards proposed that in the future for wrought iron and steel, the material obtained in the pasty state should be called "iron" and the material produced in the liquid state – "steel". Several participants objected to the proposal, referring to trade. Such a renaming seemed very complicated and questionable from a commercial point of view. Misunderstandings in the iron trade, for example with bar iron (*Stabeisen*), were inevitable. After several years of negotiations, at the end of 1923, it was agreed that the term "steel" should be defined for all industrially produced iron except pig iron and cast iron (*Roheisen und Gußeisen*) namely "mild steel" for material, obtained in a liquid state and subjected to forging without further processing, welding, etc. "Puddling steel" – for that obtained in a pasty state. The word "iron" itself should be reserved for the element iron. However, this principled decision should not affect commercial names, such as bar and shaped iron, universal iron, sheet iron, etc. (Geiger, 1925, p. 6).

The double diagram of iron-carbon alloys.



C = per cent of carbon.

Fig. 1.

● Roberts-Austen. ▢ Gutowsky. ∧ Wark

○ Carpenter & Keeling. ▲ Hanemann. Linie NQ + Charpy

× Heyn. △ Ruff u Goecke. ■ Ruer & Iljin.

Figure 4. Critical points of states proposed by various researchers before 1911 (Heyn, 1912).

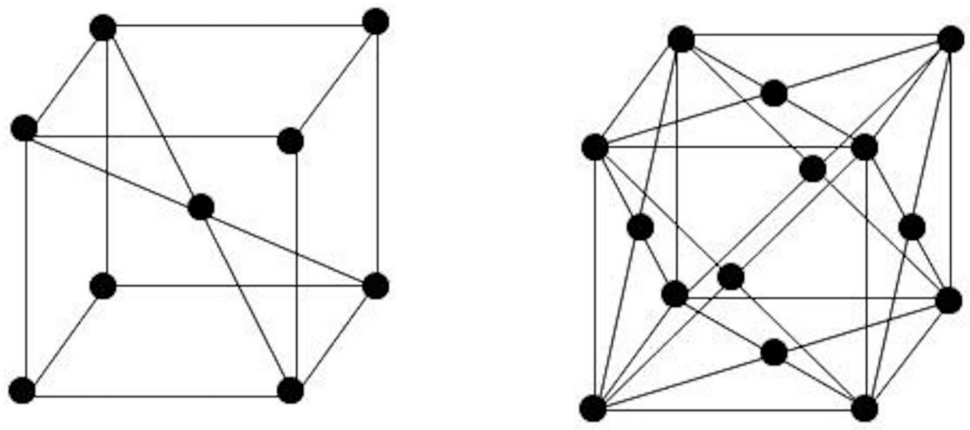
The names of iron processed into objects of everyday use by casting have also been a highly controversial area for a long time. The German Industrial Standards Committee provides the following definitions of terms:

1. Cast iron is melted and cast into molds separately or with iron scrap, steel scrap, and other smelting additives, but is not subjected to processing for the purpose of forging. Depending on the amount of precipitated graphite, the following are distinguished: a) gray cast iron with abundant graphite allocation, b) semi-gray cast iron with a small graphite allocation, c) white cast iron with no graphite or only traces of graphite release, d) chilled cast iron with a white outer zone and a gray core.

2. Malleable iron is cast as cast iron, namely from white iron, and then refined or forged by annealing with a decarbonizing agent.

3. Cast steel is made from steel produced in a crucible, Siemens-Martin, electric furnace, or in a pear-shaped converter without further processing by forging. Therefore, cast steel is already a finished product and the material is formed in the final form (Geiger, 1925, p. 6).

Later, with the development of new material research methods, the location of critical points on the Fe–C diagram gradually normalized. Thus, the first large-scale *X*-ray studies of cast iron and some steels were conducted in 1921 by Swedish researchers Arne Westgren and Axel E. Lindh (Westgren & Lindh, 1921, p. 184) according to a slightly modified Debye–Scherrer method (Debye & Scherrer, 1916, p. 4–8). Based on the assumption that metals are usually a conglomerate of very large numbers of very small crystals, these authors concluded that the Debye-Scherrer method can be applied to non-powdery metal preparations. The experiment has confirmed this assumption, it turned out that this method can be successfully tested on metals in the form of thin rods or wire without the need for additional powder coating. From the X-ray pattern obtained by scientists, it turned out that β-iron, like α-iron, has a spatially centric cubic lattice (Fig. 5, a). Further research by Arne Westgren and Axel E. Lindh conclusively demonstrated that γ-iron (Fig. 5, b) is fundamentally different from α-iron in crystallography, while β- is identical in this characteristic to α-iron (Authier, 2013, p. 144). It should be noted that the γ- to α-transformation is accompanied by an atomic volume change of approximately 1%, which can lead to the generation of internal stresses during transformation (Bhadeshia & Honeycombe, 2006, p. 4).



a b

Figure 5. α-iron (a) and γ-iron (b) structure.

The majority of researchers who began to use *X*-rays for the study of metals concluded that due to the allotropy of crystalline bodies with β-polymorphism, iron cannot be considered as a separate allotrope. In 1922, Arne Westgren and Gösta Phragmen (Westgren & Phragmen, 1922) conducted an *X*-ray diffraction study of electrolytic iron melted in a vacuum, as a result of which they found that δ-iron, like β-iron, crystallizes in the same order as α-iron and that it is spatially centric (today it is called body-centered cubic or bcc). Thus, these studies showed that the transformation of one structure into another is a reverse process. That is, at very high temperatures, iron returns to a form with properties similar to those it had in its original form (Westgren & Phragmen, 1922).

In the 1920s, several works devoted to *X*-ray studies of both carbon and alloy steels were published. In particular, this was the work by Nikolai Seljakov, Georgii Kurdjumov, and Nikolai Goodtzov (Seljakow, Kurdjumow & Goodtzow, 1927), which also included the results of G. Kurdjumov's thesis, where the crystallographic structure of *martensite* was indicated, and the mechanism of martensitic transformation was recognized. Further research conducted by G. Kurdjumov at the Institute of Metals Research in Berlin on *austenite* single crystals together with Goldman Sachs led to the creation of a scheme for the rearrangement of *austenite* crystal lattices into *martensite* lattices through two shifts. The mutual orientation of *austenite* and *martensite* crystals that occurs in this case was called the Kurdjumov-Sachs orientation (Lee & Han, 2012).

The period of 1930 to the 1940s was not marked by significant discoveries in the development of physical and chemical science that would affect the formation of the lines of the iron-carbon diagram. This was primarily related to the economic and political situations in the world. Repression and famine in the Soviet Union, the stock market crash, and, of course, the Second World War. In addition, it was not considered applicable to repeat the research to clarify the temperatures of phase transformations, instead, the researchers switched to experiments to create alloys devoid of impurities, that is, of much higher purity.

In 1941–1942, the American Bureau of Standards conducted an extensive study on the properties of pure iron, and Wm. F. Roeser and H. T. Wensel (Roeser & Wensel, 1941) were concerned only with determining the melting temperature of iron, and Harold E. Cleaves and John M. Hiegel (Cleaves & Hiegel, 1942) studied various physical properties of iron, including the A_3 transformation temperature, i.e., the lower temperatures of the γ-iron formation. During determining the iron melting points, scientists critically reviewed all previous studies in this direction and came to the conclusion that the melting point has not yet been unambiguously determined for the following reasons: 1) the researchers were mainly interested in determining the equilibrium diagram, rather than the exact determination of the melting point of iron; 2) the number of impurities in the studied samples were generally high and so different that individual results cannot be considered as referring to the same material; 3) the analysis did not take into account the content of gases that have a significant effect on the melting temperature; 4) iron was exposed to pollution, especially by gases, during the test; 5) the basis of marking of temperature measuring devices by individual researchers was not identical (Roeser & Wensel, 1941, p. 275). Roeser and Wensel used iron with a high degree of purity (total impurities below 0.01 %), obtained by reducing pure iron oxide to sponge iron (cast iron) and then remelting it twice – one time in an atmosphere of hydrogen, the second time in a vacuum. The tests were performed in a helium atmosphere, and the samples were melted in a high-frequency induction furnace in a beryllium oxide crucible. The temperature was measured using an optical pyrometer directed on a crucible with molten cast iron. As a result of these studies, the melting point (solidification point) of pure iron (99.99 % Fe) was determined at 1539±1 ºC. Before, the temperature of 1528 ºC (determined in 1914 by R. Ruer and R. Klesper (Ruer & Klesper, 1914, p. 260), was most often indicated on the iron-carbon equilibrium diagrams.

In 1948, in the Metals Handbook, John B. Austin published what is now considered the classic American diagram, where he indicated that the solubility of carbon in γ-iron in the presence of *cementite* is about 2 %, and not about 1.7 %, as previously reported (Austin, 1948, p. 1182) (Fig. 6).

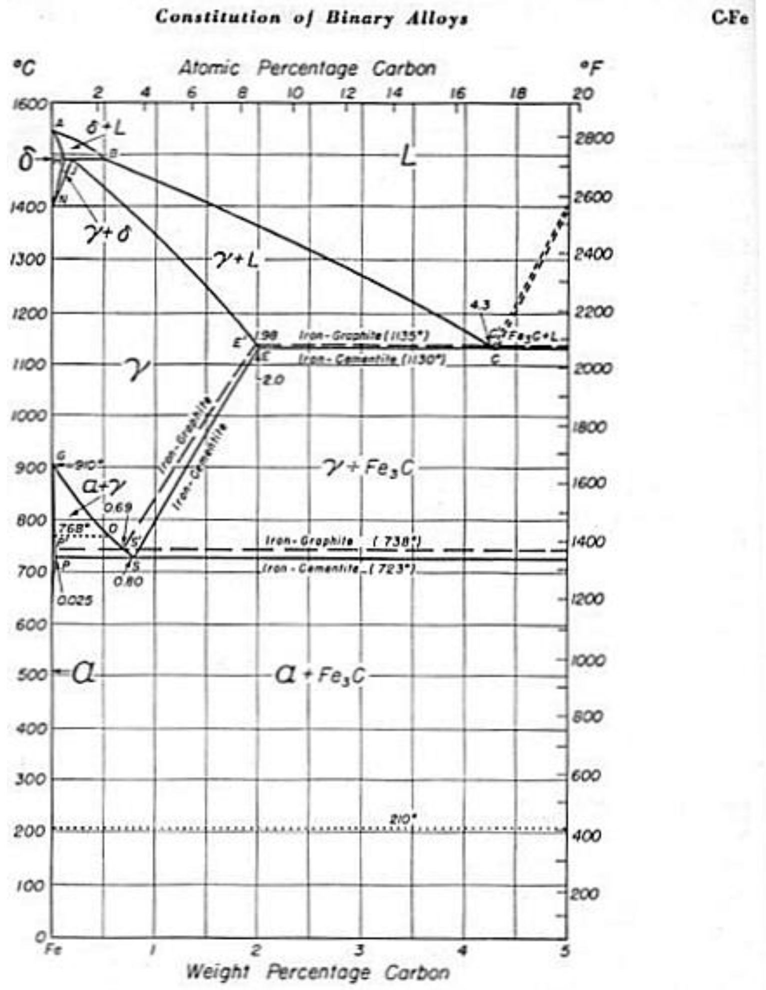


Figure 6. Diagram Fe-C by Austin (Austin, 1948, p. 1182).

In the middle of the 1970s American scientists continued their experiments with carbon steels (now known as Ultrahigh carbon steels – UHCS). That study had its origin in the development of superplastic behavior in steels and the recognition that increasing the carbon content was of importance in developing that property. The scientists summarised that the maximum solubility of carbon in Austenite is 2,1% C (Wadsworth & Sherby, 1997, p. 11). In 1978 it was determined that carbon contents beyond UCS, containing 2.1 and 2.3 % C, show superplasticity (Wadsworth & Sherby, 1997, p. 14).

In the early 1980s, Australian researchers conducted experiments on the Fe-C composition in the range from 1.5 to 4.42 % C. The possibility of a certain modification of the γ-solidus was also proposed, and a refined phase diagram was presented (Chicco & Thorpe, 1982, 1983).

The subsequent period of scientific research did not bring any new data that would significantly affect the critical points of the Fe-C diagram. At the beginning of the new millennium, there is still a difference of opinion among scientists about the carbon content in the steel. The authors of this research consider that this is related to anomalies in the plasticity of iron at certain temperatures, in particular as it was investigated in (Shakhnazarov & Pryakhin, 2016). Today's steel making research is concerned with environmental issues, in particular with the transformation of technological processes towards CO_2-reduced or -free production of steels and cast iron due to the occuring climate challenges and the global goals for a sustainable development (Ito, Langefeld, & Götz, 2020; Vercammen, 2022; Kueppers, Hodgson, Levi, Vass & Lechtenbohmer, 2022). We should add, that today, the use of hydrogen (H_2) or ammonia (NH_3) in metallurgy has the potential to become an important and promising direction of development (Ma et al., 2023). Hydrogen cannot only be used as an alternative fuel for mobility or other combustion processes to reduce greenhouse gas emissions but to improve steel production. One of the possible applications of hydrogen is its use in the production of iron and steel. Hydrogen can serve as a substitute for carbon in the direct iron reduction. Instead of carbon, which is used in traditional iron production processes, hydrogen can be used as a reducing agent to extract iron from ore, significantly reducing CO_2 emissions (Ma et al., 2023); e.g., Thyssenkrupp as only one of the steel manufacturer in Germany produces about 2.5 % of Germanys total CO_2 emissions. (Kleier & Hansmann, 2023; Leitprojekt Dekarbonisierung, 2023, p. 16–17). Currently, huge investments such as by Thyssenkrupp and Salzgitter AG (Finanzierung des SALCOS®-Programms gesichert, 2023; Hartbrich, 2023) are startet to build new direct reduction process plants as well as to provide new hydrogen pipelines in Europe to the participating steel mills or to connect already existing pipeline networks.

Conclusions.

As can be seen from the iron-carbon phase diagram, since its initial presentation in the late 19th century, it has actively evolved until the mid-20th century. Initially, scientists tried to determine the different forms in which graphite exists when combined with iron at different temperatures. Such research was simultaneously conducted in England, Sweden, France, and Germany. Even the definition of what steel or iron is undergoing lengthy discussions.

It is considered that the first representation of the Fe-C dependence in the form of a diagram was presented by William Roberts-Austen, and then the search for names for different states followed. It should be noted that all of these states were named after well-known metallurgists, such as Martensite, Austenite, Ledeburite, and others. The evolution of the iron–carbon diagram is directly related to discoveries and methods in the field of physics and chemistry. With the gradual use of microscopes and X-ray diffraction methods, critical points were especially intensively explored in the interwar period.

While the maximum carbon content in cast iron of 6.67% does not raise any objections among scientists from all countries, there are different opinions regarding the maximum carbon content in steel. Furthermore, modern textbooks repeat the information from the second half of the 20th century and do not enrich the understanding of the actual maximum carbon content in steel. Even if we assume that there was no exchange of scientific information between American and Soviet scientists (including Ukrainian scientists for a considerable period of time), it remains a mystery why different data exist among scientists from Germany, Poland, and Australia.

Despite the so-called "age of polymers" in which we live now, steel and cast iron remain the most important basic materials in mechanical and civil engineering. The basis for the development of materials science is the knowledge of metallurgy, and the Fe-C diagram is the basis for the study of phase transformations occurring in alloys.

During the 1880s and 1980s, scientists from many countries in Europe and North America, as well as Australia, actively studied phase transformations in the iron-carbon system. Today, the direction of research has shifted due to new challenges of the 21st century. Hence, in most countries, there is still no consistent definition of the percentage of carbon content in the steel.

Conflicts of interest.

The authors declare no conflict of interest

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References

Austin, J. B. (1948). C-Fe Carbon-Iron. In T. Lyman (Ed.), *Metals Handbook* (pp. 1181–1182). Cleveland: American Society for metals.

Authier, A. (2013). *Early Days of X-ray Crystallography*. Oxford: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199659845.001.0001

Berzelius, J. J. (1841). *Jahresbericht über die Fortschritte der Physischen Wissenschaften, 20*. Tübingen: Heinrich Laupp. Retrieved from https://www.digitale-sammlungen.de/de/view/bsb10130758?q=%28Jahresbericht+%C3%BCber+die+Fortschritte+der+physischen+Wissenschaften+1841%29&page=30,31 [in German].

Bhadeshia, H. K. D. H., & Honeycombe, R. (2006). Iron and its interstitial solid solutions. In *Steels: Microstructure and Properties* (3rd ed.) (pp. 1–16). Oxford: Butterworth-Heinemann. http://dx.doi.org/10.1016/B978-075068084-4/50003-0

Bobrova, T. B. (2016). *Osnovy materialoznavstva. Navchalnyi posibnyk – [Basics of materials science. Tutorial]*. Kyiv: GURT Resource Center. Retrieved from https://www.gurt.org.ua/uploads/news/files/2016-8/Матеріалознавство-min.pdf [in Ukrainian].

Chicco, B., & Thorpe, W. R. (1982). Experimental determination of the austenite + liquid phase boundaries of the Fe-C system. *Metallurgical and Materials Transactions A*, *13*, 1293–1297. https://doi.org/10.1007/BF02645513

Chicco, B., & Thorpe, W. R. (1983). A further determination of the austenite solidus of the Fe-C system. *Metallurgical and Materials Transactions A*, *14*, 312–314. https://doi.org/10.1007/BF02651629

Cleaves, H. E., & Hiegel, J. M. (1942). Properties of high purity iron. *Journal of Research of the National Bureau of Standards*, *28*(5), 643–669. http://dx.doi.org/10.6028/jres.028.027

Debye, P., & Scherrer, P. (1916). Interferenzen an regellos orientierten Teilchen im Röntgenlicht. I. In *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse, 1916* (pp. 1–15). Berlin: Weidmanndsche Buchhandlung. Retrieved from https://gdz.sub.uni-goettingen.de/id/PPN252457811_1916?tify=%7B%22view%22:%22info%22,%22pages%22:%5B5%5D%7D [in German].

Eckstein, H.-J. (1969). *Wärmebehandlung von Stahl: Metallkundliche Grundlagen*. Leipzig: Deutscher Verlag für Grundstoffindustrie VEB [in German].

Fedirko, P. Krol, V., Hutsol, T., … & Dziedzic, B. (2017). *Materialoznavstvo i sliusarna sprava – [Materials science and metalworking]*. Krakow, Kamianets-Podilskyi: Traicon. Retrieved from https://depot.ceon.pl/bitstream/handle/123456789/13411/MATERIALS%20SCIENCE%20AND%20METALWORKING.pdf?sequence=1&isAllowed=y [in Ukrainian].

Finanzierung des SALCOS®-Programms gesichert (2023). *Stahl und Technik*, (3), 30–31. Retrieved from https://www.stahl-und-technik.de/artikel/finanzierung-des-salzgitter-salcos-programms-gesichert [in German].

Geiger, C. (1925). Die Begriffe "Eisen" und "Stahl". In C. Geiger, (Ed.), *Handbuch der Eisen- und Stahlgießerei*. (pp. 1–7). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-90865-1_1 [in German].

Gutnyk, M. (2012). Robert Forester Miushet – liudyna, yaka nadala formu suchasnomu svitu [Robert Forester Mushet – the man who gave a shape to the modern world]. *Materialy 11-yi Vseukrainskoi naukovoi konferentsii «Aktualni pytannia istorii nauky i tekhniky» [Materials of the 11th All-Ukrainian Scientific Conference "Current Issues in the History of Science and Technology"],* Kyiv, October 4-6, 2012, (pp. 253–255). Kyiv: Center for Monument Studies of the National Academy of Sciences of Ukraine and UTOPIK [in Ukrainian].

Hartbrich, I. (2023, June 19). Thyssenkrupp und Zweiter Kohleausstieg an der Ruhr. *VDI Nachrichten*. Retrieved from https://www.vdi-nachrichten.com/technik/werkstoffe/thyssenkrupp-und-der-zweite-kohleausstieg-an-der-ruhr/ [in German].

Heyn, E. (1912). Report on the progress of metallography since the commencement of the year 1909 to the end of the year 1911. In *Sixth congress of the International Association for Testing Materials, held in New York, September 3–7, 1912, Vol. 1*, Part II(1). New York: McGraw-Hill. Retrieved from https://babel.hathitrust.org/cgi/pt?id=coo.31924004059048&seq=105

Horstmann, D. (1985). Das Zustandsschaubild Eisen-Kohlenstiff und die Grundlagen derv Wärmebehandlung der Eisen-Kohlenstoff-Legierungen. Düsseldorf: Verlag Stahleisen [in German].

Howe, H. M., & Sauveur, A. (1912) The Nomenclature of the Microscopic Substances and Structures of Steel. In *Sixth congress of the International Association for*

Testing Materials, held in New York, September 3–7, 1912, Vol. 1, Part II(7). New York: McGraw-Hill. Retrieved from https://babel.hathitrust.org/cgi/pt?id=coo.31924004059048&seq=246

Hucińska, J. (1995). *Metaloznawstwo materiały do ćwiczeńlaboratoryjnych*. Gdansk: Wydawnictwo Politechniki Gdańskiej. Retrieved from https://pbc.gda.pl/dlibra/publication/edition/4096/content [in Polish].

Industrienormen Deutsche (1922). *Werkstoffnormen für Eisen und Stahl, herausgegeben vom Normenausschuß der Deutschen Industrie*. Berlin: Selbstverlag des Normenausschusses [in German].

Ito, A., Langefeld, B., & Götz, N. (2020). *The Future of Steel making – How the European Steel Industry Can Achieve Carbon Neutrality*. Munich: Roland Berger GMBH. Retrieved from https://www.rolandberger.com/publications/publication_pdf/rroland_berger_future_of_steelmaking.pdf

Karsten, C. J. B. (1816). *Handbuch der Eisenhüttenkunde. Vol. 1: Die Eigenschaften des Eisens.* Halle: Curt. Retrieved from https://www.digitale-sammlungen.de/de/view/bsb10706033?page=,1 [in German].

Kayser, F. X., & Patterson, J. W. (1998). Sir William Chandler Roberts-Austen – His role in the development of binary diagrams and modern physical metallurgy. *Journal of Phase Equilibria*, *19*, 11–18. https://doi.org/10.1007/BF02904718

Kleier, T., & Hansmann, Th. (2023). Maßgeschneiderte Dekarbonisierung. *Stahl und Eisen*, 06, 16–17 [in German].

Kueppers, M., Hodgson, D., Levi, P., Vass, T., & Lechtenbohmer, T. (2022). Iron and Steel. *International Energy Agency*. Retrieved from https://www.iea.org/reports/iron-and-steel

Läpple, V. (2022). *Wärmebehandlung des Stahls*. Haan-Gruiten: Europa-Lehrmittel [in German].

Ledebur, A. (1888). Über die Benennung der verschiedenen Kohlenstofform en im Eisen. *Stahleisen*, 742 [in German].

Ledebur, A. (1906). *Handbuch der Eisenhüttenkunde, Vol. 1: Für den Gebrauch im Betriebe wie zur Benutzung Beim Unterrichte Bearbeitet; Einführung in die Eisenhüttenkunde (Classic Reprint)*. Leipzig: Arthur Felix [in German].

Lee, D. N., & Han, H. N. (2012). Directed growth of ferrite in austenite and Kurdjumov-Sachs orientation relationship. *Materials Science Forum*, *715–716*, 128–133. https://doi.org/10.4028/www.scientific.net/MSF.715-716.128

Leitprojekt Dekarbonisierung. (2023). *Stahl und Eisen*, 03, 16–17 [in German].

Ma, Y., Bae, J. W., Kim, S.-H., Jovičević-Klug, M., Li, K., Vogel, D., … & Raabe, D. (2023). Reducing iron oxide with ammonia: A sustainable path to green steel. *Advanced Science*, *10*, 2300111. https://doi.org/10.1002/advs.202300111

Mourelo, J. R. (1916). L'oeuvre de Proust en Espagne. *Revue scientifique*, *54*, 257–266 [in French].

Mushet, D. (1802). XXIV. On the different proportions of carbon which constitute the various qualities of Crude iron and steel. *Philosophical Magazine*, *13*(50), 142–149. https://doi.org/10.1080/14786440208676104

Nürnberger, F., Frolov, I., Grydin, O., Gutnyk, M., & Blank, T. (2022). *Materials Testing*. Hannover. https://doi.org/10.57961/5fbf-7745

Osmond, F. (1886). Sur les phénomènes qui se produisent pendant le chauffage et le refroidissement de l'acier fondu. *Comptes rendus,103*, 743–746; 1135–1137 [in French].

Osmond, F., & Cartaud, G. (1906). Die Kristallographie des Eisens. *Metallurgie*, 3, 522 [in German].

Ostwald, W. (1974). J. B. Richter. In *Günther Bugge: Das Buch der grossen Chemiker, Vol. 1* (p. 375). New York, Weinheim: Verlag Chemie [in German].

Pawłowski, B. (2012). Temperatura przemiany magnetycznej cementytu, *XL Szkoła Inżynierii Materiałowej, 24–27 IX 2012* (pp. 1–5). Kraków: Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie. Retrieved from https://www.researchgate.net/profile/Bogdan-Pawlowski/publication/251880650_Temperatura_przemiany_magnetycznej_cementytu/links/0c96051f247cc3500e000000/Temperatura-przemiany-magnetycznej-cementytu.pdf [in Polish].

Pawłowski, B. (2017). 8. Obróbka cieplna i cieplno-chemiczna stali. In *Wydzial Chemiczny Technologia Chemiczna* (pp. 144–167). Retrieved from https://www.studocu.com/pl/document/politechnika-slaska-w-gliwicach/wydzial-chemiczny-technologia-chemiczna/dr-inz-bogdan-pawlowski-obrobka-cieplna-i-cieplno-chemiczna-stali/31346752 [in Polish].

Pfender, M. (1990). Martens Adolf. In *Neue Deutsche Biographie (NDB), 16*, (pp. 266–273). Berlin: Band Duncker & Humblot. Retrieved from https://www.deutsche-biographie.de/pnd116800453.html#ndbcontentCC-BY-NC-SA [in German].

Roberts-Austen, W. C. (1897). Fourth report to the alloys research committee. *Proceedings of the Institution of Mechanical Engineers*, *52*(1), 31–100. https://doi.org/10.1243/PIME_PROC_1897_052_009_02

Rocke, A. J. (2005). In search of El Dorado: John Dalton and the origins of the atomic theory. *Social Research: An International Quarterly*, *72*(1), 125–158. https://doi.org/10.1353/sor.2005.0003

Roeser, Wm. F., & Wensel, H. T. (1941). Freezing temperatures of high purity iron and some steels. *Journal of Research of the National Bureau of Standards, 26*(4), 273–287. https://doi.org/10.6028/jres.026.015

Roozeboom, H. W. B. (1900). *The Metallographist*, *3*, 293–300.

Ruer, R., & Klesper, R. (1914). Die γ-δ-Umwandlung des reinen Eisens und ihre Beeinflussung durch Kohlenstoff, Silizium, Kobalt und Kupfer. *Ferrum, 11*, 257–261 [in German].

Sefström, N. G. (1828). Berättelser rörande göromalen vid Bergsskolan ar 1827. *Jern-Kontorets Annaler*, *12*, 145 [in German].

Sefström, N. G. (1829). Versuche zur Ausmittlung der Natur des Graphits. *Annalen der Physik, 16*, 168 [in German].

Seljakow, N., Kurdjumow, G., & Goodtzow, N. (1927). Eine röntgenografische Untersuchung der Struktur des Kohlenstoffstahls. *Zeitschrift für Physik*, 45, 384–408. https://doi.org/10.1007/BF01343061 [in German].

Shakhnazarov, K., & Pryakhin, E. (2016). Plasticity anomaly of iron as a result of transformation at ~650°C. *Journal of Mining Institute*, *217*, 150–154. Retrieved from https://pmi.spmi.ru/pmi/article/view/5093/2958 [in Russian].

The engineering and mining journal. (1912, September 14). *The engineering and mining journal*, *94*(11), 484.

Timofeeva, L., & Komarova, G. (2013). *Materialoznavstvo ta tekhnolohiia konstruktsiinykh materialiv. Chastyna 1 [Materials science and technology of structural materials: Lecture notes. Part 1]*. Kharkiv: UkrDAZT. Retrieved from http://lib.kart.edu.ua/handle/123456789/6702 [in Ukrainian].

Tyrkiel, E. (1963). *Wykres zelazo-węgiel w rozwoju historycznym*. Wroclaw-Warszawa-Krakow: Wydawnictwo Polskiej Akademii Nauk [in Polish].

Vercammen, S. (2022, August 1). Steel. Transition to net zero, *McKinsey Quarterly*. Retrieved from https://www.mckinsey.com/capabilities/sustainability/our-insights/spotting-green-business-opportunities-in-a-surging-net-zero-world/transition-to-net-zero/steel

Wadsworth, J., & Sherby, O. D. (1997). The History of ultrahigh carbon steels. *The Metallurgical Society 1997 Materials week, Indianapolis, IN (United States), September 14–17, 1997*, (pp. 1–42). Retrieved from https://www.osti.gov/servlets/purl/611842

Wessel, H. A. (2009). Globale Unternehmensaktivitäten im Spannungsfeld von unternehmerischem Gestaltungswillen und (wirtschafts-) politischen Realitäten. Das Beispiel der Familie Mannesmann aus Remscheid. In *Hilger, Susanne/Soénius, Ulrich S. (Hg.), Familienunternehmen im Rheinland im 19. und 20. Jahrhundert*, (pp. 66–102). Köln: Stiftung Rheinisch-Westfälisches Wirtschaftsarchiv [in German].

Westgren, A., & Lindh, A. E. (1921). Zum Kristallbau des Eisens und Stahl. *Zeitschrift fuer Physikalische Chemie*, *98*(1), 181–210. https://doi.org/10.1515/zpch-1921-9815 [in German].

Westgren, A., & Phragmen, G. (1922). X-rays studies on the crystal structure of steel. *Journal of the Iron and Steel Institute*, *105*, 241–273.

Wisniak, J. (2003). Hendrik-Willem Bakhuis Roozeboom: Equilibrium and Phase Topology. *Journal of Phase Equilibria, 24*, 422–430. https://doi.org/10.1361/105497103770330073

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Діаграма Fe-C – Історія її еволюції

Анотація. *Розглядається еволюція концепцій і методів фізичних та хімічних наук, що сприяли формуванню діаграми Fe-C протягом минулих століть. Незважаючи на класичні знання, існують відмінності у представленні діаграми Fe-C ученими з різних країн, зокрема дані науковців з Німеччини, Польщі, України, США та Австралії дещо не збігаються. Автори намагалися розібратися у причинах цієї розбіжності. Для проведення дослідження використовувалися загальні наукові методи пізнання: порівняльний аналіз і синтез, а також хронологічний підхід. Зазначається, що перші дослідження вмісту вуглецю у сталі були проведені в 1802 році. Подальший розвиток дослідження розпочався у 1827–1829 роках, коли було встановлено, що графіт – це чистий вуглець. Наголошується, що наступні дослідження вмісту вуглецю в сталі та чавуні пов'язані зі спробами створити перші графіки залежності вмісту вуглецю і температури. Це, в свою чергу, сприяло розвитку промислової революції. Вважається, що першу повну діаграму представив у 1897 році Робертс-Аустен. Пізніше, із використанням рентгенівських методів та мікроскопії, діаграма Fe-C поступово набула нового вигляду. На початку 20-го століття учені активно пропонували свої фазові діаграми. Дослідження, проведені науковцями з різних країн впродовж 1909–1911 років, були об'єднані, це відбулося на 6-му Конгресі Міжнародної асоціації для випробування матеріалів, що призвело до уніфікації назв фазових перетворень. Подальші дослідження до початку Другої світової війни були спрямовані на створення «чистої» сталі, тобто без шкідливих домішок, та уточнення температур фазових перетворень. Період Великої Депресії в США та війни в Європі не сприяли науковим експериметам. У той самий час для масового виробництва сталі та чавуну похибки в критичних точках на декілька градусів не мали суттєвого впливу, тобто уточнення температур фазових перетворень не вважали доцільним. Сучасна тенденція у наукових дослідженнях спрямована на вирішення екологічних проблем, спричинених промисловою революцією.*

Ключові слова: *діаграма Fe-C; уніфікація режимів перетворення в бінарних сплавах Fe-C; консолідація науки; матеріалознавство*

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The long way home: Migration trends of Ukrainian researchers in the modern world (1991–2023)

Abstract. *In a modern world marked by intense migration processes, the analysis of the migration of Ukrainian scientists and their choice of destination countries, especially in the context of recent events in Ukraine, is an important subject of scientific research. This study examines migration trends among Ukrainian researchers in various historical periods from the early 1990s to the present. The research is based on the analysis of scientific literature for theoretical insights and previous studies, the use of statistical data from the State Statistics Service of Ukraine, the analysis of political, economic, and sociocultural contexts to understand migration factors, methods of observing real events and processes, and historical analysis to trace the evolution of migration processes. Factors influencing scientists' decisions regarding migration and their motivations, as well as destination countries, were analyzed in the article. Three key migration stages are highlighted: the post-Soviet period (1991–2012), the post-revolutionary period (2013–2021), and the period of full-scale war (2022 and onwards). The first stage, covering the years 1991–2012, was characterized by the outflow of scientists in search of economic opportunities and stability. Destination countries during this stage included the USA, Russia, Germany, Israel, Canada, and Poland. The second stage, from 2013 to 2021, was marked by deep social and political transformations in Ukraine following the Euromaidan Revolution and the annexation of Crimea by Russia. Scientists chose Germany, Canada, and Poland for academic collaboration and research funding.The third stage, which began in 2022 and continues to the present, is defined by the full-scale war in Ukraine. Scientists are leaving the country due to a sense of danger and military conflict. The primary migration destinations are EU countries, which offer opportunities for academic cooperation and safety. Prospects for further scientific research lie in the analysis of the historical roots of the migration of Ukrainian scientists, including the impact of events and reforms in Ukraine and the world on migration processes.*

Keywords: *migration; Ukrainian researcher; brain drain; scientific mobility; forced migration; refugees*

Introduction.

In recent years, the global landscape of scientific research has undergone significant transformations, with an increasing number of researchers seeking new opportunities and collaborations beyond their home countries. Ukraine, a country known for its rich scientific heritage and intellectual capital, has been an active participant in this global scientific migration. The relocation of Ukrainian researchers to other countries in search of better resources, career prospects, and professional growth has contributed to dynamic knowledge and experience exchange on an international scale.

The study of the migration process of Ukrainian scientists holds important societal and scientific significance for several reasons. The migration of scholars from Ukraine can lead to a loss of the country's intellectual potential. Scholars who leave for abroad take with them knowledge and research experience. Ukraine already faces issues with an insufficient number of scientists, especially young and talented researchers. The migration of scientists can exacerbate this deficit and result in a loss of human resources for future research and the country's development. The loss of scientists can impact the advancement of science and education in Ukraine. A reduction in the number of researchers can limit opportunities for conducting research, developing new technologies, and fostering innovation. The migration of scientists can have economic implications for Ukraine. The loss of highly skilled professionals can lead to economic losses and a decrease in the country's competitiveness on the global market.

Several researchers have explored the issue of scientist migration: Romanjuk and Smutchak (2017) analyzed the main reasons for the migration of scientists during the years of Ukraine's independence; Oppeld and Shabardina (2013) examined trends in intellectual migration in the context of European integration; Polishchuk and Nagorna (2021) studied the lessons from the EU and the USA regarding scientist migration; Svityashchuk and Stadny (2014) examined the migration of Ukrainian scholars through two narrower issues: academic mobility and academic migration; Vavilova, Isakova, Oliynyk, Sayenko, and Troyan (2016) identified the main goals of Ukrainian scientists' departure abroad at the beginning of the 21st century, including qualification enhancement, gaining experience in international projects, and improving their and their families' well-being. A wide range of issues related to the migration of Ukrainian scientists during the full-scale war are considered in the works of Ukrainian researchers. In a study conducted by Lytvynchuk and Yurkivsky (2023), aspects of the contemporary migration crisis that arose as a result of the Russian-Ukrainian war are discussed. The scholar notes that the arrival of skilled immigrants contributes to increased labor productivity and does not require significant costs for their education in the host country. Furthermore, this process helps reduce the pace of population aging thanks to new immigrants. Fiialka (2022) examines the consequences of the war for Ukrainian researchers and explores the attitudes and motivations of Ukrainian scientists regarding their scientific activities and the publication of their results in scientific journals. Suchikova, Tsybuliak, Lopatina, Shevchenko and Popov (2023) investigate how to prevent the loss of scientific potential due to the full-scale war, identifying the connection between the residence of Ukrainian researchers and their ability to engage in scientific activities, as well as identifying factors that reduce scientific efficiency during times of war. Harashchenko, Hladchenko, and Korytnikova (2022) focused on determining the needs of Ukrainian scientists, both those who stayed in Ukraine and those who left Ukraine due to the war. Among the most important personal needs of Ukrainian scientists, the authors highlight financial support, creating new social contacts, and stable access to the internet, while the most crucial needs in their scientific work are research projects, access to scientific literature, information, and data, and mobility programs for scientists.

The intensification of migration processes in Ukraine underscores the relevance of this topic for scientific research. However, some critical aspects, such as the factors behind scientists' decisions to migrate to other countries in different contemporary periods and the directions of scientist migration, have not received enough attention and thorough investigation, both theoretically and practically. This indicates the need for further scientific research and consideration of these issues to better understand and support Ukrainian scientists. The aim of this research is to analyze the dynamics of migration among Ukrainian researchers from the early 1990s to 2023, taking into consideration specific factors and the unique characteristics of their migration patterns. Within the scope of this study, we will examine the determining factors that have motivated Ukrainian scientists to seek international migration opportunities and identify the key routes of their migration during the specified historical period.

Research Methods.

The study employs various scientific methods, including an analysis of scientific literature to understand theoretical approaches and previous research on this issue; statistical data, such as data from the State Statistics Service of Ukraine; an analysis of political, economic, and sociocultural contexts to comprehend the impact of factors on scientist migration; methods of real-time event and process observation to provide information about scientists' migration decisions; historical analysis to trace the evolution of migration processes, identify the most influential factors in scientists' decisions, and understand how changes occurred over time; a chronological approach to structure the research and highlight key events that influenced migration processes; and a problem-oriented approach to delve deeper into the causes and consequences of scientist migration.

Results and Discussion.

The migration of Ukrainian researchers can be traced back to the early 1990s, following Ukraine's declaration of independence. While academic migration also occurred during other periods in Ukraine's history, the Soviet era presented significant challenges for researchers seeking to migrate due to the totalitarian regime and geopolitical restrictions such as the Iron Curtain. However, the social and political changes in combination with economic challenges and the opening of international borders created the foundation for increased mobility among scientists. Understanding the historical context provides the basis for comprehending the factors influencing the migration of Ukrainian researchers.

The contemporary migration of Ukrainian scientists can be divided into three stages:

1. The First Stage, "Post-Soviet Period" (1991–2012): This period was characterized by the initial dissolution of the Soviet Union and economic shocks. Many people emigrated from Ukraine in search of better economic opportunities and stability. It was a time of brain drain among highly skilled professionals and labor migrants. The State Statistics Service of Ukraine also reported that the total number of scientists and educators decreased by 74% from 1991 to 2012 (Lobova, 2022). Reasons for migration often included political instability and limited local employment prospects. The breakup of the Soviet Union resulted in economic problems and the restructuring of academic institutions, prompting many scientists to seek better opportunities abroad. During this stage, there was a noticeable trend of researchers immigrating to European countries and the USA (Lobova, 2022). Economic factors, access to better research facilities, and career prospects were key motivators for migration during this period.
2. The Second Stage, "Post-Revolutionary" (2013–2021): The period from 2013 to 2021 in Ukraine was marked by profound political and social transformations, including the Euromaidan Revolution, the annexation of Crimea by Russia, and the war in the country's eastern regions. These events significantly affected Ukraine's political, economic, and social realities. A new stage of migration trends among Ukrainian researchers emerged during this time. Opportunities for academic collaboration, research funding, and participation in international research projects drew scientists to European Union countries. Countries such as Germany, Canada, and Poland became increasingly popular destinations for Ukrainian scientists during this stage (State Statistics Service of Ukraine, 2013b). The desire to integrate into the European research community and gain access to advanced academic networks played a significant role in scientists' migration decisions.
3. The Third Stage, "Full-Scale War" (2022–Present): The full-scale war in Ukraine has had a profound impact on migration trends among researchers. The sense of personal danger and threats to the lives of individuals and their families, the occupation of territories, the destruction of infrastructure, and exacerbated socio-economic issues became the primary factors influencing the migration decisions of many scientists. EU countries continue to be the most common destinations for researchers (Mishchuk & Oliinyk, 2022). Researchers Mishchuk and Oliinyk (2022) note that every seventh migrant scientist from Ukraine does not intend to continue their professional activity, making them a lost intellectual capital for Ukraine.

These three stages reflect different characteristics, factors, and dynamics of migration processes in contemporary Ukraine (see Table 1).

Table 1. Three stages of researchers' migration processes in modern Ukraine (1991–2023).

Stage	Period	Main characteristics	Factors influencing researcher migration	Migration dynamics	Countries commonly chosen by ukrainian researchers in this period
1	"Post-Soviet Period" (1991–2012)	The dissolution of the USSR. Transition to a market economy and privatization of state-owned enterprises. Social challenges, including issues of unemployment and a high level of corruption.	Economic crisis, political instability, restructuring of academic institutions, deepening financial crisis in science due to "optimization" and the cessation of program-targeted funding by the government.	Significant initial outflow with subsequent weakening.	USA, Russia, Germany, Israel, Canada, Poland.
2	"Post-Revolutionary" (2013–2021)	Annexation of Crimea; war in eastern Ukraine; security threats; political instability.	Challenging economic conditions in science, low wages, unfavorable working conditions, and difficulties in professional self-realization.	Increasing emigration, departure of skilled professionals from Ukraine.	Germany, USA, Russia, Canada, Poland.
3	"Full-Scale War" (2022–Present)	Full-scale war; internally displaced persons.	Concerns for personal safety, resource constraints, and institutional instability.	Ongoing increase in outflow due to war.	Poland, Germany, and other European countries.

First stage of the "Post-Soviet period" (1991–2012).

The first stage of the migration of Ukrainian scientists can be associated with Ukraine gaining its independence. Since 1991, the Ukrainian population has been decreasing. At the beginning of 1991, there were nearly 52 million people living in Ukraine, by 2012, the total population had decreased to almost 45 million people (Minfin, 2022). Although the proportion of scientists in the overall migration flows from Ukraine during this period (1991–2012) is relatively small, the number of scientists in the country decreased critically. The number of scientists in Ukraine fell from 313,079 individuals in 1990 to 82,032 individuals in 2012 – a decrease of nearly four times (Svityashchuk & Stadny, 2014). The decrease in the number of scientists during this period is associated not only with migration but also with the prequalification of scientists. However, it is challenging to determine the exact number of scientists who migrated from Ukraine during this period, as Ukraine does not keep complete statistics regarding the emigration of scientists abroad.

The first wave of migration of Ukrainian scientists in the period from 1991 to 2012 was driven by several factors:

1. The dissolution of the Soviet Union and Ukraine's gaining independence in 1991 led to significant political changes in the country. The reforms accompanying this transition influenced the decisions of some scientists to migrate in search of better conditions for their work.
2. In the early years of Ukraine's independence, the country faced economic challenges, including hyperinflation and financial difficulties. These economic complications were one of the reasons that pushed some scientists to seek opportunities abroad.
3. After years of isolation under the Soviet regime, Ukraine began to engage more actively with international partners. This created new opportunities for scientists to acquire knowledge and collaborate with foreign colleagues.
4. Reforms in the education and science systems were one of the reasons that motivated some scientists to seek new opportunities abroad.
5. The lack of financial resources for scientific research and professional growth was a factor that influenced scientists' decisions to migrate to countries with greater financial opportunities.

Funding for science in Ukrainian universities during that period was meager and represented only 0.6% of the total expenditures on higher education. Clearly, under such conditions, Ukrainian universities were unable to finance quality scientific research that would be of interest to the global scientific community and contribute to the improvement of the quality of education. It is not surprising that the reduction in funding led to a decrease in the share of research and development in the GDP. If in 1996 this indicator was 1.36%, by 2012 it had already fallen to 0.8% (Nikolaevskii & Omelchenko, 2006).

Due to the economic crisis, the material base of science has significantly deteriorated, and there is a threateningly insufficient level of funding for science in Ukraine. Low wages for scientists and a low quality of life are often decisive factors in the brain drain phenomenon. In addition, the decision to migrate was influenced by the reduction in material and technical support for the scientific process. Ukrainian scientists were not provided with modern scientific equipment and literature. The average age of most measuring instruments exceeds 15 years, while in the West, such instruments are considered outdated after only five years of use (Oppeld & Shabardina, 2013).

Most often, Ukrainian scientists migrated to the United States during this period – a total of 420 individuals, including 343 PhD and 77 doctoral degree holders. Russia ranks second as a destination for Ukrainian scientists, with 388 individuals migrating, including 292 PhD and 96 doctors of science. Germany was hospitable to Ukrainian researchers, attracting a total of 251 individuals, including 208 PhD and 43 doctors of science. A significant number of Ukrainian researchers also immigrated to Israel (117), Canada (109), and Poland (52). In total, 311 scientists immigrated to other countries, including 252 PhD and 59 doctors of science (Khmelovska, 2013). While emigration to all of these countries began to decrease at the end of the 1990s, it remains consistently high in the United States, primarily due to numerous scholarship programs that attract young scientists to the USA (Svityashchuk & Stadny, 2014).

Over the first decade and a half of Ukraine's independence, 600 employees of the National Academy of Sciences of Ukraine, particularly to the United States, according to the U.S. National Science Foundation, 50,000 Ukrainian scientists emigrated (Naboka & Sherstiuk, 2009). Ukraine is an important intellectual donor for the United States, as approximately 30% of highly qualified migrants currently working in the fields of science and technology in the USA originate from Ukraine. Therefore, it is worth noting that in recent years, approximately 90% of scientific inventions developed in the United States were created by highly qualified migrants, including Ukrainians (Baranyk & Romanenko, 2014). This underscores the importance of further research and analysis of this issue for the development of both Ukraine and the countries that accept Ukrainian scientists.

According to State Statistics Service data, during this period (from 1990 to 2012), representatives of the physical-mathematical, technical, biological, and medical sciences emigrated most intensively (State Statistics Service of Ukraine, 2016).

In the second half of 2011, a group of researchers, with financial support from the World Bank, conducted a large-scale sociological study to determine the nature of migration from Ukraine: "brain drain" or "brain gain." A total of 6,676 individuals from 5,985 households in 63 cities in Ukraine were surveyed. The data showed that 42.8% of migrants living abroad at the time of the survey had higher education, 1.4% were PhDs, and 0.3% doctors of science. Although the share of researchers in the overall migration flow from Ukraine is relatively small, the number of scientists in Ukraine has significantly decreased (Svityashchuk & Stadny, 2014). The substantial reduction in the number of scientists in Ukraine is also related to the transformation processes taking place in the country. Transformation, including political and economic changes, has affected the working conditions of scientists, access to resources, research funding, and the overall scientific climate in the country.

The survey conducted among scientists and educators in 2012 revealed that the main reasons for choosing destination countries during this period were better employment opportunities and income, the presence of relatives and friends, knowledge of the state language, and the geographical and cultural proximity of the destination country (Kupets, 2013).

The second stage, the "post-revolutionary" stage (2013–2021).

The second stage of migration from Ukraine, referred to as the "post-revolutionary" phase, covers the period from 2013 to 2021 and is characterized by significant events. The start of this period was marked by the Maidan and the events of the Revolution of Dignity (2013–2014), when thousands of Ukrainians took to the streets of Kyiv and other cities, demanding democratic reforms and fighting against corruption. These events led to a change in government and opened a new chapter in Ukraine's history. Russian aggression and the annexation of Crimea, as well as the 2014 conflict in eastern Ukraine, resulted in profound changes in the country. Thousands of people became internally displaced, seeking safety in other regions of Ukraine and abroad.

The second wave of migration of Ukrainian scientists, the "post-revolutionary" period covering 2013 to 2021, was driven by several factors:

1. The onset of this period was defined by the Revolution of Dignity, leading to a change in the political landscape in Ukraine and causing instability in the country's political and economic climate.
2. Russian aggression and the conflict in eastern Ukraine brought about significant societal changes, forcing many residents of the eastern regions to seek safety elsewhere in Ukraine or even beyond its borders.
3. The government of Ukraine has initiated a wide range of reforms aimed at combating corruption, improving democratic institutions, and creating a more favorable business environment. However, these reforms were often accompanied by challenging economic difficulties that affected the citizens' quality of life.
4. Complications for scientists and educators. The government was working to improve conditions for scientists and educators, but numerous challenges remained, leading many to continue their migration abroad.

A noticeable decrease in Ukraine's population was observed from 2014 to 2015, dropping from 45.4 million to 42.9 million individuals, with a continuous decline in subsequent years. This was due to the annexation of Crimea (2.3 million residents in 2014) and the war in the Donbas region (over 200,000 refugees and over 10,000 deceased citizens) (Kulu, Christison, Liu, & Mikolai, 2023). During this period, a significant influx of Ukrainians to EU countries was observed, facilitated by the introduction of visa-free travel in 2017. In 2020, Lapshyna (2022) reported that 601.2 thousand Ukrainians became the largest national group in the EU. This migration to the EU can be explained by various factors, including economic opportunities, seeking refuge, and the desire for better living conditions.

Official statistics show a significant decrease in the number of organizations engaged in scientific research and development in Ukraine during this period, as well as a corresponding reduction in the number of working scientists. If, in the initial stage (early 1990s), the country had 1,344 organizations employing 313,079 scientists, by 2015, these figures had decreased to 978 organizations and 63,864 scientists (State Statistics Service of Ukraine, 2016). At this time, the number of scientists per thousand inhabitants in Ukraine became one of the lowest in Europe (Shtyfurko, 2018).

The ongoing decrease in science funding, which in 2016 constituted only 0.48% of the GDP, drove Ukrainian scientists towards even more active migration. According to data from the State Statistics Service, just in 2014, 42 PhDs and 7 doctors of science moved to other countries (State Statistics Service of Ukraine, 2013a).

Ukraine faced a significant drain of scientific personnel; only in 2015, the National Academy of Sciences saw 2,730 scientists leave, including 95 doctors of science and 511 PhDs. One of the primary reasons was the low salaries and limited material-technical facilities (Five ways to escape from Ukraine, 2016). However, these figures are just the tip of the iceberg. Determining the number of scientists who ceased their scientific activities and emigrated is challenging. After 2015, the State Statistics Service ceased tracking migrating scientists from Ukraine (Erman, 2018).

During this stage, scientists chose migration due to low pay, excessive bureaucracy, low scientific prestige, a lack of research funding, and political instability (Rasulova, 2021). There were valid reasons for this – research conducted in 2017 among NASU scientists showed that over 52% were low-income, and factors influencing scientists' migration from Ukraine at that time included low salaries and minimal science funding (around 90%), adverse work conditions (around 60%), and professional fulfillment challenges (around 20–30%) (Zhabin, Kazmina, & Vasyliuk, 2018).

Despite the fact that the list of countries where Ukrainian scientists emigrated remained largely unchanged after 2013, including the USA, Russia, and Germany, there was an expansion in the geography of migration for Ukrainian scientists. Canada and Poland joined this group of countries (State Statistics Service of Ukraine, 2013b).

The third wave, the "full-scale war" (2022 – present).

Due to Russia's aggression, a significant number of Ukrainian scientists were forced to leave their scientific positions. Some decided to join the defense forces, while many others opted to migrate abroad, contributing to approximately six million documented departures from the country. Although it's challenging to establish precise figures amid the ongoing conflict, reports from the Council of Young Scientists under the Ministry of Education and Science of Ukraine as of April 4, 2022, indicated that between four and six thousand scientists left Ukraine due to the invasion. Recent estimates suggest this figure might reach 22,000, which accounts for approximately a quarter of the country's researchers (The future of science in Ukraine, 2022). The forced displacement and emigration of Ukrainian scientists have devastatingly impacted the scientific community and the research landscape of the country. The loss of such a significant number of talented individuals jeopardizes the continuity and development of scientific activities in Ukraine.

The third wave of migration of Ukrainian scientists from 2022 to the present was driven by several factors:

1. Military conflict and heightened political tension in Ukraine, particularly events related to the war, the occupation of parts of the territory, and losses among the population, have created feelings of danger and threat.

2. The economic situation in Ukraine has reduced funding for science and education, leading to constraints in the development of scientific institutions and the field in general.
3. Decreased opportunities for professional growth and development for scientists, and limited access to modern technologies and equipment.
4. Increased immigration policies in host countries actively seek highly qualified scientists, making their territories more attractive for Ukrainian researchers.
5. The expansion of professional networks among Ukrainian scientists abroad contributes to increased migration opportunities.

The highest risks of non-return are typical for, on the one hand, the most vulnerable groups who might expect to receive support as refugees in EU countries, and on the other hand, the most active and qualified individuals capable of quickly finding employment and adapting to new conditions (Libanova, Pozniak, & Tsymbal, 2022). Unfortunately, there are no precise statistics on the proportion of researchers in these specific migrant groups, as such data may depend on various factors, including the individual circumstances of each migrant. Researchers with higher education, candidates, or doctoral degrees may belong to both the group of active and qualified individuals who can quickly find work in other countries and the group of individuals who might expect support or refuge in complex circumstances.

A study conducted among Ukrainian scientists in April–May 2022 revealed that the financial situation worsened for 84% of academic and scientific staff compared to pre-war times. This study also showed that Ukrainian scholars more often chose Germany (26.8%) and Poland (25.1%) for migration during the full-scale war (Lutsenko et al., 2023). The third wave of migration of scientists from Ukraine is characterized by greater geographical diversity among European host countries and an increase in the number of Ukrainian scientists choosing different directions for migration.

Based on semi-structured interviews conducted by the author of this article with Ukrainian scientists who migrated from Ukraine during the war in September 2023, researchers considered several key aspects when choosing their country of residence, including the availability of job opportunities, the possibility of obtaining grants and internships for Ukrainian scientists, personal interest, the attractiveness of the chosen country for living, the influence of recommendations from friends and relatives who already lived in that country, as well as the possibility of receiving social benefits from the country. The selected countries in this case were EU member states.

The research conducted by Suchikova (2023) reveals the impact of the war on the productivity and research outcomes of Ukrainian scientists. The conclusions indicate that the location of researchers significantly influences scientific effectiveness. Additionally, 33.8% of respondents reported that they couldn't continue their research at all. These findings underscore the destructive nature of the war against the scientific community in Ukraine. The displacement of scientists from their initial research environments and the challenges associated with relocating to new places are hindering their productivity and ability to engage in scientific activities.

Fiialka (2022) investigates the effect of Russian military aggression on the scientific activities and interests of Ukrainian researchers. The results emphasize the significant impact of the war on the scientific landscape in Ukraine. According to survey data, 15.5% of respondents had stopped their scientific work due to the conflict. Moreover, half of these individuals expressed the intention not to return to scientific work in the future. These results point to the deep despair and disillusionment experienced by Ukrainian researchers due to the ongoing aggression. Challenges linked to the war, such as resource constraints, institutional instability, and concerns about personal safety, contributed to a decline in scientific activity.

The presence of numerous international grants allowing scientists to work abroad plays a significant role in facilitating the migration of Ukrainian researchers. Although determining the exact number of scientists who have secured positions abroad is challenging, there are projects that exemplify such opportunities. For instance, the Research Center for the History of Transformations – RECET (https://www.recet.at/) offers scholarships to Ukrainian scientists under the "Ukraine and the Transformation of Eastern Europe" program. Claude Bernard Lyon 1 University (https://www.univ-lyon1.fr/en) offers employment opportunities for Ukrainian researchers, their families, and doctoral students under the PAUSE program. This program is an initiative of the French Ministry of Higher Education, Research, and Innovation aimed at providing financial support to Ukrainian scientists facing complex circumstances due to the war with the Russian Federation. Moreover, the University of Duisburg-Essen (https://www.uni-due.de/en/) offers positions for Ukrainian researchers in the fields of organic chemistry, supramolecular chemistry, and organocatalysis.

Various countries have their own unique approaches to attracting Ukrainian scientists. Canada implements the "Express Entry for Skilled Workers" program (https://schindlervisa.ca/uk/immigration/express-entry/), which streamlines immigration for skilled professionals, including scientists. Canadian universities and research centers actively provide scholarships and grants for international researchers. Recognizing the destructive impact of Russian aggression on Ukrainian scientific, innovative, and intellectual potential, the Prime Minister of Canada announced the creation of the Canada-Ukraine Science Partnership, which plans to invite up to 20 scientists from Ukraine to work and live in Canada (Prime Minister of Canada Justin Trudeau, 2022).

Germany has launched the "EU Blue Card" program (https://www.recht.bund.de/bgbl/1/2023/217/VO.html), offering European Union citizens and those from other countries the opportunity to work as scientists and researchers. It's essential to note that Germany currently employs 800,000 scientists, and this number is steadily increasing. One in every ten scientists in the country is a foreign specialist, and this trend is growing. The majority of foreign scientists in Germany are content with their work and life in the country. With additional state funding, particularly for a series of elite universities, Germany's higher education institutions have become even more attractive to international scholars (Kokh & Holovko, 2013). The German Academic Exchange Service (DAAD) predicts that German universities will eventually host around 100,000 students and researchers from

Ukraine. In order to expand its support program, the DAAD has appealed to the German government to allocate 80 million euros annually (Moroz, 2022). Considering the forecasts about demographic developments in Germany, it is evident that in the future, Germany will need even more scientists from abroad to reduce the shortage of skilled professionals (Kokh & Holovko, 2013).

The United States of America (USA) offers numerous programs for scientists, including the "H-1B" for skilled professionals and the "O-1" for outstanding individuals (https://dream-visa.com/visa/viza-talantiv-o-v-ssha/). Renowned universities like the Massachusetts Institute of Technology (MIT) and Stanford University attract researchers from around the world.

Israel also offers the "Blue Card" initiative, simplifying the process of obtaining a work visa for scientists and specialists in the fields of technology and science. Israel is known for its high share of research and development in its gross domestic product (GDP). As of September 2021, this share was around 4.5% of the GDP (Science and Technology, 2023). Regarding Ukrainian scientists, they might be interested in working in Israel due to the opportunity to gain new experiences, establish international contacts, improve their financial status, and realize their scientific ambitions.

The outflow of scientists from Ukraine has a negative impact on the development of the research and development sector, the country's competitiveness on the global stage, and could limit opportunities for the development of innovative technologies and scientific achievements in the future.

Conclusions.

In summary, the intensification of migration processes in Ukraine is a relevant subject for scientific research. However, some important aspects, such as the factors influencing scientists' decisions regarding migration and their choice of destination country, require further research. This issue requires attention both theoretically and practically. This article analyzes the impact of various factors on the migration decisions of Ukrainian scientists from Ukraine during three main periods: the post-Soviet era, the post-revolutionary period, and the period of full-scale war. The research considers various aspects, including economic, sociocultural, scientific, and individual factors influencing migration decisions. The analysis reveals that each of these stages had its peculiarities and determining factors that influenced the decisions of scientists. In the first stage (1991–2012), after Ukraine gained independence, the main motivators were economic factors and the search for stability. During this stage, scientists chose destination countries such as the USA, Russia, Germany, Israel, Canada, and Poland. In the second stage (2013–2021), after the Revolution of Dignity and the events associated with the annexation of Crimea, scientists more frequently selected Germany, Canada, and Poland as migration destinations for academic collaboration and financial support for research. In the third stage (2022– to-date), during the full-scale war, the primary factors were the sense of danger and the reluctance to continue professional activities in Ukraine. During this stage, the geography of migration for Ukrainian scientists significantly expanded, with the primary migration destinations being EU countries. It is noted that many scientists are leaving Ukraine during the war and do not intend to return, resulting in a loss of intellectual potential for the country. Further research opportunities lie in examining the historical roots of migration among Ukrainian scientists and understanding how events and reforms in Ukraine and the world have influenced the dynamics of migration processes.

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References

Baranyk, Z., & Romanenko, I. (2014). Intelektualna mihgatsiya yak ob`yekt statystychnnoho doslidzhenya [Migration as an object of statistical analysis]. *Efektyvna ekonomika – Effective Economy*, (6). Retrieved from http://www.economy.nayka.com.ua/?op=1&z=3096 [in Ukrainian].

Erman, G. (2018, October 23). Osobysta yevrointehratsiya: yak "vtikayutʹ mizky" z Ukrayiny i chy mozhna yikh povernuty [Personal European integration: how "brain drain" from Ukraine and whether it is possible to return them]. *BBC News Ukraine*. Retrieved from https://www.bbc.com/ukrainian/features-45890286 [in Ukrainian].

Fiialka, S. (2022). Assessment of war effects on the publishing activity and scientific interests of Ukrainian scholars. *Knowledge and Performance Management, 6*(1), 27–37. https://doi.org/10.21511/kpm.06(1).2022.03.

Harashchenko, N., Hladchenko, L., Korytnikova, N., Lutsenko, A., Moskotina, R., & Pravdyva, O. (2022). "Ukrainian Researchers in Times of War" results of survey. *UAScience.Reload*. Retrieved from https://www.uascience-reload.org/wp-content/uploads/2022/07/UAS.R-Presentation-Results-English-June-2022.pdf.

Khmelovska, O. (2013, April 29). Naybilʹshe ukrayinsʹkykh vchenykh vyyikhalo do SShA, Rosiyi i Nimechchyny [Most Ukrainian scientists went to the USA, Russia and Germany]. *The Ukrainian Week*. Retrieved from https://tyzhden.ua/najbilshe-ukrainskykh-vchenykh-vyikhalo-do-ssha-rosii-i-nimechchyny/ [in Ukrainian].

Kokh, M., & Holovko, A. (2013, April 12). Ray dlya naukovtsiv [A paradise for scientists]. *Deutsche Welle*. Retrieved from https://www.dw.com/uk/іноземці-охоче-обирають-німеччину-для-наукової-діяльності/a-16740514 [in Ukrainian].

Kulu, H., Christison, S., Liu, C., & Mikolai, J. (2023). The war, refugees, and the future of Ukraine's population. *Population, Space and Place*, *29*(4), e2656. https://doi.org/10.1002/psp.2656.

Kupets, O. (2013). Mizhnarodna mobilʹnistʹ ukrayinsʹkykh pedahohiv i naukovtsiv [International mobility of Ukrainian teaching and research professionals]. *International Labor Organization, Technical Support Group on Decent Work* *and ILO Bureau for Central and Eastern Europe.* Budapest: ILO. Retrieved from https://www.ilo.org/wcmsp5/groups/public/---europe/---ro-geneva/---sro-budapest/documents/publication/wcms_244739.pdf [in Ukrainian].

Lapshyna, I. (2022, July 08). Ukraine – emigration and displacement in past. *Bundeszentrale für politische Bildung.* Retrieved from https://www.bpb.de/themen/migration-integration/laenderprofile/english-version-country-profiles/510002/ukraine-emigration-and-displacement-in-past-and-present/

Libanova, E. M., Pozniak, O. V., & Tsymbal, O. I. (2022). Masshtaby ta naslidky vymushenoi mihratsii naselennia Ukrainy vnaslidok zbroinoi ahresii Rosiiskoi Federatsii [Scale and consequences of forced migration of the population of Ukraine as a result of armed aggression of the Russian Federation]. *Demohrafiia ta sotsialna ekonomika – Demography and Social Economy*, *2*(48), 37–57. https://doi.org/10.15407/dse2022.02.037 [in Ukrainian].

Lobova, A. (2022). *Intelektual'na mihratsiya hromadyan Ukrayiny do SSHA [Intellectual migration of citizens of Ukraine to the USA]* (Bachelor's thesis). Retrieved from https://jarch.donnu.edu.ua/article/view/12704 [in Ukrainian].

Lutsenko, A., Harashchenko, N., Hladchenko, L., Korytnikova, N., Moskotina, R., & Pravdyva, O. (2023). The results of the survey on the needs of Ukrainian scientists (First wave report). *Max Planck Institute for Innovation & Competition Research Paper*, No. 23-03. Retrieved from https://ssrn.com/abstract=4335098.

Lytvynchuk, O. V., & Yurkivsky, O. Y. (2023). Mihratsiyni protsesy v Ukrayini: zahrozy v umovakh rosiys′ko-ukrayins′koyi viyny [Migration processes in Ukraine: threats in the conditions of the russian-ukrainian war]. *Ekonomika, upravlinnya ta administruvannya – Economics, Management and Administration*, (2(104), 71–78. https://doi.org/10.26642/ema-2023-2(104)-71-78 [in Ukrainian].

Minfin (2022). *Chysel'nist' naselennya Ukrayiny z 1990 po 2022 [The population of Ukraine from 1990 to 2022].* Retrieved from https://index.minfin.com.ua/ua/reference/people/ [in Ukrainian].

Mishchuk, H., & Oliinyk, O. (2022). Otsinka mihratsiynykh nastroyiv ta profesiynykh ustremlin′ naukovtsiv v umovakh viyny v Ukrayini [Assessment of migration attitudes and professional aspirations of scientists in the conditions of war in Ukraine]. *Sotsialna ekonomika – Social Economics*, (64), 5–12. https://doi.org/10.26565/2524-2547-2022-64-01 [in Ukrainian].

Moroz, Y. (2022, March 30). Yak u Nimechchyni dopomahayut′ studentam i naukovtsyam z Ukrayiny [How students and scientists from Ukraine are helped in Germany]. *Deutsche Welle.* Retrieved from https://www.dw.com/uk/yak-u-nimechchyni-dopomahaiut-studentam-i-naukovtsiam-z-ukrainy/a-61272871 [in Ukrainian].

Naboka, M., & Sherstiuk, N. (2009, October 13). Intelekt na eksport. Chomu ukrayins′ki naukovtsi mayut′ popyt u sviti, ale malo zatrebuvani na bat′kivshchyni? [Intelligence for export. Why do Ukrainian scientists want to drink from the world, but have little demand in Fatherlandism?]. *Radio Svoboda*. Retrieved from https://www.radiosvoboda.org/a/1850050.html [in Ukrainian].

Nauka i Tekhnolohiya [Science and Technology] (2023). *Embassy of Israel in Ukraine*. Retrieved from https://embassies.gov.il/kiev/AboutIsrael/ScienceTechnology/Pages/Science.aspx [in Ukrainian].

Nikolaevskii, V. M., & Omelchenko, V. V. (2006). Intelektual′na mihratsiya: prychyny, naslidky, vyklyky [Intellectual migration: causes, consequences, challenges]. *Visnyk KHNU im. V. N. Karazina. Sotsiolohichni doslidzhennya suchasnoho suspil'stva: metodolohiya, teoriya, metody – Bulletin of KhNU named after V. N. Karazina. Sociological research of modern society: methodology, theory, methods*, (723), 140–147 [in Ukrainian].

Oppeld, L., & Shabardina, A. (2013). Suchasni tendentsiyi mizhnarodnoyi intelektual`noyi mihratsiyi v umovakh yevrointehratsiyi [Modern trends of international intellectual migration in the conditions of European integration]. *Efektyvna ekonomika – Efficient economy*, (3). Retrieved from http://www.economy.nayka.com.ua/?op=1&z=1871 [in Ukrainian].

Organisation for Economic Co-operation and Development. (2022, November 04). *The future of science in Ukraine: Actions now will affect post-war recovery*. Retrieved from https://www.oecd.org/ukraine-hub/policy-responses/the-future-of-science-in-ukraine-afbd05df/.

Polishchuk, Ye. A., & Nagorna, O. V. (2021). Mihratsiya vchenykh u zrostanni potentsialu naukovo-osvitn′oho prostoru: uroky YES ta SShA [Migration of scientists in the growth of the potential of the scientific and educational space: Lessons from the EU and the USA]. *Visnyk SumDU. Ekonomichna seriya – Bulletin of Sumy State University. Economy series*, (1), 282–288. https://doi.org/10.21272/1817-9215.2021.1-31 [in Ukrainian].

Prime Minister of Canada Justin Trudeau. (2022, October 28). *Prime Minister announces new measures to support Ukraine*. Retrieved from https://www.pm.gc.ca/en/news/news-releases/2022/10/28/prime-minister-announces-new-measures-support-ukraine .

Rasulova, O. (2021, September 09). Chuzha nauka. Istoriyi vchenykh, shcho poyikhaly z Ukrayiny [Someone else's science. Stories of scientists who left Ukraine]. *LB.ua*. Retrieved from https://lb.ua/society/2021/09/09/493401_chuzha_nauka_istorii_vchenih_shcho.html [in Ukrainian].

Romanjuk, M. D., & Smutchak, Z. V. (2017). Mihratsiya naukovykh kadriv ta zakhody yiyi zmenshennya z metoyu zberezhennya intelektual′noho potentsialu Ukrayiny [Migration of scientific personnel and measures to reduce it in order to preserve the intellectual potential of Ukraine]. *Naukovi pratsi Kirovohrads'koho natsional'noho tekhnichnoho universytetu. Ekonomichni nauky – Science work of the Kirovohrad National Technical University. Economic sciences*, (31), 134–141. Retrieved from http://dspace.kntu.kr.ua/jspui/bitstream/123456789/6897/1/16.pdf [in Ukrainian].

Shtyfurko, T. (2018, May 21). Vidtik mizkiv za kordon: shcho mozhe zrobyty Ukrayina, poky ne pizno [Brain drain abroad: what Ukraine can do before it's too late. Public synergy]. *Civic Synergy Project*. Retrieved from https://www.civic-synergy.org.ua/articles-in-the-media/vidtik-mizkiv-za-kordon-shho-mozhe-zrobyty-ukrayina-poky-ne-pizno/ [in Ukrainian].

State Statistics Service of Ukraine. (2013a). *Fakhivtsi vyshchoyi kvalifikatsiyi v Ukrayini u 2013 rotsi: dopovid' [Specialists of higher qualification in Ukraine in 2013: report]*. Retrieved from https://ukrstat.gov.ua/ [in Ukrainian].

State Statistics Service of Ukraine. (2013b). *Naukova ta naukovo-tekhnichna diyal'nist' v Ukrayini u 2013 rotsi [Scientific and scientific-technical activity in Ukraine in 2013]*. Retrieved from https://ukrstat.gov.ua/ [in Ukrainian].

State Statistics Service of Ukraine. (2016). *Naukovi kadry ta kil'kist' orhanizatsiy [Scientific personnel and number of organizations]*. Retrieved from https://ukrstat.gov.ua/operativ/operativ2005/ni/ind_rik/ind_u/2002.html [in Ukrainian].

Suchikova, Y., Tsybuliak, N., Lopatina, H., Shevchenko, L., & Popov, A. I. (2023). Science in times of crisis: How does the war affect the efficiency of Ukrainian scientists? *Problems and Perspectives in Management*, *21*(1), 408–424. https://doi.org/10.21511/ppm.21(1).2023.35.

Svityashchuk, I., & Stadny, E. (2014). Akademichna mihratsiya [Academic migration]. *Cedos*. Retrieved from https://cedos.org.ua/system/attachments/files/000/000/050/original/AcademicMigration_CSR.pdf?1404815631 [in Ukrainian].

Typical Frankivsk. (2016). *P'yat' shlyakhiv vtechi z Ukrayiny [Five ways to escape from Ukraine]*. Retrieved from https://typical.if.ua/pyat-shlyahiv-vtechi-z-ukrajiny] [in Ukrainian].

Vavilova, I. B., Isakova, N. B., Oliynyk, M. V. , Sayenko, Yu. I. , & Troyan V. M. (2016). Intelektual'na emihratsiya ukrayins'kykh naukovtsiv na pochatku XXI st. [Intellectual emigration of Ukrainian scientists at the beginning of the 21st century]. *Nauka ta Innovatsiy – Science and Innovation*, *12*(6), 15–36. http://dx.doi.org/10.15407/scin12.06.015 [in Ukrainian].

Zhabin, S., Kazmina, O., & Vasyliuk, O. (2018). Mihratsiyni namiry molodykh uchenykh NAN Ukrayiny: za danymy sotsiolohichnoho opytuvannya 2017 [Migration intentions of young scientists of the National Academy of Sciences of Ukraine: according to the sociological survey of 2017]. *Commons*. Retrieved from https://commons.com.ua/uk/migracijni-namiri-molodih-uchenih/ [in Ukrainian].

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Довга дорога додому: тенденції міграції українських дослідників у сучасному світі (1991–2023 рр.)

Анотація. *У сучасному світі, який відзначається інтенсивними міграційними процесами, важливим об'єктом наукових досліджень є аналіз* *міграції українських науковців та їх вибору країни для переїзду, особливо в контексті останніх подій в Україні. У цьому дослідженні розглядаються тенденції міграції українських дослідників у різні історичні періоди від початку 1990-х років до сьогодення. Представлене дослідження ґрунтується на використанні аналізу наукової літератури для теоретичного уявлення та попередніх досліджень, використання статистичних даних із Державної служби статистики України, аналіз політичних, економічних і соціокультурних контекстів для розуміння факторів міграції, методи спостереження за реальними подіями та процесами, історичний аналіз для відстеження еволюції міграційних процесів. Було проаналізовано фактори, які впливають на рішення науковців щодо міграції та їхню мотивацію, а також країни призначення. У статті виділяються три ключові етапи міграції: пострадянський період (1991–2012 роки), постреволюційний період (2013–2021 роки) та період повномасштабної війни (2022 рік і до тепер). Перший етап, який охоплює 1991–2012 роки, характеризувався відтоком науковців в пошуках економічних можливостей та стабільності. Країнами призначення на цьому етапі стали США, Росія, Німеччина, Ізраїль, Канада, Польща. Другий етап, з 2013 по 2021 рік, відзначився глибокими соціальними та політичними трансформаціями в Україні, після Революції Гідності та анексії Криму Росією, науковці обирали Німеччину, Канаду та Польщу для академічного співробітництва та фінансової підтримки досліджень. Третій етап, який розпочався у 2022 році та триває до сьогодення, визначений повномасштабною війною в Україні. Науковці залишають країну через відчуття небезпеки та військовий конфлікт. Основними напрямками міграції є країни ЄС, які надають можливості для академічного співробітництва та безпеки. Перспективи подальших наукових досліджень вбачаються в аналізі історичних коренів міграції українських науковців, включаючи вплив подій і реформ в Україні та в світі на міграційні процеси.*

Ключові слова: *міграція; український дослідник; відтік мізків; наукова мобільність; вимушена міграція; біженці*

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Congresses of natural scientists and mathematicians in the “Bulletin of experimental physics and elementary mathematics” (1886–1917): Analysis of publications

Abstract. *The article presents the results of a study of publications in the “Bulletin of Experimental Physics and Elementary Mathematics”, about the organization, conduct and results of domestic and foreign congresses of mathematicians and natural scientists, published in Kyiv and Odesa during 1886–1917. The magazine was an unofficial periodical printed publication of the mathematical department of the Novorossiysk Society of Naturalists. The research was conducted with the aim of carrying out a meaningful and quantitative analysis of the texts of journal publications, which highlights the materials of such meetings of scientists and teachers. The authors used scientific methods for meaningful analysis of the research subject, and in the process of quantitative analysis – text quantification, collection of empirical data, their generalization and mathematical and statistical processing. As a result of the research of the magazine’s materials on congresses of mathematicians and natural researchers during the entire period of its publication, the authors came to the following* *conclusions. The magazine's materials on conventions and congresses for all the years of its publication accounted for slightly more than 4% of its total area. All National Congresses of Natural Scientists and Mathematicians, which met during the period of publication of the journal, were covered on its pages (this is almost 2/3 of the entire volume of information in the journal about such meetings of scientists and teachers). At the same time, the methods of presenting information and its volume differed significantly in different meetings, depending on the presence of motives of both members of the editorial board. The main motives for placing information were: a) the presence of a pedagogical component in the work of meetings; b) scientific (or pedagogical) significance of reports and meeting participants; c) availability of quality materials about meetings; d) availability of magazine space. International congresses were irregularly covered by the newspaper, the motives for placing information about such meetings in the magazine were similar. Starting in 1901, the editors of the Bulletin introduced the scheme developed during the previous years of the magazine's existence into the practice of presenting materials about scientific and pedagogical congresses: a) announcement of the event; b) publication of the regulation (statute, program) of the event; c) description of preparation for the event; d) overview of the features of the event; e) presentation of the texts of important speeches. Such a scheme of presentation of meetings was introduced for the first time in popular science and educational periodicals of the Russian Empire. The pedagogical component was the most important motive for both staffs of the Bulletin editorial board when deciding on the features and scope of coverage of materials on the work of domestic and foreign congresses. The materials of Bulletin (and other similar publications of that time) covering the work of domestic and foreign congresses of teachers and researchers of nature and mathematics, which reveal the content of the educational activities of famous scientists and teachers, are an important element of the source base of biographical studies, which conducted by historians of science.*

Keywords: *educational and scientific periodicals; history of meetings of scientists; teachers; substantive analysis; quantitative analysis*

Introduction.

Popular scientific and educational periodicals of the late 19th and early 20th centuries took the first steps in mass distribution in the society of that time. It was private publications that faced special difficulties in preparation, printing and distribution. Only a few of them, due to various organizational irregularities, lack of funds, censorship, weak public interest, were able to remain islands of enlightenment. Such a publication was the "Bulletin of Experimental Physics and Elementary Mathematics" (hereinafter referred to as the "Bulletin"), which was founded for young people with the aim of "knowing more than is determined by the official program" and for teachers of physics and elementary mathematics to "unite pedagogical forces" (Editorial, 1886). During the entire period of publication of the Bulletin, in addition to theoretical and practical and educational materials on elementary mathematics, natural science and experimental physics, articles on didactics and biographical studies, and the "Tasks" section, materials from the chronicle of scientific events in which domestic and foreign natural scientists and mathematicians participated were published here – congresses, scientific congresses and conferences, meetings of scientific societies and circles. The study of this direction of Bulletin's publications can reveal the peculiarities and results of the integration of efforts in the educational activities of natural science and mathematics of teachers and researchers of that period.

Literature Review.

Researches of the development of Bulletin as a popular science and educational publication, its influence on the formation of natural and mathematical knowledge among young people, the implementation of the function of educating teachers, as well as the study of the peculiarities of holding natural and mathematical congresses were carried out by various scientists. Among the variety of works, various reports, diaries of congresses, collections of speeches of participants of scientific and pedagogical meetings, we will single out the general characteristics of the content of the Bulletin during the entire period of its existence, which was created by S. A. Dahiya (Dahiya, 1956), software monographs by V. S. Savchuk (Savchuk, 1994), Yu. V. Pavlenko, S. P. Ruda, S. A. Khorosheva, Yu. O. Khramov (Pavlenko, Ruda, Khorosheva, & Khramov, 2001) and M. Yu. Karavanska (Karavanska, 2006). The authors also participated in the development of this issue. In work (Pasichnyk, Rizhniak, & Deforzh, 2022), the peculiarities of coverage of biographical materials about famous scientists and teachers in Bulletin were studied using descriptive and quantitative methods.

In this scientific investigation, we will use the listed developments and conduct an analysis of the publication in the Bulletin of the content of materials about domestic and foreign congresses of mathematicians and natural scientists.

Research Methods.

When organizing the research, the analysis of publication information and the synthesis of logical references and conclusions, as well as the generalization of the facts presented in the publications and the systematization of descriptions of scientific events were used for the meaningful analysis of its subject. Quantification of text, collection of empirical data, their generalization and mathematical and statistical processing were used in the process of quantitative analysis (Atteslander, 2003; Früh, 2003). At the stage of text quantification, the magazine issues were used as a unit of content, which were combined by the years of publication, and as a unit of account – the number of pages in a specific issue, on which the features of congresses of natural scientists and mathematicians were revealed (parts of the volume of pages were determined from the ratio of occupied space on the page).

Results.

Bulletin was one of the most authoritative journals among teachers and teachers of mathematics and physics in the late 19th and early 20th centuries, not only in the territory of modern Ukraine, but also in the territory of the entire Russian Empire. Since its foundation in 1886, the magazine was edited by *E. K. Shpachinskyi* (see (Pasichnyk, Rizhniak, & Deforzh, 2022) for more details on the features of the magazine's foundation). In 1891, the editorial office moved to Odesa, and the fate of the Bulletin was connected with the members of the mathematical department of the Novorossiysk Society of Naturalists and the teachers of the Novorossiysk (Odesa) University (Pasichnyk, Rizhniak, & Deforzh, 2022; Dahiya, 1956). Editing of the magazine after the retirement of *E. K. Shpachinskyi* since 1898 (after a short stay as the chief editor of Professor *V. Ya. Zimmerman*) and until the termination of its publication, private docent *V. F. Kagan*, and the publisher of the magazine during 1897–1917 (from No. 259) was *V. O. Gernet*. According to the changes in the editorship, historians divide the magazine's existence into two periods: 1886–1897 and 1898–1917 (Pasichnyk, Rizhniak, & Deforzh, 2022). Active contributors and members of the journal's informal editorial staff were scientists from Kyiv, Kharkiv and Odesa: *S. M. Bernshtein, E. L. Bunytskyi, V. F. Kagan, D. M. Syntsov, I. Yu. Tymchenko, I. V. Sleshinsky, S. O. Shatunovskyi, V. Ya. Zimmerman* and others.

During the years 1886–1917, the editorial office published 674 issues of the magazine in 627 books with a total volume of 16,066 units of area (further on in the text – u.a.). The materials of the chronicle of scientific events were published in 232 books of the journal and accounted for slightly more than 8% (1.286 u.a.) of its total volume. Materials on congresses of naturalists and mathematicians occupied more than half of the coverage of scientific events in the magazine (in 110 books, 685.9 u.a.). The general distribution of the volume of magazine materials with reports on congresses of teachers and scientists by year is shown in fig. 1 (note that the journal did not publish materials about the specified forums in 1887, 1891–1893, and 1906; in 1899, the journal was not published).

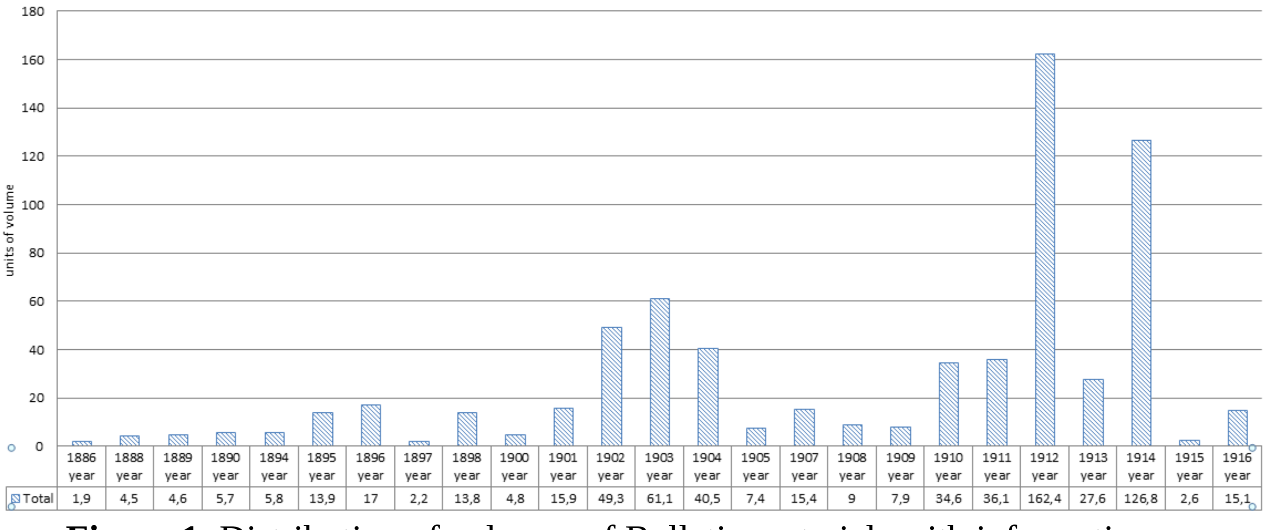

Figure 1. Distribution of volumes of Bulletin materials with information on congresses by year (Source: compiled by the authors).

The Bulletin covered the course of preparation and holding of congresses of teachers and scientists according to their organizational features:

A) national congresses of teachers of natural sciences and mathematics – the I Congress of 1889, the II Congress of 1895, the III Congress of 1903 of technical and professional education workers; The I Warsaw Congress of 1902 teachers of Physics and Mathematics, the III Kyiv Congress of 1903 teachers of natural sciences, the I Congress of 1911, the II Congress of 1913 teachers of Mathematics; The I Congress of 1913 of teachers of Physics, Chemistry and Cosmography.

B) national congresses of naturalists – the VIII Congress of 1890, the IX Congress of 1894, the X Congress of 1898, the XI Congress of 1901, the XII Congress of 1910, the XIII Congress of 1913 of naturalists (and doctors); I Mendeleev's in 1907, II Mendeleev's in 1911 Congresses on general and applied chemistry.

C) international congresses of naturalists – LIX (1886) and LXXXVI (1916) Congresses of the British Association, LVI (1886), LXII (1889), LXVII (1895), LXXIII (1901), LXXIV (1902), LXXV (1903) and LXXXII (1910) Congresses of German Naturalists and Physicians, I (1902) Northern Congress of Naturalists and Physicians in Helsingfors, V (1912) Congress of the Italian Aid Society progress of science, Congress (1913) of naturalists in Vienna, Neperivsky (1914) Congress in Edinburgh.

D) international congresses – I (1905) Congress on Radiology and Ionization, I (1900) Paris Physical Congress, I (1897), II (1900), III (1904), IV (1908), V (1912) Mathematical Congresses, the Berlin (1903) Congress of Applied Chemistry, I (1914) Congress of the Philosophy of Mathematics.

The general distribution of the volume of materials of the magazine with publications on the holding of congresses of teachers and scientists by organizational features is shown in fig. 2.

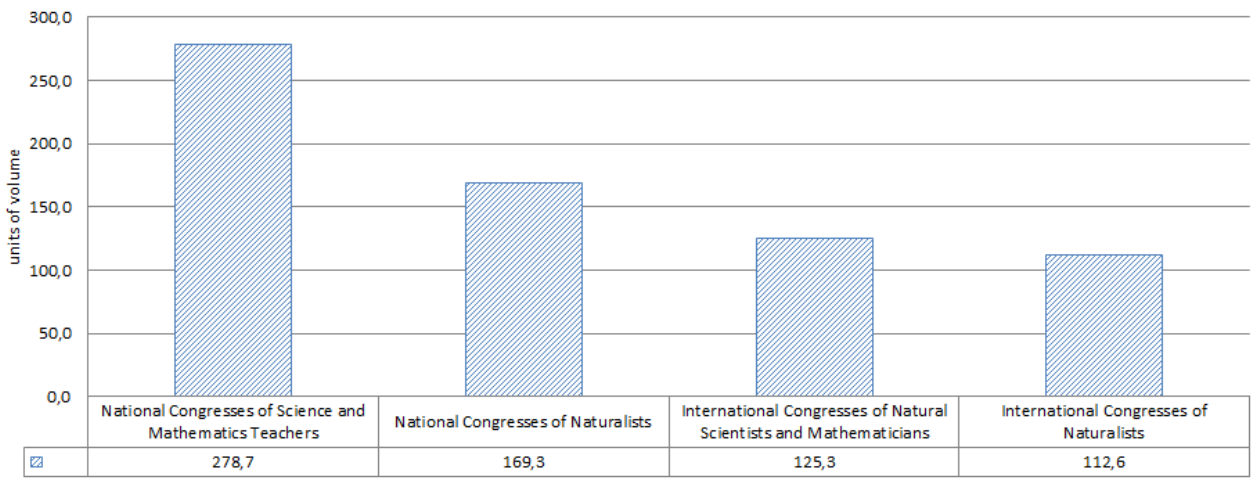

Figure 2. Distribution of volumes of Bulletin materials with information on Congresses by their organizational features (Source: compiled by the authors).

The features of submitting materials about the scientific events defined above are detailed as follows: information submission algorithm, volumes of information, contextual analysis of the disclosure of the content of the event. For compact placement of part of the information, we will use Table 1.

Table 1. Scheme of coverage by the Bulletin of Congresses of Domestic Natural Scientists and Mathematicians and Teachers (Source: compiled by the Author's).

Congress number, place of departure, date of departure	Announcement of intentions, No. (amount in u.a.)	Regulation (rules), No. (amount in u.a.)	Preparation materials, No. (volume in u.a.)	Results reports, No. (amount in u.a.)	Publication of marked presentations, No. (volume in u.a.)	The total volume of publications (u.a.)
1. Congresses of National Figures of Technical and Professional Education						
I, St.P., 26.12.1889–03.01.1890	№ 79 (0,8)	Is not published	Is not published	Is not published	Is not published	0,8
II, Moscow, 28.12.1895–05.01.1896	Is not published	Is not published	Is not published	№ 232, 233 (12,4)	Is not published	12,4
III, `St.P., 26.12.1903–06.01.1904	Is not published	№ 352 (2,7)	№ 352 (1,3)	Is not published	Is not published	4,0
2. Warsaw Congress of Physics and Mathematics Teachers						
I, Warsaw, 27.12.1902-30.12.1902	Is not published	Is not published	Is not published	№ 337 (6,4); 344, 345, 346 (19,7)	Is not published	26,1
3. Kyiv Congress of Eeachers of Tatural Iciences						
III, Kyiv , 28.12.1904-31.12.1904	№ 359 (0,8)	№ 359 (1,2)	№ 381 (2,7)	Is not published	№ 385 (7,4)	12,1
4. Congresses of National Teachers of Mathematics						
I, St.P., 27.12.1911-03.01.1912	№ 537 (1,9): 543 (0,4)	№ 538 (1,3)	№ 547 (5,0); 548 (0,8)	№ 553, 554, 556 (16,0)	№ 555 (5,0); 556 (7,3); 559 (7,2); 563-564 (9,4); 565 (9,6); 567 (5,8); 570, 572-573 (19,7)	89,4
II, Moscow, 27.12.1913-03.01.1914	№ 580 (1,0)	№ 580 (0,9)	№ 592 (1,4); 595 (5,4); 604 (0,3)	№ 601 (0,5); 602 (1,7); 603 (10,9)	Is not published	22,1
5. Congress of National Teachers of Physics, Chemistry and Cosmography						
I, St.P., 27.12.1913-06.01.1914	№ 576 (0,6)	№ 576 (0,5)	№ 594 (3,7)	№ 601 (0,6); 602, 605-606, 608, 609 (33,4)	№ 604, 605-606 (37,4); 607, 608 (29,1)	105,3
6. Congresses of National Natural Scientists and Doctors						
VIII, St.P., 28.12.1889-07.01.1890	№ 40 (4,5); № 65 (0,1); № 73 (0,5)	№ 69 (2,8)	Is not published	№ 85, 87, 89 (5,0), № 86 (0,7)	Is not published	13,6
IX, Moscow, 04.01.1894-11.01.1894	Is not published	Is not published	Is not published	№ 181 (0,2), № 183, 188 (5,6)	Is not published	5,8
X, Kyiv, 21.08.1898-30.08.1898	№ 244 (0,1); № 255 (2,2)	№ 244 (4,5); № 265 (1,5)	№ 265 (12,3)	Is not published	Is not published	20,6
XI, St.P., 20.12.1901-30.12.1901	№ 291 (0,6)	№ 291 (1,7); № 309 (1,9)	№ 310 (0,9)	№ 312 (2,0); № 313, 314 (12,5); № 315 (4,6); № 317 (7); № 319 (4,0)	№ 321 (14,4)	49,6
XII, Moscow, 28.12.1909-06.01.1910	№ 490 (1,2)	№ 499 (1,5)	№ 499 (0,5)	№ 503–504 (0,3); № 505, 506 (16,9); № 508 (13,9);	№ 515 (4)	38,1
XIII, Tiflis, 16.06.1913-24.06.1913	Is not published	Is not published	Is not published	№ 591 (6,2)	Is not published	6,2
7. Mendeleev Congresses of General and Applied Chemistry						
I, St.P., 20.12.1907-30.12-1907	№ 445 (0,4)	№ 445 (0,8)	Is not published	Is not published	Is not published	1,2
II, St.P., 21.12.1911-28.12-1911	№ 539 (0,8)	Is not published	№ 548 (0,7)	№ 553, 555 (23,3)	№ 576 (6,4)	34,2

The features of the Bulletin's coverage of the work of the first three congresses of national figures of technical and professional education were not characterized by regularity and systematicity (Table 1, Item 1). Before the I Congress, the editors published only an announcement in No. 79. Information about the II Congress was presented by the Bulletin in the form of "A Brief Report on the Activities of the 2nd Section (Section of Real Schools)..." (Mai, 1896a, 1896b) (author – from Odessa *K. V. Mai*). But qualitatively, the report did not look "short", as it contained a wide overview of both the reports at the general meetings of the congress and a detailed analysis of sectional reports on the problems of the structure of the educational process organization of real schools and the provision of textbooks and manuals, teacher training, curricula and programs individual disciplines, features of current and final assessment of students. The Bulletin's report on the III Congress was limited to the publication of the rules, program, features of the organization and composition of the congress committee. It should be noted that the congress was held in St. Petersburg, although according to the decisions of the II Congress it was supposed to meet in Odesa. And the congress committee consisted of St. Petersburg officials and functionaries and did not include a single representative from educators.

The I Warsaw Congress of Teachers of Physics and Mathematics was presented by Bulletin in the January issue of the magazine (Table 1, Item 2) with an editorial description of the work of the congress (with detailed hourly annotations of the speeches of the meeting participants), as well as the text of the speech by *E. K. Shpachinskyi* "On the question of the basic principles of electrostatics" (Shpachinskyi, 1903a, 1903b, 1903c).

Covering the work of the III Kyiv Congress of Natural Sciences Teachers was the magazine's first step towards using the future scheme of describing educational meetings. In the December issue of 1903 (Table 1, Item 3), the Bulletin contained an announcement about the congress and its program, later a description of the preparations for the congress and a questionnaire for the participants of the meeting (No. 381). And although a complete description of the events at the congress was not published, the speech (welcoming speech) of Professor *G. G. De-Metz* (De-Metz, 1905) basically made it possible to imagine the atmosphere among the participants and predict the main decisions of the congress. In his speech, the speaker mentioned the success of the first two Kyiv Congresses (1861 and 1862 – the first such Congresses in the History of the Russian Empire), which were inspired by Professor *K. F. Kessler*, and expressed confidence in the effectiveness of the hard work of the participants of the meeting regarding the creation of the secondary school reform project and the establishment of museums and natural science offices in schools.

The announcement of the First Congress of Mathematics Teachers appeared in Bulletin in May 1911 (No. 537, Table 1, Item 4). The draft regulation on the First Congress was already printed in the next issue of Bulletin. The project included the work of the congress in 8 directions: 1) psychological foundations of Mathematics learning, 2) content of the school Mathematics Course, 3) coordination of the high school Mathematics Program with the programs of higher and lower schools, 4) methodological issues, 5) textbooks and study materials, 6) historical and philosophical elements in the high school Mathematics Course, 7) aids for teaching Mathematics, 8) teachers' training. In the next message (October 1911, No. 547), the contents of the preparatory work were highlighted: the definition of the organizing committee (the organizing committee included professor *D. M. Syntsov* from Kharkiv, *S. I. Shokhor-Trotsky*, a native of Kamianets-Podilskyi, and private associate professor *V. F. Kagan*) and the bureau of the congress, planning of reports and those responsible for the preparation of short reviews on individual issues of the program, which would establish the main motives for the "leading" reports (*S. I. Shokhor-Trotsky* was chosen as the person responsible for direction "1", "2" – *V. F. Garnet* and *S. O. Shatunovskyi* from Odesa, "3" – *D. M. Syntsov*, "7" – *V. F. Kagan*, "8" – *S. I. Shokhor-Trotsky*). Already in the January-February issues of Bulletin for 1912, a general review of *V. F. Kagan* (Kagan, 1912a) features of the congress according to the following scheme: a) organization; b) reports; c) reviews of participants; d) congress resolutions; e) review of resolutions. The author of the post summarized that the following were the main pedagogical ideas of the congress: the movement towards reform according to Klein's program, the implementation of experimental psychology trends, the practical direction according to Perry's English program, the logical direction according to the program of Italian geometers. The next stage of coverage of the congress was the publication of the most significant speeches of the congress participants: professor *K. O. Posse* (Posse, 1912), professor *V. B. Struve* (Struve, 1912), private associate professor *S. M. Bernshtein* (Bernshtein, 1912), professor *D. M. Syntsov* (Syntsov, 1912a), private associate professor *V. F. Kagan* (Kagan, 1912a, 1912b, 1912c, 1912d, 1912e, 1912f), *I. I. Chistyakov* (Chistyakov, 1912). Thus, the scheme of the Bulletin's coverage of the work of the First Congress of Mathematics Teachers was as follows: a) announcement of intentions; b) publication of the regulation (or its draft) on the convention; c) description of preparations for the organization of the congress; d) an overview of the features of the congress; e) publication of significant and important speeches of the congress participants (Table 1, Item 4).

Information about the II Congress of Mathematics teachers appeared in Bulletin in February 1913 (Table 1, Item 4). In the same issue, the regulation on the II Congress was published. It should be noted that compared to the provisions of the First Congress, the number of directions has changed – there are 5: 1) scientific questions of elementary mathematics (new); 2) teaching methods in educational institutions of various types, mainly secondary schools; 3) teaching of mathematical sciences (new); 4) methods of teaching mathematics and related sciences, methods of testing students' knowledge (new); 5) training of mathematics teachers. In the summer issue of 1913, the course of preparatory work for the organization of the congress was covered. And the November 595th issue of Bulletin contained a thorough review by *V. Kagan* (Kagan, 1913) of the problems facing the organizing committee of the congress in the context of implementing the resolution of the previous congress and preparing for the effective holding of the current one. The coverage of the features of the II Congress began with a short message by *D. Syntsov* (No. 601), continued with the coverage of the resolution of the congress (No. 602), and ended with a detailed review by

D. Syntsov of the reports of the participants of the congress according to the scheme: a) general meetings; b) joint meetings; c) meeting of sections (Syntsov, 1914). It should be noted that the scheme of the Bulletin's coverage of the work of the II Congress of Mathematics teachers differed from the previous congress by the lack of publication of the most important reports.

The III Congress of Mathematics Teachers was to be held in Kharkiv in the winter of 1917–1918. Bulletin's editors applied the tried-and-tested scheme of its presentation. The first message about the congress was published in May 1915 (No. 630, volume – 2.3 u.a.), the second message (beginning of 1916, No. 652, volume – 2.5 u.a.) highlighted directions, around which discussions will be organized: a) general basics of the mathematics course in high school; b) the structure of various sections of mathematics in secondary school; c) teacher training; d) knowledge test; e) the issue of teaching mathematics. In the third message (November 1916, No. 669–670, volume – 1.4 u.a) the work plan of the organizing committee of the congress was published. However, due to the revolutionary events of 1917, the III Congress of Mathematics Teachers was not destined to take place.

The Bulletin's coverage of the First Congress of Physics, Chemistry, and Cosmography Teachers took place according to the scenario of the First Congress of Mathematics Teachers (Table 1, Item 5). In the December 1912 issue of the magazine, announcements about the congress, its provisions and program were presented. In the October issue of 1913, there was information about the preparatory work carried out by the organizing committee (premises for the congress, distribution of commissions, planning of reports; invitations to participate in the congress were sent, including, to scientists and teachers from Kyiv, Odesa, Kharkiv, Poltava and Mykolaiv). Immediately after the end of the congress, Bulletin published two articles by I. Haber in several issues – a short report on the congress (No. 601) and a detailed description of all events (Gaber, 1914a, 1914b, 1914c, 1914d). In the detailed description, the content of the work of the congress was disclosed in the following sections: a) history of the congress; b) organization of the convention; c) general meetings; d) questionnaire; e) practical classes of students; e) teacher training; g) exhibition and excursions; g) final meeting and resolution of the congress; h) conclusion and wishes adopted by the general meeting and individual sections. The Bulletin editorial office also published some significant and important speeches of the participants of the congress: academician *P. I. Walden* "On the influence of physics on the development of Chemistry" (Walden, 1914a, 1914b*)* and professor *M. O. Umov* "Evolution of physical sciences and their ideological significance" (Umov, 1914a, 1914b).

The VIII Congress of National Natural Scientists (and Doctors) in 1890 became the first congress for this direction, the progress of which was covered by the Bulletin (the first 7 Congresses took place before the journal was founded). The presentation of the congress was preceded by an article by the editor *E. K. Shpachinskyi* (Shpachinskyi, 1888), which contained a critical assessment of the previous congresses of naturalists (lack of discussion of real problems of educational activity, exclusion of the pedagogic section from the program at the III Congress in Kyiv in 1871, neglect of serious preparations for the congress). The author expressed hope that the

VIII Congress, which was planned to be held in Kharkov in 1888, would become an effective platform for discussing the problems of teaching natural sciences and mathematics. However, the author's hopes were not fulfilled – firstly, the congress was postponed to the end of 1889 – the beginning of 1890 to St. Petersburg; secondly, the pedagogical section was created only in 1913 at the XIII Congress in Tiflis. The Bulletin's reports on the progress of the VIII Congress were limited only to short abstracts of the speeches that were announced at the meetings of the physical section, and information about the implementation of the decisions of the congress regarding the printing of its materials and the establishment of the journal "Bulletin of Natural Science" (Table 1, Item 6).

Reports on the progress of the IX Congress of natural scientists (and doctors) contained an overview of the general meetings of the Congress (on January 4, 1894, professors of Biology *K. A. Timiryazev*, *I. M. Sechenov*, *S. M. Vinogradskyi* and professor-physicist *M. O. Umov*; on 11.01.1894, academician, physic-chemist *M. M. Beketov* spoke at the general meeting), as well as brief annotations of the speeches of the participants of the Congress at the combined sections – agronomy and agriculture; natural sciences, anthropology and ethnography; physics, mathematics and chemistry; agronomy, mineralogy and geology (Table 1, Item 6). By tradition, the Bulletin presented a detailed review of the meetings of the physics section. However, the last review of the Congress's events contained the post "to be continued", although the magazine did not provide a continuation of the review.

Bulletin did not publish reports on the X Congress, which was held in Kyiv on the basis of St. Volodymyr University (Table 1, Item 6). But we can infer the events at the Congress from the detailed schedule of meetings and all the events prepared by the organizers. Professor-chemist spoke at the opening of the Congress (1st meeting) *D. I. Mendeleev* and professor-mathematician *M. V. Bugayev*, and at the 2nd general meeting of the congress – the creator of aerodynamics *M. E. Zhukovsky* and academician *M. M. Beketov*. Congress participants had the opportunity to attend meetings of 14 sections – agronomy, anatomy, physiology, botany, statistics, hygiene, zoology, mathematics, mechanics, etc. A special feature of the congress was the continuation of the competition to receive professor Kessler's prizes for the best essay on the description of the Crimean Peninsula in a geographical, zoological, botanical and medical sense, as well as the announcement of a new competition (sponsored by the Odesa resident – Privy Councilor *H. G. Marazli*) to receive two prizes of 500 rubles per problem, one of which was related to the study of the geology of Odesa and its surroundings, and the second to the study of the impact of Zemstvo institutions on improving the health of the population of Odesa, Mykolaiv Oblast, Kherson Oblast, and Crimea.

The work progress of the XI Congress was covered in sufficient detail by the Bulletin (Table 1, Item 6). It was to cover the events of this congress in 1901 that the Bulletin used the following scheme for the first time in its entirety: *announcement – publication of the regulations (statute) – description of preparation – overview of the specifics of the event – publication of significant and important speeches.* Among the most important reports at the general meetings, we note the speeches of professor

M. O. Umov "Physico-mathematical model of living matter", *I. P. Pavlov* "On natural-scientific research of mental phenomena" and professor *D. O. Goldhammer* "Century of Physics" (exactly the text of the last speech was printed in No. 321 of Bulletin as one of the landmark reports at the Congress (Goldhammer, 1902). From the materials of the reports in the 13 sections of the congress, the Bulletin printed detailed reports on the work of 3: sections of pure mathematics and mechanics (Kagan, 1902a, 1902b) (author – private associate professor *V. Kagan*), physics section (Weinberg, 1902) (author – private associate professor *B. Weinberg*) and sections of meteorology and geophysics (Danilov, 1902) (author – private associate professor *L. Danilov*). In issue 319, the editors placed information on the creation and approval of the statute of the Association of Naturalists and Doctors at the XI Congress.

The XII Congress was covered by the Bulletin using the already "developed" editorial scheme (Table 1, Item 6). In the reports on the work of the Congress, the magazine limited itself to a detailed coverage of the work of two sections – the physics section (Iollos, 1910a, 1910b) and the pure mathematics section (Syntsov, 1910) (author professor *D. Syntsov*). As the most significant report, the Bulletin in No. 515 published the text of the speech of the historian of mathematics, private associate professor *V. Bobynin* "Natural and artificial ways of restoration of ancient proofs and conclusions by historians of mathematics" (*Bobynin*, 1910*)*. Another text of the speech (*S. Vinogradov* "Development of the concept of number in its history and at school") was printed by Bulletin as a report that was read at a meeting of the Moscow Mathematical Circle (Vinogradov, 1910*)*.

The magazine published a report on the work of only certain sections of the XIII Congress in Tiflis (Table 1, Item 6). The Bulletin noted the most important feature of the meeting, which was the appearance of a section on pedagogical issues. As a result, a detailed analysis of reports on Mathematics and the peculiarities of teaching Mathematics and natural sciences appeared in the journal (Syntsov, 1913) (author professor *D. Syntsov*). These two sections were the most numerous and active at the congress. The new section of pedagogic issues consisted of two departments – physical-mathematical and natural-historical. In addition, the organizers of the Congress organized, among other events, a pedagogical exhibition for the first time. At the Congress, it was decided to hold the next meeting in 1916 in Kharkiv. But the XIV Congress of Naturalists and Doctors was never destined to take place.

According to a similar scheme, Bulletin revealed the features of the II Mendeleev Congress on General and Applied Chemistry (Table 1, Item 7). About the First Congress, only the announcement, regulations and a short program of the meeting were published in the magazine. The report on the results of the work of the II Congress was presented in the article by *M. Jacobson* (Jacobson, 1912), in which the author provided a detailed overview of all events and a summary of the reports that were presented at the meeting. The author divided the analysis of the speeches of the speakers into two parts: reports revealing the results of fundamental research in the field of Physics and Chemistry; reports on teaching Physics and Chemistry. The author paid special attention to the popularity at that time of the question of the principle of relativity (namely, its different interpretations by *Albert Einstein* and *Walter Ritz*), which was presented in the speeches of *M. Umov*, *D. Goldhammer*, and *P. Ehrenfest*. Among the pedagogical reports, the author deleted the "Report of the Didactic Commission at the Physical Department of the Russian Physical and Chemical Society" (Editorial, 1912), which was later printed. The method of work of the didactic commission was the development of a Physics course program for secondary educational institutions. Another special feature of the presentation of material about the congress was the placement in the journal of the abstracts of the speeches of the authors of the pedagogical reports.

International congresses of scientists and teachers were covered by the Bulletin in the form of messages of various volumes or by placing the texts of the most significant reports on the pages of the magazine which are presented in Table 2.

In the Bulletin, attention is paid to only two Congresses of the British Association of Naturalists (Table 2, Item 1). The Congress of 1886 (No. 6 of the magazine) was marked by the speech of professor *George Darwin* (son of *Charles Robert Darwin*) with a report on the antiquity of the earth from an astronomical point of view, as well as the speeches of physicist professors *William Thomson* (*Baron Kelvin*) (theoretical studies of waves in water) and *A. U. Ricker* (study of interference of light in soap bubbles). And in number 652 of the magazine, the text of the speech at the 1916 Congress of the president of the British Astronomical Association, *F. W. Dyson* (Editorial, 1916) with a review of recent astronomical research.

More attention of the journal was paid to the congresses of German naturalists and doctors (Table 2, Item 2), which were held regularly. However, information about not all congresses was published in the Bulletin. A short report on the LIX Congress was already published in the 12th issue of the magazine with the aim of pointing out the main difference between the domestic and German congresses – the participants of the gatherings of German naturalists paid great attention to the discussion of the teaching of Natural Sciences and Mathematics (the authorship of the message probably belonged to *E. K. Shpachinskyi*). The report on the LXII Congress contained information on the radical reform of congresses in the context of streamlining their work in Germany. The author *Sh.* (probably *E. K. Shpachinskyi* again) expressed his regret that "our congresses ... will have to wait for such an arrangement for a long time". Information about the LXVII Congress compared to the previous ones more fully described the features of this meeting – the note contained short annotations of speeches in the sections of mathematics and astronomy, physics and meteorology, chemistry, instruments. The author *V.H.* of the material is noted as the most interesting reports those prepared by the German Association of Mathematicians and the German Botanical Society. A feature of informing about the events at the LXVII Congress was the publication of a translation of professor *Wilhelm Friedrich Ostwald's* speech "Victory over Scientific Materialism" (Editorial, 1895a; 1895b), which caused a wave of discussion and criticism from scientists – *Marie Alfred Cornu* and *Louis Marcel Brillouin* from France, *Ludwig Eduard Boltzmann* from Austria and *Max Karl Ernst Ludwig Planck* from Germany, *George Francis Fitzgerald* from Ireland (Fitzgerald, 1896).

Table 2. Scheme of coverage by the Bulletin of Congresses of International Natural Scientists and Mathematicians (Source: compiled by the authors).

Congress number, venue, date of event	Publication of information about the congress, No. (volume in u.a.)	Publication of landmark performances, No. (volume in u.a.)	The total volume of publications (u.a.)
1. Congresses of the British Association of Naturalists			
LVI, Birmingham , 1886	№ 6 (1,1)	Is not published	1,1
LXXXVI, Manchester, 1916	Is not published	№ 652 (11,2)	11,2
2. Congresses of German Naturalists and Doctors			
LXI, Berlin, September 1886	№ 12 (0,8)	Is not published	0,8
LXII, Heidelberg, September 1889	№ 79 (0,4)	Is not published	0,4
LXVII, Lubeck, 16.09.1895-21.09.1895	№ 221 (1,4)	№ 227, 228 (12,5)	13,9
LXXIII, Hamburg, 22.09.1901-28.09.1901	№ 303 (0,3), 309 (0,1)	Is not published	0,4
LXXIV, Carlsbad, 22.09.1902-27.09.1902	Is not published	№ 332 (3,1)	3,1
LXXV, Kassel, 21.09.1903-26.09.1903	№ 350 (0,6)	№ 356, 357 (13,6), 370, 371 (11,5)	25,7
LXXXII, Koenigsberg, September 1910	Is not published	№ 534, 535 (24,6)	24,6
3. International Mathematical Congresses			
I, Zurich, 1897	Is not published	Is not published	0
II, Paris, 06.08.1900-12.08.1900	№ 291 (7,4)	№ 342, 343 (13,7)	21,1
III, Heidelberg, 08.08.1904-15.08.1904	№ 349 (1,1); 368 (3,8); 378 (7,0)	Is not published	11,9
IV, Rome, 06.04.1908-11.04.1908	№ 436 (1,0); 454 (2,4); 460 (9,0)	№ 488 (4,4)	16,8
V, Cambridge, 21.08.1912-28.08.1912	№ 543 (0,6); 560 (1,7); 569 (8,0)	№ 570, 572–573 (19,2); 581 (6,0)	35,5
4. International Physics Congress			
I, Paris, 1900	№ 283 (4,8); 289 (0,9)	Is not published	5,7
5. Northern Congress of Naturalists and Doctors			
I, Helsingfors, 24.06.1902-29.06.1902	№ 326 (3,7)	Is not published	3,7
6. International Congress of Applied Chemistry			
V, Berlin, June 1903	№ 303 (0,1)	№ 365, 366 (15,5)	15,6
7. International Congress on Radiology and Ionization			
I, Liège, 12.09.1905-14.09.1905	№443–444 (10,8)	Is not published	10,8
8. Congress of the Italian Society for the Advancement of Science			
V, 1912	Is not published	№ 570, 571 (19,7)	19,7
9. Vienna Congress of Naturalists			
Vienna, 1913	Is not published	№ 596 (3,0)	3,0
10. Congress on the Philosophy of Mathematics			
I, Paris, 06.04.1914-08.04.1914	№ 617 (7,9)	Is not published	7,9
11. Neperiv Congress			
Edinburgh, 11.07.1914-14.07.1914	№ 614–615 (5,0)	Is not published	5,0

The LXXIV Congress of German nature researchers and doctors was presented by Bulletin with a report on a topical topic at the time – electrical engineer *O. V. Miller* presented the abstract “Forces of nature at the service of electrical engineering”. The next, LXXV Congress, in addition to a brief report on the main events and speakers of the general meeting, was presented by the Bulletin with two reports – professor *William Ramsay* (Scotland) “On the periodic system of elements” (Ramsay, 1903a; 1903b) and professor *Karl Schwarzschild* (Gottingen) “On celestial mechanics” (Schwarzschild, 1904a, 1904b). And the speech of professor Jonathan Zennek “Utilization of atmospheric nitrogen with the help of a voltaic arc” (Zennek, 1911) (the author substantiated the solution to the practical problem of artificial production of saltpeter) became, according to the editors of Bulletin, a landmark for the LXXXII Congress of German natural researchers and doctors.

The first unsuccessful attempt to organize the International Mathematical Congress was in 1893, when the World Exhibition was held in Chicago (Syntsov, 1900). Only in 1897 in Zurich, the world mathematical community, with the active support of the German Association of Mathematicians, managed to jointly hold the first ever official meeting. The Bulletin did not cover the work of this Congress – mentions of its holding are contained in regular reports of professor *D. Syntsov* on subsequent congresses (see, for example, (Syntsov, 1900, 1908, 1912b). And already the II (Paris) Congress, which was held during the World Exhibition of 1900, the magazine paid significant attention (Table 2, Item 3). Professor *D. Syntsov’s* extensive material with a professional analysis of the speeches of the participants and the main events of the Congress revealed in detail the course of his work. The author of the article noted two important events at the Congress: *David Hilbert’s* future famous speech “On the future problems of mathematics” (23 important mathematical problems were formulated here, the solution of which, according to *D. Hilbert*, would contribute to the further development of mathematics) and professor *Henri Poincare* “The role of Intuition and Logic in Mathematics” (Editorial, 1903a, 1903b) (it was this speech that was printed in the journal as the text of one of the important reports of the Congress). The III International Mathematical Congress was organized by the German Association of Mathematicians in Heidelberg and was announced in summer and winter issues of the Bulletin. A detailed report (Editorial, 1904a) on the progress of the Congress contained emphasis on 3 of its features: 1) celebration of the 100th anniversary of the German physicist *Moritz Hermann von Jacobi*; 2) speech by *David Hilbert* with the report “Mathematical problems”; 3) presentation of the first volume of the “Encyclopedia of Mathematical Sciences” by professor *Felix Christian Klein* of Göttingen University. We should note one more feature of the congress, namely the participation in its work of the Ukrainian mathematician *H. F. Voronoi*. The IV Congress took place in Rome and was organized by the Roman Academy of Sciences at the University of Rome. Information about the meeting was presented by the Bulletin editors in the form of an analytical report by professor *D. Syntsov* (Syntsov, 1908), as well as the text of professor *John Perry’s* speech “Teaching Mathematics in connection with the teaching of natural sciences” (Perry, 1909) (the speaker proposed to build the teaching of Mathematics according to the scheme – from natural models to

Mathematics; the discussion of the report by the participants of the meeting was reduced to remarks about the individuality of learning mathematical material and the existence of another path – from Mathematics to the application of mathematical models in natural science). Information about the V International Mathematical Congress in Cambridge is presented by the Bulletin in the most comprehensive manner compared to the previous ones. In the summer issue of 1911, the magazine published an announcement about the meeting, in the spring of 1912 – an expanded schedule of work, and in one of the first autumn issues – a detailed report by professor *D. M. Syntsov* on the content of the speeches, the decisions of the congress and all stages of the implementation of its program (Syntsov, 1912b). In addition, as the most significant speeches, the editors published the texts of the report of professor *D. E. Smith* to the International Commission for Teaching Mathematics "Intuition and Experience in Teaching Mathematics in Secondary School" (Smith, 1912a, 1912b) and the report of professor *A. N. Whitehead* "Fundamentals of mathematics and elementary education" (Whitehead, 1913). A feature of the congress was a speech by the president of the Cambridge Philosophical Society, *George Darwin*, dedicated to the memory of the mathematician *Henri Poincare*. In addition to this speech, the increased attention of the meeting participants was focused on the report of the German mathematician and physicist *Carl David Tolme Runge* "Mathematical education of physicists at the university" (the speaker's idea was that professors of Mathematics should understand the problems and needs of Physics).

The First International Physics Congress (as well as the II Mathematical Congress) was held as part of the World Exhibition in Paris in 1900. Immediately after the end of the meeting, the Bulletin presented information about the congress with an overview of the events of private docent *B. P. Weinberg* (Weinberg, 1900). The author gave short summaries of the speeches of the Congress participants and paid special attention to the significant events: 1) prompt publication of the Congress proceedings; 2) speech by *Henri Poincare* "Relation between experimental and mathematical physics"; 3) experiments with radioactive substances by *Antoine Henri Becquerel* and spouses *Marie Curie* and *Pierre Curie*. We note the participation in the work of the congress of professors *G. G. De-Metz* (Kyiv), *M. D. Pilchikova* and *F. N. Shvedova* (Odesa).

The First Northern Congress of Naturalists and Doctors in 1902, the progress of which was covered by Bulletin in a report with brief abstracts of the speeches and features of its organization, united scientists from Denmark, Norway, Sweden, Finland, and Russia (Table 2, Item 5). The Congress was hosted by Alexander University in Helsingfors.

The V Congress of Applied Chemistry, held in 1904 in Berlin (Table 2, Item 6), was documented in the Bulletin with the text of a speech by William Crookes, a member of the Royal Society of London, "The Modern Theory of Matter" (Editorial, 1904b; 1904c), in which the speaker attempted to substantiate the electronic nature of matter.

The course of work of the First International Congress on Radiology and Ionization (Table 2, Item 7) is covered by Bulletin in an abstract by *D. I. Fefelov*

(Fefelov, 1907), which contained an annotated overview of the congress participants' speeches. The author classified the materials of the congress according to the specialty of scientists who showed interest in radiology issues: Physics section – dielectric conductivity and electrification of bodies under the influence of radioactivity, X-rays, spectral analysis, nature of radioactivity; section of biology – methods of quantitative and qualitative metroradiography, use of X-rays and radium in medicine, the influence of radiation on the living organism. The author paid special attention to *Antoine Henri Becquerel's* speech "Analysis of radiation from radioactive bodies", in which the scientist revealed the content of the photographic method for studying radioactivity.

The V Congress of the Italian Society for the Advancement of Science was covered by the Bulletin (Table 2, Item 8) with the speech of *Augusto Righi*, professor of the universities of Palermo, Padua and Bologna, "New Physics" (Righi, 1912a, 1912b), in which the speaker provided an analysis of the latest achievements of physicists in the field electricity and magnetism. The main idea of the speech of the Italian physicist was the assumption that three substances – electricity, matter and ether – can provide a basis for the general study of the phenomena of the physical world.

The Congress of Natural Researchers held in Vienna in 1913 was marked by the publication of a summary of *Albert Einstein's* speech "On the Problems of Gravitation" (Einstein, 1913) in Bulletin (Table 2, Item 9). The preparation and announcement of the report by a prominent scientist took place precisely during the period of his mathematical formulation of the ideas of the theory of relativity.

Bulletin paid attention to two more congresses on its pages – the First Paris Congress on the Philosophy of Mathematics (Raymond, 1914) (Table 2, Item 10, the author is professor *A. Raymond*) and the Neperiv Congress (K. M., 1914) (Table 2, Item 11, the author is *K. M.*). In both cases, the materials take the form of a detailed annotated account of the main events at the meetings. The Congress on the Philosophy of Mathematics was held under the patronage of the French Philosophical Society. And the conference in Edinburgh was dedicated to the 300th anniversary of the publication of the first logarithmic tables – "Description of a wonderful table of logarithms" – by the Scottish mathematician *John Napier*.

Discussions.

We will note in the form of comments a few special opinions regarding the Bulletin's coverage of national and foreign congresses and congresses of naturalists and mathematicians.

First of all, we were interested in the time it took the Bulletin editorial office to develop a simple (at first glance) coverage scheme for the specified events. Considering that for the first time the magazine applied the full scheme (namely, starting with the announcement, publication of the regulations (statute), description of preparation, overview of the specifics of the conduct and ending with the presentation of the texts of important speeches) in 1901 when covering the work of the XI Congress of Naturalists and Doctors, then it is obvious there is a 15-year period from the moment the journal was founded, which the editors needed to develop the specified scheme. Moreover, this scheme was fully applied at the next, XII Congress of natural scientists and doctors, as well as at the first congresses of teachers of physics, chemistry and cosmography, and teachers of mathematics. An incomplete version of the scheme is used to cover the work of the III Kyiv Congress of Natural Sciences Teachers, the II Congress of Mathematics Teachers and the II Mendeleev Congress of General and Applied Chemistry. However, after 1901, the III Congress of national figures of technical and professional education, the I Warsaw Congress of teachers of physics and mathematics, the XIII Congress of natural scientists and doctors, and the I Mendeleev Congress of general and applied science were covered without the use of this applied chemistry This may indicate: a) the influence of subjective factors – lack of editorial interest in covering the event, reluctance of Odesa, Kharkiv or Kyiv congress delegates to share information with the editorial board, etc.; b) the influence of objective factors – lack of editorial access to congress materials, lack of space in the magazine, consequences of censorship. The study of this problem can be the topic of future studies. However, the analysis of the "editor's portfolio" of other contemporary publications on natural and mathematical topics leads to the conclusion that the described scheme was applied by the Bulletin for the first time for similar publications of the Russian Empire at the beginning of the 20th century.

Secondly, we analyzed the possible reasons for the presence (or absence) of publications about the work of conventions and congresses. Let's name, in our opinion, the main one. The fact is that both editorial staffs of the magazine positioned the publication as popular science and educational, which existed for mathematics lovers, teachers and students. And therefore, all such gatherings were covered in the magazine, taking into account the presence of an educational (methodical) section (section, direction) in their work schedule. This can be confirmed by the magazine's coverage of the VIII Congress of natural scientists and doctors in 1889, when on the eve of its holding *E. K. Shpachinskyi* in (Shpachinskyi, 1888) expressed the hope of resuming the work of the pedagogical section (as well as holding this Congress in Kharkiv). But the congress was not held in Kharkiv and without consideration of training issues at the relevant section. As a result, only short abstracts of the speeches of the participants of the meeting of the physical section of the congress were published in Bulletin. On the contrary, the journal materials of the XIII Congress of natural scientists and doctors in 1913 contained only information about the work of the mathematical section and the pedagogical section, which resumed its work at this congress. In addition, the reason for the coverage of events at separate congresses of German naturalists and doctors (for example, the LIX Congress of 1886) was the attention that German naturalists paid to the discussion of the issues of teaching natural sciences and mathematics. And when the Bulletin covered the work of five foreign mathematical congresses, the peculiarities of teaching mathematics in educational institutions of various levels were revealed both in the reports on the progress of the congresses (see (Editorial, 1904a; Syntsov, 1900, 1908, 1908)) and in the publication of the texts of the most important speeches in the opinion of the editors participants (Perry, 1909; Editorial, 1903a, 1903b; Smith, 1912; Whitehead, 1913).

Thirdly, the priorities of the Bulletin editorial office in covering the work of conventions and congresses can be determined by analyzing the volume of information presented (fig. 3).

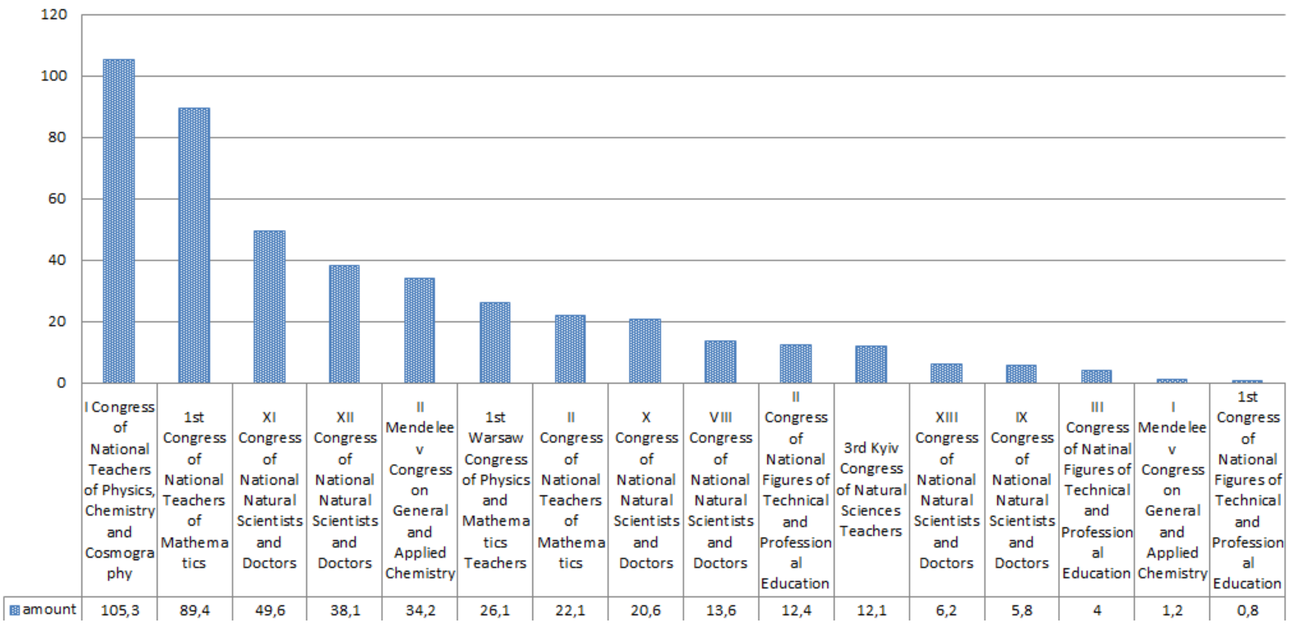

Figure 3. Volumes of submission of information about Congresses of National Teachers and Researchers of Natural Sciences and Mathematics(Source: compiled by the Author's).

The Bulletin paid the most attention to the coverage of the First Congress of Physics, Chemistry, and Cosmography Teachers and the First Congress of Mathematics Teachers from the point of view of the editor's use of the information presentation scheme and the largest volume allocated. The journal publications noted the active role of representatives of Kharkiv, Kyiv and Novorossiysk (Odesa) universities, as well as teachers from Kharkiv, Kyiv, Odesa, Mykolaiv, and Poltava in the work of both congresses. The broad format of the disclosure of the events of the XI and XII Congresses of natural scientists and doctors and the II Mendeleev Congress on general and applied chemistry can be understood based on the names of authoritative scientists and practitioners who participated in the meetings – *I. Pavlov*, *M. Umov*, *D. Goldhammer* and *P. Ehrenfest*.

The ratio of volumes of information about the work of foreign congresses is shown in fig. 4.

The broad representation of the work of mathematical congresses in the materials of the Bulletin can be explained by the readers' interest in the content of *David Hilbert's* report, in which the scientist formulated 23 important mathematical problems, the solution of which would contribute to the further development of mathematics; to the speeches of professor *Henri Poincare* (as an unqualified world authority among mathematicians and philosophers); to the presentation by *Felix Christian Klein*, professor of the University of Göttingen, of the features of the reform of mathematics education.

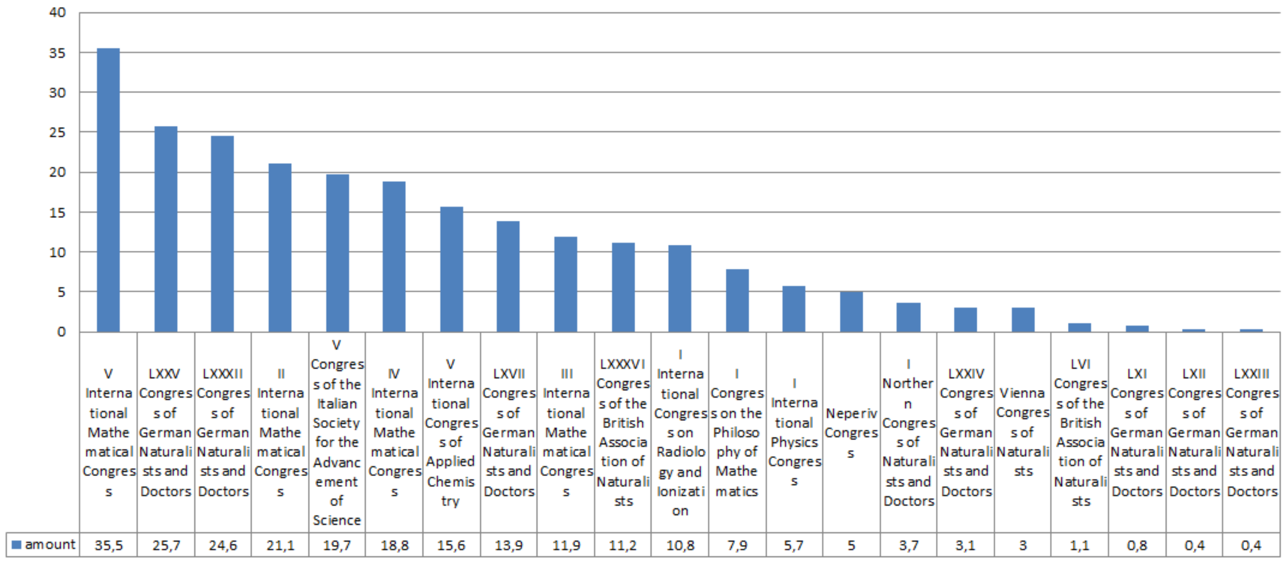

Figure 4. Volumes of submission of information about Foreign Congresses of Mathematicians and Natural Researchers (Source: compiled by the Author's).

Fourthly, the Bulletin's coverage of individual conventions and congresses was obviously also motivated by the presence of domestic and international celebrities among the participants. The names of *D. Mendeleev, H. Voronoi, I. Pavlov, M. Umov, D. Goldhammer, K. Timiryazev, I. Sechenov, M. Zhukovsky, M. Beketov*, and *P. Ehrenfest* at that time attracted the attention of the public, symbolizing advanced domestic science. Even greater attention of the educated public was focused on world scientific celebrities – *George Darwin* (son of *Charles Robert Darwin*), *William Thomson (Baron Kelvin), Ludwig Eduard Boltzmann, Max Karl Ernst Ludwig Planck, George Francis Fitzgerald, David Hilbert, Henri Poincare, Felix Christian Klein, Carl David Tolme Runge, Antoine Henri Becquerel, Marie Curie and Pierre Curie, Augusto Righi, Albert Einstein* – active participants in scientific meetings at that time. On the other hand, the materials of Bulletin about Congresses of Natural Scientists and Mathematicians described important pages of scientific biographies of prominent researchers and teachers. Moreover, these publications revealed the content of educational activities of scientists, which did not so often become a source for biographical materials. And that is why it is expedient for historians of science to consider such publications as an element of the source base of their own research.

Conclusions.

The study of Bulletin materials on the work of Domestic and Foreign Congresses of Natural Science and Mathematics Teachers and Researchers gives us the opportunity to formulate the following conclusions.

1. The journal's materials on congresses for all the years of its publication accounted for slightly more than 4% of its total area. During the more than 30 years of its publication, the magazine provided information on exclusively All National Congresses of Natural Scientists and Mathematicians that met during the specified period (this accounted for almost 2/3 of the magazine's total volume of information on

such gatherings of scientists and teachers). At the same time, the methods of presenting information and its volume differed significantly in different meetings, depending on the presence of motives of both members of the editorial board. And the editorship of *E. K. Shpachinskyi*, and the editorship of *V. F. Kagan* made decisions regarding the amount of placement of such materials based on: a) the presence of a pedagogical component in them; b) scientific (or pedagogical) significance of reports and meeting participants; c) availability of quality materials about meetings; d) availability of magazine space. In contrast to domestic international conventions and congresses, Bulletin covered them irregularly. However, the motives for posting information about foreign meetings in the magazine were the same as those listed above.

2. It took 15 years for the editors of the collection to work out and implement the scheme of presenting materials about scientific and pedagogical congresses into practice: a) announcement of the event; b) publication of the regulation (statute, program) of the event; c) description of preparation for the event; d) overview of the features of the event; e) presentation of the texts of important speeches. It was precisely the second (*V. F. Kagan*) editorial team that managed to do this. However, such a scheme of presentation of meetings was introduced for the first time in popular science and educational periodicals of the Russian Empire.

3. The educational (pedagogical, methodical) component was the most important motive for both members of the Bulletin editorial board when deciding on the features and scope of coverage of materials on the work of domestic and foreign congresses.

4. The materials of Bulletin (and other similar publications of that time) covering the work of domestic and foreign congresses of teachers and researchers of nature and mathematics, which covered the educational activities of famous scientists and teachers, are an important element of the source base of biographical studies, which conducted by historians of science.

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References

Atteslander, P. (2003). *Methoden der empirischen Sozialforschung* (10th edition). Berlin: De Gruyter Studienbuch [in German].

Bernshtein, S. *(*1912). Istoricheskiy obzor razvitiya ponyatiya o funktsii [Historical overview of the development of the concept of function]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (559), 177–184. Retrieved from https://www.vofem.ru/ru/articles/55901/ [in Russian].

Bobynin, V. V. (1910). Estestvennyie i iskusstvennyie puti vosstanovleniya istorikami matematiki drevnih dokazatelstv i vyivodov [Natural and artificial ways of restoration by historians of mathematics of ancient proofs and conclusions].

Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics, (515), 277–281. Retrieved from https://www.vofem.ru/ru/articles/51503/ [in Russian].

Chistyakov, I. I. (1912). K reforme prepodavaniya matematiki v sredney shkole. V. Elementyi teorii chisel v sredney shkole [To reform the teaching of mathematics in secondary school. V. Elements of number theory in secondary school]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (567), 80–86. Retrieved from https://www.vofem.ru/ru/articles/56703/ [in Russian].

Dahiya, S. A. (1956). "Zhurnal elementarnoj matematiki" ["Journal of Elementary Mathematics"]. *Istoriko-matematicheskie issledovaniya – Historical and mathematical research,* (9), 537–612. Retrieved from http://pyrkov-professor.ru/default.aspx?tabid=195&ArticleId=47 [in Russian].

Danilov, L. (1902). XI S'ezd Russkih Estestvoispyitateley i Vrachey. Sektsiya meteorologii i geofiziki [11th Congress of Russian Naturalists and Physicians. Section of Meteorology and Geophysics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (317), 97–103. Retrieved from https://www.vofem.ru/ru/articles/31701/ [in Russian].

De-Metz, G. G. (1905). Privetstvie 3-mu Kievskomu S'ezdu prepodavateley estestvennyih nauk, skazannoe Predsedatelem Rasporyaditelnogo Komiteta S'ezda prof. G. G. De-Mettsom [Greetings to the 3rd Kyiv Congress of Natural Sciences Teachers by the Chairman of the Administrative Committee of the Congress prof. G. G. De-Metz]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (385), 1–8. Retrieved from https://www.vofem.ru/ru/articles/38501/ [in Russian].

Einstein, A. (1913). K probleme tyagoteniya [To the problem of gravity]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (596), 218–221. Retrieved from https://www.vofem.ru/ru/articles/59604/ [in Russian].

Fefelov, D. I. (1907). Pervyiy mezhdunarodnyiy kongress po voprosam radiologii i ionizatsii [The First International Congress on Radiology and Ionization]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (443–444), 248–258. Retrieved from https://www.vofem.ru/ru/articles/44302/ [in Russian].

Fitzgerald, J. Fr. (1896). Energetika Ostvalda [Ostwald's energetics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (231), 57–62. Retrieved from https://www.vofem.ru/ru/articles/23101/ [in Russian].

Früh, W. (2003). *Inhaltsanalyse: Theorie und Praxis* 6th edition). Konstanz: UVK Verlag-Gesellschaft [in German].

Gaber, I. (1914a). Pervyiy Vserossiyskiy S'ezd prepodavateley fiziki, himii i kosmografii [First All-Russian Congress of Physics, Chemistry and

Cosmography Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (602), 38–49. Retrieved from https://www.vofem.ru/ru/articles/60204/ [in Russian].

Gaber, I. (1914b). Pervyiy Vserossiyskiy S'ezd prepodavateley fiziki, himii i kosmografii [First All-Russian Congress of Physics, Chemistry and Cosmography Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (605–606), 159–165. Retrieved from https://www.vofem.ru/ru/articles/60504/ [in Russian].

Gaber, I. (1914c). Pervyiy Vserossiyskiy S'ezd prepodavateley fiziki, himii i kosmografii [First All-Russian Congress of Physics, Chemistry and Cosmography Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (608), 233–238. Retrieved from https://www.vofem.ru/ru/articles/60803/ [in Russian].

Gaber, I. (1914d). Pervyiy Vserossiyskiy S'ezd prepodavateley fiziki, himii i kosmografii [First All-Russian Congress of Physics, Chemistry and Cosmography Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (609), 253–263. Retrieved from https://www.vofem.ru/ru/articles/60903/ [in Russian].

Goldhammer, D. O. (1902). XI S'ezd Russkih Estestvoispyitateley i Vrachey. Stoletie fiziki [11th Congress of Russian Naturalists and Physicians. A century of Physics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (321), 193–207. Retrieved from https://www.vofem.ru/ru/articles/32101/ [in Russian].

Iollos, A. (1910a). XII S'ezd Russkih Estestvoispyitateley i Vrachey. Sektsiya fiziki [12th Congress of Russian Naturalists and Physicians. Section of Physics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (505), 16–25. Retrieved from https://www.vofem.ru/ru/articles/50504/ [in Russian].

Iollos, A. (1910b). XII S'ezd Russkih Estestvoispyitateley i Vrachey. Sektsiya fiziki [12th Congress of Russian Naturalists and Physicians. Section of Physics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (506), 43–50. Retrieved from https://www.vofem.ru/ru/articles/50602/ [in Russian].

Jacobson, M. (1912a). II-oy Mendeleevskiy S'ezd [2nd Mendeleev Congress]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (553), 19–28. Retrieved from https://www.vofem.ru/ru/articles/55303/ [in Russian].

Jacobson, M. (1912b). II-oy Mendeleevskiy S'ezd [2nd Mendeleev Congress]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (555), 70–86. Retrieved from https://www.vofem.ru/ru/articles/55502/ [in Russian].

K. M. (1914). Chestvovanie pamyati Nepera v Edinburge *[*Commemoration of Naper in Edinburgh]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of*

Experimental Physics and Elementary Mathematics, (614–615), 50–54. Retrieved from https://www.vofem.ru/ru/articles/61403/ [in Russian].

Kagan, V. (1902a). XI S'ezd Russkih Estestvoispyitateley i Vrachey. Sektsiya chistoy matematiki i mehaniki [11th Congress of Russian Naturalists and Physicians. Section of Pure Mathematics and Mechanics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (313), 1–7. Retrieved from https://www.vofem.ru/ru/articles/31301/ [in Russian].

Kagan, V. (1902b). XI S'ezd Russkih Estestvoispyitateley i Vrachey. Sektsiya chistoy matematiki i mehaniki [11th Congress of Russian Naturalists and Physicians. Section of Pure Mathematics and Mechanics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (314), 25–30. Retrieved from https://www.vofem.ru/ru/articles/31401/ [in Russian].

Kagan, V. (1912a). K reforme prepodavaniya matematiki v sredney shkole. IV. Soobrazheniya otnositelno postanovki dela podgotovleniya uchiteley matematiki v srednih uchebnyih zavedeniyah [To Reform the Teaching of Mathematics in the Secondary School. IV. Considerations regarding the Preparation of Mathematics Teachers in Secondary Schools]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (565,) 2–11. Retrieved from https://www.vofem.ru/ru/articles/56502/ [in Russian].

Kagan, V. (1912b). O preobrazovanii mnogogrannikov [On the Transformation of Polyhedron]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (570), 145–151. Retrieved from https://www.vofem.ru/ru/articles/57001/ [in Russian].

Kagan, V. (1912c). O preobrazovanii mnogogrannikov [On the Transformation of Polyhedron]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (572–573), 219–231. Retrieved from https://www.vofem.ru/ru/articles/57202/ [in Russian].

Kagan, V. (1912d). Pervyiy Vserossiyskiy S'ezd prepodavateley matematiki [The First All-Russian Congress of Mathematics Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (553), 10–18. Retrieved from https://www.vofem.ru/ru/articles/55302/ [in Russian].

Kagan, V. (1912e). Pervyiy Vserossiyskiy S'ezd prepodavateley matematiki [The First All-Russian Congress of Mathematics Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (554), 49–54. Retrieved from https://www.vofem.ru/ru/articles/55403/ [in Russian].

Kagan, V. (1912f). Pervyiy Vserossiyskiy S'ezd prepodavateley matematiki [The First All-Russian Congress of Mathematics Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary*

Mathematics, (556), 121–122. Retrieved from https://www.vofem.ru/ru/articles/55605/ [in Russian].

Kagan, V. (1913). K predstoyaschemu II-mu Vserossiyskomu S'ezdu prepodavateley matematiki [To the upcoming 2nd All-Russian Congress of Mathematics Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (595), 187–192. Retrieved from https://www.vofem.ru/ru/articles/59502/ [in Russian].

Karavanska, M. Yu. (2006). *Pryrodnycho-naukovi zizdy v istorii ukrainskoi nauky (druha polovyna XIX – pochatok XX st.) [Natural and Scientific Congresses in the History of Ukrainian Science (second half of the 19th – beginning of the 20th century)]*. (Candidate's thesis). NAS of Ukraine, Kyiv [in Ukrainian].

Mai, K. B. (1896a). Kratkiy otchet o deyatelnosti 2-y sektsii (sektsii realnyih uchilisch) 2-go S'ezda Russkih Deyateley po Tehnicheskomu i Professionalnomu Obrazovaniyu v Moskve [Brief report on the activities of the 2nd section (section of real schools) of the 2nd Congress of Russian Workers on Technical and Professional Education in Moscow]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (232), 100–105. Retrieved from https://www.vofem.ru/ru/articles/23205/ [in Russian].

Mai, K. B. (1896b). Kratkiy otchet o deyatelnosti 2-y sektsii (sektsii realnyih uchilisch) 2-go S'ezda Russkih Deyateley po Tehnicheskomu i Professionalnomu Obrazovaniyu v Moskve [Brief report on the activities of the 2nd section (section of real schools) of the 2nd Congress of Russian Workers on Technical and Professional Education in Moscow]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (233), 129–136. Retrieved from https://www.vofem.ru/ru/articles/23303/ [in Russian].

Pasichnyk, N., Rizhniak, R., & Deforzh, H. (2022). Biographical materials of mathematicians and natural scientists in "Bulletin of Experimental Physics and Elementary Mathematics" (1886–1917): meaningful and content analysis. *History of Science and Technology*, *12*(2), 279–301. https://doi.org/10.32703/2415-7422-2022-12-2-279-301

Pavlenko, Yu. V., Ruda, S. P., Khorosheva, S. A., & Khramov, Yu. O. (2001). *Pryrodoznavstvo v Ukraini do pochatku XX st. v istorychnomu, kulturnomu ta osvitnomu kontekstakh [Natural science in Ukraine until the beginning of the 20th century. in historical, cultural and educational contexts]*. Kyiv: Akademperiodika [in Ukrainian].

Perry, J. (1909). Prepodavanie matematiki v svyazi s prepodavaniem estestvennyih nauk [Teaching Mathematics in Connection with the Teaching of Natural Sciences]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (488), 179–183. Retrieved from https://www.vofem.ru/ru/articles/48803/ [in Russian].

Posse, K. (1912). O soglasovanii programm v sredney i vyisshey shkolah [About the Coordination of Programs in Secondary and Higher Schools]. *Vestnik opyitnoy* *fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (555), 65–69. Retrieved from https://www.vofem.ru/ru/articles/55501/ [in Russian].

Ramsay, W. (1903a). Neskolko soobrazheniy o periodicheskom zakone elementov. Doklad, prochitannyiy na 75 s'ezde nemetskih estestvoispyitateley i vrachey v Kassele (v sentyabre 1903 goda) [Some thoughts about the periodic law of elements. Report at the 75th Congress of German Naturalists and Doctors in Kassel (in September 1903)]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (356), 169–178. Retrieved from https://www.vofem.ru/ru/articles/35601/ [in Russian].

Ramsay, W. (1903b). Neskolko soobrazheniy o periodicheskom zakone elementov. Doklad, prochitannyiy na 75 s'ezde nemetskih estestvoispyitateley i vrachey v Kassele (v sentyabre 1903 goda) [Some thoughts about the periodic law of elements. Report at the 75th Congress of German Naturalists and Doctors in Kassel (in September 1903)]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (357), 206–210. Retrieved from https://www.vofem.ru/ru/articles/35703/ [in Russian].

Raymond, A. (1914). Pervyiy Kongress po filosofii matematiki [First Congress on the Philosophy of Mathematics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (617), 110–118. Retrieved from https://www.vofem.ru/ru/articles/61703/ [in Russian].

Redakciya [Editorial] (1886). *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (1), 1–4. Retrieved from https://www.vofem.ru/ru/articles/101/ [in Russian].

Redakciya [Editorial] (1895a). Rech V. Ostvalda «Pobeda nad nauchnyim materializmom» (perevod s nemetskogo) [V. Ostwald's speech "Victory over Scientific Materialism" (translated from German)]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (227), 249–254. Retrieved from https://www.vofem.ru/ru/articles/22703/ [in Russian].

Redakciya [Editorial] (1895b). Rech V. Ostvalda «Pobeda nad nauchnyim materializmom» (perevod s nemetskogo) [V. Ostwald's speech "Victory over Scientific Materialism" (translated from German)]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (228), 272–279. Retrieved from https://www.vofem.ru/ru/articles/22802/ [in Russian].

Redakciya [Editorial] (1903a). Rol intuitsii i logiki v matematike. Rech, proiznesennaya professorom Anri Puankare v Parizhe, na vtorom mezhdunarodnom kongresse matematikov [The role of Intuition and Logic in Mathematics. Speech delivered by Professor Henri Poincare in Paris at the Second International Congress of Mathematicians]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (342), 121–127. Retrieved from https://www.vofem.ru/ru/articles/34201/ [in Russian].

Redakciya [Editorial] (1903b). Rol intuitsii i logiki v matematike. Rech, proiznesennaya professorom Anri Puankare v Parizhe, na vtorom mezhdunarodnom kongresse matematikov [The role of Intuition and Logic in Mathematics. Speech delivered by Professor Henri Poincare in Paris at the Second International Congress of Mathematicians]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (343), 145–151. Retrieved from https://www.vofem.ru/ru/articles/34301/ [in Russian].

Redakciya [Editorial] (1904a). III Mezhdunarodnyiy matematicheskiy kongress [3rd International Mathematical Congress]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (378), 121–127. Retrieved from https://www.vofem.ru/ru/articles/37801/ [in Russian].

Redakciya [Editorial] (1904b). Sovremennyie teorii materii. Osuschestvlenie mechtyi. Doklad sera V. Kruksa na kongresse prikladnoy himii v Berline 5-go iyunya 1903 goda [Modern theories of matter. A dream come true. Sir W. Crookes' speech at the Congress of Applied Chemistry in Berlin on June 5, 1903]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (365), 97–104. Retrieved from https://www.vofem.ru/ru/articles/36501/ [in Russian].

Redakciya [Editorial] (1904c). Sovremennyie teorii materii. Osuschestvlenie mechtyi. Doklad sera V. Kruksa na kongresse prikladnoy himii v Berline 5-go iyunya 1903 goda [Modern theories of matter. A dream come true. Sir W. Crookes' speech at the Congress of Applied Chemistry in Berlin on June 5, 1903]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (366), 121–128. Retrieved from https://www.vofem.ru/ru/articles/36601/ [in Russian].

Redakciya [Editorial] (1912). K reforme prepodavaniya matematiki i fiziki v sredney shkole. V. Doklad Didakticheskoy Komissii pri Russkom Fiziko-Himicheskom Obschestve [To Reform the Teaching of Mathematics and Physics in Secondary School. V. Report of the Didactic Commission at the Russian Physical and Chemical Society]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (576), 324–331. Retrieved from https://www.vofem.ru/ru/articles/57602/ [in Russian].

Redakciya [Editorial] (1916). S'ezd Britanskoy assotsiatsii v Manchestere [Congress of the British Association in Manchester]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (652), 77–88. Retrieved from https://www.vofem.ru/ru/articles/65202/ [in Russian].

Righi, A. (1912a). Novaya fizika [New Physics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (570), 151–159. Retrieved from https://www.vofem.ru/ru/articles/57002/ [in Russian].

Righi, A. (1912b). Novaya fizika [New Physics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (571), 189–200. Retrieved from https://www.vofem.ru/ru/articles/57102/ [in Russian].

Savchuk, V. S. (1994). *Pryrodnycho-naukovi tovarystva Pivdnia Rosiiskoi imperii: druha polovyna XIX – pochatok XX st. [Natural and scientific societies of the South of the Russian Empire: the second half of the 19th – the beginning of the 20th century]*. Dnipropetrovsk: DSU Publishing House [in Ukrainian].

Schwarzschild, K. (1904a). O nebesnoy mehanike [About Heavenly Mechanics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (370), 220–226. Retrieved from https://www.vofem.ru/ru/articles/37002/ [in Russian].

Schwarzschild, K. (1904b). O nebesnoy mehanike [About Heavenly Mechanics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (371), 241–246. Retrieved from https://www.vofem.ru/ru/articles/37101/ [in Russian].

Shpachinskyi, E. K. (1888). Po povodu predpolagaemogo s'ezda estestvoispyitateley v g. Harkove [Regarding the Alleged Congress of Naturalists in Kharkiv]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (40), 73–77. Retrieved from https://www.vofem.ru/ru/articles/4001/ [in Russian].

Shpachinskyi, E. K. (1903a). Iz metodologii fiziki. K voprosu ob osnovnyih printsipah elektrostatiki [From the Methodology of Physics. To the question about the basic principles of electrostatics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (344), 176–182. Retrieved from https://www.vofem.ru/ru/articles/34402/ [in Russian].

Shpachinskyi, E. K. (1903b). Iz metodologii fiziki. K voprosu ob osnovnyih printsipah elektrostatiki [From the Methodology of Physics. To the question about the basic principles of electrostatics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (345), 205–212. Retrieved from https://www.vofem.ru/ru/articles/34402/ [in Russian].

Shpachinskyi, E. K. (1903c). Iz metodologii fiziki. K voprosu ob osnovnyih printsipah elektrostatiki [From the Methodology of Physics. To the question about the basic principles of electrostatics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (346), 217–223. Retrieved from https://www.vofem.ru/ru/articles/34601/ [in Russian].

Smith, D. E. (1912a). Mezhdunarodnaya komissiya po prepodavaniyu matematiki. Intuitsiya i opyit pri prepodavanii matematiki v sredney shkole. Doklad, predstavlennyiy Mezhdunarodnoy komissii po prepodavaniyu matematiki na V-m Mezhdunarodnom matematicheskom kongresse v Kembridzhe. [International commission for teaching mathematics. Intuition and experience in teaching mathematics in secondary school. Report presented by the International Commission on Teaching Mathematics at the 5th International Mathematical Congress in Cambridge]. *Vestnik opyitnoy fiziki i elementarnoy matematiki –*

Bulletin of Experimental Physics and Elementary Mathematics, (570), 167–172. Retrieved from https://www.vofem.ru/ru/articles/57004/ [in Russian].

Smith, D. E. (1912b). Mezhdunarodnaya komissiya po prepodavaniyu matematiki. Intuitsiya i opyit pri prepodavanii matematiki v sredney shkole. Doklad, predstavlennyiy Mezhdunarodnoy komissii po prepodavaniyu matematiki na V-m Mezhdunarodnom matematicheskom kongresse v Kembridzhe. [International commission for teaching mathematics. Intuition and experience in teaching mathematics in secondary school. Report presented by the International Commission on Teaching Mathematics at the 5th International Mathematical Congress in Cambridge]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (572–573), 232–244. Retrieved from https://www.vofem.ru/ru/articles/57203/ [in Russian].

Struve, V. B. (1912). K voprosu o soglasovanii programm v sredney i vyisshey shkole [To the question of coordination of programs in Secondary and Higher Schools]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (556), 101–108. Retrieved from https://www.vofem.ru/ru/articles/55603/ [in Russian].

Syntsov, D. (1900). Vtoroy mezhdunarodnyiy matematicheskiy kongress [Second International Mathematical Congress]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (291), 49–56. Retrieved from https://www.vofem.ru/ru/articles/29101/ [in Russian].

Syntsov, D. (1908). Chetvertyiy Mezhdunarodnyiy matematicheskiy kongress v Rime 6–11 apr. [The Fourth International Mathematical Congress in Rome April 6–11]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics*, (460), 73–81. Retrieved from https://www.vofem.ru/ru/articles/46001/ [in Russian].

Syntsov, D. (1910). XII S'ezd Russkih Estestvoispyitateley i Vrachey. Sektsiya chistoy matematiki [12th Congress of Russian Naturalists and Physicians. Section of pure mathematics]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (508), 93–107. Retrieved from https://www.vofem.ru/ru/articles/50803/ [in Russian].

Syntsov, D. (1912a). K reforme prepodavaniya matematiki v sredney shkole. III. O soglasovanii programm sredney i vyisshey shkolyi [To reform the teaching of Mathematics in the Secondary School. III. On coordination of secondary and higher school programs]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (563–564), 289–298. Retrieved from https://www.vofem.ru/ru/articles/56301/ [in Russian].

Syntsov, D. (1912b). V-y Mezhdunarodnyiy matematicheskiy s'ezd v Kembridzhe [The 5th International Mathematical Congress in Cambridge]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (569), 129–136. Retrieved from https://www.vofem.ru/ru/articles/56905/ [in Russian].

Syntsov, D. (1913). XIII S'ezd russkih estestvoispyitateley i vrachey v Tiflise [13th Congress of Russian Naturalists and Doctors in Tiflis]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (591), 75–81. Retrieved from https://www.vofem.ru/ru/articles/59102/ [in Russian].

Syntsov, D. (1914). II-oy Vserossiyskiy S'ezd prepodavateley matematiki [2nd All-Russian Congress of Mathematics Teachers]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (603), 72–82. Retrieved from https://www.vofem.ru/ru/articles/60304/ [in Russian].

Umov, M. (1914a). Evolyutsiya fizicheskih nauk i ee ideynoe znachenie [Evolution of Physical Sciences and its Ideological Significance]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (607), 177–191. Retrieved from https://www.vofem.ru/ru/articles/60701/ [in Russian].

Umov, M. (1914b). Evolyutsiya fizicheskih nauk i ee ideynoe znachenie [Evolution of Physical Sciences and its Ideological Significance]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (608), 209–223. Retrieved from https://www.vofem.ru/ru/articles/60801/ [in Russian].

Vinogradov, S. (1910). Razvitie ponyatiya o chisle v ego istorii i v shkole *[The development of the concept of number in ego history and at school]. Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (509), 113–121. Retrieved from https://www.vofem.ru/ru/articles/50901/ [in Russian].

Walden, P. I. (1914a). O vliyanii fiziki na razvitie himii *[On the influence of Physics on the development of Chemistry]. Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (604), 90–102. Retrieved from https://www.vofem.ru/ru/articles/60402/ [in Russian].

Walden, P. I. (1914b). O vliyanii fiziki na razvitie himii *[On the influence of Physics on the development of Chemistry]. Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (605–606), 128–152. Retrieved from https://www.vofem.ru/ru/articles/60502/ [in Russian].

Weinberg, B. P. (1900). Vpechatlenie ot pervogo Mezhdunarodnogo fizicheskogo kongressa [Impression from the First International Physics Congress]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (283), 145–150. Retrieved from https://www.vofem.ru/ru/articles/28302/ [in Russian].

Weinberg, B. P. (1902*).* XI S'ezd Russkih Estestvoispyitateley i Vrachey. Sektsiya fiziki *[11th Congress of Russian Naturalists and Physicians. Section of Physics]. Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental*

Physics and Elementary Mathematics, (315), 49–53. Retrieved from https://www.vofem.ru/ru/articles/31501/ [in Russian].

Whitehead, A. N. (1913). Osnovyi matematiki i elementarnoe obrazovanie [Fundamentals of Mathematics and Elementary Education]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (581), 132–137. Retrieved from https://www.vofem.ru/ru/articles/58102/ [in Russian].

Zennek, J. (1911). Utilizatsiya atmosfernogo azota pri pomoschi voltovoy dugi [Utilization of atmospheric nitrogen with the help of a voltaic arc]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (534), 137–153. Retrieved from https://www.vofem.ru/ru/articles/53401/ [in Russian].

Zennek, J. (1911). Utilizatsiya atmosfernogo azota pri pomoschi voltovoy dugi [Utilization of atmospheric nitrogen with the help of a voltaic arc]. *Vestnik opyitnoy fiziki i elementarnoy matematiki – Bulletin of Experimental Physics and Elementary Mathematics,* (535), 169–177. Retrieved from https://www.vofem.ru/ru/articles/53501/ [in Russian].

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З'їзди й конгреси природознавців і математиків у "Віснику дослідної фізики та елементарної математики" (1886–1917 рр.): Аналіз публікацій

Анотація. *У статті представлені результати дослідження публікацій у «Віснику дослідної фізики та елементарної математики», що видавався в Києві та Одесі протягом 1886–1917 рр., про організацію, проведення та результати вітчизняних і закордонних з'їздів та конгресів математиків і природознавців. Журнал був неофіційним періодичним друкованим виданням математичного відділення Новоросійського товариства дослідників природи. Дослідження проведене з метою здійснення змістовного та кількісного аналізу текстів публікацій журналу, в яких висвітлюються матеріали таких зібрань науковців та педагогів. Авторами для змістовного аналізу предмету дослідження використовувалися наукові методи, а в процесі кількісного аналізу – квантифікація тексту, збирання емпіричних даних, їхнє узагальнення та* *математико-статистична обробка. У результаті проведеного дослідження матеріалів журналу про з'їзди та конгреси математиків і дослідників природи протягом всього періоду його видання автори дійшли таких висновків. Матеріали журналу про з'їзди та конгреси за всі роки його видання становили трохи більше 4 % його загальної площі. Усі вітчизняні з'їзди природодослідників та математиків, які збиралися протягом періоду видання журналу, були висвітлені на його сторінках (це майже 2/3 від всього обсягу інформації журналу про такі зібрання науковців та педагогів). При цьому способи подання інформації та її обсяг суттєво відрізнялися за різними зібраннями в залежності від наявності мотивів обох складів редакційної колегії. Мотивами розміщення інформації були: а) наявність в роботі зібрань педагогічної складової; б) наукова (або педагогічна) значимість доповідей та учасників зібрання; в) доступність якісних матеріалів про зібрання; г) наявність журнального місця. Міжнародні з'їзди та конгреси висвітлювалися вісником нерегулярно, мотиви для розміщення в журналі інформації про такі зібрання були аналогічними. Починаючи з 1901 року редакція збірника впровадила до практики представлення матеріалів про наукові й педагогічні з'їзди та конгреси відпрацьовану протягом попередніх років існування журналу схему: а) оголошення про подію; б) публікація положення (статуту, програми) події; в) опис підготовки до події; г) огляду особливостей проведення події; д) презентація текстів важливих виступів. Така схема презентації зібрань була запроваджена вперше в науково-популярній та навчальній періодиці Російської імперії. Педагогічна складова була найбільш вагомим мотивом для обох складів редакції Вісника при прийнятті рішення щодо особливостей та обсягів висвітлення матеріалів про роботу вітчизняних та закордонних з'їздів і конгресів. Матеріали Вісника (та інших подібних видань того часу) про висвітлення роботи вітчизняних та закордонних з'їздів і конгресів викладачів та дослідників природи і математики, у яких розкривається зміст просвітницької діяльності знаменитих вчених та педагогів, є важливим елементом джерельної бази біографічних досліджень, які проводять історики науки.*

Ключові слова: *навчально-наукова періодика; історія зібрань науковців; викладачі; змістовний аналіз; кількісний аналіз*

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Evolution of techno-nationalism: The role of the space factor

Abstract. *Technological changes of the last four decades (1980s – 2020s) encourage scientists of various fields to assess the impact of technologies on the transformation of the system of international relations and national strategies of states. In particular, the main focus of many studies is devoted to the system of relations between countries with conflicting technological interests. Therefore, in the presented article, let's focus on the theoretical understanding of the evolution of the concept of techno-nationalism. Consideration of techno-nationalism through the prism of space policy, in particular US-China relations, is appropriate from the point of view of determining the relevance of the obtained research results. In view of this, the research methodology is based on an interdisciplinary approach, which made it possible to look at the problem through the perspective of historical, economic, political sciences and the theory of international relations. The analysis of publications on this issue shows that the development of techno-nationalism took place in a dichotomous relationship with techno-globalism. In the context of the end of the Cold War, techno-nationalism was used to refer to the protectionist policies of states that opposed the free exchange of technology. Space technology, which is an indicator of leadership and has a dual purpose, has become an important element of interstate communication in the post-bipolar era. Changes in this system led to an attempt by the United States to balance the interests of national security and commercial benefits from the use of space. However, these efforts led to a further strengthening of the export control regime from the second half of the 1990s. These restrictions were mainly based on concerns about the transfer of space technology to China, which was showing signs of military modernization. Thus, the leadership challenge facing the US and China in the space industry continued to strengthen the techno-nationalist elements of innovation systems throughout the 2000s and 2010s. Based on the views of the studied scientists, the author of the article provides his own definition of techno-nationalism as a state policy, scientific approach and ideology where national factors play a key role. The results of the study showed that the components of technological systems can be affected by the process of globalization to varying degrees. And therefore, techno-globalism and techno-nationalism are components of these systems and demonstrate*

interdependence. In this light, such categories as digital nationalism, digital identity, and techno-authoritarianism need further development.
Keywords: *techno-nationalism; techno-globalism; space policy; American-Chinese relations; scientific diplomacy; techno-diplomacy; export control*

Introduction.

Globalization and globalism today are almost the most used terms in assessments of the modern world order. And techno-globalism, as its important component, became the subject of study by many scientists in the 1990s – early 2000s (Mothe & Dufour, 1995; Montresor, 1998; Montresor, 2001; Tonelson, 1995; Tonelson, 1997). But, at the same time, the world scientific community relentlessly continues to focus on the opposite phenomenon of techno-globalism – techno-nationalism. Interest in which has only been growing in recent years. Attention to this phenomenon was drawn by the economic conflict between the administration of D. Trump and Beijing, which intensified in 2018. These events demonstrated that the world economic space is as much global as it is local. In particular, A. Capri, a well-known specialist in the field of international economic relations, claims that the change in the technological landscape has led to the emergence of a new hybrid war. This issue is particularly acute in relation to US-China relations, which, according to Capri, are on the threshold of a technological race similar to the space race between the USA and the USSR (Capri, 2021).

Researchers of space policy and technology naturally focus on the problem of interaction between the so-called "members of the space club", on the one hand, and the relations of these countries with states that have not yet joined it, on the other (Paikowsky, 2017). D. Krige, a brilliant historian of science and technology and space technologies, reveals these relations through the concept of "techno-diplomacy" (Krige, 2020).

The concept of "techno-diplomacy" was discussed in scientific circles as early as the late 1980s (Schweitzer, 1989) and certainly became a reflection of the transformational processes of the end of the Cold War. Therefore, the decisive place was assigned to the military-technological competition between the two strongest members of the space club – the USA and the USSR. With the destruction of the old system of international relations, techno-diplomacy aimed to steer relations towards improved cooperation (Salzman, 2017), which was indeed the case after 1991. Cooperation in the field of space activities was considered by the USA in the post-bipolar world as a tool of "soft power" capable of ensuring a new level of stability in the system of international relations (Eisenhower, 2004). The example of the International Space Station (ISS), as one of the most productive results of this cooperation, gives reason to optimistically evaluate the possibilities of this channel for the exchange of technologies and data (Stewart & Dittmer, 2023).

As a historiographic direction, the problem of techno-diplomacy continues to develop in the context of the broad scientific discourse of "scientific diplomacy" – the use of scientific cooperation between countries to solve common problems and build a constructive international partnership (Turchetti, Adamson, Rispoli, Olsakova, &

Robinson, 2020). The result of activities in this area was the creation in 2017 of the Historical Commission on Science, Technology and Diplomacy. This commission was formed on the initiative of the Department of History of Science and Technology of the International Union of History and Philosophy of Science and Technology. Since then, the organization's primary mission has been to promote and coordinate interdisciplinary historical research on the relationships between science, technology, and diplomacy (Turchetti, Adamson, Rispoli, Olsakova, & Robinson, 2020).

However, the concept of techno-diplomacy as a way of interaction does not exclude the desire of states to ensure national interests. It connects technology and national security, seeks to secure geo-economic interests in an integrated global market for state-building processes (Park, 2022, p. 1). At the same time, the topic of regulating the leakage of knowledge and technologies is definitely connected with the security system. Thus, the problem of the functioning of the system of export control of knowledge and the latest technologies, as the main manifestation of techno-nationalism, is being brought up to date again by modern historians (Daniels & Krige, 2022). Under such conditions, special attention is paid to the space industry, as it is directly related to the defense capability of states and political blocs, as well as to the functioning of economic systems.

It is worth noting that modern Ukrainian historical science, although actively discussing the problems of American-Chinese relations (Horodnya, 2014; Ishchuk & Ivanytska, 2018; Levytska-Doba, 2021; Taran, 2017; Shevchuk, 2010) and the economic effect of techno-globalism (Kozachenko, 2014; Chernyavska, 2010), but the problem of techno-nationalism is practically unexplored. Ukrainian political scientists (Petrenko & Oleshchuk, 2021) and economists (Koshova, Britchenko, & Bezpartochnyi, 2022) devoted their research to the potential of Ukraine in the space industry. However, they do not touch on the topic of techno-nationalism and its effect on the Ukrainian space program. Therefore, the security challenges faced by Ukraine under the conditions of Russian aggression determine the urgent need to study the role of the scientific and technical factor in the national strategies of the countries of the world.

The main aim of this article is to trace the evolution of the concept of techno-nationalism in the conditions of the end of the Cold War and in the post-bipolar period. Also, the aim of the article is to improve the understanding of the role of the space factor in the formation of the problem of techno-nationalism in the scientific discourse. The author tries to determine further research prospects in this direction.

Research Methods.

The research methodology is based on the principle of historicism, which made it possible to provide an unbiased interpretation of the concept of techno-nationalism through a critical understanding of the sources. In the article, we also used the problem-chronological method to follow how the scientific awareness of the problem developed at different historical stages.

The need to determine the impact of space policy on the formation of the problem of techno-nationalism led to the use of an interdisciplinary approach. Thus, political and legal analysis helped to better understand the relationship and mutual influence of security and commercial interests in the national technological strategies of states. The work used approaches developed within the framework of the theory of international relations, in particular, the concepts of "Cold War", post-bipolarity and unipolarity.

Where to look for sources of techno-nationalism?

The very concept of techno-nationalism is not something new today. On the contrary, it is quite used both in scientific literature and in politics. And in a broad sense, the desire of states to develop national technologies does not raise questions. However, the process of formation of techno-nationalism itself and its simultaneous theoretical understanding by scientists has its own historical stages and features.

This concept was introduced into scientific circulation in 1987 by Harvard University professor and political activist R. Reich (Reich, 1987). He then applied this definition to characterize American-Japanese economic relations and, in particular, the problem of their competing values in these relations. When formulating his vision of this phenomenon, R. Reich proceeded from the inverse concept of "techno-globalism", giving arguments that America was already, in the 1980s, turning towards techno-nationalism precisely because of the realization of the impossibility of simultaneous and balanced development of technologies in the USA and Japan and the growing threats to American economic and political leadership (Reich, 1987).

It can be agreed that it was Japan's positive experience in combining the public and private sectors in the development of new technologies that became the driving force behind the paradigm shift in the US towards financing technologies for non-military purposes. In the same 1987, the American government, together with the private sector, founded the company "Sematech" (SEMATECH - SEmiconductor MAnufacturing TECHnology), which became the first project in the history of the USA financed by public-private efforts for the research and development of commercial technologies (Yamada, 2000).

R. Reich himself gives a vivid example from the state of development of the space industry. The researcher states that "most of the memory chips in the world, including almost all the electronics required for the Star Wars program, were manufactured in Japan at the time" (Reich, 1987, p. 65). Why does the author give this particular example? After all, researchers today agree that the "Strategic Defense Initiative" (the official name of the program) was more of a political decision to involve the Soviet Union in the pursuit of weapons than a real prospect. In the same 1987, the American Physical Society (American Physical Society) concluded that if such a system were to be created, it would not be in the coming decades (Bloembergen et al., 1987).

Obviously, R. Reich did not analyze the question of whether the creation of this space initiative was possible and relied on the real state of affairs in the electronics market. He cites this particular example, because space policy in the 1980s was a hotly contested area in the Cold War, and therefore was one of the highest geostrategic tasks. At the same time, R. Reich does not give a concrete definition of techno-nationalism or techno-globalism. However, explaining techno-nationalism, he says that the main features of this principle are "the national direction of the development of new technologies, the purpose of which is to preserve technological knowledge here" (Reich, 1987, p. 66), that is, on the spot. In other words, the researcher talks about limiting the leakage of technologies and knowledge that help these technologies develop.

It is possibel to agree that the space chase was a kind of techno-nationalist policy of the Cold War period. But if technological prowess was an indicator of power during the Cold War, why did techno-nationalism not only retain its importance but also intensify after it ended? But can techno-nationalism be reduced to state support of commercial companies operating in the USA? Will techno-nationalism develop if the same companies are involved in international cooperation? These and other questions became even more acute in the late 1980s.

Space diplomacy in the conditions of the end of the Cold War.

One of the historical forms of techno-nationalism was the space pursuit of the Cold War period. The technological systems of the leaders of this pursuit depended on pendulum swings towards the cooling of international relations or their warming. Periods of warming brought with them excellent results of technological cooperation: the Apollo-Soyuz joint manned flight program, the international satellite search and rescue system "Cospas-Sarsat". However, one can agree with D. Krige that "technological leadership, which was the leitmotif of the US national strategy in the postwar period, was embedded in the support network of "hard" power structures" (Krige, 2016, p. 158). And therefore, the problem of non-proliferation of nuclear weapons and space technologies, as dual-use technologies, was a key component of the American strategy in technological policy.

However, the geopolitical and technological changes of the late 1980s and early 1990s required a serious reassessment of the goals and scope of export controls over dual-use technologies. National security could no longer be considered only from a military point of view. And military superiority was no longer sufficient to ensure America's global dominance. Economic security and industrial competitiveness is becoming a vital element of US technology policy (Daniels, Mario, & Krige, 2022, p. 231).

One of the powerful changes that forced American politicians to reconsider the system of export control and techno-diplomacy was the disaster of the space shuttle "Challenger" in 1986, which completely suspended the American space program for two years (Eisenhower, 2004, p. 34). The complete revision of the US space policy, which followed this event, called into question the expediency of implementing one of the most odious technological projects of the 20th century. reusable transport space shuttles "Space-Shuttle". By the end of the 1980s, all funding and efforts were invested in the shuttle program. And the fulfillment of obligations to launch payloads into space, which was undertaken by NASA, had to be fulfilled. The solution could be to provide support to the private sector. The creation of a targeted state policy on the development of the commercial space launch industry began (Logsdon & Reed, 1999, p. 415).

If to analyze the presidential directives of the USA in the field of space from the end of the 1980s until today (National Space Policy (NSP), 1988; NSP, 1989; NSP, 1996; NSP, 2006; NSP, 2010; NSP, 2020) then it becomes obvious that the commercialization was aimed at supporting, first of all, national American companies in the field of space activities. Already in the goals of the 1989 space policy, the following wording is indicative: "The United States will carry out international joint space activities that are expected to provide sufficient scientific, political, economic, or security benefits to the nation" (NSP, 1989). All subsequent directives have a similar meaning and reiterate that the main goal is American leadership in space industry and technology. In fact, the commercialization of space activities, which has become a key element of the American space program since the late 1980s, contained techno-nationalist elements. But securing the claimed technological leadership over the next decade was not easy.

Techno-globalism and techno-nationalism – the search for a balance.

The need to construct a new system of international relations, Japan's ever-increasing technological competition, and a severe crisis in the space industry are the main problems faced by the administrations of G. H. W. Bush and B. Clinton. At the same time, this is the period of the digital revolution and the emergence of the global Internet network, which brought the use of technology to a new level.

The administration of B. Clinton began to actively push for the creation of a comprehensive technological policy of the United States (Kyrychenko, 2011). In Clinton-Gore's Technology Policy of 1992 (A Techn. Policy for America, 1992), it is possible to see, at the same time, the desire to protect the American private sector from excessive control in the field of technology, and to ensure national security with the help of the same export controls. Proponents of techno-globalism in the US Congress have targeted many government programs to promote the commercialization of new technologies, "subject to the participation of foreign participants in these programs, as well as the numerous export promotion programs that flow from these interventionist impulses" (Tonelson, 1995, p. 31).

This has led researchers to argue that the rise of techno-nationalism during the 1980s was replaced by its decline during the 1990s. The diminishing role of military procurement led American governments to encourage technological progress in more direct ways. By closing their markets to imports, countries encouraged foreign firms to open branches within their borders. Through a policy of buying nationals or supporting only national firms, governments have listed firms by location and alliance (Ostry & Nelson, 1995, p. 61). Therefore, it gave reason to consider techno-globalism as a policy of internationalization of private technologies, and techno-nationalism as a technological policy of the public sector with an orientation towards the predominance of the national nature of technologies (Ostry & Nelson, 1995, p. 2–10). Techno-nationalism in this sense assumes that the initiative in directing technological progress belongs not to the market, but to the government, which, at the same time, provides support exclusively to national companies.

In this regard, US-Chinese relations in the space industry are indicative. Starting with the "Agreement between the Government of the United States and the People's Republic of China on cooperation in the field of science and technology" in 1979

(China-US science and technology agreement, 1979), China received considerable dividends from this cooperation (in the form of consultations and exchange of experience). Already on January 23, 1989, China and the USA officially signed the "Memorandum on the agreement on commercial launch services in international trade" (China-US Agreements, 1989).

This allowed the United States to establish the rules of trade early on while it still held the lead in the market for payload launch services. The deal also allowed American satellite manufacturers to sell satellites to China in exchange for contracts to launch them on Chinese launch vehicles. Despite protests from Western launch service providers, the terms of the deal were recognized as the best approach to avoid market destabilization by China and the expansion of the United States' markets (Reed, 1999, pp. 165–166). And although during the first half of the 1990s there were a number of launches of American satellites by Chinese rockets, "from 1989 to 1993, China was subjected to numerous sanctions regarding the export of satellites" (Reed, 1999, p. 167). Each such launch went through a series of procedures of an individual nature, which were considered separately in each specific case. Therefore, cooperation in the market of launching payloads into space demonstrates the simultaneous functioning of both techno-globalist and techno-nationalist elements.

Here it is worth noting that since the non-proliferation of nuclear weapons was an important issue for American policy in the 1990s, the issue of exporting space technologies was on the agenda. The interests of the powerful commercial satellite industry were opposed by national security advocates concerned about the threat of China's military modernization. But, as before, the latter argued that China's promotion of civil space cooperation creates leverage for achieving the non-proliferation goals sought by the United States (Zhang & Seely, 2019, p. 15–16). This is precisely the dualism of the nature of techno-globalism and techno-nationalism. Finding a balance between national security and economic benefits has always been and remains the main strategic task of states. Depending on the international situation and the state of the economy, technological systems respond to these circumstances by changing the balance with the involvement of certain elements of techno-globalism and techno-nationalism.

A shift towards techno-nationalism?

In the case of China, since the mid-1990s, techno-nationalist tendencies have clearly begun to dominate. This was due to the fact that the US governments sought cooperation in space primarily to achieve political goals. Techno-nationalism in this light appears as a political tool for stimulating the development of technology and an indicator of geostrategic power (Johnson-Freese, 2014).

In addition, in the mid-1990s, China experienced a series of fatal space launch pad disasters (Zhang & Seely, 2019, p. 42). The investigation into the causes of the failed rocket launches led to a review by the US government of the rules for the transfer of sensitive technology and confidential information related to the launch of spacecraft. As a conclusion, the "Cox Commission Report" asserted that "the PRC has stolen or otherwise illegally obtained US missile and space technology that enhances the PRC's military and intelligence capabilities" (Report, 1999). Under these circumstances, private American companies that were already integrated into the process of development and use of space and involved in the transfer of space technology to China suffered (Pooley, 1998).

The strengthening of export controls against China was intended to counter the leakage of space technology through commercial international partnerships to ensure the national security of the United States. As the US export control regime strengthened, so did Asian technological nationalism.

However, tighter export controls from the United States were not the only reason for China's techno-nationalist policy. This is rather an additional incentive. Which pushed China during the 1990s – 2000s to develop its own information and technological space, and later - its own space program. Its sources were China's ambitions for regional leadership in Asia, and its real opportunities to achieve this status. In the 1990s, China moved from an ally to a competitor of the US, primarily due to rapid economic growth (Zhang & Seely, 2019).

At the same time, the 1990s was a period of extensive international cooperation in the space industry. After all, almost all modern achievements in space technologies, such as the ISS, the James Webb Space Telescope, etc., were created thanks to international cooperation. It is also possible to observe the deepening of the commercialization of space activities during the 1990s – 2000s (Zhuravliova, 2017). This begs the question – can techno-nationalism as a government policy apply only to selected international actors?

So, if to look more closely at the list of countries in these large international projects, it is possibel to see that there is always cooperation with European countries and almost never with Asian countries (the exception is Japan in the ISS project). Apart from general bilateral agreements on cooperation in space (Embassy of India, Washington DC, USA, 2005), the United States has a clearly protectionist technology policy towards the East. Therefore, it can be argued that when issues of national security prevail over pragmatism, which is undoubtedly the main motive that pushes governments to cooperate in space, techno-nationalism relegates internationalism to second place. J. Freese calls this phenomenon "leadership challenge" (Johnson-Freese, 2014, p. 12). That is, it is not about economic benefits, but political dividends from space exploration. In the end, the national factor is decisive in technological space policy as well.

However, in space activities, which contain many risks, not all countries can show techno-nationalism. Because at a certain stage of the development of the space program, cooperation with other countries is necessary. Those states that seek to acquire new technologies will always insist on the exchange of experience. Cooperation in the field of space technology was enjoyed at one time by Japan and India, which became full members of the space club in 1970 and 1980, respectively (Johnson-Freese, 2014). And although the efforts in the field of space exploration of these countries are less outstanding than those of the USA and China, the very belonging to this club has put them on the highest level in the system of world order. And gradually they also began to move to the politics of techno-nationalism (Cheng, 1994). In other words, the formation of techno-nationalism requires really challenging conditions. In the process, the respective national states receive certain benefits.

Techno-nationalism can be defined as the idea that technological prowess is a valid determinant of national power in a fiercely competitive world that shapes both Chinese and American perceptions of China's space development. Then, "such a perspective elevates all space activities—manned, unmanned, military, and scientific – to the strategic level" (Johnson-Freese & Erickson, 2006, p. 12). Thus, techno-nationalism, and in the space sphere in particular, always includes an aspiration for leadership. In addition, in the field of space activities, this level of leadership reaches another level. After all, space exploration is, without exaggeration, the most risky technological activity. Using space technology and being a space state are different things.

Thus, after the collapse of the Soviet Union, Ukraine inherited almost a third of its missile and space potential. "By 1992, the Ukrainian space industry produced more than 10,000 ballistic launch vehicles, about 300 spacecraft and more than 400 artificial satellites for military and civilian purposes" (Petrenko & Oleshchuk, 2021, p. 85). But the erected political barriers between the republics of the former USSR with their internal completely uncompetitive currency destroyed a complex system of economic relations, which hit the space industry especially hard (Eisenhower, 2004). Having a powerful potential in the field of development and use of outer space, Ukraine was never able to turn into a strong space state. The reliance on cooperation with Russia in space activities, the difficult economic situation and, at the same time, the high capital intensity and long payback periods of the space industry (Koshova, Britchenko, & Bezpartochnyi, 2022), did not create the conditions for this "leadership challenge" for Ukraine.

The American leadership in relations with the former Soviet republic was mainly interested in the problem of non-proliferation. Through the implementation of the "Nunn-Lugar" program, US President B. Clinton managed to take control of the process of nuclear disarmament, including reducing the number of intercontinental ballistic missiles. The Ukrainian side was also persuaded to terminate the contract with Iran for the construction of a nuclear reactor in Bushehr. In the future, the USA never compensated the Kharkiv plant for the damages caused as a result of this refusal (Zaborsky, 1999). Already in 1995, Russia agreed with Iran to complete the construction of this reactor in Iran. Therefore, at the beginning of the 1990s, the USA was interested in Ukraine not so much in the possibility of using the potential of space technology of the Ukrainian SSR, but rather in the presence of a significant arsenal of nuclear weapons on Ukrainian lands (Zhuravliova, 2016a, pp. 64–65).

The administration of B. Clinton was guided by the same goal of deterrence when initiating the joint American-Russian project "Shuttle-Mir" in the mid-1990s (Stewart & Dittmer, 2023). The many tools of techno-diplomacy that were created during the Cold War to counter the Soviet threat have been reimagined and strengthened to meet the new challenges of the proliferation of ballistic missiles and nuclear weapons among rogue states in this club, as well as the emergence of China as a technological rival, an economic competitor and a military threat (Krige, 2020, p. 115).

Therefore, the exceptional position in the international arena of the countries that are part of the space club really has its advantages. Membership in this club directly affects the international status of the state. And technological progress is the key to national well-being. States' perceptions of power and the means of achieving it are shaped by international norms and conventions, as well as by specific national features, goals, and internal needs. The domestic policy of the state modifies these ideas and turns them into real preferences, priorities and programs that correspond to the principles of techno-nationalism. Therefore, the very structure of national-state clubs makes it possible to integrate international factors and domestic political discourse into one structure (Paikowsky, 2017).

Therefore, international relations in the space industry are based on international interaction. The starting point of this interaction is the national interests of governments, for the benefit of which, wherever possible, international cooperation is involved. To talk about the weakening of techno-nationalism during the 1990s based on the development of research and industrial cooperation (Mothe & Dufour, 1995, p. 228–229) means to ignore geopolitical factors. Therefore, the differentiation of actors in relation to which the levers of techno-globalism or techno-nationalism act are really necessary for state policy.

Scientific ideas about the dichotomy of techno-globalism – techno-nationalism.

Simultaneously with the process of changes in the technological policies of the states in the 1990s, the theoretical understanding of these categories in the scientific environment is taking place.

L. Cheng, from the beginning, emphasizes that techno-nationalism and techno-globalism are two different approaches to determining the role of technology in the formation of international relations and the key factors that influence these relations. In addition, the phenomenon of techno-nationalism is specific to East Asia and tends to strengthen there (Cheng, 1994). In his opinion, "techno-nationalism focuses attention on the competitiveness of national states as a result of scientific and technological development. Technological power is seen, in this approach, as one of the determinants of the growth or decline of state power" (Cheng, 1994, p. 2).

In general, by 2000, although there was no single accepted definition of this concept, the concept of techno-nationalism had already crystallized among Japanese researchers. By which they understood the state policy whose main goal is to increase the competitiveness of national technologies through financial support, export-import policy, public procurement system and so on (Yamada, 2000). In addition, A. Yamada points to the transformation of "pure" techno-nationalism, where support is provided only to national technology companies. By involving foreign organizations, in one way or another, in the creation and distribution of new technologies, the state does so on certain conditions for these partners. This tendency to mix national and international can be labeled as neo-techno-nationalism (Yamada, 2000).

Thus, a dichotomous view of the globalization choice (either free trade or protectionism) significantly primitives the understanding of techno-globalism and techno-nationalism. Like any large-scale trend with far-reaching and profound consequences, globalization is very complex. This term describes an unfathomable number of relationships and arrangements that are inevitably subject to strategic, political, social and cultural – as well as purely economic – influences (Tonelson, 1997). A closer economic analysis shows that techno-globalism can develop to different extents and at different speeds (Archibugi & Michie, 1997, p. 124–126).

Applying the economic and political taxonomy to these categories in the late 1990s, the Italian economist S. Montresor structured the components of the global and local levels of development of innovation systems. "Based on the fact that the globalization process causes tension between national, supranational and subnational forces, he distinguishes the following dimensions of techno-globalization: techno-territoriality, techno-sovereignty, techno-citizenship, techno-nationality" (Montresor, 1998, p. 21) . Each of these four components contains both global and national specificities to varying degrees. At the same time, the first three points actually acquired a global specification, but without the complete loss of national or even more local characteristics. Regarding techno-nationality, since a certain commonality of language and culture within a country, as well as its historically shaped institutional environment, contribute to different technological styles and outcomes, techno-national systems of innovation thus still retain an important meaning (Montresor, 1998, p. 1).

In further developments, S. Montresor points out that the globalization process encompasses complex technological systems, the components of which are affected by the process itself in different ways. Therefore, it is difficult to establish a certain general balance between techno-nationalism and techno-globalism (Montresor, 2001, p. 400). The researcher emphasizes that although the term "techno-nationality" is very similar to "techno-nationalism", it is used in a more specific sense – to indicate the technological relevance of socio-cultural elements, which are usually national, but also sub-national. That is, "the main question is whether common nationality or other similar, less formal elements of cohesion between innovative agents (for example, common knowledge, culture and ideology) retain a certain role in the formation of technological change?" (Montresor, 2001, p. 407).

Such a multi-level system actually allows for a better understanding of the co-existence of techno-globalism and techno-nationalism and how they relate to each other. Isolating different components of technological systems can provide more accurate conclusions about global processes and their consequences for national economies.

During the 2000s, a deep understanding of techno-nationalism in historical retrospect takes place. Thus, known for his research in the history of science, technology and medicine, the British historian D. Edgerton in 2007 made an attempt to define "techno-nationalism and techno-globalism as two opposite approaches, ideologies, to the study of technology and society in their relationship "connection"

(Edgerton, 2007, p. 1). That is, he saw these concepts from a research point of view, and not as some specific national policy.

Taking the nation as the starting unit of analysis in the study of technology, techno-nationalists, at the same time, resort to an innovation-centric understanding in the study of national histories of technology, just like techno-globalists. This would mean that there should be a direct connection between national innovations and the economic progress of a particular country. However, D. Edgerton convincingly proves that the connection between innovations and the use of technology is far from direct, and national innovations were not the main source of the development of national technology (Edgerton, 2007). That is, the main thesis that the development of technologies had a direct impact on the economic and social well-being of nations does not look so convincing. And therefore, the academic understanding of the categories of techno-nationalism and techno-globalism is incomplete, just like the understanding of its historical forms.

A new technological pursuit.

The beginning of the 2000s again brings new challenges for the global world, and for American-Chinese relations, in particular. The terrorist acts of September 11, 2001 powerfully updated the security tools of the US foreign policy. In 2003, another tragedy occurred – the disaster of the shuttle "Columbia" (Zhang & Seely, 2019, p. 28). In the same year, the People's Republic of China made its first human flight into space. China becomes the third country in the world with its own manned cosmonautics, which effectively includes it in the elite status of the "chosen among the chosen" in the space club. This further pushes the US government to strengthen the system of export regulation in the field of space technologies (Zhuravliova, 2016b).

A modern researcher of international economic relations A. Capri insists that the reason for the escalation of the new technological cold war between the USA and China should be sought in the further development of techno-nationalism. By which the researcher understands "a model of behavior similar to mercantilism that directly links technological innovation and entrepreneurship to national security, economic prosperity and social stability of the nation" (Capri, 2020b, p. 5).

So, let’s return again to the "challenge of leadership" as one of the important components of techno-nationalism. It manifests itself most obviously in the space industry. After all, a leader can be clearly defined by the specific achievements of states or private companies. And, naturally, from a geopolitical point of view, the main task of this leader is to preserve his status. And those states that claim world, or at least regional, leadership will always proceed from pragmatism.

The concept of techno-diplomacy does not exclude this factor in interstate relations. However, techno-diplomacy does not limit the place of technology in interstate relations only to the number of weapons and does not draw a sharp line between intangible "knowledge" and material "technology" (Krige, 2020, p. 102). In this context, technological knowledge acts as a component of techno-diplomacy and techno-nationalism. It all depends on how to use them. They can be used selectively to form or restrain the technological potential of another state.

However, controlling knowledge in a global world is a very difficult task for governments. Strict restrictions on the space industry not only did not lead to the desired effect for the United States, but on the contrary, worsened the position of American business in this high-tech industry. Since 2005, European aerospace companies have begun to actively reject American-made parts for satellite technologies. They began to build a whole market for "ITAR-free technologies" (for U.S. International Traffic in Arms Regulations (ITAR)) (Abbey & Lane, 2009, pp. 4–5). That is, those that would not fall under the restrictions of the International Arms Trade Regulations, which determine the conditions for the export and temporary import of defense products and services over which the jurisdiction of the US State Department extends.

Naturally, the US policy of prohibiting China from launching satellites with American components forced China to seek customers among second-tier operators in Asia, Africa, and South America (Abbey & Lane, 2009, p. 5). As a result, by 2008 China had become the world's second largest economy, and China-USA strategic competition between China and the USA was growing. In 2008, the administration of G. Bush Jr. vetoed NASA's proposal to develop space cooperation with China (Zhang & Seely, 2019, p. 29). Thus, the American government views national politics as a confrontation between the United States (and its allies) on the one hand, and China and russia on the other. The national space policy aims to separate competitors and reduce their role in the development of outer space (Petrenko & Oleshchuk, 2021).

Another aspect of this policy is to encourage the commercialization of space activities. The growing role of non-governmental actors in key state space programs also introduces new structural elements both to the system of international relations and to techno-nationalism as part of these relations. First, as the USA-China technological rivalry intensifies, the largest technology firms will increasingly engage in techno-nationalism. Second, new tensions will emerge between these public and private actors. This tension will emerge from the opposing narratives between market-oriented preferences on the one hand and aggressive state activism on the other (Capri, 2020b, p. 20). And therefore, techno-nationalism includes rivalry not only at the level of national economies, but also between governmental and non-governmental participants in relations in the field of development and use of technology. Therefore, the technological pursuit really leads to the formation of what S. Montresor called techno-nationality (Montresor, 2001).

Latest research and promising directions.

Such complexity of techno-globalism and techno-nationalism continues to generate lively discussions in the scientific discourse regarding the relationship of various elements of these phenomena, their essence and impact on the political and socio-economic life of mankind.

However, to reduce techno-nationalism only to political or economic benefits, from a historical point of view, means to narrow this phenomenon to domestic political and geopolitical tools. In particular, the Peruvian researcher P. Gayozo focuses on the ideological aspect. Comparing techno-nationalism with digital nationalism, the author of the article concludes that "techno-nationalism is a type of digital nationalism that necessarily derives from ideological nationalism that is adapted to the fourth industrial revolution" (Gayozzo, 2022, p. 215–216). Thus, for P. Gayoso, techno-nationalism is one of the types of classical nationalism. "Both digital nationalism and techno-nationalism are directly related, not only because they are modern forms of nationalism, but also because they require information technology advances to exist" (Gayozzo, 2022, p. 214). Thus, techno-nationalism is a complex phenomenon that is not limited solely to the superiority or geopolitical influence of one country over others through technology companies (political techno-nationalism). "Techno-nationalism is the construction, defense, and promotion of a nation in cyberspace based on arbitrary values and criteria deemed typical of the nation that develops them" (Gayozzo, 2022, p. 217).

Therefore, P. Gayozo does not agree with J. Freeze's point of view on techno-nationalism as a geopolitical project opposed to techno-globalism. He believes that “techno-nationalism is a digital nationalism that seeks to: 1) extend national identity to the virtual world to build a digital identity; 2) extension of state sovereignty to the digital sphere and its protection through the implementation of the technological territorialization project; 3) protection of culture and interaction of citizens on the Internet. At the same time, digital identity refers to the state's presence in cyberspace. That is, what are the limits of its autonomy, how much it can control national resources and how its digital platforms help in nation-building" (Gayozzo, 2022, p. 219).

Thus, based on the point of view of this researcher, techno-nationalism is the result of the adaptation of classical nationalism to the fourth industrial revolution. But the concept of the fourth industrial revolution was formed only in the 2010s (Philbeck & Davis, 2019). Iti is possibel to note that tying this concept to the fourth industrial revolution significantly narrows its content, especially in historical retrospect.

Regarding the issue of digital nationalism, it is possible to agree with researchers from the United Kingdom S. Miguel and S. Martinez that the current wave of nationalism is not new. After all, "nationalism in its banal form never disappeared from communication, but was simply "updated" to meet the specific possibilities of the digital communication environment" (Mihelj & Jiménez-Martínez, 2020, p. 332).

The modern understanding of techno-nationalism, as a certain concept, is increasingly moving in the direction of understanding the nature of the connections between state national interests and the private sector's desire to increase profits. In a review article on techno-nationalism, the Japanese researcher E. Park points out the need to include business interests in the strategic additions of the state as a critical criterion of techno-nationalism. In addition, techno-nationalism is a narrowly defined concept that includes state actors dealing with national security issues and high-tech business actors (Park, 2022). Therefore, the integration of business interests into the strategic agenda of the state really becomes a component of the techno-nationalist policy of today. This is how scientists are developing the concept of "democratization of space." Which, according to them, presupposes "that commercial interests play a leading role, or at least that the resources of governments and commercial enterprises must be combined to improve efficiency in this field" (Koshova, Britchenko, & Bezpartochnyi, 2022, p. 94).

There is also a tendency to consider techno-nationalism as a geopolitical strategy. A. Capri claims that the rapid spread of Beijing's techno-authoritarian model caused countermeasures from liberalized world markets and democracies (Capri, 2021). That is, techno-nationalism continues to be understood as the technological policy of states with the aim of maintaining or aspiring to leadership on the international arena and world market. As a result, the phenomenon of "techno-authoritarianism" is emerging – "in which the state relies on heavy technology, digital platforms and data from Chinese technology companies to censor, monitor and control citizens" (Capri, 2020a, p. 13).

However, the dynamics of global competition for technological superiority and high interdependence with the global production complex have changed the mode of promotion and the nature of techno-nationalism. As states grapple with escalating high-tech pursuits, they are increasingly using their high-tech capabilities for geopolitical purposes, attracting domestic high-tech firms. Thus, the contemporary paradigm of techno-nationalism argues that state power is derived from domestic market power in high technology, using potential technological asymmetry to advance state power in international politics (Park, 2023, p. 8).

Thus, the future potential of techno-nationalism research is: firstly, in the need to use an interdisciplinary approach to develop a historical taxonomy of techno-diplomacy and clarify the sources of Chinese techno-authoritarianism; secondly, in the need to use new methodological methods of studying history, which are currently being developed by the world community. Thus, in the latest magazine "New Technical and Humanities", the American historian J. Owens tries to answer the question "what is important today in the study of world history, how to identify places where knowledge is produced and transmitted, how to emphasize the importance of narratives as answers to interpretative challenges" (Owens, 2023, p. 6) He proposes to apply a new methodology to the study of global history through its visualization on a complex landscape model. The researcher believes that this visual metaphor will significantly improve researchers' understanding of the processes most important for world history (Owens, 2023, p. 13).

For Ukraine, the study of the historical forms of functioning of the International Traffic in Arms Regulations (ITAR) remains particularly relevant. As space technologies and artificial intelligence become increasingly involved in post-cold war conflicts, it is worth deepening the understanding of the historical retrospective of these phenomena.

Conclusions.

Today, there is no single understanding of the concept of techno-nationalism, just like techno-globalism. The idea of techno-nationalism had its historical stages, which was connected with the very technological changes and transformations of the system of international relations.

The formation of the problem of techno-nationalism initially took place in the context of the American-Japanese competition in the technological sphere during the 1980s. In the conditions of the post-industrial society and the end of the Cold War, technical innovation became the equivalent of national power in the global world. Therefore, the understanding of the phenomenon of techno-nationalism began with the opposition to techno-globalism. This dichotomy arose from the understanding that the balance between international cooperation and national interests will always tip one way or the other. Therefore, techno-nationalism is in circulation as a protectionist model of the state's behavior to ensure its geopolitical interests by increasing the competitiveness of national technologies.

In the conditions of the construction of a new system of international relations, space policy became an indicator of leadership and the main component of techno-diplomacy in the early 1990s. At the same time, the need to form a comprehensive technological policy of the United States, which remained the undisputed leader in space exploration at the time, led to a reassessment of the goals and the scope of export control over dual-use technologies. Attempts by American administrations to improve the functioning of the system of export control of knowledge and the latest technologies have become a key tool for finding a balance between national security priorities and global economic and political benefits.

However, this balance could not be found. This is evidenced by the strengthening of techno-nationalist elements in the space policy of both the United States itself and the formation of Asian technological nationalism since the mid-1990s. Despite the comprehensive support of the United States for the commercialization of space activities, American business in this risky area has not received the desired freedom of action. on international markets. Thus, where the political dividends outweigh the economic benefits, national governments will always adhere to protectionism.

At the same time, there was a theoretical understanding of the concept of techno-globalism and techno-nationalism among the scientific community. Applying an interdisciplinary approach to this problem, it can be argued that the dichotomous view of techno-globalism and techno-nationalism reduced the understanding of these concepts to components of the global and local levels of development of innovation systems. Both of these approaches are characterized by an innovation-centric orientation. But if for techno-nationalists, the nation acts as the initial unit of analysis in the study of technology. Techno-globalists focus on the study of world economic and political systems.

The application of economic and political taxonomy to these categories indicates that the components of technological systems (techno-territoriality, techno-sovereignty, techno-citizenship, techno-nationality) are affected by the process of globalization to varying degrees. And therefore, techno-globalism and techno-nationalism can develop at different speeds in each of them. Techno-nationalism will develop faster in those areas where geopolitical interests exceed the benefits of international cooperation.

An analysis of US space policy and its relationship with China in the 2000s demonstrates that globalization has increased the importance of national technological aspects. Technologies as an indicator of geostrategic power form a leadership challenge, which undoubtedly becomes an incentive to strengthen techno-nationalism. This gives reason to talk about the beginning of a new technological race between the USA and China.

At the same time, technological advances in space activities create competition, both among participants in international relations and among private actors. In these conditions, techno-nationalism involves rivalry not only at the level of national economies, but also between governmental and non-governmental actors. Because between them there will always be a conflict between national security and profit.

The author of the article herself came to the conclusion that techno-nationalism is 1) a state policy of creating a nationally oriented technological market in order to ensure national interests, where the technological power of individual nations is a guarantee of their geostrategic power; 2) a scientific approach to understanding the relationship between technology development and society, where national factors play a key role; 3) an ideology that determines that states strive to establish a connection between national and digital identity and, in the process, technological sovereignty is formed.

Recent studies show that the view of techno-nationalism as a geopolitical strategy is complemented by an ideological component. These scholarly pursuits link techno-nationalism to digital nationalism and digital identity. Being components of techno-nationalism, these two concepts reflect that part of the activity of the state and private actors that ensures the maintenance of national identity through digital technologies. It is these components of techno-nationalism that require further study to clarify the sources of Chinese techno-authoritarianism and how they relate to techno-diplomacy. The methodology of research in this field also requires significant refinement through the use of new technological methodologies, such as computational methods, data visualization.

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References

A Technology Policy for America Six Broad Initiatives by Bill Clinton. (1992). *A Publication of the Electronic Frontier Foundation*. Retrieved from https://www.eff.org/effector/3/8

Abbey, G., & Lane, N. (2009). *United States Space Policy: Challenges and Opportunities Gone Astray*. Cambridge: American Academy of Arts and Sciences. Retrieved from https://www.amacad.org/sites/default/files/publication/downloads/spaceUS.pdf

Agreement between the Government of the United States of America and the Government of the People's Republic of China on Cooperation in Science and Technology.

(1979). *China-U.S. science and technology agreement*. Retrieved from https://www.energy.gov/node/4812404

Archibugi, D., & Michie, J. (1997). Technological globalisation or national systems of innovation? *Futures*, *29*(2), 121–137. https://doi.org/10.1016/s0016-3287(96)00072-9

Bloembergen, N., Patel, C. K., Avizonis, P., Clem, R. G., Hertzberg, A., Johnson, T. H., ... & York, H. (1987). Report to The American Physical Society of the study group on science and technology of directed energy weapons. *Reviews of Modern Physics*, *59*(3), 1–200. https://doi.org/10.1103/RevModPhys.59.S1

Capri, A. (2020a). Techno-nationalism and diplomacy: The US-China race to reshape alliances, institutions and standards. *Hinrich Foundation Report*. Retrieved from https://www.hinrichfoundation.com/research/wp/tech/techno-nationalism-and-diplomacy/

Capri, A. (2020b). Techno-nationalism: The US-China tech innovation race: New challenges for markets, business and academia. *Hinrich Foundation Report*. Retrieved from https://s3.iois.me/Hinrich-Foundation-Techno-nationalism-and-the-US-China-tech-innovation-race-August-2020.pdf

Capri, A. (2021). Techno-Nationalism via Semiconductors: Can chip manufacturing return to America? *Hinrich Foundation Report*. Retrieved from https://www.wita.org/wp-content/uploads/2021/06/Techno-nationalism-via-semiconductors-Hinrich-Foundation-white-paper-Alex-Capri-June-2021.pdf

Cheng, L. (1994). Techno-Nationalism vs. Techno-globalism: East Asia in Search of a New Vision for the 21st Century. *Newsletter The Yin and Yang of East Asia*. Retrieved from http://www.icwa.org/wp-content/uploads/2015/09/CL-12.pdf

Cherniavska, O. I. (2010). *Ekonomichni faktory stanovlennia ta rozvytku tekhnohlobalizmu [Economic factors of formation and development of technoglobalizm]* (Extended abstract of candidate's thesis). Kyiv: Vadym Hetman Kyiv National Economic University [in Ukrainian].

China-United States: Agreements regarding Commercial Satellite Launches. (1989). *International Legal Materials*, *28*(3), 596–610. https://doi.org/10.1017/S0020782900021835

Daniels, M., & Krige J. (2022). *Knowledge Regulation and National Security in Postwar America*. Chicago: University of Chicago Press. https://doi.org/10.7208/chicago/9780226817521.001.0001

Edgerton, D. E. H. (2007). The contradictions of techno-nationalism and techno-globalism: A historical perspective. *New Global Studies*, *1*(1), 1–32. https://doi.org/10.2202/1940-0004.1013

Eisenhower, S. (2004). *Partners in Space: US-Russian Cooperation After the Cold War*. Gettysburg: The Eisenhower Institute.

Embassy of India, Washington DC, USA (2005, July 14). India–U.S. Joint Working Group on Civil Space Cooperation Joint Statement. *Embassy of India, Washington DC, USA*. Retrieved from https://www.indianembassyusa.gov.in/ArchivesDetails?id=571

Gayozzo, P. (2022). Tecno-nacionalismo y nacionalismo digital en la cuarta revolución industrial. *Teknokultura. Revista de Cultura Digital y Movimientos Sociales*, *19*(2), 95–102. https://doi.org/10.5209/tekn.80449 [in Spanish].

Horodnia, N. D. (2014). *Skhidna Aziia u zovnishnii polityts SShA (1989–2013 rr.) [East Asia in US foreign policy (1989–2013)]*. Kyiv: «Print-Servis» [in Ukrainian].

Ishchuk, M. O., & Ivanytska, O. P. (2018). Rozvytok amerykano-kytaiskykh vidnosyn za prezydenstva Dzh. Busha-molodshoho [The Development of US-China Relations under the Presidency of George W. Bush]. *Visnyk studentskoho naukovoho tovarystva Donetskoho natsionalnoho universytetu imeni Vasylia Stusa – Bulletin of the Student Scientific Society of Vasyl' Stus Donetsk National University*, *1*(10), 45–49. [in Ukrainian].

Johnson-Freese, J. (2014). The Geostrategic, Techno-Nationalist Push Into Space. *Oasis*, *20*, 9–22. Retrieved from https://revistas.uexternado.edu.co/index.php/oasis/article/view/4006

Johnson-Freese, J., & Erickson, A. S. (2006). The emerging China–EU space partnership: A geotechnological balancer. *Space Policy*, *22*(1), 12–22. https://doi.org/10.1016/j.spacepol.2005.11.001

Koshova, S., Britchenko, I., & Bezpartochnyi, M. (2022). Investment in the Space Industry: a Comparative Analysis of Ukraine and the EU. *Baltic Journal of Economic Studies*, *8*(3), 92–100. https://doi.org/10.30525/2256-0742/2022-8-3-92-100

Kozachenko, R. P. (2014). Hlobalizatsiini chynnyky v konteksti ekzohennykh faktoriv konkurentnoho rozvytku krain v umovakh tekhno-hlobalizmu [Globalization Factors in the Context of Exogenous Factors of Competitive Countries Development in the Era of Technological Globalization]. *Naukovyi visnyk Khersonskoho derzhavnoho universytetu: naukove periodychne vydannia – Scientific Bulletin of Kherson State University: scientific periodical*, (9-1), Part 2, 18–21. Retrieved from http://www.ej.kherson.ua/journal/economic_09-1/58.pdf [in Ukrainian].

Krige, J. (2016). *Sharing Knowledge, Shaping Europe: U.S. Technological Collaboration and Nonproliferation*. Cambridge, MA: MIT Press. https://doi.org/10.7551/mitpress/10861.001.0001

Krige, J. (2020). Technodiplomacy: A Concept and its Application to U.S. – France Nuclear Cooperation in the Nixon-Kissinger Era. *Federal Register*, *12*, 99–116. Retrieved from https://shfg.wildapricot.org/resources/Documents/8-Technodiplomacy%20web.pdf

Kyrychenko, I. (2011). Stratehichni imperatyvy natsionalnoi informatsiinoi bezpeky administratsii B. Klintona [Strategic imperatives of the national information security of the administration of B. Clinton Administration]. *Aktualni problemy mizhnarodnykh vidnosyn – Current Issues in International Relations*, *103*(1), 165–171. Retrieved from http://apir.iir.edu.ua/index.php/apmv/article/view/691 [in Ukrainian].

Levytska-Doba, Ye. O. (2021). *Polityka SShA ta KNR v Aziisko-Tykhookeanskomu rehioni [The USA and China's Policy in the Asia-Pacific Region]*. (Extended abstract of candidate's thesis). Chernivtsi: Yuriy Fedkovych Chernivtsi National University [in Ukrainian].

Logsdon, J., & Reed, C. (1999). Commercializing Space Transportation. In J. Logsdon (Ed.), *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program* (pp. 405–422). Retrieved from https://history.nasa.gov/SP-4407/vol4/cover.pdf

Mihelj, S., & Jiménez-Martínez, C. (2020). Digital nationalism: Understanding the role of digital media in the rise of 'new' nationalism. *Nations and Nationalism, 27*(2), 331–346. https://doi.org/10.1111/nana.12685

Montresor, S. (1998). Techno-Globalism and Techno-Nationalism: an Interpretative Framework. Quaderni – *Working Paper DSE*, *330*, 1–34. Retrieved from https://ideas.repec.org/p/bol/bodewp/330.html

Montresor, S. (2001). Techno-globalism, techno-nationalism and technological systems: organizing the evidence. *Technovation*, *21*(7), 399–412. https://doi.org/10.1016/s0166-4972(00)00061-4

Mothe, J., & Dufour, P. R. (1995). Techno-Globalism and the Challenges to Science and Technology Policy. *Daedalus*, *124*(3), 219–235. Retrieved from http://www.jstor.org/stable/20027317

National Space Policy (2020). *National Space Policy of the Unined States of America.* (released December 9, 2020). Retrieved from https://history.nasa.gov/NationalSpacePolicy12-9-20.pdf

National Space Policy №293. (1988). *Presidential Directive on National Space Policy*. (released February 11, 1988). Retrieved from https://spp.fas.org/military/docops/national/policy88.htm

National Space Policy №30. (1989). *Presidential Directive on National Space Policy*. (released November 2, 1989). Retrieved from https://spp.fas.org/military/docops/national/nspd1.htm

National Space Policy №4. (2010). *National Space Policy of the Unined States of America.* (released June 29, 2010). Retrieved from https://history.nasa.gov/national_space_policy_6-28-10.pdf

National Space Policy №49. (1996). *Presidential Decision Directive National Space Policy.* (released September 19, 1996). Retrieved from https://irp.fas.org/offdocs/pdd/index.html

National Space Policy №49. (2006). *National Security Presidential Directive National Space Policy.* (released August 31, 2006). Retrieved from: https://irp.fas.org/offdocs/nspd/space.html

Ostry, S., & Nelson, R. (1995). *Techno-Nationalism and Techno-Globalism: Conflict and Cooperation.* Washington D.C.: The Brookings Institution.

Owens, J. (2023). A complex-systems landscape: Recognizing what is important in world history. *New Techno Humanities*, *3*(1), 6–14. https://doi.org/10.1016/j.techum.2023.05.003

Paikowsky, D. (2017). *The Power of the Space Club*. Cambridge: Cambridge University Press. https://doi.org/10.1017/9781108159883

Park, S. (2022). *The Review Article on Technonationalism. Preprints, 1, 2022*. https://doi.org/10.20944/preprints202211.0131.v1

Park, S. (2023). Semiconductors at the Intersection of Geoeconomics, Technonationalism, and Global Value Chains. *Social Sciences, 12*(8), 466. https://doi.org/10.3390/socsci12080466

Petrenko, I. & Oleshchuk, P. (2021). National Space Policy of Ukraine: Changing Challenges and Threats. *Philosophy and Cosmology, 27*, 83–93. https://doi.org/10.29202/phil-cosm/27/6

Philbeck, T., & Davis, N. (2019). The Fourth Industrial Revolution: Shaping a New Era. *Journal of International Affairs, 72*(1), 17–22. Retrieved from https://www.jstor.org/stable/26588339

Pooley, E. (1998, June 1). Red Face Over China: Did a Chinese plot persuade Clinton to let a U.S. company give China its rocket science? No. Politics (and policy) did. *Time*. Retrieved from https://edition.cnn.com/ALLPOLITICS/1998/05/25/time/china.missles.html

Reich, R. B. (1987). The rise of techno-nationalism. *The Atlantic Monthly, 259*(5), 63–69. Retrieved from https://www.theatlantic.com/magazine/archive/1987/05/the-rise-of-techno-nationalism/665772/

Salzman, R. (2017). *«Techno-Diplomacy» for the Twenty-First Century: Lessons of U.S.-Soviet Space Cooperation for U.S.-Russian Cooperation in the Arctic.* (Research Paper No. 6, pp. 1–32). US: 2015–2016 Hurford Next Generation Fellowship Research Papers. Retrieved from https://www.europeanleadershipnetwork.org/wp-content/uploads/2017/10/Techno-Diplomacy-for-the-Twenty-First-Century-Rachel-Salzman.pdf

Schweitzer, G. (1989). *Techno-Diplomacy: US-Soviet Confrontations in Science and Technology*. New York: Plenum Press. https://doi.org/10.1007/978-1-4899-6046-7

Shevchuk, O. V. (2010). Kytai u zovnishnopolitychnii stratehii SShA (1990-ti – 2000-ni rr.) [China in the US Foreign Policy Strategy (1990s – 2000s)]. *Naukovi pratsi Chornomorskoho derzhavnoho universytetu imeni Petra Mohyly – Scientific works of Petro Mohyla Black Sea State University, Political Science series, 131*(118), 157–162 [in Ukrainian].

Stewart, W., & Dittmer, J. (2023). More-than-Human Space Diplomacy: Assembling Internationalism in Orbit. *The Hague Journal of Diplomacy, 18*(2–3), 219–252. https://doi.org/10.1163/1871191x-bja10149

Taran, M. A. (2017). Kytaiska initsiatyva «Odyn poias–Odyn shliakh» ta stratehichni vyklyky dlia SShA [China`S «One Belt – One Road» Initiative and Strategic Challenges to The USA*]. Amerykanska istoriia ta polityka – American History & Politics, 4*, 139–151. Retrieved from http://www.americanstudies.history.knu.ua/wp-content/uploads/2018/05/13-Taran.pdf [in Ukrainian].

Tonelson, A. (1995). The Perils of Techno-Globalism. *Issues in Science and Technology, 11(*4), 31–38. Retrieved from http://www.jstor.org/stable/43311451

Tonelson, A. (1997). Globalization: The Great American Non-Debate. *Current History, 96*(613), 353–359. Retrieved from https://www.jstor.org/stable/45317737

Turchetti, S., Adamson, M., Rispoli, G., Olsakova, D., & Robinson, S. (2020). Introduction: Just Needham to Nixon? On Writing the History of «Science Diplomacy». *Historical Studies in the Natural Sciences, 50*(4), 323–339. https://doi.org/10.1525/hsns.2020.50.4.323

U.S. National Security and Military/Commercial Concerns with the People's Republic of China. (1999). *Report of The Select Committee on U.S. National Security And Military/Commercial Concerns With The People's Republic of China.* Retrieved from https://www.congress.gov/105/crpt/hrpt851/CRPT-105hrpt851.pdf

United States Space Priorities Framework. (2021). *Framework for space policy*. (released December 1, 2021). Retrieved from https://www.whitehouse.gov/wp-content/uploads/2021/12/united-states-space-priorities-framework-_-december-1-2021.pdf

Yamada, A. (2000). Neo-techno-nationalism: How and why it grows. *Paper presented to the international studies association conference, 14–18 March,2000, Los Angeles*. Retrieved from https://ciaotest.cc.columbia.edu/isa/yaa01/

Zaborsky, V. (1999). US-Ukrainian nuclear cooperation: Is Kyiv ready for it? *The Nonproliferation Review, 6*(3), 131–139. https://doi.org/10.1080/10736709908436772

Zhang, Z., & Seely, B. (2019). A Historical Review of China–U.S. Cooperation in Space: Launching Commercial Satellites and Technology Transfer, 1978–2000. *Space Policy, 50*, 101333. https://doi.org/10.1016/j.spacepol.2019.08.003

Zhuravlova, L. V. (2016a). Amerykano-ukrainski vidnosyny u sferi kosmichnoi diialnosti(komertsiinyi aspekt) [US–Ukraine Relations in Space Activities (Commercial Aspect)]. *Amerykanska istoriia ta polityka: naukovyi zhurnal – American history and politics,* (1), 63–72. Retrieved from http://nbuv.gov.ua/UJRN/ahp_2016_1_10 [in Ukrainian].

Zhuravlova, L. V. (2016b). Problema eksportnoho kontroliu ta polityka SShA shchodo komertsializatsii kosmichnoi diialnosti u 1990-ti – 2010-ti roky. [Export control problem and US policy toward commercialization of space activity in the 1990 – 2010-ies]. *Voienno-istorychnyi visnyk: Zbirnyk naukovykh prats Natsionalnoho universytetu oborony Ukrainy – Military Historical Bulletin: Collection of scientific papers of the National Defense University of Ukraine, 3*(21), 34–40 [in Ukrainian].

Zhuravlova, L. V. (2017). *Polityka SShA shchodo komertsializatsii kosmichnoi diialnosti (1989 – 2012 rr.) [US policy on commercialization of space activities]* (Candidate's thesis). Kyiv: National Pedagogical University named after M. P. Dragomanov [in Ukrainian].

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Еволюція техно-нацоналізму: Роль космічного чинника

Анотація. *Технологічні зміни останніх чотирьох десятиліть (1980-ті – 2020-ті рр.) спонукають науковців різних галузей оцінювати вплив технологій на* *трансформацію системи міжнародних відносин та національних стратегій держав. Зокрема головна увага багатьох досліджень присвячена системі відносин між країнами з конфліктними технологічними інтересами. Тому у представленій статті ми зосереджуємося на теоретичному осмисленні еволюції концепції техно-націоналізму. Розгляд техно-націоналізму через призму космічної політики, зокрема американо-китайських відносин, є доцільним з точки зору визначення релевантності отриманих результатів дослідження. З огляду на це методологія дослідження побудована на міждисциплінарному підході, який дав можливість поглянути на проблему через перспективу історичної, економічної, політичної наук та теорії міжнародних відносин. Аналіз публікацій з цього питання показує що розвиток техно-націоналізму відбувався у дихотомічному зв'язку із техно-глобалізмом. В умовах завершення холодної війни техно-націоналізм використовувався для позначення протекціоністської політики держав, яка протиставлялася вільному обміну технологій. Космічні технології, які є показником лідерства й мають подвійне призначення стали важливим елементом міждержавних зносин у постбіполярну епоху. Зміни у цій системі призвели до спроби Сполученими Штатами збалансувати інтереси національної безпеки та комерційних вигод від використання космосу. Одначе ці намагання призвели до подальшого посилення режиму експортного контролю з другої половини 1990-х рр. Переважно ці обмеження ґрунтувалися на занепокоєнні з приводу передачі космічних технологій Китаю, який демонстрував ознаки військової модернізації. Таким чином виклик лідерства, який постав перед США та Китаєм у космічній галузі, продовжив зміцнювати техно-націоналістичні елементи інноваційних систем протягом 2000-х й 2010-х рр. Спираючись на погляди досліджених науковців, автор статті надає власне визначення техно-націоналізму, як державної політики, наукового підходу та ідеології де ключову роль відіграють національні чинники. Результати дослідження показали що компоненти технологічних систем можуть бути різною мірою зачеплені процесом глобалізації. А отже техно-глобалізм й техно-націоналізм є складовими цих систем і демонструють взаємозалежність. У цьому світлі подальшої розробки потребують такі категорії, як цифровий націоналізм, цифрова ідентичність, техно-авторитаризм.*

Ключові слова: *техно-націоналізм; техно-глобалізм; космічна політика; американо-китайські відносини; наукова дипломатія; техно-дипломатія; експортний контроль*

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Developmental review of metal additive manufacturing processes

Abstract. *This work is devoted to the study of the progress in various areas of additive manufacturing technology usage - from the first theories of layer-by-layer manufacturing to modern additive manufacturing technologies. Additive manufacturing technologies are some of the most rapidly developing sectors of manufacturing, maintaining significant interest of the scientific community due to the their represent of both an alternative manufacturing method for existing structures, as well as opening up opportunities for the development of new structures with structural complexity unattainable for traditional technologies. During historical review of the development and implementation of various technological processes in additive manufacturing for metals, a gap in compiling a comprehensive picture of the general development of additive manufacturing technologies in metallurgy was discovered. For a better understanding and systematization of knowledge about additive manufacturing, on top of answering a number of common questions about these technologies, an analysis of publicly known knowledge about their historical applications in the leading countries of the world was conducted. A number of additive manufacturing technologies were considered, such as Wire-Arc Additive Manufacturing, Selective Laser Sintering, Selective Laser Melting, Electron Beam Melting, and Laser-Engineered Net Shaping. The study focused on the developments carried out by various countries of the world in the 20th and 21st centuries by scientists from such countries as the USA, the United Kingdom, France, Germany, Japan, Canada, the USSR and others. The main documents for the initial research efforts for each family of additive manufacturing processes and various applications of these* *technologies - from topography and stereolithography to modern medicine with the aerospace industry – were reviewed; their main findings, breakthroughs and challenges were discussed. An analysis and classification of previous studies that focus on the development of various technological processes and their implementation was carried out. As a result of the analysis, a systematized approach to the creation of a comprehensive scheme for the development of additive technologies related to the development of technologies in various directions was proposed.*

Keywords: *additive technologies; history; classification; 3D-printing; selective laser melting; metal products*

Introduction.

What is additive manufacturing?

Additive manufacturing is a type of production technology in which a three-dimensional object is created by applying (printing, growing) successive layers of material according to the data of a digital model. Printing in additive manufacturing is carried out by a specialized device that ensures the creation of a physical object by sequentially layering material on the basis of a virtual 3D model. Because of this, additive manufacturing (AM) is often referred to as 3D-printing. Additive manufacturing technologies have found their place in the development of many industries and various spheres of life. They are widely used in medicine (Izonin, Tkachenko, Gregus, Duriagina, & Shakhovska, 2022; Kim, K.-B., Kim, J.-H., Kim, W.-C., Kim, H.-Y., & Kim, J.-H., 2013; Murr et al., 2012; SLM Solutions, 2023), aircraft and rocket engineering (NASA, 2017; Soller et al., 2016), for the manufacture and repair of gas turbine industry parts (Zielinski, 2021), etc. (Shelyagin et al., 2005; Haskin, Bernatskyi, Siora, & Nikulin, 2011; Shelyagin et al., 2021; Fatoba & Jen, 2023; Schlett, 2023).

Additive manufacturing is one of the most rapidly developing directions of scientific development, maintaining a significant interest of the scientific community, while offering an alternative way of manufacturing for existing structures, and also allowing for creation of new structures with a complexity unattainable using traditional technologies. There are many types of additive manufacturing, but most methods related to metalworking use lasers as a working tool (Yuan, Ding, & Wen, 2019; Dutta, Babu, & Jared, 2019). An example of products manufactured using these technologies are the injectors of spacecraft engines (NASA, 2017), shown in Fig. 1.

Modern reviews focus on the differences between different technologies of additive manufacturing (Moeinfar, Khodabakhshi, Kashani-bozorg, Mohammadi, & Gerlich, 2022) or review the history of the development of these technologies on a comparatively surface level, focusing on specifics (Yuan et al., 2019; Pelz, Ku, Meyers, & Vargas-Gonzalez, 2021). At the moment, practically no works that focus on the task of creation of a complete additive manufacturing development picture for metals.

Nevertheless, by reviewing the history of the development and implementation of various technological processes of additive manufacturing for metals, a general picture of the most important achievements in the development of metal additive manufacturing technologies can be attained. Such an analysis allows us to better define various methods of interaction between scientific progress and the integration of new technological achievements into industry.

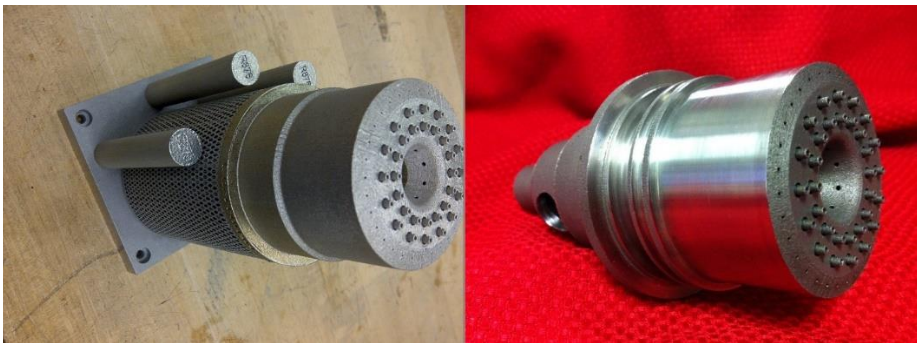

Figure 1. SLS system engine injector (NASA, 2017).

The purpose of this study is the search into the various principles of the interaction of scientific progress and its integration into industry over time through an in-depth analysis of the development and implementation of various technological processes of additive manufacturing for metals in the world. This analysis will be divided into several categories, each of which will focus on the chronology of the development of a certain technological process of additive manufacturing in industry.

However, it must be emphasized that there are many different forms of additive technologies, so, this article will focus on the most common ones.

The problem of terminology and classification in additive manufacturing.

Before beginning the developmental review of additive manufacturing technologies, it is necessary to answer the question of their terminology and classification. Often, additive technologies are called "3D printing" (used mainly in the post-Soviet space) and "Rapid Prototyping" (Yuan et al., 2019; Moeinfar et al., 2022; Karayel & Bozkurt, 2020). The name "3D printing" is usually applied to additive manufacturing processes related to the layer-by-layer production of parts using polymer wires, its extension to additive manufacturing in general is incorrect, because there are additive manufacturing processes that are technically radically different (Masiuchok et al., 2022). "Rapid Prototyping" is a rather outdated name that was used for all processes of additive manufacturing in the 1980s and 1990s, however, nowadays this naming has shifted towards the industrial process of manufacturing a mock-up or test sample of a part using additive technologies.

However, it should be noted that different authors have radically different classifications of these technologies. Standardization and classification of these technologies is one of the issues of the development of additive manufacturing that have not yet been resolved due to different views on these technologies. For example, a review of additive manufacturing technologies by Yuan, Ding, and Wen separately identified three groups of additive manufacturing technologies for metals, such as (Yuan et al., 2019):

- Powder bed fusion (L-PBF), consisting of Selective laser sintering (SLS), Selective laser melting (SLM) and Electron beam melting (EBM),
- Direct energy deposition (DED), Laser engineered net shaping (LENS) та Direct metal deposition (DMD),
- Laminated object manufacturing (LOM).

In this study, the dividing line was drawn according to the form of the metal used: L-PBF uses metal powders, the DED group uses metal wires, and the LOM technology uses thin plates.

A review by Moeinfar et al. brings these technologies under one term LAM/LMAM – Laser (Metal) Additive Manufacturing – Laser additive manufacturing (of metals). (Moeinfar et al., 2022; Zhang et al., 2022).) This classification was expanded in other works, for example, Karayel and Bozkurt divide LMAM into LAM and WAAM (Wire-Arc Additive Manufacturing) (Karayel & Bozkurt, 2020). However, it should be noted that this terminology is not universal, since most articles, such as the article by Singh and others use the names of individual technologies (L-PBF, SLS, SLM, etc.) (Singh et al., 2020).

The first technological steps towards the creation of additive technologies.

The roots of additive technologies can be found in the development of multiple areas of industry, such as topography and photosculpture. Back in 1892, Blanther proposed a layer-by-layer method of creating topographic relief maps, being the first application of a layered manufacturing methodic for creation of complex shapes (Blanther, 1892). The first application of technologies that would later become known as additive manufacturing in metals dates back to 1920, when the American inventor Baker used the process of electric arc welding with a metal electrode to form thin-walled structures and decorative products (Dutta et al., 2019)

The first research, focused on describing the single-beam laser approach to additive technologies was the work of the Japanese scientist Hideo Kodama of the Nagoya Municipal Industrial Research Institute. His patent was accepted for consideration in May 1980, but the application did not pass due to lack of funds. In October of that year, Kodama published an article, detailing the construction of such a system. The experiments were carried out with the help of ultrasound rays and photosensitive resin. Said article also described the usage of a coordinate table and an optical fiber for the delivery of ultrasound beams. The technology was described in more detail in the following work, in which the three main technologies used in modern stereolithography were described and derived (Kodama, 1981).

Overall, Kodama's work is considered the first additive manufacturing technology to be used on a large scale. These technologies later found use in the SOUP 530, 600, and 850 brand machines manufactured by CMET.

The next important stepping stone in the development of additive manufacturing is considered to be the work of Sachs, Cima, and Cornie (1990). This work is important for its representation of the first successful experiment in the use of additive manufacturing using non-polymeric materials.

Development of individual additive manufacturing technologies.

Wire Arc Additive Manufacturing (WAAM, L-WAAM) is a technology that consists in applying material supplied in the form of a fusible metal wire (Kvasnytskyi et al., 2020; Zavdoveev et al., 2022; Schwab, Selin, & Voron, 2023). This technology allows you to apply up to 10m/min material in one pass with a material application rate of 1–3 kg/h using laser radiation with a power of up to 5 kW. The size of the working part during usage of this technology is limited only by the technological limitations of the equipment (Fig. 2).

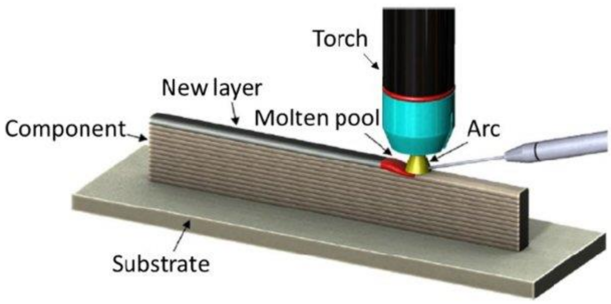

Figure 2. WAAM process scheme (Rodrigues, Duarte, Miranda, Santos, & Oliveira, 2019).

The main features of this technology include its relative simplicity and the possibility of various energy source usage (Zavdoveev et al., 2023). However, when using this technology, it is necessary to control the structure of the obtained material, as well as take into account the relatively low accuracy of the deposited part and the quality of its surface without additional processing (Liu, Xu, Ge, Hou, & Chen, 2020).

This technology was developed in 1920 by Baker, who filed a patent for the formation of a "superposed deposit of metal" using spiral manipulation of a fusible electrode to create ornaments on various surfaces (Baker, 1920). Subsequently, Shockey in 1930 described the use of cladding, in which a roll with recommended overlap of one-third of the previously applied pass was applied to successive passes, producing the best results (Shockey, 1930). Later, Ujiie demonstrated a technique for forming a high-pressure vessel of circular cross-section solely by gradual deposition of weld metal (Ujiie, 1971).

Currently, this technology is used in a variety of applications, such as the manufacture of turbine (Fig. 3) and generator parts (Zielinski, 2021), as well as for the manufacture of various aerospace industry parts, such as the nozzles of spacecraft engines shown in Fig. 4 (Optics.org, 2018).

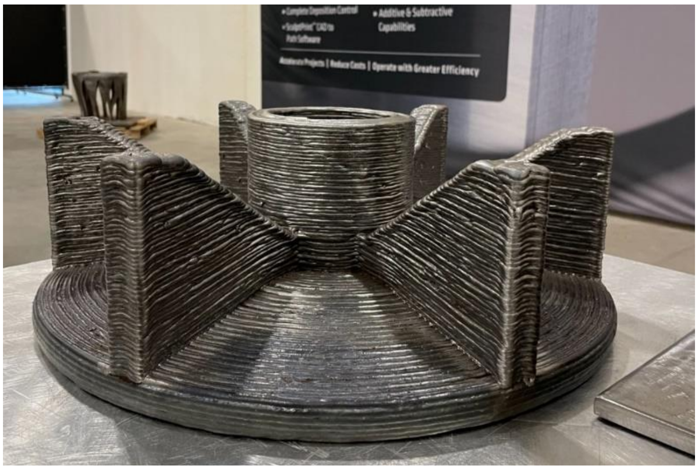

Figure 3. Electric motor part manufactured by Lincoln Electric (Zielinski, 2021).

Figure 4. NASA-produced nozzle blank (Optics.org, 2018).

Selective Laser Sintering (SLS) is an additive manufacturing process, used for the manufacture of products of complex shapes and structures from powder materials, as well as optional polymer applications (Trajković et al., 2023).). This process consists of successive layer-by-layer sintering (or partial melting) of the powder material using laser radiation (Fig. 5). This technology allows for application of metal, plastic or ceramic layers with a 40–150 microns thickness utilizing a laser beam with a diameter of up to 300 microns and a power of up to 10 kW. A feature of this technology is the possibility of using a variety of materials in the design of the part with high accuracy at the cost of obtaining a high porosity part (Serin et al., 2016; Yuan et al., 2019).

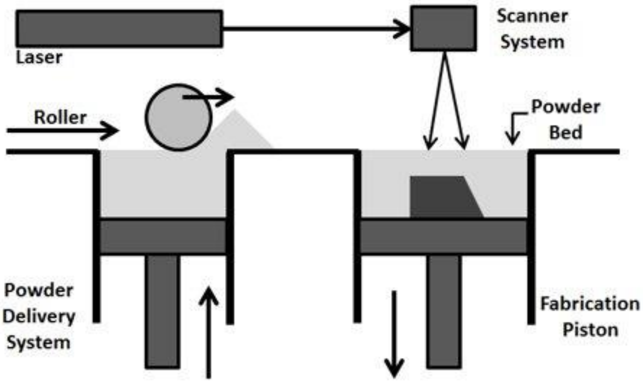

Figure 5. Scheme of the SLS process (Serin et al., 2016).

The first developments in selective laser sintering (SLS) began at the University of Texas in the early 1980s, when Deckard proposed fusing powder particles using a directed beam of energy. Together with his professor Beaman, Deckard developed selective laser sintering and applied for a patent for his invention in October 1986. The first working SLS machine was named "Betsy". Initially, it was capable of producing only small plastic cubes, which at the time was considered sufficient to demonstrate the potential of the process (Deckard, 1986, as cited by Prinz, Atwood, & Aubin, 1997). Selective laser sintering (SLS) equipment from DTM (now part of 3D Systems) became available in 1992. Later, this technology became the property of the German company EOS, which, together with the Fraunhofer Institute, developed the technology for the use of powder metallurgy and produced the first DMLS-machine EOSINT M 160 in 1994 (EOS, 2023)

Currently, this technology is used in various works, such as the manufacture of medical and other high-tech parts, for example (Fig. 6), medical prostheses for teeth (Kim et al., 2013).

Figure 6. Dental prosthesis made using SLS technology (Kim et al., 2013).

Selective Laser Melting (SLM) is one of the modern technologies of additive manufacturing, which is used for the manufacture of products of complex shape and structure from powder materials (Lesyk, Martinez, Mordyuk, Dzhemelinskyi, &

Lamikiz, A., 2019; Lesyk, Martinez, Dzhemelinkyi, & Lamikiz, 2020; Duriagina et al., 2021). This process consists in successive layer-by-layer melting of metal powder material with the help of powerful laser radiation. This technology makes it possible to weld 20–200 μm thick layers of metals utilizing a laser beam with power varying from 100 W to 2–3 kW (Yuan et al., 2019).

The main difference between the SLS and SLM processes is that SLS sinters the powder material at a temperature approximate to 85% of the melting temperature of the deposited material; while SLM joins the powder material by classical laser melting (Korzhyk, Khaskin, Voitenko, Sydorets, & Dolianovskaia, 2017).

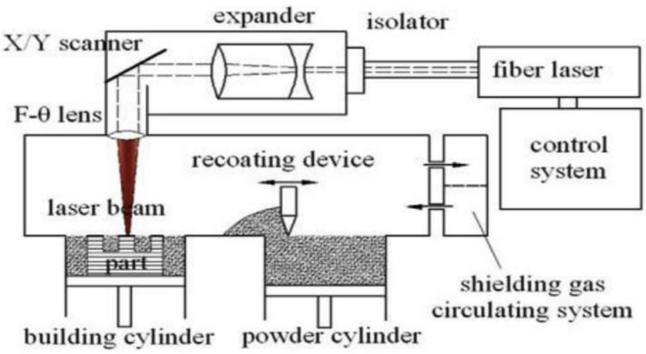

Figure 7. Scheme of an SLM installation (Yuan et al., 2019).

The main features of SLM technology are:

• the mechanical characteristics of products manufactured using this technology can be compared to those manufactured via casting;

• the possibility of this technology to solve complex technological tasks related to the manufacture of geometrically complex products;

The main limitations when using this technology are their low productivity, as well as the impossibility of manufacturing large-sized parts due to the use of a gas chamber, the size of which limits the size of the obtained part.

Selective laser melting, one of several 3D printing technologies, started in 1995 at the Fraunhofer Institute ILT in Aachen, Germany, with a German research project resulting in the so-called ILT SLM Basic Patent DE 19649865, which describes the basic tenets of SLM technology (Meiners, Wissenbach, & Gasser, 1998).

Meanwhile, the Fraunhofer Institute for Production Technology (IPT) has developed a process for the direct production of fully dense metal parts using a laser welding process called LGRP, which featured a cutter for trimming of the walls and surfaces of each layer of deposited material for an improvement in accuracy and surface finish. The process was first publicly demonstrated in December 1995 at Euromold 95 in Frankfurt, Germany (Agarwala, Bourell, Beaman, Marcus, & Barlow, 1995).

As of 1996, similar methods were being used in the United States, but lacked any integrated processing. A review of technology trends for 1997 did not identify any companies in Japan developing additive manufacturing processes for the direct fabrication of metal components, but did find significant interest in metal component fabrication using die casting, metal spraying, and the like (Prinz et al., 1997).

Meanwhile, in 1996–1998, the inventions of Ciraud (1972, as cited by Prinz et al., 1997) were brought to the industrial level by scientists in the works of Jeantette et al. (1996, as cited by Dutta et al., 2019), as well as Koch and Mazumder (1998, as cited by Dutta et al., 2019) in them, introducing the Direct Energy Deposition (DED) technology in its modern form (Dutta et al., 2019).

At the same time, progress in additive manufacturing of ceramic materials in the 1990s focused on improving basic technologies, optimizing processing parameters, and modeling the process. This led to the production of dense, mechanically strong parts and the expansion of the choice of materials (Pelz et al., 2021).

Currently, these technologies are used for a variety of tasks, including the manufacture of jet engine injectors from Inconel 718 steels, as shown on Fig. 8 (Soller et al., 2016), orthopedic implants from medical steels, shown on Fig. 9 (SLM Solutions, 2023), and many other types of parts.

Figure 8. Vulcain 2 jet engine injector, manufactured via usage of SLM technology (Soller et al., 2016).

Figure 9. Orthopedic implant, manufactured using SLM technology (SLM Solutions, 2023).

Electron Beam Melting (EBM) is a technology that belongs to the family of additive manufacturing, being used for the manufacture of products with a complex shape and structure (Akhonin et al., 2019). Process-wise, the process consists from successive layer-by-layer melting of powder material utilizing powerful electron guns in vacuum chambers (Fig. 10) (Legutko, 2018).

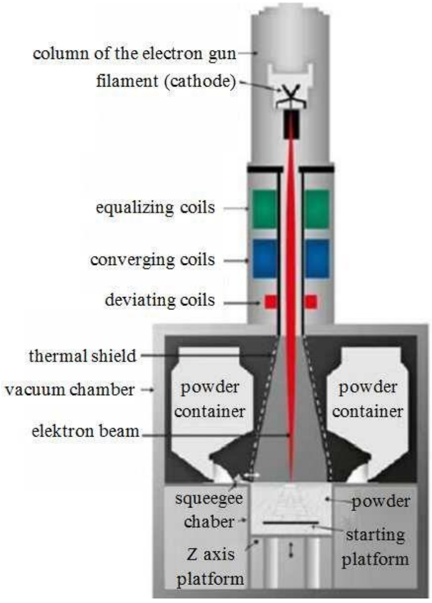

Figure 10. EBM process schematic (Legutko, 2018).

The features of this process include a combination of the wide selection of metal material forms (both powder and wire) and the high quality of the manufactured parts (Kritskiy, Pohudina, Kovalevskyi, Tsegelnyk, Kombarov, 2022). The disadvantages of this process include its price per part, the difficulty of manufacturing large-sized parts due to the need for a vacuum, as well as the high amount of time required for manufacturing a single part utilizing this process.

The first applications of electron beam processes are attributed to Dr. Steigerwald, who created the first electron beam unit in 1952. It is shown in fig. 11 (Steigerwald StrahlTechnik, 2023).

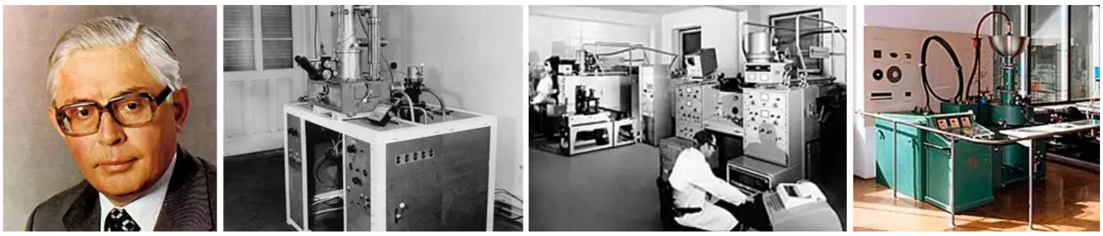

Figure 11. Left to right – Dr. Steigerwald, the first electron beam welding installations created in 1952, 1958 and 1963 respectively (Steigerwald StrahlTechnik, 2023).

Subsequently, considerable attention to these technologies was paid in the USSR, where a considerable amount of research work focused on the electron beam melting process was carried out. This is evidenced by a number of works and exhibitions at which the results of the works of Soviet scientists were presented (Arzhakova, 1984). Of various research centers, Paton Electric Welding Institute is considered to be one such center of development of the EBM technologies (Matviichuk, Nesterenkov, & Berdnikova, 2022). In its walls, several types of industrial installations for the production of high-quality, corrosion-resistant and other types of steels, as well as titanium, was introduced (Paton et al. 1971). Later a number of electron-beam industrial equipment, as well as created a number of equipment intended for use in space (Strelko et al., 2019; Strelko, 2021), was introduced at various enterprises of the USSR and post-Soviet countries in the 1984–1993 period. (Paton & Kubasov, 1970; Paton & Lapchinskij, 1998; Strelko, Pylypchuk, & Berdnychenko, 2019).

The first mass application of these technologies is considered to be carried out by the Swedish "Arcam" company in 1997, which used EBM to manufacture light, strong and dense final parts (Bahnini, Rivette, Rechia, Siadat, & Elmesbahi, 2018).

Currently, these technologies are used for various parts of mechanical engineering and medicine, for example, the creation of prostheses (Murr et al, 2012) (Fig. 12).

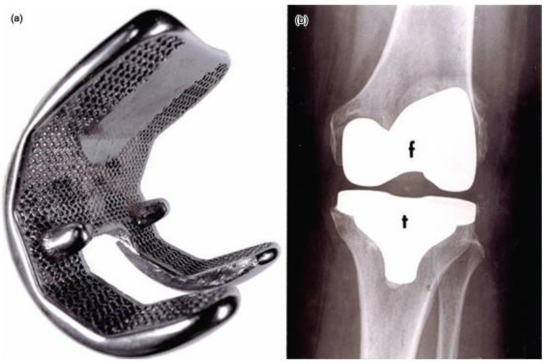

Figure 12. Knee prosthesis. a) fabricated assembly of a prosthetic knee part, b) X-ray imagery showing various knee parts that have been replaced with prosthetic ones (Murr et al, 2012).

Direct Energy Deposition (DED), *Direct Metal Deposition* (DMD), *Laser-Engineered Net Shapin*g (LENS) (Fig. 13) are a number of additive manufacturing technologies that are similar to SLS and SLM technologies in a certain way, but technologically are a series hybrid technologies between these processes and Fused Deposition Modeling (FDM) process due to the difference in layer thickness as well as differences in the manufacturing technology (Lee et al., 2021).

Unlike in SLM, where the process is based on an availability of a pre-coated powder layer, during LENS the powder is fed through a nozzle and irradiated with a high energy density laser beam to melt and deposit onto the base plate of the design layer by layer pattern. Although the technology was primarily developed for the fabrication of complex geometric components, it is also considered to be ideally suited for the repair and restoration of various damaged components and structures.

Currently, these technologies are used for the manufacture of various parts, such as the nozzles of the RS25 rocket units for NASA (Davies, 2021) (Fig. 14) and the welding of technological nodes on various machinery parts. (Schlett, 2023) (Fig. 15).

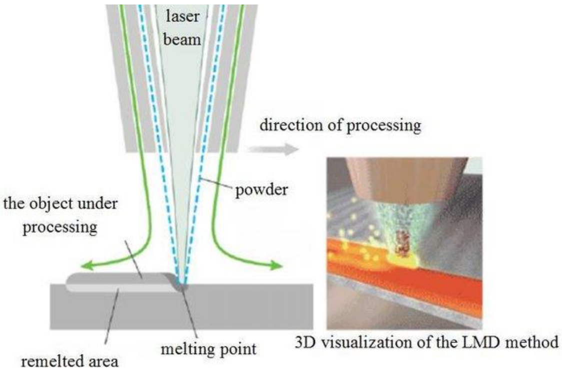

Figure 13. LENS process schematic (Legutko, 2018).

Figure 14. The manufacturing process and the finished nozzle of the 2 ton RS25 rocket unit (Davies, 2021).

Figure 15. Additive manufacturing of a technological element during the ADDIFLAP program (Schlett, 2023).

This technology was first developed at Sandia National Laboratories in 1995 under the name LENS (Laser Engineering Net Shape). It was later commercialized by the Optomec company in United States. Due to different variables in the construction of its energy source and end use, LENS is sometimes referred to as Direct Energy Deposition (DED), Laser Metal Deposition (LMD), 3D laser coating, or "direct light fabrication".

Diversification of the additive technology technological basis.

Currently, due to the global geopolitical situation following the end of the "Cold War" and patent disputes, the absolute majority of the rights on core processes, as well as various parts of SLS and SLM technologies was concentrated in Germany. Thus, all rights to SLM technology were concentrated in the hands of the Fraunhofer Institute for Production Technology (IPT) and the Trumpf company, while the patents for SLS/DMLS technologies were obtained by the EOS, a German company, which granted access to the use of these technologies to a small number of companies worldwide. For this reason, the development of these technologies in the period of the 2000s and 2010s (until the expiration of Deckard's patent on SLS in 2014) was based on the discoveries and iterations of the process of machinery originating from these manufacturers. Because of this, the further development of technologies on an industrial scale mainly focused on theoretical changes and process optimization, which became a focus for various scientific studies of scientists from many countries, such as PRC, India, UK, Japan, etc. (Wohler & Gornet, 2016).

Current state of additive technologies and its prospects.

At the current moment, additive technologies are an integral part of modern industry and play a major role in its development. They are widely used in light industry, in the development and modelling of new parts, in medicine, aircraft and rocket engineering, as well as for the repair of labor-intensive parts.

The additive manufacturing sector of ceramic materials is actively developing, its latest efforts are considered to be focused on structural research, multi-material possibilities and further improvements in the production of structural and functional parts. The commercial ceramic additive manufacturing sector focuses on the next processes: photopolymerization in a cube, jet bonding, powder bed fusion, sheet lamination and material extrusion (Pelz et al., 2021).

Additive manufacturing technologies are widely used in aircraft and rocket engineering. For example, in 2013, Elon Musk has published an image of SpaceX's regeneratively cooled SuperDraco rocket motor chamber emerging from an EOS-manufactured SLS machine, noting that it was made of Inconel series refractory alloy. In May 2014, SpaceX unexpectedly announced that a flight-qualified version of the SuperDraco engine was fully printed, becoming the first fully printed rocket engine (SpaceX, 2014).

Worthy of note is the active development of the medical additive manufacturing sector. It is known about the use of AM technologies for the manufacture of medicines, prostheses, and even artificial organs (Ramola, Yadav, & Jain, 2019) According to Yuan, Ding, and Wen (2019), the US market for the medical sector of additive manufacturing was estimated at $134 billion circa 2017 (Yuan et al., 2019).

It is necessary not to forget about the use of additive technologies in the repair of critical components, such as, for example, blades of jet engines and gas turbines (Singh et al., 2020).

Overall, the common conclusion notes that the global industry is trying to expand the list of various applications for additive technology usage, as well as coordinating efforts to reduce the cost of additive manufacturing equipment (Berdnikova et al., 2021; Romanova et al., 2021). However, there are also local goals for the development of additive technologies. Thus, it is believed that the long-term goal of European research institutes and equipment manufacturers is the development of manufacturing equipment parts and machine of additive manufacturing, as well as deepening knowledge about the processes of tool manufacturing (Wohler & Gornet, 2016).

In terms of reaching the goals of proliferation and decreasing costs of additive manufacturing equipment, a simple 3D printer had a price of thousands of dollars in 2003, while now, in 2023, any small business owner can purchase a simple additive manufacturing machine for $200–300. This fact is slowly changing the industry's view of this equipment as a low-cost alternative for the production of mock-ups, prototypes, low-volume products, and souvenirs. It can also be assumed that due to the recent expiration of the patent protection of SLS technological details and the upcoming expiration of the patent protection of SLM/DMD/DED technologies, this equipment will become more widespread in the industry due to the widening pool of manufacturers of equipment, created to utilise these technologies.

Discussions.

According to the authors research, the works that focused their study on the history and development of additive manufacturing can be divided into three types:

1. General articles that ignore the historical part and focus on the differences between different additive manufacturing technologies. Representatives of such articles are the works of Moeinfar, Khodabakhshi, Kashani-bozorg, Mohammadi and Gerlich (2022), Karayel and Bozkurt (2020) etc.
2. Articles that superficially covered the history of the development of these technologies in general, focusing on one direction of additive technologies. Representatives of such articles are works by Yuan, Ding and Wen (2019), Pelz, Ku, Meyers and Vargas-Gonzalez (2021), Ramola, Yadav and Jain (2019) etc.
3. Articles, that focus on the commercial aspects of the development of additive manufacturing. Representatives of such articles are the article by Wohlers and Gornet (2016) and others.

In regards to the work of Yuan, Ding and Wen (2019), this review only touches recent technological innovations in additive manufacturing processes, while the study by Pelz et al. (2021) provides a better summary of the general development of additive manufacturing, but only provides periodic data on the first uses of the main additive technologies, without describing details, previous and subsequent important scientific discoveries.

The work of Ramola et al. (2019), unlike the previously mentioned works, focuses not only on the first uses of most additive technologies, but also provides examples of modern scientific works related to the use of additive technologies in biomedicine. In the work, the methodology and statistical data of the review are well presented, which helps in data processing. However, this work skips most if not all intermediate stages of AM technology development.

Of great interest was the article by Wohler and Gornet (2016). This article provides a sufficient review of the technologies that created a basis for development of additive manufacturing technologies. However, the vast majority of the article focuses on commercial changes in production rights (lawsuits, patent purchases, etc.), and does not focus on scientific discoveries after the first technological applications of various additive manufacturing processes.

As a result of this review, it can be seen that after the first commercial applications of additive manufacturing were obtained, the focus of scientific development shifted to techniques related to the manufacture of metal parts. In view of this, it is possible to propose a scheme for periodizing the development of additive manufacturing that would focus on the main material, the manufacture of parts from which required the most scientific effort. The key events in the transition between these periods are the combination of the discovery of SLS and SLM processes and their appearance on the global market. The result of such an analysis of the scientific development of additive manufacturing technologies is an open-ended diagram:

1. Photopolymer/Plastic Era – continues until about 1995–1998. In this period, science mainly focuses on stereolithography and the production of parts from photopolymers or plastics.
2. Metal era – began in 1995–1998 and continues to this day. In this period, the main efforts of the scientific community are related to the deepening of knowledge regarding the production of metal parts via additive manufacturing. However, it is possible to notice trends that in recent years the scientific community is focusing on the additive production of heat-resistant steel alloys, as well as titanium alloys.

This system openly shows the main focus of the scientific community's momentum in discovering new methods of additive manufacturing and deepening knowledge in existing technologies. At the same time, this system leaves room for future changes in the paradigms of the scientific community regarding new materials that will be used in the science of the future. However, with this periodization, it should be noted that even with the shift in the main focus of development, the process of continuous modernization and improvement of existing additive manufacturing processes for pre-existing materials has never stopped.

An alternative is the classical development scheme, which is associated with technology development cycles. Since most additive manufacturing technologies have come to full maturity in a relatively short period of time, it is possible to propose a three-epoch periodization of additive manufacturing technologies:

1. The starting period of basic discoveirs – lasts from 1892 until 1981–1984. This era focuses on the discovery of all prerequisite technologies, that were necessary for the discovery and implementation of additive manufacturing technologies.

2. The era of discoveries and implementation – lasted from 1981–1984 to 1999. The beginning of this era can be associated with two discoveries: the work of Kodama (1981) and the patent of Hull (1998), since each of two works are considered to be some of the first successful proper additive manufacturing technological developments. The end of this era is the year 1999, namely: the year of introduction of the latest widely used technology of additive manufacturing (DED/DMD) developed in modern times into production with the release of this technology to the world market.

3. The era of diversification of applications and development of developed processes (1999–present) is associated with the transition of the efforts of the scientific community to the diversification of possible applications of additive manufacturing, the deepening of knowledge about additive manufacturing processes, as well as the modernization of equipment for AM processes.

This option of periodization better shows the progress made by the scientific community in the development of additive manufacturing technologies.

Conclusions.

In the process of analyzing the available information on the creation and development of additive manufacturing technologies, it was proposed to define the turning points in the development and implementation of additive manufacturing technologies, namely: the completion of the first photopolymer stereolithography systems (1981–1984), as well as the completion of the development of the main technologies for the additive manufacturing of metal parts (SLS/SLM/DMD/DED), which took place in 1995–1999. It was observed that the change in the main focus of the development of additive technologies was mainly relegated to the technological progress. In general, in a period of almost 50 years since the first additive technologies were introduced, they have found their place in rapidly developing modern technologies, for example, in medicine, aircraft and rocketry, for the manufacture and repair of parts in the gas turbine industry, and for the manufacture of models and small-scale products.

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Conflicts of interest.

The authors declare no conflict of interest.

References

Agarwala, M., Bourell, D., Beaman, J., Marcus, H., & Barlow, J. (1995). Post-processing of selective laser sintered metal parts. *Rapid Prototyping Journal, 1*(2), 36–44. https://doi.org/10.1108/13552549510086853

Akhonin, S., Berezos, V., Severyn, A., Gadzyra, M., Tymoschenko, Y., & Davydchuk, N. (2019). Structure and properties of titanium modified silicon-carbide at EBM. *IOP Conference Series: Materials Science and Engineering*, *582*(1), 012051. https://doi.org/10.1088/1757-899X/582/1/012051

Arzhakova, V. M. (1984). Elektronno-luchevaya plavka tugoplavkih metallov i splavov [Electron beam melting of refractory metals and alloys]. *Atomnaya energiya – Atomic Energy*, *57*(3) [in Russian].

Bahnini, I., Rivette, M., Rechia, A., Siadat, A., & Elmesbahi, A. (2018). Additive manufacturing technology: the status, applications, and prospects. *The International Journal of Advanced Manufacturing Technology*, *97*, 147–161. https://doi.org/10.1007/s00170-018-1932-y

Baker, R. (1920). Method of making decorative articles. *US Patent No. US1533300A*. Washington, DC: U.S. Patent and Trademark Office. Retrieved from https://patents.google.com/patent/US1533300A/en

Berdnikova, O., Kushnarova, O., Bernatskyi, A., Polovetskyi, Y., Kostin, V., & Khokhlov, M. (2021). Structure features of surface layers in structural steel after laser-plasma alloying with 48(WC–W_2C)+ 48Cr+ 4Al powder. In *2021 IEEE 11th International Conference Nanomaterials: Applications & Properties (NAP)*, 05–11 September 2021, Odessa, Ukraine, (pp. 1–4). Odessa: IEEE. https://doi.org/10.1109/NAP51885.2021.9568516

Blanther, J. E. (1892). Manufacture of contour relief-maps. *US Patent No. US473901A*. Washington, DC: U.S. Patent and Trademark Office. Retrieved from https://patents.google.com/patent/US473901A/en

Davies, S. (2021, August 24). DM3D technology manufactures ten-foot-tall rocket nozzle liner for NASA project with DED 3D printing. *TCT Magazine*. Retrieved from https://www.tctmagazine.com/additive-manufacturing-3d-printing-news/metal-additive-manufacturing-news/dm3d-technologies-manufactures-ten-foot-tall-rocket-nozzle-l/

Duriagina, Z., Lemishka, I., Litvinchev, I., Marmolejo, J. A., Pankratov, A., Romanova, T., & Yaskov, G. (2021). Optimized filling of a given cuboid with spherical powders for additive manufacturing. *Journal of the Operations Research Society of China*, *9*, 853–868. https://doi.org/10.1007/s40305-020-00314-9

Dutta, B., Babu, S., & Jared, B. (2019). Chapter 1 – Metal additive manufacturing. In B. Dutta, S. Babu, & B. Jared (Eds.), *Science, Technology and Applications of Metals in Additive Manufacturing* (pp. 1–10). Oak Ridge, United States: Elsevier. https://doi.org/10.1016/B978-0-12-816634-5.00001-7.

EOS GmbH. (2023). The story of EOS GmbH and industrial 3D printing. *EOS.info* Retrieved from https://www.eos.info/en/who-we-are/history

Fatoba, O. S., & Jen, T. C. (2023). Acoustic-based in-situ monitoring of additive manufacturing fabrication: A review. In *2023 14th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMIMT)*, 26–28 May

2023, Cape Town, South Africa, (pp. 250–256). Cape Town, South Africa: IEEE. https://doi.org/10.1109/ICMIMT59138.2023.10200667

Haskin, V. Yu., Bernatskyi, A. V., Siora, O. V., & Nikulin, O. T. (2011). Study of influence of conditions of process of laser superficial processing of the loaded steel articles on structure and properties of obtained layers. *Metallofizika i Noveishie Tekhnologii, 33*, 561–567.

Hull, Ch. W. (1998). Method and apparatus for production of three-dimensional objects by stereolithography. *US Patent No. US5779967*. Washington, DC: U.S. Patent and Trademark Office. Retrieved from https://patents.google.com/patent/US5779967

Izonin, I., Tkachenko, R., Gregus, M., Duriagina, Z., & Shakhovska, N. (2022). PNN-SVM approach of Ti-based powder's properties evaluation for biomedical implants production. *Computers, Materials & Continua*, *71*(3), 5933–5947. https://doi.org/10.32604/cmc.2022.022582

Karayel, E., & Bozkurt, Y. (2020). Additive manufacturing method and different welding applications, *Journal of Materials Research and Technology*, *9*(5), 11424–11438. https://doi.org/10.1016/j.jmrt.2020.08.039.

Kim, K.-B., Kim, J.-H., Kim, W.-C., Kim, H.-Y., & Kim, J.-H. (2013). Evaluation of the marginal and internal gap of metal-ceramic crown fabricated with a selective laser sintering technology: Two- and three-dimensional replica techniques. *The Journal of Advanced Prosthodontics*, *5*(2), 179–186. https://doi.org/10.4047/jap.2013.5.2.179

Kodama, H., (1981). Automatic method for fabricating a three-dimensional plastic model with photo-hardening polymer, *Review of Scientific Instruments*, *52*(11), 1770–1773. https://doi.org/10.1063/1.1136492

Korzhyk, V., Khaskin, V., Voitenko, O., Sydorets, V., & Dolianovskaia, O. (2017). Welding technology in additive manufacturing processes of 3D objects. *Materials Science Forum*, *906*, 121–130. https://doi.org/10.4028/www.scientific.net/msf.906.121

Kritskiy, D., Pohudina, O., Kovalevskyi, M., Tsegelnyk, Ye., & Kombarov, V. (2022). Powder mixtures analysis for laser cladding using OpenCV library. In: M. Nechyporuk, V. Pavlikov, D. Kritskiy (Eds.), *Integrated Computer Technologies in Mechanical Engineering – 2021, ICTM 2021, Lecture Notes in Networks and Systems*, *367* (pp. 924–937). Cham: Springer. https://doi.org/10.1007/978-3-030-94259-5_72

Kvasnytskyi, V., Korzhyk, V., Lahodzinkyi, I., Illiashenko, Y., Peleshenko, S., & Voitenko, O. (2020). Creation of volumetric products using additive arc cladding with compact and powder filler materials. In *2020 IEEE 10th International Conference Nanomaterials: Applications & Properties (NAP)*, 09–13 November 2020, Sumy, Ukraine (pp. 02SAMA16-1 – 02SAMA16-5). Sumy, Ukraine: IEEE. https://doi.org/10.1109/NAP51477.2020.9309696

Lee, J., Park, H. J., Chai, S., Kim, G. R., Yong, H., Bae, S. J., & Kwon, D. (2021). Review on quality control methods in metal additive manufacturing. *Applied Sciences, 11*(4), 1966. https://doi.org/10.3390/app11041966

Legutko, S. (2018). Additive techniques of manufacturing functional products from metal materials. *IOP Conference Series: Materials Science and Engineering*, *393*, 012003. https://doi.org/10.1088/1757-899X/393/1/012003

Lesyk, D., Martinez, S., Dzhemelinkyi, V., & Lamikiz, A. (2020). Additive manufacturing of the superalloy turbine blades by selective laser melting: surface quality, microstructure and porosity. In: I. Karabegović (Ed.), *New Technologies, Development and Application III. NT 2020. Lecture Notes in Networks and Systems, 128* (pp. 267–275). Cham: Springer. https://doi.org/10.1007/978-3-030-46817-0_30

Lesyk, D., Martinez, S., Mordyuk, B., Dzhemelinskyi, V., & Lamikiz, A. (2019, September). Surface finishing of complexly shaped parts fabricated by selective laser melting. In V. Tonkonogyi et al. (Eds.), *Advanced Manufacturing Processes Selected Papers from the Grabchenko's International Conference on Advanced Manufacturing Processes (InterPartner–2019),* September 10–13, 2019, Odessa, Ukraine, (pp. 186–195). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-40724-7_19

Liu, J., Xu, Y., Ge, Y., Hou, Z., & Chen, S. (2020). Wire and arc additive manufacturing of metal components: a review of recent research developments. *The International Journal of Advanced Manufacturing Technology*, *111*, 149–198. https://doi.org/10.1007/s00170-020-05966-8

Masiuchok, O., Iurzhenko, M., Kolisnyk, R., Mamunya, Y., Godzierz, M., Demchenko, V., ... & Shadrin, A. (2022). Polylactide/Carbon black segregated composites for 3D printing of conductive products. *Polymers*, *14*(19), 4022. https://doi.org/10.3390/polym14194022

Matviichuk, V., Nesterenkov, V., & Berdnikova, O. (2022). Determining the influence of technological parameters of the electron-beam surfacing process on quality indicators. *Eastern-European Journal of Enterprise Technologies*, *1*(12(115), 21–30. https://doi.org/10.15587/1729-4061.2022.253473

Meiners, W., Wissenbach, K., & Gasser, A. (1998). Shaped body especially prototype or replacement part production. *EU Patent No. DE19649865C1*. München: Deutsches Patent- und Markenamt. Retrieved from https://patents.google.com/patent/DE19649865C1/en

Moeinfar, Kh., Khodabakhshi, F., Kashani-bozorg, S. F., Mohammadi, M., & Gerlich, A. P. (2022). A review on metallurgical aspects of laser additive manufacturing (LAM): Stainless steels, nickel superalloys, and titanium alloys, *Journal of Materials Research and Technology*, *16*, 1029–1068. https://doi.org/10.1016/j.jmrt.2021.12.039.

Murr, L., Gaytan, S., Ramirez, D., Martinez, E., Hernandez, J., Amato, K., … & Wicker, R. (2012). Metal fabrication by additive manufacturing using laser and electron beam melting technologies. *Journal of Materials Science & Technology*, *28*(1), 1–14. https://doi.org/10.1016/S1005-0302(12)60016-4

NASA. (2017). Rocket engine injector manufactured with 3-D printing machine. *The National Aeronautics and Space Administration*. Retrieved from https://www.nasa.gov/exploration/systems/sls/multimedia/gallery/3d_printer_2.html

Optics.org. (2018, Mar 20). NASA improves 3D-printing for faster, cheaper nozzles. *SPIE Europe*. Retrieved from https://optics.org/news/9/3/27

Paton, B. E., & Kubasov, V. N. (1970). Eksperiment po svarke v kosmose [Experiment on welding in space]. *Avtomaticheskaya svarka – Automatic Welding*, (5), 7–12 [in Russian].

Paton, B. E., & Lapchinskij, V. F. (1998). *Svarka i rodstvennye tehnologii v kosmose. Osobennosti i perspektivy [Welding and related technologies in space. Features and prospects]*. Kyiv: Naukova Dumka [in Russian].

Paton, B. E., Nazarenko, O. K., Chalov, V. I., Neporozhnij, Y. V., Lebedev, V. K., & Zaruba, I. I. (1971). Features of equipment and processes of electron beam welding and cutting in space. *Avtomaticheskaya svarka – Automatic Welding*, (3), 3–8 [in Russian].

Pelz, J. S., Ku, N., Meyers, M. A., & Vargas-Gonzalez, L. R. (2021). Additive manufacturing of structural ceramics: a historical perspective, *Journal of Materials Research and Technology, 15,* 670–695. https://doi.org/10.1016/j.jmrt.2021.07.155

Prinz, F. B., Atwood, C. L., & Aubin, R. F. (1997). *JTEC/WTEC panel report on rapid prototyping in Europe and Japan. Volume 1: Analytical chapters* (No. DOE/ER/30259-T1). Baltimore, MD (United States): Loyola College, International Technology Research Institute.

Ramola, M., Yadav, V., & Jain, R. (2019). On the adoption of additive manufacturing in healthcare: A literature review. *Journal of Manufacturing Technology Management*, *30*(1), 48–69. https://doi.org/10.1108/JMTM-03-2018-0094

Rodrigues, T. A., Duarte, V., Miranda, R. M., Santos, T. G., & Oliveira, J. P. (2019). Current status and perspectives on wire and arc additive manufacturing (WAAM). *Materials, 12*, 1121. https://doi.org/10.3390/ma12071121

Romanova, T., Stoyan, Y., Pankratov, A., Litvinchev, I., Plankovskyy, S., Tsegelnyk, Y., & Shypul, O. (2021). Sparsest balanced packing of irregular 3D objects in a cylindrical container. *European Journal of Operational Research*, *291*(1), 84–100. https://doi.org/10.1016/j.ejor.2020.09.021

Sachs, E., Cima, M., & Cornie, J. (1990). Three-dimensional printing: rapid tooling and prototypes directly from a CAD model. *CIRP Annals, 39*(1), 201–204. https://doi.org/10.1016/S0007-8506(07)61035-X

Schlett, J. (2023, January). Lasers shape a new future for additive manufacturing of metal parts. *Photonics Media*. Retrieved from https://www.photonics.com/Articles/Lasers_Shape_a_New_Future_for_Additive/a68560

Schwab, S., Selin, R., & Voron, M. (2023). Welding materials for TIG welding, surfacing, and WAAM technology of titanium alloys. *Welding in the World*, *67*(4), 981–986. https://doi.org/10.1007/s40194-023-01464-z

Serin, G., Kahya, M., Unver, H. O., Gulec, Y., Durlu, N., & Erogul, O. (2016). A review of additive manufacturing technologies. In *Proceeding the 17th International Conference on Machine Design and Production*, 12–15 July 2016, Bursa, Turkiye (pp. 1–18). Retrieved from https://www.researchgate.net/profile/Hakki-Ozgur-

Unver/publication/322745252_A_REVIEW_OF_ADDITIVE_MANUFACTURING_TECHNOLOGIES/links/5a6cacd4a6fdcc317b17c4ad/A-REVIEW-OF-ADDITIVE-MANUFACTURING-TECHNOLOGIES.pdf

Shelyagin, V., Bernatskyi, A., Siora, O., Nabok, T., Shamsutdinova, N., & Sokolovskyi, M. (2021). Historical review of technological CO_2 lasers development, manufacturing and operation stages at E. O. Paton Electric Welding Institute of the NAS of Ukraine. In *2021 IEEE 3rd Ukraine Conference on Electrical and Computer Engineering (UKRCON)*, 26–28 August 2021, Lviv, Ukraine, (pp. 589–593). https://doi.org/10.1109/UKRCON53503.2021.9575940.

Shelyagin, V., Krivtsun, I., Borisov, Yu., Khaskin, V., Nabok, T., Siora, A., … & Nedej, T. (2005). Laser-arc and laser-plasma welding and coating technologies. *Avtomaticheskaya Svarka– Automatic Welding*, (8), 49–54.

Shockey, H. (1930). Machine for reclaiming worn brake drums. *US Patent No. US1886503A*. Washington, DC: U.S. Patent and Trademark Office. Retrieved from https://patents.google.com/patent/US1886503A/en.

Singh, R., Gupta, A., Tripathi, O., Srivastava, S., Singh, B., Awasthi, A., ... & Saxena, K. K. (2020). Powder bed fusion process in additive manufacturing: An overview. *Materials Today: Proceedings*, *26*(2), 3058–3070. https://doi.org/10.1016/j.matpr.2020.02.635

SLM Solutions. (2023). Selective laser melting solutions for healthcare applications. *SLM Solutions*. Retrieved from https://www.slm-solutions.com/industries/healthcare/

Soller, S., Barata, A., Beyer, S., Dahlhaus, A., Guichard, D., Humbert, E., … & Zeiss, W. (2016). Selective laser melting (SLM) of Inconel 718 and stainless steel injectors for liquid rocket engines. In *2016 SPACE PROPULSION Conference*, 02–06 May 2016, Rome, Italy (SPC2016_312478, pp. 1–10). Paris: 3AF – Association Aéronautique et Astronautique de France.

SpaceX. (2014). SpaceX launches 3D-printed part to space, creates printed engine chamber for crewed Spaceflight. *SpaceX*. Retrieved from http://www.spacex.com/news/2014/07/31/spacex-launches-3d-printed-part-space-creates-printed-engine-chamber-crewed

Steigerwald StrahlTechnik. (2023). History of electron beam technology. *Steigerwald StrahlTechnik*. Retrieved from https://www.sst-ebeam.com/en/electron-beam-technology/history-of-eb-technology.html

Strelko, O. H., Pylypchuk, O. Ya., & Berdnychenko, Yu. A. (2019). The fiftieth anniversary of the first space welding experiment. *Space Science and Technology*, *25*(5), 76–84. https://doi.org/10.15407/knit2019.05.076

Strelko, O., Pylypchuk, O., Berdnychenko, Yu., Hurinchuk, S., Gamaliia, V., & Sorochynska, O. (2019). Historical milestones of electrotechnical equipment creation for active experiments in the Near-Earth Space by Ukrainian scientists. In *2019 IEEE 2nd Ukraine Conference on Electrical and Computer Engineering (UKRCON)*, 02–06 July 2019, Lviv, Ukraine, (pp. 1229–1234). Lviv: IEEE. https://doi.org/10.1109/UKRCON.2019.8879983

Strelko, O. (2021). Stages of development, improvement and application of equipment for welding in space, created with the participation of Ukrainian scientists. *Studia Historiae Scientiarum, 20*, 263–283. https://doi.org/10.4467/2543702XSHS.21.010.14041

Trajković, I., Rakin, M., Milošević, M., Mitrović, N., Travica, M., Sedmak, A., & Medjo, B. (2023). Selective laser sintered Pipe Ring Notched Tension specimens for examination of fracture properties of pipeline materials. *Engineering Fracture Mechanics, 292*, 109573. https://doi.org/10.1016/j.engfracmech.2023.109573

Ujiie, A. (1971). Method of and apparatus for constructing substantially circular cross section vessel by welding. *US Patent No. US3558846*. Washington, DC: U.S. Patent and Trademark Office. Retrieved from https://patents.google.com/patent/US3558846A/en

Wohlers, T., & Gornet, T. (2016). History of additive manufacturing. *Wohler's Report 2016*. Washington, USA: ASTM International. Retrieved from https://wohlersassociates.com/wp-content/uploads/2022/08/history2016.pdf

Yuan, L., Ding, S., & Wen, C. (2019). Additive manufacturing technology for porous metal implant applications and triple minimal surface structures: A review. *Bioactive Materials, 4*, 56–70. https://doi.org/10.1016/j.bioactmat.2018.12.003

Zavdoveev, A., Klapatyuk, A., Karasevska, O., Baudin, Th., Rogante, M. Pozniakov, V., & Gaivoronskii, O. (2023). X-ray analysis of the microstructure of the wire arc additively manufactured high entropy alloy. In *12th International Conference on Mechanical Technologies and Structural Materials, MTSM 2023*, 21–22 September 2023, Split, Croatia, Issue 60, (pp. 329–334). Split, Croatia: University of Split. Retrieved from http://www.strojarska-tehnologija.hr/img/pdf/Conference_Proceedings_MTSM_2023.pdf

Zavdoveev, A., Pozniakov, V., Baudin, T., Kim, H. S., Klochkov, I., Motrunich, S., ... & Skoryk, M. (2022). Optimization of the pulsed arc welding parameters for wire arc additive manufacturing in austenitic steel applications. *The International Journal of Advanced Manufacturing Technology, 119*(7–8), 5175–5193. https://doi.org/10.1007/s00170-022-08704-4

Zhang, W., Xu, Y., Shi, Y., Su, G., Gu, Y., & Korzhyk, V. (2022). Intergranular corrosion characteristics of high-efficiency wire laser additive manufactured Inconel 625 alloys. *Corrosion Science, 205*, 110422. https://doi.org/10.1016/j.corsci.2022.110422

Zielinski, P. (2021, October 13). The way ahead for wire arc additive manufacturing. *Additive Manufacturing*. Retrieved from https://www.additivemanufacturing.media/articles/the-way-ahead-for-wire-arc-additive-manufacturing

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Огляд розвитку адитивних технологій металів

Анотація. *Дана робота присвячена вивченню прогресу та сфер використання технологій адитивного виробництва – від перших теорій пошарового виробництва до сучасних технологій. Технології адитивного виробництва – одні з найбільш стрімко розвиваючихся та зберігають значний інтерес наукової спільноти через те, що вони представляють собою як альтернативний шлях виготовлення для існуючих конструкцій, так і відкривають можливості до розробки нових конструкцій з комплексністю структури, недосяжною для традиційних технологій. Оглядаючи історію розвитку та впровадження різних технологічних процесів адитивного виробництва для металів, було знайдено, що існує пробіл у складанні комплексної картини загального розвитку технологій адитивного виробництва у металургії. Для кращого розуміння та систематизації знань про адитивного виробництва, а також для відповіді на ряд розповсюджених питань щодо даних технологій, було проведено аналіз публічно відомих знань, щодо їх історичних застосувань у провідних країнах світу. Було розглянуто ряд таких технологій адитивного виробництва, як дугове з використанням дроту адитивне виробництво, селективне лазерне спікання, селективне лазерне плавлення, електронно-променеве плавлення, а також лазерне сітчасте формування. Дослідження фокусувалось на розробках, що проводились різними країнами світу в 20 та 21 століттях вченими таких країн, як США, Великобританія, Франція, Німеччина, Японія, Канада, СРСР та інших. Було розглянуто основні документи для початкових дослідницьких зусиль для кожного сімейства процесів адитивного виробництва та різних застосувань даних технологій – від топографії та стереолітографії, до сучасної медицини з авіакосмічною індустрією, обговорено їх основні висновки, прориви та проблеми. Було проведено аналіз та класифікацію робіт, які розглядають розвиток різних технологічних процесів та їх впровадження. У результаті проведеного аналізу було запропоновано систематизований підхід до створення комплексної схеми розвитку адитивних технологій, пов'язаних з розвитком технологій у різних руслах.*

Ключові слова*: адитивні технології; історія; класифікація; 3Д-друк; селективне лазерне плавлення; металеві вироби*

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Activities of Professor Tomasz Rylski (1838–1924) in the birth and development of tests of agricultural machines in the second half of the 19th century

Abstract. *The aim of the study is a comprehensive assessment of the activity, scientific and creative achievements of Professor Tomasz Nikodem Ścibor-Rylski in the development of the field of testing agricultural machines in the second half of the 19th century. To achieve the aim of the study, the principles of historicism, scientificity and objectivity of coverage of historical phenomena and events were used based on the application of the historical-scientific method, methods of analysis and generalization. For the first time, a number of archival documents were introduced into scientific circulation, which shed light on the scientist's activities in the field of testing agricultural machines. In the article, based on archival data, the available creative work of the scientist, the main stages of his activity in the issue of the origin and formation of tests of agricultural machines and tools are updated. The activities of Professor T. Rylski contributed to the birth of the scientific foundations of agricultural tests, the formation of the principles of rational use of agricultural equipment by farmers of the Austro-Hungarian Empire. The professor's long-term participation in various agricultural exhibitions and competitions led to the laying of the foundations for the creation of the first agricultural testing station in Dublyany on the territory of western Ukraine. Justifying the need to create a test station, T. Rylski relies on the importance of the transition from the "exhibition" method of testing agricultural machines to testing at specialized stations. The scientist believed that it is the scientific approach to testing that will contribute to increasing the efficiency of the use of agricultural equipment and reducing errors during its operation. The formation of the Dublyany Higher Agricultural School, as a powerful scientific and testing center on the territory of modern Ukraine and Poland, is connected with the scientist's name. The creative heritage of T. Rylski indicates his invaluable contribution to the emergence of the scientific foundations of agricultural equipment testing. Therefore, it is precisely the absence of a special comprehensive study of scientific, creative and organizational activity of a scientist in the historiography of science and technology that determines the relevance of this study.*

Keywords: *Tomasz Rylski; testing of agricultural machines; testing station of agricultural machines and tools; analysis of the structure of agricultural tools; agricultural industry; exhibitions of agricultural machines*

Introduction.

The problem of testing agricultural machines has always been in the field of view of researchers and scientists. This is especially relevant for the period of formation of this branch of agricultural science. A prominent figure here is the professor of the *Dublyany* Higher Agricultural School – Tomas Rylski (Fig. 1). The relevance of the selected research topic is determined by the "white spots" in the historiography of science and technology, which relate to the professor's testing activities. The need to conduct the most complete and independent analysis of the scientist's contribution to the origin and development of tests of agricultural machines in the second half of the 19th century.

Figure 1. Professor of the Dublyany Higher Agricultural School Tomas Nikodem Scibor-Rylski (photo by S. Bizanskyi, 1882).

In the second half of the 19th century, quite a few researchers devoted their works to the issue of testing agricultural machines. In particular, Yu. O. Sokolovych-Altunina devoted her own research to determining the place of the Dublyan agricultural school in the development and establishment of agricultural science and research in Galicia (Sokolovych-Altunina, 2010).

T. B. Kharyk reveals the problems of the formation of agricultural research in Eastern Galicia in the middle of the 19th and early 20th centuries. on the example of the Dublin Agricultural School (Kharyk, 2016).

Equally important is the work of O. O. Visyn (2021), which examines the development of the trial case in Galicia at the turn of the 19th and 20th centuries. The author describes in detail the stages of development of agricultural machinery tests at the Dublyany agricultural school, partially paying attention to the contribution of Professor T. Rylski to the process of establishing the test station in Dublyany. She notes that "participation in agricultural machine competitions at many International Agricultural Machinery Exhibitions gave Professor Rylski an opportunity to familiarize himself with European achievements. That's why he was the first initiator of the creation of the first in the region of Dublyany experimental station of agricultural machines, where it would be possible to assess the quality and forecast the needs of agricultural machinery".

The creative path and activities of the scientist are fragmentarily covered in the works of Yuriy Tokarskyi "Engineering and technical studios in Dublyany" (Tokarskyi, 2008), "Professors, associate professors and assistants of educational and scientific institutions in Dublyany (1856–1947)" (Tokarskyi, 2004), "Dublyany: History of Agrarian Studies (1856–1946)" (Tokarskyi, 1996). Tadeusz Woskowski wrote about T. Rylski as the founder of the mechanics of agricultural work in Dublany in his work "Dzieje studiów rolniczo-lasowych w ośrodku lwowsko-dublańskich w opracowaniu Tadeusza Wośkowskiego" (Woskowski, 2011). Lyubov Pinda in the work "Agroengineering research in the Dublyany Scientific Center of the end XIX – beginning XX" (Pynda, 2020) conducted an analysis of T. Rylski's work "Podręcznik mechaniki rolniczej dla gospodarzy praktycznych: wybrák i użyce żyęty i machin rolniczych" (Rylski, 1877). The achievements of Professor T. Rylski in the development of agricultural mechanics are highlighted in the work of Mykhailo Klymenko "Contribution of Professor Tomas Rylski (1838–1924) to the development of agricultural mechanics in the second half of the 19th century" (Klymenko, 2022).

In the modern history of science and technology, extremely little attention has been paid to the figure of Professor T. Rylski. For the first time, the scientist's biography was published in the 33rd volume of the "Polski Słownik Biograficzny" (Markiewicz, 1992). It is worth noting that there are quite a lot of "white spots" in this work, in particular, those related to the place and date of birth of the scientist, information about T. Rylski's parents, and his bibliography.

A small mention of the activity of the professor at the Dublyany Higher Agricultural School is present in the work "Przeglad tygodniowy (1866–1876), teksty, analizy, komentarze", which was published under the editorship of A. Janicka (Janicka, 2019, p. 156). In the work of F. Kucharzewski "Piśmenstwo techniczne polskie" there is some biographical information about Professor T. Rylski, which, however, does not give a general idea of the scientist's life and creative path. It is stated in the work that during the preparation of the publication for printing, the publication "Assembly machine, its history, design and use. A guide for technicians and farmers" authors Marczewski, Strzelecki and Pietraszek use scientific articles by T. Rylski, when analyzing the structure of harvesters and harvesting machines (Kucharzewski, 1921, pp. 397–398). In addition, a fragmentary bibliography of T. Rylski is mentioned in the work "Bibliografia Polska: XIX. stólecia dopętsenia (P–Ż), Volume 7" (Estreicher, 1882, pp. 105–106).

One of the contemporaries of Professor S. Surzycki in the work "Die landwirtschaftliche Betriebsmittel in ihrem Einfluense auf den Zustand und die Entwickelung des Grossgrundbesitzes, sowie der Bauernwirtschaften in Galizien" presents T. Rylski's conclusions about the errors of plow operation, using the scientist's direct language (Surzycki, 1896) .

In his own work, K. Bartoszewicz talks about T. Rylski's speech at the celebration of the anniversary of the constitution, which gives an idea of the scientist as a person with deeply patriotic views, who loyally respects and supports his own Motherland (Bartoszewicz, 1891, p. 173). About T. Rylski as a popularizer of agricultural knowledge, O. Leixner notes in his work (Leixner, 1895, p. 525). In "Rolnik: czasopismo dla gospodarzy wiejskich", the editors of the newspaper note that at the exhibition of agricultural machines in Przemyśl, T. Rylski gave a very simple and accurate method of evaluating machines (Rolnik, 1870).

Analyzing the above sources, we can come to the conclusion that the contribution of Professor T. Rylski to the practical study and research of agricultural machines is not covered enough and needs to be revised.

The aim of research is to conduct an analysis of scientific and practical activities and the contribution of Professor Tomasz Rylski to the testing of agricultural machines and equipment. Determining the place and role of this figure in establishing the practical foundations of testing agricultural machines.

Research Methods.

The methodological component of this study includes the principles of historicism, scientificity, and objectivity in covering the events of the past, which are based on the application of the historical-scientific method, methods of analysis, and generalization. An important component of this research is the use of research methods: general scientific, interdisciplinary, problem-chronological, comparative-historical.

Results and Discussions.

The beginning of the trial activity of Professor T. Rylski can be considered with certainty on September 12, 1868, when, by the decision of the Committee of the Economic Society (Rolnik, 1868), he was appointed to a permanent position at the Dublin school. Since the field of scientific interests of the scientist was, in particular, issues of mechanization of agricultural work, Tomasz Rylski begins painstaking work on studying the mechanical features of agricultural machines.

In July 1869, Professor T. Rylski published his own report in the newspaper "Rolnik" (Rylski, 1869) about his visit to the technical department at the agricultural and industrial exhibition in Krakow. The scientist writes that this exhibition cannot be called "epochal", although it presented some novelties of agricultural machines. Forming the report, the author divides the equipment presented at the exhibition by types of work performed and purpose.

Evaluating the presented plows, T. Rylski pays special attention to "Camecnr-Vereirispflüge" – a full-metal wheelless plow presented by Werner from Javornik (Silesia), noting that in general the product is not bad, but has a serious drawback. It consists in the fact that half of the wall is deflected from the end of the blade to the right. This creates a shoe on the plow, which leads to the device twisting during plowing and its jumping out of the furrow. At the same time, another reversible plow of the same manufacturer is much better to use. Also, the professor did not ignore the English and American models of plows, praising them highly. Regarding Polish plows, the author was much more critical, emphasizing some of the shortcomings of their design, in particular, regarding too short rakes, which makes it difficult to adjust the depth and width of the furrow. Although at the same time, T. Rylski states that the price of domestic plows is quite "democratic", and they deserve to be distributed in the country. At the exhibition, various types of cultivators and harrows were presented, the author does not dwell on them in detail, while noting that he cannot properly assess their advantages and disadvantages due to the insufficient amount of test data.

The professor presents a detailed analysis of the design features of planters. A special place in the report was given to the analysis of the design of the "Cegielski" planter. The author considers its system to be the best, as it is designed on telescopic tubes. The professor considers such planters more practical than with rubber tubes or Garetto funnels. As the author noted, other planters were equipped with the "Victoria-Drill" spoon system and Garetto types of funnels. "Zimmerman" planters were distinguished by a tool for adjusting the shaft for changing the sowing rate, but T. Rylski believes that this design will be too difficult to operate. Also, interesting is the fact that a large number of planters were so heavily painted that even the gears are covered with varnish. The author believes that this was done in order to hide the low quality of the equipment. One of the novelties was a four-row beet harvester, the idea of creating which, as the author notes, is not bad. But since this planter had as many as twelve wheels, its operation will cause certain difficulties.

Next, the scientist gives a description of the design of the newly presented harvesters, describing their advantages and disadvantages. The professor especially "got" their manufacturers, because they gave the teeth an irregular shape, which, as he believed, is a significant obstacle for the widespread use of such reapers in practice. Criticism of manufacturers of potato diggers who did not conduct proper tests of their equipment is presented. A description of combined steam mills, forage harvesters, threshers was carried out. The scientist notes that domestic manufacturers are not making progress in some issues of thresher manufacturing, especially the number of revolutions of the drum. In turn, when threshers of newer English, French and German designs have from 800 to 1000 drum revolutions per minute, domestic ones barely produce from 536 to 600 drum revolutions per minute. To T. Rylski's remark to the producers, he was answered that when the speed of rotation increases, the grain breaks, and in order to prevent this from happening, it is possible to change the structure of the chains and concavities of the drum. Tomasz Rylski believes that in this case it is worth using the Clayton-Szuttleworth drum design, which would reduce the percentage of lost grain. From this we can conclude that the professor had deep knowledge about the design features of agricultural equipment. During the exhibition, he gives clear recommendations to manufacturers to improve the structure of threshers.

It will not be superfluous to say that in this report, Professor T. Rylski lays the scientific foundations for testing agricultural machines. At the end of the report, the scientist makes several important comments on the testing methodology. The professor admits that the testing of agricultural machines, if carried out carefully and with knowledge of the matter, can bring great benefits to agriculture. T. Rylski undertook to promote the spread of high-quality agricultural tools and the exclusion of unnecessary ones, because he believed that in this regard the farming community was "wandering" without any guidance. The scientist constructively criticizes the tests made at the exhibition in Krakow. The tests conducted there could not convince anyone of the quality of this or that tool, as they were conducted with significant violations of the procedure. It is emphasized that the exhibition committee did not test the harvesters, which, according to the professor, will have a very negative impact on the agriculture of Galicia. Since every year there is a growing shortage of workers during the harvest, and the only way out of the situation is to use machines. By purchasing untested or unusable agricultural machinery, farmers will experience a significant reduction in productivity. Also, as the scientist notes, thresher tests were organized by manufacturers arbitrarily and did not provide any grounds for a fair evaluation of the equipment.

As for the tests of plows, T. Rylski does not single out anything better here. The author notes that a clear procedure must be followed: division of plows into classes, assessment of the performance of each specific plow, assessment of the amount of expended forces, assessment of structural and technical performance. When conducting testing, it is not possible to test several instruments at the same time, because in this way the attention of the judging panel will be scattered and the assessment will be inaccurate.

The judging panel paid no attention to any of these points, they plowed with three plows at a time, one directly behind the other, so that the furrow of one plow was covered by the furrow of another. When one plow stopped, others stopped, so it was impossible to judge the quantity and quality of the work done. T. Rylski was very disappointed by the lack of a dynamometer at the tests.

Finally, as the author points out, there should be a field specially adapted to such tests. The field should be demarcated so that the audience does not greatly interfere with the use of weapons. What was shocking was that the audience did the tests themselves. According to the methodology, the control of tools during tests should be entrusted to experienced people, but the same ones, and by no means representatives of manufacturers. It is emphasized that tests conducted with violations do not bring any benefit, neither to producers, nor to farmers.

From July 2 to 5, 1870, Professor Tomasz Rylski visited an agricultural exhibition in the city of Rzeszów (now the territory of Poland). One of the features of this exhibition was the extremely low number of presented exhibits and equipment, which is explained by the lack of exhibition space. In the February issue of the newspaper "Rolnik" for 1871, the professor publishes a report on this visit (Rylski, 1871). As the author points out, the largest collection of machines was exhibited by the "Peterseim" company from Krakow, whose products show that their production is on the rise. At the same time, the professor criticizes the mechanical features of their products. The scientist provides recommendations for improving the design of the equipment – when the thresher is unfolded, the transmission of movement energy from the drive is not carried out correctly, which leads to the fact that the rod of the horse drive makes too few revolutions per minute. In order to get the required drum rotation speed, it was necessary to install non-proportional pulleys so that the pulley on the horse drive rod was larger and the pulley on the drum shaft was smaller. Also, the scientist points to a too tight drum belt, which creates unnecessary additional resistance.

Forage harvesters of the "Peterseim" company also, from the scientist's point of view, needed refinement, because they had a drive wheel with concave knives, which did not ensure high-quality cutting of the tops. T. Rylski devoted part of the report to the analysis of the design of the "Ceres" harvester, and also provided recommendations for its improvement. The author noted that this harvester is multifunctional. Its main feature was the correct placement of the front headstock on the extension of the axis of the running wheel and a good distribution of the machine's weight. According to the report, the harvester weighed only 8.5 tons. (about 425 kg). T. Rylski expresses significant comments regarding its design. The use of a cast-iron rudder and rake has been criticized, as it does not provide sufficient wear resistance during long-term use. Possible damage will entail significant difficulties in repair and costs for replacing components. Also, the features of the milling cutter, which is significantly moved forward, are emphasized.

In addition, the professor provided recommendations to some manufacturers in the report. "Eliasiewicza" dyers are recommended to focus on the production of threshers, because they are the best. Both the state and the enterprise would benefit from this. Plows for wrapping, plows with a cylindrical blade of the company "Jodłowa" are rated very low, the author considers them only initial attempts to create such machines. T. Rylski considers the "Mogilańskie" plows to be good, but expresses a desire to make small corrections to the design, for example, the screws in the cover wall should be recessed, it is recommended to lighten the frame and pay attention to the strength of the joints.

Paying attention to the English rake "Howarda", T. Rylski did not pass by the criticism of the national manufacturer, believing that domestic factories produce not enough rakes, strive only for lightness and cheapness, therefore they make them of too low quality. The iron wheels used are the most subject to wear, and being quite thin, they bend when the car is turned, the wrought iron teeth not being as wear-resistant as the steel ones.

In the January issue of the newspaper "Rolnik" from 1873, a report by Professor Tomasz Rylski on the trials of reapers, which took place between July 31 and August 2, 1872, in Gostyvice near Prague (Czech Republic) was published (Rylski, 1873a).

Covering this event, T. Rylski pointed out that there were so many farmers and other interested persons that separate trains had to be sent to transport visitors from Prague. 28 machines were applied for the competition, of which six were not admitted due to late arrival, one, as the property of the ministry, was not submitted for awarding, another six were not provided for testing at all. 9 American, 4 English and 2 German machines were tested. Only one of them was declared exclusively for horse harness, the others for draft horses or oxen. In the process of testing, horse teams performed work on one-hectare plots, and with ox teams – on one and a half hectares. In addition, the professor talks about the weather conditions, notes the high methodical level of conducting the tests, describes in detail the method of conducting and the conditions for determining the winners. At the same time, the professor expresses certain doubts about some of the conditions of the event. In particular, he does not agree with the fact that the cheapness of the car (along with other attributes) is counted as an unconditional advantage, although this should take place only under certain conditions and have clearly defined limits. Neglecting this important aspect can lead to abuse, since the cost of the equipment is set exclusively by the manufacturers, and can be revised at any time. In addition, the professor points to the absence of a dynamometer during the tests and the haste during their conduct, since 4 cars were tested in one pass, which distracted the jury's attention. Next, the author provides his own assessment of the presented harvesters, analyzing their structure, identifying the disadvantages and advantages of specific specimens. The scientist speaks positively about the "Royal" harvesters, which are imitations of new models of American harvesters. He is impressed with the lubrication devices of the new design harvester, which he thinks should be very practical to use, if they contain enough oil for 3 hours of work.

T. Rylski focuses on one more development – the harvester of the M. Hofherra system, which is an analogue of the English harvester. The professor notes that when he was present at the assembly of this machine, he discovered that the manufacturer assembled it using only a wrench. The improvements that this company made to the original design are very practical, combining the advantages of the original design and the maximum correction of its shortcomings.

An exhibition in the city of Vienna (the capital of the then Austro-Hungarian Empire, now Austria) became a significant milestone in the process of scientific development of agricultural machinery testing. Professor Tomash Rylski could not ignore her either. Believing that progress in the field of mechanics can be used as a scale by which it is possible to judge the general level of civilization of peoples, T. Rylski after visiting this exhibition publishes a large-scale report in the newspaper "Rolnik". This work appeared in two issues of the publication for November and December 1873 (Rylski, 1873b; Rylski, 1873c).

Although the exhibition was not a trial, in the strict sense of the word, it presented many completely new models of agricultural equipment. As the professor points out, earlier, when machines were almost not used in agriculture, with all inventions, before they could become widespread, it was necessary to conduct a whole series of tests. The means for their implementation were almost exclusively exhibitions. Today, at least in civilized countries, such problems practically do not occur, since the spread of specialized test stations has begun. A manufacturer seeking to distribute his invention or improvement has ways of conducting this trial much more quickly without waiting for an exhibition. And the progressive farmer no longer waits for the exhibition, but makes the right choice based on the evaluation of the experimental station or the results of competitive tests. Thus, Professor T. Rylski expresses the opinion that the future of tests of agricultural machines lies only in the plane of their proper and strictly scientific evaluation. Conducting such an assessment should be carried out only at competitions (for each type of machine separately) or at experimental stations.

Touching directly on the holding of the exhibition itself, Tomasz Rylski divided his report into sections, according to the represented producing countries. The English pavilion was characterized by a huge amount of exhibited equipment. In particular, the professor gives a description of the design of the steam-powered plows presented there, gives a description of the design features of steam threshers, determining the advantages of their use. The author focuses the reader's attention on the high quality of "Howarda" rakes, recognizing the prospects and advantages of its use, and presents the method of its use. The author, having noticed the new harvester of the company "Hornsby" called "Advance", was pleasantly surprised by the new approaches to its design. A special feature is that the movable hinged rake of the harvester is placed on fixed rods and can be used turned by 90°. The operator, using an angle lever, can move them in any direction. With a free inclination of the rake, the teeth take a position parallel to the table and the rake does not lower, but only tilts the grain stalks. Among the relative advantages of this harvester, the author attributes the combination of a crank and a knife saw. Although here it is worth noting that the professor does not completely agree with the design of the transmission device. In particular, he notes that the main and gear shaft of the transmission device, which are at an angle, cause significant friction and quickly wear out the bearings. In addition, the professor analyzes machines for planting potatoes and planters, but does not indicate anything remarkable, writing that additional tests are needed for analysis.

T. Rylski notes the magnificence of the American pavilion, a large part of which is occupied by reapers. American manufacturers made a significant contribution to the spread and improvement of agricultural machinery, although there was not a variety of equipment presented at the exhibition, and most of the harvesters available were already well known. The professor pays more attention to the comparison of the characteristics of English and American models, notes that English cars are much heavier than American ones. In the process of writing the report, he ponders the reasons for this phenomenon, suggesting that it has to do with the use of different materials for the construction of the machines and the more filigree work of American manufacturers. Although he emphasizes the fact that often reducing the weight of the mechanism leads to a decrease in its wear resistance, which in his case can lead to problems with breakdowns, especially with national soil characteristics. In the future, the author notes the originality of the design of the harvesters "Aultman, Milleret Comp." and "Locke's Harvester" and compares them with each other. In addition, the professor conducted an in-depth analysis of the newly presented dynamometers.

The scientist was somewhat disappointed after visiting the Austro-Hungarian pavilion. T. Rylski pointed to a deep stagnation in the production of agricultural machines in Austria-Hungary. He emphasized the need to improve the quality of machines to the level of foreign countries, the lack of flexibility in doing business, as well as the failure to meet delivery deadlines. Being a sincere patriot of his country, T. Rylski found it difficult to observe the absence of Polish manufacturers at the well-known international exhibition. The reason for this, the professor cites the inability of many factories to withstand competition with first-class products, for example, English production. Nevertheless, the author singled out several products of the Austrian manufacturers "Claytonet Shuttleworth" and "M. Hofherr", highlighting generally good production quality and decent test results of their machines. A collection of plows was also presented, which immediately won the attention of farmers. T. Rylski points out that many of them are manufactured at the proper level, and the cost is affordable for the average Polish farmer.

A special place in the scientist's report was awarded to the German pavilion. The author accompanied the description of the presented agricultural machines with several drawings to better explain their design features. It is determined that the main aspiration of German manufacturers is to maintain a level of quality in the manufacture of machines that English products would not be able to withstand. Professor T. Rylski notes the significant progress of German mechanical engineering since the last similar exhibition in Paris, but the technical level of the proposed machines, in his opinion, leaves much to be desired. The author carefully analyzes the construction of agricultural machines, presents, in his characteristic manner, the advantages and disadvantages. Fertilizer machines shown at the exhibition were criticized by the professor due to the impracticality of the proposed design. The professor's attention was drawn to the "Weil" threshers from Frankfurt, which are characterized by low cost and lightness, but have a rather weak structural performance. T. Rylski made an interesting remark about the threshing device. The handle system used with both these and many other German-made threshers was specified by the manufacturers as an entirely new development. Although in fact it was already used in Europe more than

20 years ago and many people refuse it. The manual system does not provide any advantages, on the contrary, it creates many inconveniences in practical use.

The scientist did not ignore the products of some other countries. "Cichocki" plows are characterized by a good design. These plows, if well made, deserve rapid adoption among the farming community, especially this manufacturer's double hull plows. Other specimens presented at the exhibition, according to the professor, only prove that in some countries, for example, Russia, Italy, agricultural mechanics is still in its infancy.

In the period of the 70s of the 19th century in the Dubliany Higher Agricultural School, serious scientific research and testing of agricultural machines began, although fully adapted to practical requirements from the point of view of theory (Surzycki, 1928). This was largely made possible thanks to the activities of Professor T. Rylski, his experience and the newest approach to the issue of studying construction, practical features of the use of agricultural machines and tools.

The establishment of a test experimental station of agricultural machines was a kind of turning point in the activity of the Dublyany research center. The first mention of this station dates back to July 1874, when the newspaper "Rolnik" published an announcement about the start of its operations (Rolnik, 1874). It can be assumed that this was one of the first such testing stations in Ukraine. Professor T. Rylski took the most active part in its creation and activity. In September 1874, the professor submitted his own article to the newspaper "Rolnik" with reasons for the need to create and operate such a station (Rylski, 1874). T. Rylski believed that agriculture is changing, as opposed to manual peasant labor, machines are coming that are driven by the power of animals, steam, etc. In this connection, there is an urgent need to form a strictly scientific approach to the issue of choosing agricultural machines and tools. More than once, the professor, with his works, draws the attention of farmers to the fact that the useful use of agricultural machinery depends on the appropriate reasoned choice and correct use. T. Rylski points out that currently in Poland, farmers who need to buy agricultural machinery rely either on their own knowledge and experience when choosing, or try to find out the advantages and disadvantages of using one or another technique by trial and error. Or, in the best case, use the test protocols conducted by the manufacturers themselves for selection. These considerations, which are guided by the choice of machines, very often become the cause of painful disappointments and material losses, which, in turn, slow down the development of agriculture. And therefore it is easy to understand that the choice made on this basis is at least risky. The same applies to the option when tools are chosen on the recommendation of friends, colleagues. After all, according to the professor, in such a situation it is necessary to remember – "what is good for one person is not always good for another". Also, in the article, the scientist talks about the existing methods of testing agricultural machines at agricultural exhibitions, competitions and research stations.

Without rejecting the advantages of any of the test models, T. Rylski was convinced that the tests conducted by research stations are the best and most informative. It is not enough for a farmer to know that this tool or machine is the best among a number of others. For practical use, the farmer must know the value of each machine, each design separately, and that this design is professionally evaluated from a technical and agricultural point of view. He must be absolutely sure of the advantages of using the technique in his own natural conditions. In addition to the above purpose, the testing station is important for detecting errors in the manufacture, design and use of machinery, both mechanically and agriculturally, taking into account the national needs in the broadest sense, so as to draw the attention of the producers to the needs of the peasants. The aim of the experimental test station is to create a kind of intermediary body between producers and farmers, which could provide expert advice to both parties.

The station operated successfully until at least 1879, having conducted many experimental tests of the equipment. During this period, ten reports on its activities were issued (Rylski, 1879), three of them were issued by T. Rylski, which indicates his direct participation in its functioning. Although this does not negate the fact that the station later collapsed due to low subsidies (Markiewicz, 1992).

In 1882, the scientist wrote a paper on plow tests in Lundenburg (London, Great Britain) (Rylski, 1882). In his work, T. Rylski expresses the opinion that the test as a whole passed at a decent level. But at the same time, the professor expresses serious reservations about the methodology of the tests, which, as he believed, led to the distortion of the results. There were mainly two mistakes: there was not enough time to test such a large number of agricultural tools and machines, and the division of plots for cultivation was not done correctly. The test field was divided into plots of 30 acres each, then the plots were divided between the tested plows with very different types of soil, some with heavy clay soil, others with light sandy soil. This circumstance clearly affected not only the accuracy of the results of the tests themselves, but also to a large extent the amount of mechanical work performed. Also, an equally important role was played by the fact that the tests were conducted not only during the day, but also at night under artificial lighting. In addition, the scientist, in his characteristic manner, described changes in the design of plows, worked out possible features of their practical application.

In the same year, T. Rylski presented an oral report on the exhibition in Przemyśl (Rolnik, 1882) at the meeting of the Galician Economic Society. To the remarks of some participants of the meeting about certain inaccuracies, Tomasz Rylski replied that during the entire exhibition he was also busy with the work of the panel of judges. This once again confirms the high professionalism of the scientist and the demand for his professional assessments.

The year 1886 in terms of testing activities was marked for the scientist by visiting an exhibition in Chernivtsi, where both already known models of agricultural machines and new fans for grain cleaning were presented (Rylski, 1886). In his report based on the results of this event, T. Rylski provides a professional analysis of the structure of horse-powered threshers and rakes. The professor was particularly interested in the design of a single-horse chain drive, presented by K. Drossier (manufacturer from Novy Jichyn, Czech Republic). The scientist considers it not efficient enough, because the number of revolutions (about 600) of the drive disk is too small for the thresher. However, T. Rylski notes the extremely low cost of the specified structure – only 600 zlotys. In addition, the scientist touches the newly presented steam plows, evaluates changes in their design, determines the expediency and effectiveness of the changes made.

Another, no less important, stage in Tomasz Rylski's testing activity was his many years of work as a judge at exhibitions and competitions of agricultural machines. In 1876, Professor T. Rylski was appointed a member of the commission for checking and testing the device for knitting sheaves, which was presented by Erasm Zablotskyi (Rolnik, 1876). 1888 – T. Rylski was the head of the panel of judges for the assessment of agricultural machines and tools, which took place within the framework of the fifth general meeting of members of agricultural circles (Rolnik, 1888). 1894 – the scientist received a written thank you from the committee of the Galician Economic Society for participating in the national agricultural exhibition in Lviv (Rolnik, 1894). In 1900, thanks to the efforts of the professor, a competition of harvesters was organized on July 25–26, here T. Rylski was the secretary of the panel of judges (Rolnik, 1900). 1901 – panel judge at an exhibition-trial of agricultural machinery and tools for growing sugar beets in Przewodsk (Poland) (Rolnik, 1901).

A detailed analysis of the testing activities of Professor Tomasz Rylski makes it possible to assess his contribution to the development of agricultural mechanical engineering. We have established that the historiography of T. Rylski's work in the context of the development of agricultural equipment testing is represented by a number of publications. However, these works illuminate the professor's activities superficially and fragmentarily, thereby leveling the role of the scientist in the birth and development of agricultural research.

Summarizing the above, we can say with confidence that T. Rylski made an invaluable contribution to the problem of testing agricultural machines. His judging activity at many competitions, exhibitions and tests contributed to the improvement of the quality of manufactured agricultural machines and tools. Hard work and lobbying of the scientist led to the creation of the first agricultural research station in the region, which became a signpost for farmers and manufacturers of agricultural equipment. T. Rylski's visit to many national and international exhibitions contributed to the formation of a powerful scientific, research and mechanization center in Dublyany. Publication of reports by scientists on attended events helped popularize the mechanization of field work, spread new inventions and achievements of rural engineering.

Conclusions.

In this review article, based on the principle of historicism, objectivity, and scientificity, we attempted to conduct a comprehensive analysis of the contribution of

Tomasz Rylski, professor of the Dublyany Higher Agricultural School, to the issue of the origin and development of testing agricultural machines in the second half of the 19th century. This made it possible to determine the place and role of the figure of T. Rylski in establishing the foundations of the practical use of agricultural machines and equipment. In addition, the article analyzes the professor's contribution to the creation of the first agricultural machinery and equipment testing station in Dublyany on the territory of modern Ukraine. Taking into account the fact that the vast majority of researchers ignore the scientific and creative heritage of T. Rylski, the results of this study "shed light" on the activities of the scientist, who played one of the leading roles in the formation of scientifically based use of technical means for agricultural production. The conducted analysis confirms the significance of the creative achievements of Professor T. Rylski, as one of the founders of agricultural mechanics in Ukraine and Poland, which had a significant impact on the understanding of the stages of development of agricultural research in general and agricultural mechanics in particular.

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References

Bartoszewicz, K. (1891). *Księga pamiątkowa setnej rocznicy ustanowienia konstytucji 3 Maja [Commemorative book of the hundredth anniversary of the establishment of the Constitution of May 3], Vol. 2*. Krakow: K. Bartoszewicz. Retrieved from https://bc.radom.pl/Content/44186/download/ [in Polish].

Bizanskyi, S. (1882). *Tomasz Scibor Rylski*. [Photo]. Krakow. Retrieved from https://gw.geneanet.org/hikuri1?lang=nl&n=scibor+rylski&oc=0&p=tomasz

Estreicher, K. (1882). *Bibliografia polska XIX stólecia. [Lata 1800–1881.]. T. 7: (P–Ż): dopełnienia [Polish Bibliography of the 19th century. [Years 1800–1881]. Vol. 7: (P–Ż): complements]*. Krakow: Drukarnia Uniwersytetu Jagiellońskiego. Retrieved from https://archive.org/details/estreicher-bibliografia-xix-stulecia-t.-7-dopelnienia-p-z-1882/page/104/mode/2up?view=theater [in Polish].

Janicka, A. (Ed.). (2019). Bolesław Limanowski. Szkoła rolnicza w Dublanach. „Przegląd Tygodniowy" 1873, nr. 29, s. 230–231. [Bolesław Limanowski. Agricultural school in Dublany. "Przegląd Tygoniczy" 1873, no. 29, pp. 230–231.]. In A. Janicka (Ed.), *"Przegląd Tygodniowy" 1866–1876. Teksty. Analizy. Komentarze. Seria I: Pozytywiści, idee, programy. Tom II: Pismo, utopie, projekty. Część 2 ["Weekly Review" 1866–1876. Lyrics. Analyzes. Comments. Series I: Positivists, ideas, programs. Volume II: Writing, utopias, projects.*

Part 2], (pp. 154–157). Bialystok: PRYMAT. Retrieved from https://repozytorium.uwb.edu.pl/jspui/bitstream/11320/12436/1/Przegl%C4%85d%20Tygodniowy%20tom%20II%2C%20cz.%202.pdf [in Polish].

Kharyk, T. B. (2016). Vnesok Dublianskoi rilnychoi shkoly (akademii) u rozvytok silskohospodarskoi nauky i doslidnoi spravy v Skhidnii Halychyni (seredyna XIX – pochatok XX st.) [The contribution of the Dublian agricultural school (academy) to the development of agricultural science and research in Eastern Galicia (mid-19th – early 20th centuries)]. *Istoriia nauky i biohrafistyka – History of science and biography*, (1). Retrieved from https://inb.dnsgb.com.ua/2016-1/19.pdf [in Ukrainian].

Klymenko, M. B. (2022). Vnesok profesora Tomasza Rylskoho (1838–1924) u rozvytok zemlerobskoi mekhaniky druhoi polovyny XIX st. [The contribution of Professor Tomasz Rylski (1838–1924) to the development of agricultural mechanics in the second half of the 19th century]. *Istoriia nauky i biohrafistyka – History of science and biography*, (4), 31–45. https://doi.org/10.31073/istnauka202204-03 [in Ukrainian].

Kucharzewski, F. (1921). Ostatnie czasy (1875–1912) [Recent times (1875–1912)]. In *Piśmiennictwo techniczne polskie. T. 2. Mechanika z technologią mechaniczną i elektrotechniką. Technologia chemiczna [Polish technical writing. Vol. 2. Mechanics with mechanical technology and electrical engineering. Chemical Technology]*, (pp. 395–526). Warszawa: Skład główny w księgarni E. Wendego i S-ki. Retrieved from https://bcpw.bg.pw.edu.pl/Content/3871/PDF/04fkpt2_od1875.pdf [in Polish].

Leixner, O. (1895). *Wiek XIX: obraz ważniejszych wypadków na tle cywilizacji w dziedzinie historyi, sztuki, nauki, przemysłu i polityki, z licznemi ilustracyami [19th century: a picture of the most important events against the background of civilization in the fields of history, art, science, industry and politics, with numerous illustrations], Vol. 2.* Warszawa: Gebethner i Wolff. Retrieved from https://repozytorium.biblos.pk.edu.pl/redo/resources/39654/file/scans/DEFAULT/OCR_rezultaty/100000299776_A_v1_200dpi_q60.pdf [in Polish].

Markiewicz, H. (1992). Tomasz Scibor-Rylski [Tomasz Scibor-Rylski]. *Polski Słownik Biograficzny [Polish Biographical Dictionary], Vol. 33,* p. 226. Vratislavia: Zakład Narodowy im. Ossolińskich [in Polish].

Pynda, L. A. (2020). Ahroinzhenerni doslidzhennia v Dublianskomu naukovomu oseredku kin. XIX – poch. XX st. (Za materialamy fondu starodrukiv i ridkisnykh vydan NB LNAU) [Agroengineering research at the dublin research center kkin. XIX-early XX century (According to the materials of the fund of old prints and rare editions of the national library of LNAU))]. *Materialy II-oi Vseukrainskoi naukovo-praktychnoi konferentsii «Bibliotechno-informatsiine seredovyshche yak draiver zmin ta innovatsii v osviti»: do 90 richchia Naukovoi biblioteky KhNTUSH – Materials of the 2nd All-Ukrainian scientific and practical conference "Library and information environment as a driver of* *changes and innovations in education": to the 90th anniversary of the Scientific Library of the KhNTUSH*, (pp. 69–75). Kharkiv: Kharkiv Petro Vasylenko National Technical University of Agriculture. Retrieved from https://repo.btu.kharkov.ua/bitstream/123456789/13381/1/ahroinzhenerni_doslidzhennia_v_Dublianskomu_naukovomu_oseredku.pdf [in Ukrainian].

Rolnik – Farmer. (1868). 9(3), 212 [in Polish].

Rolnik – Farmer. (1870). 7(1), 28 [in Polish].

Rolnik – Farmer. (1874). 1(15), 48 [in Polish].

Rolnik – Farmer. (1876). 6(18), 347–353 [in Polish].

Rolnik – Farmer. (1882). 11(31), 128 [in Polish].

Rolnik. – Farmer. (1888). 2(42), 14 [in Polish].

Rolnik – Farmer. (1894). 23(54), 180 [in Polish].

Rolnik – Farmer. (1900). 50(63), 475 [in Polish].

Rolnik – Farmer. (1901). 20(64), 191 [in Polish].

Rylski, T. (1869). Sprawozdanie z działu machin rolniczych będących na wystawie Krakowskiej w r. 1869 [Report on the agricultural machinery section of the 1869 Krakow exhibition]. *Rolnik: czasopismo rolniczo-przemysłowe – Farmer: an agro-industrial magazine, 1*(5), 48–53 [in Polish].

Rylski, T. (1871). Sprawozdania z działu machin rolniczych na wystawie w Rzeszowie [Reports from the agricultural machinery section at the Rzeszow exhibition]. *Rolnik: czasopismo dla gospodarzy wiejskich – Farmer: magazine for rural farmers, 2*(9), 140–142 [in Polish].

Rylski, T. (1873a). Sprawozdanie z prób żniwiarek, przeprowadzonych w r. 1872 w Hostiwitz pod Pragą Czeską [Report on the harvester trials carried out in 1872 in Hostiwitz near Bohemian Prague]. *Rolnik: czasopismo dla gospodarzy wiejskich – Farmer: magazine for rural farmers*, *1*(12), 25–37 [in Polish].

Rylski, T. (1873b). Dział machin rolniczych na wystawie powszechnej w Wiedniu 1873 r [Agricultural machinery section at the Vienna Universal Exhibition 1873]. *Rolnik: czasopismo dla gospodarzy wiejskich – Farmer: the magazine for rural farmers*, *5*(13), 306–317 [in Polish].

Rylski, T. (1873c). Dział machin rolniczych na wystawie powszechnej w Wiedniu 1873 r [Agricultural machinery section at the Vienna Universal Exhibition 1873]. *Rolnik: czasopismo dla gospodarzy wiejskich – Farmer: the magazine for rural farmers, 6*(13), 360–377 [in Polish].

Rylski, T. (1874). Stacja doświadczalna мachin i narzędzi rolniczych w Dublanach [Experimental station of agricultural machines and tools in Dublany]. *Rolnik: czasopismo dla gospodarzy wiejskich – Farmer: magazine for rural farmers, 3*(15), 157–159 [in Polish].

Rylski, T. (1877). *Podrecznik mechaniki rolniczej dla gospodarzy praktycznych: wybor i uzycie narzedzi i machin rolniczych [Handbook of agricultural mechanics for practical farmers: selection and use of agricultural tools and machines]*. Lwow: Gubrynowicz i Schmidt [in Polish].

Rylski, T. (1879). Dziesiąte sprawozdanie stacyi doświadczalnej machin i narzędzi rolniczych w Dublanach [Tenth report of the experimental station of agricultural machines and tools in Dublany]. *Rolnik: czasopismo dla gospodarzy wiejskich – Farmer: the magazine for rural farmers, 7*(24), 84–86 [in Polish].

Rylski, T. (1882). Konkurencujne proby plugow w Lundenburgu [Competitive plug trials in Lundenburg]. *Rolnik: czasopismo dla gospodarzy wiejskich – Farmer: the magazine for rural farmers, 7–8*(31), 84–86 [in Polish].

Rylski, T. (1886). Sprawozdanie z działu narzędzi i machin rolniczych na wystawie w Czerniowcach [Report on the section of agricultural tools and machinery at the exhibition in Chernivtsi]. *Rolnik: tygodnik dla gospodarzy wiejskich – Farmer: the magazine for rural farmers, 16*(38), 121–123 [in Polish].

Sokolovych-Altunina, Y. O. (2010). Rol Dublianskoi rilnychoi shkoly u rozvytku ahrarnoi osvity v Ukraini ta Polshchi [The role of the Dubliany School of Agriculture in the development of agricultural education in Ukraine and Poland]. *Pedahohichni nauky: teoriia, istoriia, innovatsiini tekhnolohii – Pedagogical sciences: theory, history, innovative technologies,* (5(7)), 116–123. Retrieved from http://repository.sspu.sumy.ua/handle/123456789/6237 [in Ukrainian].

Surzycki, S. (1896). *Die landwirtschaftlichen Betriebsmittel in ihrem Einflusse auf den Zustand und die Entwickelung des Grossgrundbesitzes, sowie der Bauernwirtschaften in Galizien [The agricultural resources and their influence on the condition and development of large estates and peasant farms in Galicia].* Leipzig: Sellmann & Henne [in German].

Surzycki, S. (1928). *Rozwój wiedzy rolniczej w Polsce [Development of agricultural knowledge in Poland].* Krakow: Ksiegarnia Gebethnera i Wolffa [in Polish].

Tokarskyi, Yu. M. (1996). *Dublyany: Istoriia ahrarnykh studii (1856–1946) [Dublyany: History of Agrarian Studies (1856–1946)].* Lviv: I. Krypyakevych Institute of Ukrainian Studies of the National Academy of Sciences of Ukraine [in Ukrainian].

Tokarskyi, Yu. M. (2004). *Profesory, dotsenty ta asystenty navchalno-naukovykh ustanov u Dublianakh (1856–1947): biohrafichnyi slovnyk [Professors, associate professors and assistants of educational and scientific institutions in Dublyany (1856–1947): biographical dictionary].* Lviv: Lviv State Agrarian University [in Ukrainian].

Tokarskyi, Yu. M. (2008). *Inzhenerno-tekhnichni studii v Dublianakh [Engineering and technical studios in Dublyany].* Lviv: Lviv National Agrarian University [in Ukrainian].

Visyn, O. O. (2021). Stanovlennia ta rozvytok systemy vyprobuvannia silskohospodarskoi tekhniky na Halychyni (70-ti roky XIX – 20-ti roky XX st.) [Formation and development of a testing system for agricultural machinery in Galichina (70s of the XIXth – 20s of the XXth centry)]. *Istoriia nauky i biohrafistyka – History of science and biography,* (3). Retrieved from http://inb.dnsgb.com.ua/2021-3/09.pdf [in Ukrainian].

Woskowski, T. (2011). *Dzieje studiów rolniczo-lasowych w ośrodku lwowsko-dublańskich w opracowaniu Tadeusza Wośkowskiego [The history of agricultural and forest studies in the Lviv-Dublin center, prepared by Tadeusz Wośkowski]*. Warszawa: Centralna Biblioteka Rolnicza im. Michala Oczapowskiego. Retrieved from http://web.archive.org/web/20150413055944/http://delta.cbr.edu.pl/Content/768/138755.pdf [in Polish].

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Діяльність професора Томаша Рильського (1838–1924) у зародженні та розвитку випробувань землеробських машин другої половини XIX ст.

Анотація. *Метою дослідження є комплексна оцінка діяльності, наукових та творчих звитяг професора Томаша Сцібора-Рильського (польською мовою Tomasz Nikodem Ścibor-Rylski) у розвитку справи випробувань землеробських машин у другій половині XIX століття. Для досягнення поставленої мети дослідження використано принципи історизму, науковості та об'єктивності висвітлення історичних явищ та подій на основі застосування історико-наукового методу, методів аналізу та узагальнення. До наукового обігу уперше введено ряд архівних документів, котрі проливають світло на діяльність вченого у галузі випробувань землеробських машин. У статті на основі архівних даних, наявного творчого доробку вченого актуалізовано основні етапи його діяльності у питанні зародження та становлення випробувань землеробських машин і знарядь. Діяльність професора Т. Рильського сприяла зародженню наукових основ землеробських випробувань, формуванню принципів раціонального використання сільськогосподарського устаткування фермерами Австро-Угорської імперії. Багаторічна участь професора у різноманітних сільськогосподарських виставках та конкурсах призвела до закладення основ для створення першої на території західної України сільськогосподарської випробувальної станції у Дублянах. Обґрунтовуючи необхідність створення випробувальної станції Т. Рильський спирається на важливість переходу від «виставкового» способу випробування землеробських машин до випробування на спеціалізованих станціях. Вчений вважав, що саме науковий підхід до випробувань сприятиме підвищенню ефективності використання землеробського устаткування, зменшенню помилок при його експлуатації. З іменем науковця пов'язане становлення Вищої рільничої школи у Дублянах, як потужного наукового та випробувального осередку на території сучасних України та Польщі. Творча спадщина Т. Рильського вказує на його неоціненний внесок у зародження наукових основ випробування землеробського обладнання.*

Тому, саме відсутність спеціального комплексного дослідження наукової, творчої та організаційної діяльності вченого в історіографії науки і техніки зумовлює актуальність даного дослідження.

Ключові слова: *Томаш Рильський; випробування землеробських машин; випробувальна станція землеробських машин і знарядь; аналіз будови сільськогосподарських знарядь; сільськогосподарська промисловість; виставки сільськогосподарських машин*

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The electrification of the tin mining in Kinta Valley: Role of Perak River Hydroelectric Power Company (1927–1940)

Abstract. *Electricity, first introduced in Colonial Malaya as early as the 1890s, and by the 1920s became the major source of power in the tin-mining industry. Surprisingly, despite its vital role in the economy, electricity has received little attention in Malaysian historiography. In the country's main tin-mining center, Kinta Valley, Perak, the Perak River Hydro-Electric Power Company with its head-office in London, played a significant role in supplying electricity for mine operator. Since early 1920s, British Government aimed to develop hydroelectric power by building dams on the Perak River. They viewed the Perak River as an important source of hydroelectric power for electrifying Colonial Malaya especially for tin mining-industry. Financial constraints forced the British Government, however, to hand over responsibilities to the PRHEPC. This article aims to identify how PRHEPC managed the development of electricity supply facilities and its significance to the tin miners in the Kinta Valley before 1940. The PRHEPC diversified its energy facilities development strategies to*

guarantee electricity supply to mine operators covering a wide area. Their ability to exploit the Perak River through the construction of a large-capacity hydroelectric station and the strategy to combine steam generation and grid supply systems allowed the PRHEPC to effectively supply electricity to a large number of mine operators in the Kinta Valley. The development was financially beneficial to the power companies because this capital-saving approach allowed them to generate electricity at a far lower price than the fossil fuel power stations for their consumers. Cheap energy allowed mine operators to minimize the cost of the tin mining operation, particularly the sector shifted from labour-intensive to a capital-intensive business strategy. To dominate the tin mining sector, the operators greatly invested in modernizing mining methods through utilization of machinery such as the high-cost dredges. It was therefore imperative for mine operators to obtain cheap energy to offset the cost of investments. This case study clearly displayed the development of the tin mining sector in Kinta Valley was not merely influenced by electricity use, but also its economical generation through hydroelectric.
Keywords: *tin mining; Perak River; hydroelectric; mining method; capital intensive*

Introduction.

Electricity was first developed as a basic public utility in Malaya in the 1890s a few years after its commercial use in Europe. British control over Malaya was the catalyst to the spread of Western science and technology, such as electrical engineering, incorporated into the development of basic public utility. Through their administration, the British made its obligation the provision of basic public utility. It was the practice of the Colonial Office in London to introduce any new technology in its colonies as a projection of its sense of power and prestige. These efforts were carried out through the shaping of British institutions and administrative policies that prioritised providing basic facilities. Aside from streamlining administration, the British viewed basic public utility as important in creating a conducive environment to attract foreign financiers to invest in the commercial economic sector. This viewpoint was articulated by Frank Swettenham (1906), "The Government cannot do the mining and the agriculture, but it can make it profitable for others to embark in such speculations by giving them every reasonable facility, and that we have tried to do". Therefore, immediately following his appointment as the first Resident-General of the Federated Malay States (FMS), which placed the four states of Perak, Selangor, Pahang, and Negeri Sembilan under one central administration in 1895, Swettenham stressed that his main role was, "to open up the country by great works: roads, railways, telegraphs, wharves" (Drake, 1979). In fact, William Hood Treacher, who replaced Swettenham in 1901 also underscored the same policy by stating that, "The general policy of the British Adviser…to assist the development…of the States by making roads whenever the necessity of them was apparent, by constructing railways, by works of drainage and irrigation" (Chan, 1967). The development of basic facilities was fully carried out by the government through the establishment of specific departments such as Works, Railways, Irrigation and Drainage, and Post and Telegraph.

British colonial policies in Malaya prioritised the economic sector, especially tin mining that contributed largely to government coffers. To develop this sector, the government initially encouraged the influx of mainly Chinese labour. The emergence of electricity as a more efficient energy source meant efforts to develop it became important in basic facilities development policy to provide new energy source to mine operators. With this in mind, the government established the Electricity Board in 1921 before it was restructured and renamed the Electrical Department in 1927 to manage electricity supplies in the FMS. The establishment of these departments functioned as a development agent for the government, playing a key role in spurring economic growth. This situation illustrated that the British was responsible for creating modern infrastructure to develop the commercial economic sector, as acknowledged by a number of scholars. For instance, P. J. Drake (1979) states that the British government provided facilities for foreign investors to encourage the growth of private industry. P. P. Courtney (1972) stressed that the change in tin mining patterns was due to British policy and encouragement of foreign financiers. J. S. Sidhu (1980) opined that the British economic policy to modernise the tin mining sector included providing modern facilities to mine operators. Undoubtedly, the British played an important role in encouraging the growth of the tin mining sector as the backbone of FMS economy. In Kuala Lumpur, the main tin mining centre after Perak, the Electrical Department took the initiative and built a sub-station near the mining areas to facilitate electricity supply to the operators. In Perak, although the government did set up an electrical department, supply of electricity was managed by a private company, the Perak River Hydro-Electric Power Company (PRHEPC). The services of the PRHEPC challenged the earlier perception that the British government was fully responsible for the provision of basic facilities for economic development. The PRHEPC was responsible in ensuring the Kinta Valley, which functioned as the largest tin mining centre in Perak specifically and in Malaya generally, received ample supply of electricity. Although the British administration worked to develop electricity supply facilities, the cooperation with PRHEPC was necessary to guarantee the success of a high-impact project for the government.

The establishment of the PRHEPC was historically significant in the electricity industry of this country, especially in the framework of the colonial period. The services provided set a benchmark for the development of electricity supply, as it became the leader in hydro-based electricity industry. The PRHEPC was successful in managing the construction of the largest hydro-electric power station, specifically in Perak and generally in Malaya, with the capacity of generating up to 27,000 kW. Undeniably, a number of private companies had utilised the hydro method to generate electricity before PRHEPC. However, their generating capacity were low, and much generated electricity was limited to private use. For instance, the Raub Australian Gold Mining Company was the first company to apply the hydro method through the building of a hydro-electric power station in Sempam River in the 1890s to facilitate gold-mining operation in Raub, Pahang (Richardson, 1939; Warnford-Lock, 1907). The Societe des Etains de Kinta, the French capitalist-owned tin-mining company also used electricity generated by the Rawang River in 1906 for prospecting work in Kampar (Ingham & Bradford, 1960). However, compared to its two precursors, the PRHEPC developed hydroelectricity to benefit consumers, especially tin mine operators in Kinta Valley. The role played by PRHEPC was significant, as the tin mining sector was the fundamental economic activity in Perak and in Malaya. Furthermore, the Kinta Valley served as the main tin mining centre that contributed a large amount of tin for the international market. Therefore, efficient energy supply such as electricity guaranteed the continuation and strengthening of the tin mining activity. This situation highlighted the significant role the PRHEPC played to drive forward the growth of the tin mining sector in Kinta Valley.

Although electricity as supplied by PRHEPC contributed to the development of the tin mining sector, no exists to specific topic on it. In fact, studies on the development of electricity facilities are still lacking in Malaysian historiography. Muzaffar Tate is arguably one of the few researchers that produced a study on the development of electricity facilities in Peninsular Malaysia from its introduction in the 1890s to 1990 (Muzaffar, 1989; Muzaffar, 1991). His discussion focuses on the role of the government and its impact on governing the development of basic facilities during nationalisation. Although his discussion also focused on the setting up of the PRHEPC and the implemented development projects, a more detailed study is needed to fully comprehend the role, significance, and relationship between the services provided and the consumer aspect, especially the tin mining sector. Furthermore, Hellstrom (1935) and Rennie (1935), who also discussed PRHEPC, only focused on its main project, the construction of the hydro-electric power station. As their study was published a few years after the PRHEPC launched its electricity-generating power station operation, there was no information on the impact of its development on the consumer aspect. Clearly, existing literature do not comprehensively cover the issue, although providing electricity for the tin mining sector, centred in Kinta Valley, was the responsibility of the PRHEPC. In addition, electricity became the main source of energy used by mine operators by the 1920s.

As studies on the production of new energy technology such as electricity received little attention in Malaysian historiography, its impact on economic growth has not been analysed as much. This present article seeks to overcome one limitation of the economic literature by drawing attention not only to the evolution of energy development and electricity system, but, crucially, also to the adoption of electricity as a new energy source in tin mining sector, focusing on the role of the PRHEPC. This is in line with N. R. Jackson’s (1963) recommendation to further research on the topic of change in the tin mining sector, as it was the core of economic history in Malaysia. According to Arthur W. King (1940), the transition from wood-fuel to coal and oil, to electricity, was among the largest change to occur in the tin mining sector. Therefore, this article analyses how PRHEPC managed the development of electricity supply facilities to fulfil the demands of mine operators within a large area, and identifying its significance. This study uses the case study approach, in line with the structure of the electricity industry in the FMS prior to the 1940s, managed separately by the Electrical Department of each state. Interestingly, the situation in Perak differed from the others, as electricity supply services was led by the PRHEPC, responsible for supplying electricity to tin mining operators centred around Kinta Valley. Generally, more than 90 per cent of electricity use in Malaya focused around the tin mining sector (Kinloch, 1966). Perak, specifically the Kinta Valley, rapidly grew with tin mining, influencing electricity use. In 1938, 151,000 tonnes of tin were produced internationally, and 43,247 tonnes came from Malaya (Fermor, 1940). A large number of Malayan tin production was contributed by Perak, with 24,958 tonnes (Report on the Administration of the Mines Department and on the Mining Industries for the year 1939). Therefore, this case study approach, focusing on the Kinta Valley, allows for a more detailed analysis to identify the significance of electricity towards the growth of the tin mining sector, as well as measure the role of the PRHEPC as a private company within the framework of development of basic facilities, which was basically the responsibility of the government. The first part of this article looks at the theoretical relationship between electricity and economic growth. Next, the second part of the article identifies the establishment and background of the PRHEPC as the party responsible for managing the supply of electricity in Perak. Then the third part of the article focuses on the strategies employed by the PRHEPC to develop and manage generator infrastructure to ensure the effectiveness of supplying electricity to a large number of mine operators centred in Kinta Valley. The final part of this article will analyse the significant of electricity to mine operators. This article provides two important contributions to Malaysian historiography. Firstly, it provides further detail on the history of electricity services from the perspective of private ventures, such as PRHEPC which emerged as the main player in the electricity industry. Secondly, it fills in the gap in our history, on the relationship between electricity supply facilities with the tin mining sector, and the significance of PRHEPC services to the mine operators across Kinta Valley.

Methodology.

This study uses the historical method and qualitative research to reconstruct past events. Accordingly, this study requires the use of archival materials obtained from National Archives of Malaysia, which is located in Kuala Lumpur. The type of primary sources, we collected including the Annual Report and Account of the Electrical Department (1927–1938); Annual Report on The Social and Economic Progress of The People of Perak; Report on The Administration of The Mines Department and on The Mining Industries. In additional, we also use secondary sources, including dissertations, books, and journal. All information gathered was analysis using a narrative approach.

Results and Discussions.

The emergence of electricity as a more efficient, productive, and flexible source of energy had a tremendous impact on economic growth. The use of electricity as the driving power for motor and engines was proven to be more flexible than steam engines and allowed the reorganisation of work in factories and workshop. Work hitherto difficult or almost impossible for humans could be easily handled by electricity-generated machinery, and electricity was widely used to replace manpower and polluting traditional fuels. A few economic historians such as Wilkinson (1973), Wrigley (1988), and Allen (2009) viewed that energy-related innovation and improvement in energy supply and quality played a significant role in ensuring economic growth. They also viewed energy as a key component in explaining the Industrial Revolution. Furthermore, David I. Stern (1997) argued that energy is an essential factor of production and continuous supplies of energy are needed to maintain existing levels of economic activity as well as to grow and develop the economy. In general, these ideas originated from the theory forwarded by Robert Solow and Trevor Swan in 1956. This theory, known as the Solow Growth Model, states that economic growth is caused by three factors: labour, capital, and technology. Of the three factors, technology was seen as the most dominant. Although labour and capital were limited economic resources, the contribution from technology to growth is boundless. According to this Solow Growth Model, technological transformation has a significant influence on the economy, and growth could not effectively happen without advancements in technology (Solow, 1956; Solow, 1957).

Electricity was an example how technological advancement became the trigger for economic growth. One way to evaluate the role of electricity in economic growth is by studying historical success stories. Using the Solow Growth Model, from the lens of technology, this article reviews empirical evidence by analysing the link between electricity as supplied by the PRHEPC with the tin mining sector in Kinta Valley in a colonial setting. The formation of the PRHEPC was identified as bringing development in electricity supply, thus contributing to the growth of the tin mining sector. The effectiveness on electricity system-building by prioritising the hydro method and combining with steam, and implementing the grid supply, ensured the continuous rapid growth in mining in the Kinta Valley, even as they faced lack of labour and capital, especially among Chinese businessmen. The effects on infrastructure and supply quality were an essential factor of production and maintaining existing levels of mining activity, as well as growing and developing the economy.

The Establishment of the Perak River Hydro-Electric Power Company.

The PRHEPC involvement, until it emerged as the main plater of the electricity industry in Perak, began with the government's plan to implement a high-impact project through developing hydroelectricity. By the second decade of the 20th century, the British government took the initiative to improve electricity supply in Malaya.

Therefore, Frederick Bolton, an experienced hydro-electric engineer involved in multiple projects in Britain and South Africa, was appointed as Electrical Adviser to formulate a comprehensive development plan (High Commissioner Office, 1919). As an expert in this field, Bolton identified the potential of the Perak River as a source for hydro-electricity generation. With this in mind, a proposal was submitted to the government to implement the Perak River Hydro-Electric Scheme (PRHES) and exploit the Perak River (The Public Supply of Electricity Power and Light in Malaya: Interim Report, 1921). This implementation was able to meet the energy demands in the ever-growing tin mining sector in the Kinta Valley. However, financial troubles prevented the government from implementing the PRHES. In 1921, the FMS merely earned around $73,450,779, while its expenditure reached $101,426,220. In the following year, the FMS finances saw a further deficit, with an expenditure of $67,151,142 to an income of $59,818,670 (Rus, 2006). This problem emerged as a consequence of large-scale spending on development of basic facilities to boost growth in the export economy.

This financial crisis hindered the government' plan to implement large-scale projects such as the PRHES, which required a lot of capital. At the same time, however, the development of the PRHES needed to be expedited to provide electricity supply to tin mine operators. To overcome this problem, the government worked to attract investment from private companies. After lobbying a number of investors in London, Bolton managed to capture the interest of Armstrong Whitworth to invest in PRHES. This joint venture with Armstrong was not really new, as his company was previously responsible for the building of the battleship H. M. S. Malaya for the FMS, launched on 18 March 1915 (Yusof, 2019). Armstrong Whitworth & Company was among the leading companies in engineering, providing their services in shipbuilding, locomotives, and airplanes. In addition, the company was also involved in a number of hydroelectric projects such as in Deer Lake, Newfoundland and Nymboida, New South Wales in the 1920s. This rich experience, as well as the guarantee by the company to complete the PRHES without FMS financial aid, convinced the government to grant a concession Muzaffar, 1989). With that, an agreement was signed between the Sultan of Perak, Sultan Iskandar Shah and Sir W.G. Armstrong Whitworth & Company on December 1925 (Perak River Hydro Electric Company: Title to Land, 1929). The PRHEPC was formed in 1926 as a developer for PRHES, responsible for managing the generation, transmission, and supply of electricity to consumers, especially tin mine operators in the Kinta Valley for 80 years. For domestic use, the PRHEPC was granted a concession to supply electricity in Kuala Kangsar District, the *mukims* of Durian Pipit, Temelong, and Lenggor in Upper Perak; Kinta District; the *mukims* of Chenderiang, Batang Padang, and Bidor in Batang Padang District; the *mukims* of Pulau Tiga, Kampung Gajah, and Panjang Ulu in Lower Perak (Perak River Hydro Electric Company: Title to Land, 1929).

Taking this vast responsibility, the PRHEPC took steps to strengthen administrative and implementation through network-building with a number of parties.

The formation of this organisational structure allowed the company to manage administrative affairs and development projects more efficiently and effectively. On administrative, the appointed company board members were experienced individuals, directly involved in the electricity industry. Among them were Lord Meston of Agra and Dunottar, the Manager of Calcutta Electric Supply Corporation Limited, while Col. B. C. Lockhart-Jarvis was the Director of Kensington and Notting Hill Electric Light Corporation Limited. For implementation, the PRHEPC appointed the Rendel, Palmer & Tritton Company as Consultant Engineers, with Preece, Cardew & Rider Company as Technical Advisors to help manage the development project (Perak Hydro-electric Scheme, 1927). Furthermore, the PRHEPC also cooperated with a consultant company from Sweden, the *Vattenbyggnadsbyrån*, among the pioneers in hydro-electric engineering in Europe. Through this cooperation, the PRHEPC benefited from access to the latest technology in building electricity supply, thus ensuring its efficiency. In addition, Armstrong also brought his skilled and experienced staff in hydroelectricity to be seconded in Perak to help implement the PRHES. For instance, Edwin Charles Steer, who worked with Armstrong Whitworth & Company since 1925 and involved in drawing up hydro-electric schemes in a number of areas in Great Britain, and the construction of a dam in Newfoundland, was appointed as Chief Assistant Engineer, later Resident Engineer, to manage PRHES in 1928 (Anonymous, 1958). Gordon Mabor Walker, who served as Assistant Engineer of Hydro-Electric Department, Manchester was appointed Assistant Engineer and Mechanical Engineer in PRHEPC (B. C. L .- J., 1957).

The Implementation of the Perak River Hydro-Electric Scheme.

Developing the river for hydro-electricity generation proved to be more economical, as it was fully dependent on natural water flows. In contrast, the use of fossil fuels such as coal, natural gas, or oil, could manipulate the electricity supply process, due to their limited availability and unrenewable nature. This situation made their price unstable, influencing costs of generating electricity and affecting both operators and consumers. Furthermore, other consumer sectors already compete for access to fuel supply. In the FMS, aside from the electricity industry, coal supply was largely allocated to railway transportation. Therefore, the energy industry players tirelessly worked to diversify their electricity generation methods, depending on renewable energy sources such as water. However, the suitability of water source should also be identified before exploitation, as providing hydroelectricity should not only focus on present needs, but also future interests, and its impact on the ecosystem. The Perak River was discovered to possess suitable characteristics to be developed as a main source of hydro-electricity generation, with a height of 105 feet from sea-level, which flowed as far as 170 miles (Perak Administration Report for the year 1931, 1932; Winstedt, 1927). In addition, the rapid water flow was able to produce high kinetic energy, thus usable to generate electricity in large quantities.

When the PRHEPC took over the PRHES scheme, the company began monitoring to identify strategies areas along the Perak River as the site for a hydro-electric power station. This step was important to ensure company operation, and the process of generating and supplying electricity remain smooth. According to Robert J. Michaels (2006), "Electricity can be produced and delivered economically only if highly specialized assets are in place…some generators must be close to consumer…Investment in generation and transmission is a long and costly process and once in place, the equipment cannot be cheaply redeployed to some other location or use". Through the monitoring, Chenderoh was selected as the site for a hydro-electric power station. Undeniably, other sites such as Kenering, Bersia and Temenggor could also be potentially exploited as a source of hydro-electricity generation. These areas were later developed by the National Electricity Board in the 1970s to generate hydroelectricity. However, the selection of Chenderoh by PRHEPC was due to its close geographic location to tin mines in Kinta Valley compared to the aforementioned sites, located far into Upper Perak. The distance between the hydro-electric power station and the consumers was the main factor considered, as it minimised expenditure on transmission lines, and reduced loss of electricity during supplying. Furthermore, Chenderoh also has a natural lake that could function as a catchment to prevent river overflow when the dam was finally complete.

Construction work on the hydro-electric power station began in 1927, involving a number of contractors such as Topham, Jones & Railton Limited (construction engineering), Glenfield & Kennedy Limited (water gates), Ransomes & Rapier Limited (sector & intake gates), The English Steel Corporation Limited (water turbine), and The English Electric Limited (alternators) (Hellstrom, 1935). The dam structure was built with the length of 231 feet on the right side of the riverbank, fortified with concrete and steel piles 60-feet deep. On the left side of the riverbank, dam construction covered a length of 120 feet, fortified with concrete and steel piles 30-feet deep. The dam wall, to stop water flow from the right side of the river, was built with a length of 245 feet, with a height of 193 feet, while on the left side of the river covered an area of 434 feet with a height of 193 feet. The sector gate section, located at the mid-part of the river, was built at a height of 177 feet (Hellstrom, 1935). Aside from the dam, other main sections of the hydro-electric power station include the powerhouse. The building had reinforced concrete, divided into three sections that placed the water-turbine to generate electricity via kinetic energy, produced through streamflow. Its height was between 145 and 174 feet, and also equipped with apparatuses such as turbine scroll-cases, generators, governors, travelling cranes, and so on (Hellstrom, 1935). The height of the dam and building was key to preventing river overflow during a flood. The station, with a generating capacity of 27,000kW was completed, and began its electricity supply operations to consumers on 27 July 1930 (Report on The Administration of The Mines Department and on The Mining Industries for the year 1930). The construction of the Chenderoh Hydro-Electric Power Station made it the largest station, specifically in Perak and generally in Malaya.

Merging Methods of Generation.

The challenge to supply electricity to a large area with long-term guarantees to customers propelled the PRHEPC to take the initiative to diversify and merge methods of generation. Although the Chenderoh Hydro-Electric Power Station could generate large quantities of electricity, the generating process itself was unpredictable and dependent on the weather. Erratic rainfall distribution and droughts affected river-flow and quantity. The decision to merge methods of generation was the best approach to this challenge. The construction of a separate and alternatively operated power station gave the advantage to PRHEPC to reduce risk in electricity generation. This was supported by Matsunaga Yasuzeamon, "when you can't produce enough power because the volume of river is too low, you have to secure other means to augment the supply and compensate for the shortage" (Kikkawa, 2006). In October 1927, PRHEPC built a power station in Malim Nawar as a back-up to the Chenderoh Hydro-Electric Power Station, especially during the drought season (Annual Report and Accounts of the Electrical Department for the year 1927, 1928). In the event of disruption in transmission between Chenderoh Hydro-Electric Power Station and consumers in Kinta Valley, the Malim Nawar Power Station served to ensure electricity supply remained undisrupted (Report on The Administration of The Mines Department and on The Mining Industries for the year 1930). In addition, the Malim Nawar Power Station also expedited electricity supply to mine operators. This was because steam-type power stations took a relatively shorter time to complete compared to a hydro-electric one.

In October 1927, construction work on the Malim Nawar Power Station began, with the cooperation of a number of contractor companies such as the International Combustion Limited (boiler-plant and building), The English Electric Company Limited (turbo alternators), James Howden & Company (air-preheaters), Ledward & Beckett Limited, and S. Bullock Company (spray-pumps and piping) (Hellstrom, 1935). At the early stage, generation capacity was set at 5,000kW before the PRHEPC decided to increase capacity to 18,000 kW (Annual Report and Accounts of the Electrical Department for the year 1927, 1928.; Muzaffar, 1989). Construction took almost a year to complete, before official operations began in November 1928. Through the Malim Nawar Power Station, around 1,690,833 units of electricity were generated, and it increased to 5,927,728 units as soon as it merged with the Chenderoh Hydro-Electric Power Station (Perak River Hydro-Electric Power Company, 1931). The PRHEPC identified a strategic location to build a power station, southern Kinta Valley. The Chenderoh Hydro-Electric Power Station was located to the north. This location allowed the company to connect all tin mining areas located between the two stations. In other words, PRHEPC could supply electricity to all mine operators across Kinta Valley through connecting transmission lines along the area between the two stations.

Transmission Line Network.

The two high-capacity power stations were built in Chenderoh (27,000 kW) and Malim Nawar (18,000 kW) allowed PRHEPC to supply electricity to a large number of tin mining operators across the Kinta Valley. In other words, the operation of two stations was capable of producing electricity in large quantities, in line with the needs of the tin mining sector. For instance, the Chenderoh Hydro-electric Power Station was capable of generating around 26,399,230 units since operation began in 1930. Through the merging with the Malim Nawar Power Station, around 53,231,172 units of electricity was generated and supplied to tin mine operators (Report on The Administration of The Mines Department and on The Mining Industries for the year 1930). Therefore, the PRHEPC must manage the supply system efficiently so generated electricity can be fully utilised while preventing waste, as electricity could not be stored and must be directly supplied to consumers. To ensure the process of supplying electricity to consumers ran smoothly, the PRHEPC developed a supply network and grid distribution system, which connected the two power stations with the consumers. According to Robert J. Michaels, "Distribution lines must physically reach users, and transmission lines must cover the distance between distribution lines and generation" (Michaels, 2006). A transmission line of 66 kV was built, connecting the Chenderoh Hydro-Electric Power Station and the Malim Nawar Power Station. There were eight 22 kV sub-stations built along the line, in Temoh, Kampar, Petaling, Tanjong Toh Alang, Tronoh, Batu Gajah, Papan, and Menglembu, while two 66 kV sub-stations were built in Talang Pamaya and Selibin, connected to the 22 kV transmission lines. This distribution network allowed PRHEPC to supply electricity to every tin mine along the line.

Electrification on Kinta Valley.

In 1889, Kinta Valley emerged as the main tin mining centre in Perak, and generally in Malaya, replacing Latur. Since then, the Kinta Valley became the largest producer of tin. Between 1919 and 1923, Kinta Valley produced 398,478 *piculs* of tin from the total production in Perak of 492,961 *piculs* (Fermor, 1940). This followed the mass opening of tin-rich mines in Kinta Valley. Kinta Valley emerged as the district with vast areas of tin mines compared to the other six districts in Perak. By January 1939, there were 3,820 tin mines covering an area of 125,215 acres in Perak, and 2,811 mines in an area of 85,530 acres in Kinta Valley alone (Annual Report on the Social and Economic Progress of the People of Perak for the year 1938, 1939). This growth was further supported by supply of alternative energy and utilisation of more modern equipment such as dredges and gravel pumps. In general, use of alternative energy such as steam, hydraulics, and electricity, made tin extraction easier and more effective compared to human labour. One horsepower (h.p.) of alternative energy used to activate machinery could do the work of eight human labour (Ken, 1965). This meant use of alternative energy such as electricity became more popular among tin miners to carry out their prospecting.

The introduction of electricity as a more effective energy source received encouraging demands from mine operators. In Kinta Valley, electricity supply by PRHEPC allowed a large number of tin mine operators to turn to them. According to Figure 1 below, it is clear that electricity became the energy source of choice for tin mine operators since 1930. This increasing trend was influenced by PRHEPC's success to manage the construction of a high-capacity power generator asset. As soon as the Malim Nawar Power Station began operation in 1928, the use of electricity continued to increase before it overtook alternative energy sources when the Chenderoh Hydro-Electric Power Station in 1930. From 47,963 h.p. of electricity used in 1934, around 39,622 h.p. was supplied by PRHEPC (Report on The Administration of The Mines Department and on The Mining Industries for the year 1934). By 1936, PRHEPC supplied 59,331 h.p. out of 80,828 h.p. electricity used in tin mines in Perak (Report on The Administration of The Mines Department and on The Mining Industries for the year 1936). The statistics proved the capability of PRHEPC to manage electricity supply to meet the demands of mine operators covering a large area, and its contributions in further developing the tin mining sector.

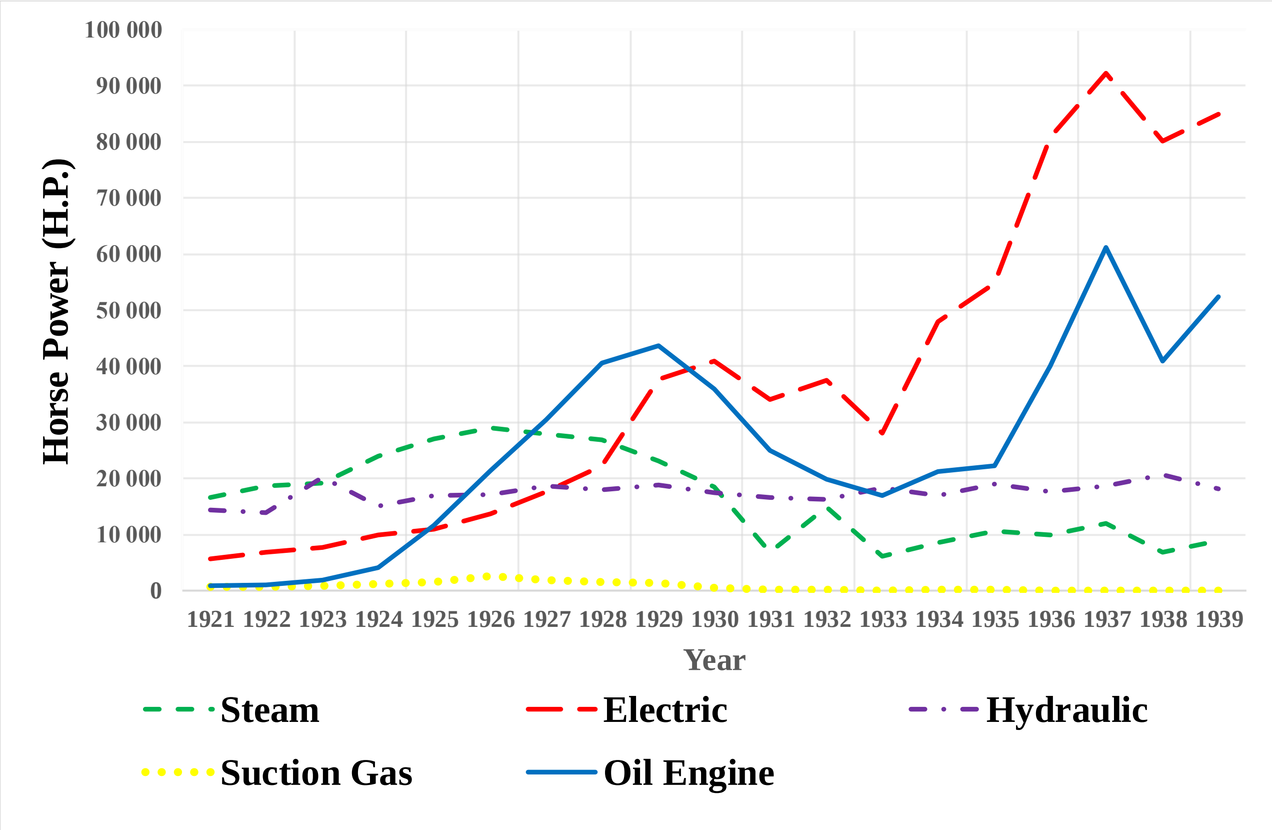

Figure 1. Energy Usage in the Tin Mining Sector in Perak, 1921–1938 (Source: Compiled from Federated Malay States: Report on The Administration of The Mines Department and on the Mining Industries, 1921–1938).

Supply of electricity as provided by PRHEPC was significant, as it was in line with conditions in the tin mining sector, which required a more stable and guaranteed source of energy. This was in line with Perak's, and Kinta Valley by extension, role as the largest producer of tin in Malaya for the international market. Between 1898 and 1938, no less than 27 per cent of the world's tin production came out of Malaya (Fermor, 1940). In the Malayan context, Perak contributed more than half of the total tin production. For instance, from the 63,974 tonnes of tin produced in Malaya in 1930, 39,825 tonnes were produced in Perak (Fermor, 1940). Therefore, it was important for mine operators to get a more consistent and suitable energy source for tin exploitation work to run smoothly. Before the introduction of electricity, mine operators turned to various energy sources. However, dependence of these energy sources was seen as risky and no longer suitable as the main power source to spur the export economic development, such as the rapidly growing tin mining sector.

Up to the early days of the 20th century, tin mining was still labour-intensive, especially Chinese labour. Throughout this period, mine operators had no problem obtaining labour, as the offers were high and sufficient for each demand. A large number of Chinese labours brought into Malaya worked in the tin mining sector. However, by the early decades of the 20th century, problems in supplying labour became more serious, as emigrants outpaced newly brought in labour. In addition, current and new labour diversified their services into other sectors, such as road construction, railway construction, and rickshaw-pulling, and this also affected labour supplies in the tin mining sector (Ken, 1965). At the same time, the growth of the rubber industry forced European businessmen to use Chinese labour as extra labour to support Indian labour in the plantations (Ken, 1965). Furthermore, health problems such as the spread of beriberi, of which labourers were especially vulnerable, and the low quality of life due to exposure to vices such as opium, meant labour was unstable and detrimental to mining operations. To overcome the problem of labour shortage, mine operators took the initiative to turn to alternative energy sources such as steam and hydraulics, produced through combustion. Undeniably, these energy sources did not require many labourers, as operators turned to labour-saving devices such as gravel pumps to excavate tin. However, even these energy sources proved unstable because of limited and unstable fuel availability, as they were also needed in other sectors such as trains and export commodities. Only two main coal mines supplied fuel to consumers, which were the Malayan Collieries Limited in Arang Batu, Selangor and Enggor Coal Syndicate in Enggor, Perak. However, the closure of the mine in Enggor in 1928 affected coal supplies (Report on The Administration of The Mines Department and on The Mining Industries for the year 1928). Meanwhile, mine operators such as in Tanjong Toh Alang, hitherto dependent on wood-fuel for energy production, also faced fuel shortage (Perak Administration Report for the year 1923, 1924).

Clearly, use of electricity as supplied by PRHEPC proved best for mine operators, as they were capable of supplying a stabler energy source. The diverse generating methods operating through renewable and unrenewable energy sources allowed PRHEPC to reduce problems in supplying electricity to consumers. Although the Malim Nawar Power Station operated with coal, fuel shortage was no problem for the PRHEPC, as the majority of energy was generated by the Chenderoh Hydro-Electric Power Station. Electricity generation through renewable sources such as water from the Perak River and the high generating asset capacity guaranteed a stabler energy supply to fulfil current and long-term needs. PRHEPC's ability was unquestioned with the supply of electricity to its ever-increasing consumers. In 1932, around 35,778,199 units of electricity was provided by PRHEPC to mine operators in Kinta Valley (Annual Report on The Social and Economic Progress of The People of Perak for the year 1933, 1934). Supplied electricity units increased to 89,403,198 units in the following two years (Annual Report on The Social and Economic Progress of The People of Perak for the year 1934, 1935). By 1936, electricity use reached 202,099,958 units, further increasing to 247,097,397 units in the following year (Annual Report on The Social and Economic Progress of The People of Perak for the year 1937, 1938). The ability to generate electricity in large quantities also caused the government to shut down operations of power stations in Ipoh and Batu Gajah, and purchased electricity from PRHEPC to supply to the locals (Annual Report and Account of the Electrical Department for the year 1930, 1931; Annual Report and Account of the Electrical Department for the year 1932, 1933). Since 1929, purchase of electricity from PRHEPC continued to increase from 2,833,883 units to 4,794,694 units by 1939 (Annual Report and Account of the Electrical Department for the year 1929, 1930; Annual Report and Account of the Electrical Department for the year 1939, 1940). This indirectly explained the company's capability of ensuring continued energy supplies for consumer demands. Undeniably, electricity usage for the tin mining sector in Perak showed a decline between 1930 and 1933. However, this was not due to problems in supplying electricity, but a result of the economic recession and the collapse of tin prices, which forced mine operators to limit operations. Tin dumping led to the implementation of the International Tin Agreement in 1931 to restore market price by imposing tin production quotas among producing countries (Hoong, 1969). Later, as the tin market recuperated, tin production quotas were liberalised through the International Tin Agreement, renewed in 1933 (Hoong, 1969). Almost immediately, mine operators re-started their tin mining activities, thus increased electricity usage.

The transition to electricity as used by PRHEPC allowed mine operators to minimise expenditure on energy supply. According to the report by J. Laird, Senior Warden of Mines, the use of engines to generate energy- and labour-saving devices proved to reduce the operation costs borne by operators (Report on the Administration of the Mines Department and on the Mining Industries for the year 1930). In this regard, the implementation of the PRHES by PRHEPC could potentially supply electricity at a cheaper rate to mine operators (Perak Administration Report for the year 1925, 1926). Through services provided, operators no longer have to bear the costs on construction, generation, and maintenance of power stations, as they could directly receive electricity from PRHEPC. In addition, hydro-based electricity generation via natural water flow from the Perak River allowed the company to reduce operating costs, thus provide electricity to all consumers at a lower rate. For instance, in 1935, the PRHEPC only spent around £26,878 to generate electricity (Perak River Hydro-Electric Power Co., "Directors' Report and Statement of Accounts for the year ended 31st July 1935, 1936). In that year, around 124,810,523 units were generated and supplied to tin mine operators in Kinta Valley, while a further 3,348,090 units were sold to the government to be supplied to consumers in Ipoh and Batu Gajah (Annual Report on The Social and Economic Progress of The People of Perak for the year 1935, 1936). In contrast, the government, through the Electricity Department, spent £38,734 to purchase fuel such as coal and oil to generate 53,297,401 units of electricity (Annual Report and Account of the Electrical Department for the year 1935, 1936).

Although tin mining areas in the Kinta Valley were vast and with many mining companies, the generation asset capability owned by PRHEPC provided operators with the opportunity to obtain electricity. For instance, the number of mine operators that engaged the services of PRHEPC showed an upward trend. In 1933, 39,663,579 units of electricity were supplied to PRHEPC to 66 consumers (Annual Report on the Social and Economic Progress of the People of Perak for the year 1933, 1934). This number increased to 110 consumers in the following year, with the sale of 89,403,198 units of electricity (Annual Report on the Social and Economic Progress of the People of Perak for the year 1934, 1935). By 1937, PRHEPC had 223 consumers, with a total 247,097,397 units of electricity sold (Annual Report on the Social and Economic Progress of the People of Perak for the year 1937, 1938). A large amount of mine operators in Kinta Valley that operated with dredges, such as the Jelapang Tin Dredging Limited, Kramat Tin Dredging Limited, Lower Perak Tin Dredging Limited, Malayan Tin Dredging Limited, and Southern Kinta Consolidated Limited, also depended on electricity supplied by PRHEPC (Ingham & Bradford, 1960).

Aside from new consumers, the capability of PRHEPC also drove a number of mine operators that initially managed their own electricity generation to switch to the company's services. This decision could further reduce to expenditure costs of these operators. For example, the Societe des Etains de Kinta ceased operations of their power station and signed a power purchase agreement with PRHEPC (Perak Hydro-Electric Company, 1929). Other large companies operating with dredges such as Anglo-Oriental and Osborne & Chappel also obtained electricity from PRHEPC (Perak Hydro-Electric Company, 1929). Dredges were more suitable for mine operators doing more effective tin excavation work. As tin ore yield from the surface up to a depth of less than 30 feet progressively decreases, operators were forced to dig deeper. The traditional mining method of using labour and equipment such as hoes and rattan baskets became more exhausting as they reached a depth of 30–50 feet. Although operators could turn to engine-generated power, it necessitated huge capital to purchase extra equipment such as pumping machineries, with the sodden mine surface (Hoong, 1969). Therefore, operators must improve their mining methods by using modern machinery such as dredges, that could be used in watery mines. Although they invested heavily in dredges, mine operators could bear the cost by obtaining cheap electricity from PRHEPC.

At the same time, opencast mine operators, most of them Chinese, which operated with steam- and diesel engine-driven gravel pumps also transitioned to electricity and electric motors obtained from PRHEPC (Annual Report on the Social and Economic Progress of the People of Perak for the year 1933, 1934), as energy generated from steam, hydraulics, gas or oil methods require mine operators to manage their own power station. The fuel needed such as oil, coal, and wood were not always available, as other sectors such as the railways also compete for these resources. In addition, fuel prices were also unstable due to fickle market prices. This made it difficult for operators to ensure fuel supplies could meet the demands, not to mention to effects on expenditure. For Chinese operators, operation cost-reduction by turning to electricity and labour-saving devices such as gravel pumps and electric motors were in step with the changes in the mining sector. Up to the early 20th century, Chinese operators still possessed strong financial resources through sale of opium and gambling activities in the mines. According to Wong Li Ken, the revenue allowed Chinese operators to finance mining operations even as tin market price declined (Ken, 1965). However, the dissolution of opium monopolies by the government in November 1910 and gambling activities in December 1912 deprived them of a source of revenue (Voules, 1921; Ken, 1965). This made it difficult for operators to continue recruiting labour in large quantities. Furthermore, limited number of labourers led to a rise in wages. Lack of capital to manage energy supply themselves also led to increase in demands for cheaper electricity among these Chinese operators (Perak Administration Report for the year 1923, 1924). By using electricity also allowed Chinese operators to continue with their tin prospecting ventures (Perak Administration Report for the year 1926, 1927). Therefore, as soon as PRHEPC began their operations, a number of Chinese-owned mines such as Chan Tat Cho (Kampar & Chenderiang), Wong Peng Sam (Kampar), Choo Hoy (Temoh & Chenderiang) Wong Seong (Kampar), Loke Man Choke (Kampar), Leong Mong Chew (Kampar), Wan Fook (Kampar), Hah Liew Yee (Selibin), Chen Yoong Seong (Kampar), Leow Yee Thong (Kampar), Lai Weng Huin (Papan), Chong Foong (Pusing), Keat Hock Tong Mining Kongsi (Pusing), Yap Chin (Batu Gajah), Lim Boon Haw (Malim Nawar), and Tai Chee Show (Kampar), which operated opencast mines signed power purchase agreements with PRHEPC (Perak Hydro-Electric Company, 1929). For mine operators in Tanjong Toh Alang, fuel shortage such as wood could be overcome with the building of a sub-station in that area by PRHEPC, which provided electricity. Clearly, the facilities provided by PRHEPC helped Chinese operators to minimise their operation costs and at the same time ensured their survival in the tin mining sector.

Electricity and the Rise of Western Mining Company.

PRHEPC participation in the electricity industry indirectly changed the pattern of development in the tin mining sector. Through supplying of stable and cheap energy, PRHEPC helped European entrepreneurs to take control of the tin mining sector from the Chinese operators. Since the 19th century, both European and Chinese operators were involved in tin mining activities, specifically in Perak, and generally in Malaya. However, the influence of European operators, especially in tin production, were minimal compared to their Chinese counterparts. The period between 1820 and the early 20th century witnessed the domination of Chinese operators in the tin mining industry. Throughout this period, Chinese operators managed to contribute between 60 and 80 per cent of the annual tin production. This dominance was supported by their full control over manpower, i.e., Chinese labourers. In other words, the failure of European operators to control labour limited their involvement in the sector. Prior to the 20th century, Chinese labour was synonymous to tin mining, as tin ores located on the surface could be extracted with labour work and simple tools, such as hoes, rattan baskets, pans, and so on.

However, changes in the tin mining sector, from a labour-intensive to a capital-intensive model, opened the gates for European operators to take control of the sector from the Chinese. The dearth of tin on the surface up to a depth of 30 feet required the operators to dig deeper to extract tin. In this situation, manpower was no longer suitable, and operators turned to modern equipment and machinery such as dredges. For Chinese operators, the lack of capital hindered them from purchasing cost-prohibitive dredges. As for the Europeans, their financial strength allowed them to utilise dredges and other labour-saving devices, thus monopolising tin production (Annual Report on the Social and Economic Progress of the People of Perak for the year 1935, 1936). The initiatives taken by these Europeans were further streamlined with the supply of far cheaper and more efficient electricity by PRHEPC. With that, the problem of labour shortage among European entrepreneurs were countered by cheap electricity from the company. Compared to labour, which was fully controlled by Chinese operators, electricity was not monopolised by any one operator. PRHEPC, as the body responsible for supplying electricity facilities, provided it to all consumers, without privilege to any one group. In addition, the huge generation capacity did not hamper any operator from obtaining electricity. Since 1929, no less than 60 per cent of tin produce were contributed by European operators, overtaking the Chinese. A large part of tin production as recorded by European operators were done through dredges. As mentioned earlier, most European-owned and dredge-operated tin mines obtained their electricity from PRHEPC. In 1936, through dredges, the Europeans could produce over 291,670 *piculs* of tin, and another 145,183 *piculs* through other means, compared to the Chinese that produced 286,141 *piculs* of tin (Annual Report on the Social and Economic Progress of the People of Perak for the year 1936, 1937). Although tin production saw an overall decline in 1938, European operators using dredges still dominated production. Through dredges, around 220,465 *piculs* of tin were produced, with another 116,338 *piculs* through other methods.

Meanwhile, the Chinese operators only managed to be produced 38 per cent of tin output, or 202,336 *piculs* (Annual Report on the Social and Economic Progress of the People of Perak for the year 1938, 1939).

Conclusions.

The establishment of the PRHEPC aimed to implement the PRHES, had a significant impact not only in its role to supply electricity to mine operators in Kinta Valley, but also ensured the continuation and development of the tin mining sector, through their supply of a more stable, consistent, and cheaper energy source. As a new company established to take over the scheme drawn up by the government, the PRHEPC proved their capability to realise this high0impact project. They did not merely focus on hydro-electricity development in the Perak River, but also took the initiative to diversify their generation methods to ensure the effectiveness in supplying electricity to their consumers. Clearly, their infrastructure development strategy, merging both hydro and steam generation, and the grid system, was suited to Kinta Valley's location as the main mining centre, with a large area, involving many prospecting companies. In other words, these constructed assets allowed the PRHEPC to supply electricity to a large number of mine operators to meet current and long-term demands effectively. This situation guaranteed each mine operator sufficient electricity supply, turning it into the main energy source for tin mining. Since its inception, the PRHEPC was responsible for driving the tin mining sector in Kinta Valley. The effort to develop electricity facilities was not limited to providing a newer and more efficient energy source, but also adapt to the changes in the sector. Labour and alternative energy sources such as steam were unreliable, involved a high cost, and were a constant problem for mine operators. Dependence of these energy sources also made mining methods limited and impractical. Therefore, the PRHEPC provided the best solution to mine operators to overcome these challenges. Their ability to supply electricity consistently and cheaply turned mine operators to their services. This was very beneficial to European entrepreneurs that used dredges to strengthen their operations, thus dominate the tin mining sector. Meanwhile, the transition to electricity among Chinese businessmen ensured their survival in the mining sector. Although faced with lack of labour and financial losses, electricity supply as provided by PRHEPC allowed Chinese businessmen to participate in tin mining activities, and to innovate mining methods. Evidently, the role played by PRHEPC through supplying electricity has a significant impact on ensuring the growth of the tin mining sector in Kinta Valley.

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Conflicts of interest.

The authors declare no conflict of interest.

References

Allen, R. C. (2009). *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511816680

Annual Report and Account of the Electrical Department for the year 1927. (1928). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report and Account of the Electrical Department for the year 1929. (1930). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report and Account of the Electrical Department for the year 1930. (1931). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report and Account of the Electrical Department for the year 1932. (1933). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report and Account of the Electrical Department for the year 1935. (1936). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report and Account of the Electrical Department for the year 1939. (1940). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report on The Social and Economic Progress of The People of Perak for the year 1933. (1934). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report on The Social and Economic Progress of The People of Perak for the year 1934. (1935). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report on The Social and Economic Progress of The People of Perak for the year 1935. (1936). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report on the Social and Economic Progress of the People of Perak for the year 1936. (1937). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report on The Social and Economic Progress of The People of Perak for the year 1937. (1938). Kuala Lumpur: The Federated Malay States Government Press.

Annual Report on the Social and Economic Progress of the People of Perak for the year 1938. (1939). Kuala Lumpur: The Federated Malay States Government Press.

Anonymous. (1958). Obituary: Edwin Charles Steer, 1893–1957. *Proceedings of the Institution of Civil Engineers*, *9*(2), 190–191. https://doi.org/10.1680/iicep.1958.2290

B. C. L.-J. (1957). Gordon Mabor Walker. *Journal of the Institutional of Electrical Engineers*, *3*(27), 173–174. https://digital-library.theiet.org/content/journals/10.1049/jiee-3.1957.0093

Chan, Ch. H. (1967). *The Development of British Malaya, 1896–1909.* Kuala Lumpur, New York: Oxford University Press.

Courtney, P. P. (1972). *A Geography of Trade and Development in Malaya*. London: G. Bell and Sons Limited.

Drake, P. J. (1979). The economic development of British Malaya to 1914: An essay in historiography with some questions for historians. *Journal of Southeast Asian Studies*, *10*(2), 262–290. https://doi.org/10.1017/S0022463400014247

Fermor, L. L. (1940). *Report upon the Mining Industry of Malaya*. Kuala Lumpur: Government Press.

Hellstrom, B. M. (1935). The Perak River Hydro-Electric Power Scheme. *Minutes of the Proceedings of the Institution of Civil Engineers*, *239*(1935), 253–312. https://doi.org/10.1680/imotp.1935.15278

High Commissioner Office. (1919). 2530. *High Commissioner Office.* Engagement of Mr. F. Bolton as Expert Adviser on Electric.

Hoong, Y. Y. (1969). *The Development of the Tin Mining Industry of Malaya*. Kuala Lumpur: Oxford University Press.

Ingham, F. T., & Bradford, E. F. (1960). *The Geology and Mineral Resources of the Kinta Valley, Perak.* Kuala Lumpur: The Government Press.

Jackson, N. R. (1963). Changing patterns of employment in Malayan tin mining. *Journal of Southeast Asian History*, *4*(2), 141–153. https://doi.org/10.1017/S0217781100002830

Ken, W. L. (1965). *The Malayan Tin Industry to 1914*, Tucson: University of Arizona Press.

Kikkawa, T. (2006). The role of Matsunaga Yasuzeamon in the development of Japan's electric power industry. *Social Science Japan Journal*, *9*(2), 203–219. https://doi.org/10.1093/ssjj/jyl032

King, A. W. (1940). Changes in the tin mining industry of Malaya. *Geography*, *25*(3), 130–134. https://www.jstor.org/stable/40561301

Kinloch, R. F., (1966). The growth of electric power production in Malaya. *Annals of the Association of American Geographers*, *56*(2), 220–235. https://doi.org/10.1111/j.1467-8306.1966.tb00555.x

Michaels, R. J. (2006, July 13). Vertical Integration and the Restructuring of the U.S. Electricity Industry. *Policy Analysis*, (572), 1–32. https://www.cato.org/sites/cato.org/files/pubs/pdf/pa572.pdf

Muzaffar, T. (1989). *Power Builds The Nation: The National Electricity Board of the States of Malaya and Its Predecessors (Vol. I: The Formative Years)*. Kuala Lumpur: The National Electricity Board of the States of Malaya.

Muzaffar, T. (1991). *Power Builds The Nation: The National Electricity Board of the States of Malaya and Its Predecessors (Vol. II: Transition and Fulfilment)*. Kuala Lumpur: Tenaga Nasional Berhad.

Perak Administration Report for the year 1923. (1924). Kuala Lumpur: Federated Malay States Government Printing Office.

Perak Administration Report for the year 1925. (1926). Kuala Lumpur: Federated Malay States Government Printing Office.

Perak Administration Report for the year 1926. (1927). Kuala Lumpur: Federated Malay States Government Printing Office.

Perak Administration Report for the year 1931. (1932). Kuala Lumpur: Federated Malay States Government Printing Office.

Perak Hydro-Electric Company. (1929). CO 717/64/62367. Colonial Office: Federated Malay States Original Correspondence.

Perak Hydro-electric Scheme. (1927). CO 717/56/29074. Colonial Office: Federated Malay States Original Correspondence.

Perak River Hydro Electric Company: Title to Land. (1929). CO 717/65/62367/C. Colonial Office: Federated Malay States Original Correspondence.

Perak River Hydro-Electric Power Co. (1936). CO 717/51556. *Directors' Report and Statement of Accounts for the year ended 31st July 1935*. Colonial Office: Federated Malay States Original Correspondence.

Perak River Hydro-Electric Power Company. (1931). CO 717/79/82367. Colonial Office: Federated Malay States Original Correspondence.

Rennie, W. J. H. (1935). The construction of the Chenderoh water-power plant of the Perak river hydro-electric power scheme. *Minutes of the Proceeding of the Institution of Civil Engineering*, *239*(1935), 313–355. https://doi.org/10.1680/imotp.1935.15279

Report on The Administration of The Mines Department and on The Mining Industries for the year 1928. (1929). Kuala Lumpur: The Federated Malay States Government Press.

Report on The Administration of The Mines Department and on The Mining Industries for the year 1930. (1931). Kuala Lumpur: The Federated Malay States Government Press.

Report on The Administration of The Mines Department and on The Mining Industries for the year 1934. (1935). Kuala Lumpur: The Federated Malay States Government Press.

Report on The Administration of The Mines Department and on The Mining Industries for the year 1936. (1937). Kuala Lumpur: The Federated Malay States Government Press.

Report on The Administration of The Mines Department and on The Mining Industries for the year 1939. (1940). Kuala Lumpur: The Federated Malay States Government Press.

Richardson, J. A. (1939). *The geology and mineral resources of the neighbourhood of Raub, Pahang, Federated Malay States, with an account of the geology of the raub australian gold mine*. Singapore: Geological Survey Department.

Rus, A. K. A. M. (2006). *Perkembangan Majlis Mesyuarat Persekutuan, 1909–1927 [The Development of Federal Council, 1909–1927]* (Unpublished Doctoral dissertation). Kuala Lumpur: Universiti Malaya [in Malay].

Sidhu, J. S. (1980). *Administration in the Federated Malay States, 1896–1920*. Kuala Lumpur, New York: Oxford University Press.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, *70*(1), 65–94. https://doi.org/10.2307/1884513

Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, *39*(3), 312–320. https://doi.org/10.2307/1926047

Stern, D. I. (1997). Limits to substitutional and irreversibility in production and consumption: A neoclassical interpretation of ecological economics. *Ecological Economics*, *21*(3), 197–215. https://doi.org/10.1016/S0921-8009(96)00103-6

Swettenham, F. (1906). *British Malaya: An Account of the origin and progress of British influence in Malaya*, London: John Lane The Bodley Head. https://doi.org/10.4324/9780429459047

The public supply of electricity power and light in Malaya: Interim Report. (1921, July 26). C. O. 576/23. Colonial Office: Federated Malay States, Minutes of Meeting and Proceedings of the Federal Council.

Voules, A. B. (1921). *The Laws of the Federated Malay States, 1877–1920, Vol. 2.* London: Hazell, Watson & Viney.

Warnford-Lock, C. G. (1907). *Mining in Malaya for gold and tin*. London: Crowther and Goodman.

Wilkinson, R. G. (1973). *Poverty and progress: An ecological model of economic development*. London: Methuen.

Winstedt, R. O. (1927). The Great Flood, 1926. *Journal of Malaysian Branch of Royal Asiatic Society*, *5*(2), 295–309. https://www.jstor.org/stable/24249117

Wrigley, E. A. (1988). *Continuity, Chance and Change: The Character of the Industrial Revolution in England*. Cambridge: Cambridge University Press.

Yusof, T. A. (2019, March 18). HMS Malaya: Federated Malay States paid for ship. *New Straits Times*. Retrieved from https://www.nst.com.my/news/nation/2019/03/470285/hms-malaya-federated-malay-states-paid-ship

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Електрифікація шахтової промисловості в долині Кінта: Роль компанії "Гідроелектроенергетична компанія "Річка Перак" (1927–1940)

Анотація. *Електрику почали впроваджувати в колоніальній Малайзії вже з 1890-х років, а до 1920-х вона стала основним джерелом енергії в гірничій промисловості з видобутку олова. Дивно, що, незважаючи на її важливу роль у економіці, електроенергетика отримала мало уваги в історіографії Малайзії. У головному центрі гірництва олова країни, у долині Кінта в Пераку, компанія "Гідроелектроенергетична компанія "Річка Перак" зі штаб-квартирою в Лондоні відігравала значну роль у постачанні електроенергії гірничим операторам. З початку 1920-х років британський уряд планував розвивати гідроенергетику, будуючи греблі на річці Перак. Вони вважали річку Перак важливим джерелом гідроенергії для електрифікації колоніальної Малайзії, особливо для гірничої промисловості. Фінансові обмеження, однак, змусили британський уряд передати відповідальність компанії "Гідроелектроенергетична компанія "Річка Перак". Ця стаття спрямована на визначення того, як "Гідроелектроенергетична компанія "Річка Перак" керувала розвитком електропостачання та його значення для гірників у долині Кінта до 1940 року. "Гідроелектроенергетична компанія "Річка Перак" диверсифікувала стратегії розвитку енергетичних об'єктів, щоб гарантувати постачання електроенергії гірничим операторам на великій території. Їх здатність експлуатувати річку Перак через будівництво гідроелектростанції великої потужності та стратегія поєднання систем генерації пари і мережевих систем дозволили "Гідроелектроенергетична компанія "Річка Перак" ефективно забезпечувати електроенергією велику кількість гірничих операторів у долині Кінта. Розвиток був фінансово вигідним для енергетичних компаній, оскільки цей капіталозберігаючий підхід дозволив їм генерувати електроенергію за значно нижчою ціною, ніж станції на кам'яному вугіллі для їхніх споживачів. Дешева енергія дозволила гірничим операторам мінімізувати витрати на видобуток олова, особливо коли сектор перейшов від праце-інтенсивної до капіталомісткої стратегії бізнесу. Для домінування в гірничому секторі оператори вкладали значні інвестиції в модернізацію методів видобутку за допомогою використання машин, таких як високовартісні екскаватори. Тому було надзвичайно важливо для гірничих операторів отримувати дешеву енергію для компенсації витрат на інвестиції. Цей кейс показав, що розвиток гірничого сектору в долині Кінта був важливим не лише використанням електрики, але й її економічним виробництвом за допомогою гідроелектрики.*

Ключові слова: *видобуток олова; річка Перак; гідроелектрика; методи гірничого видобутку; капіталомісткі*

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Synergizing multi-criteria diagnosis for safeguarding cultural heritage and the restoration of vanished legacy: A historical exploration in science, technology, and archaeology

Abstract. *The urgent need to preserve cultural heritage is starkly evident in contemporary society, particularly poignant in Morocco where its rich cultural legacy faces unprecedented threats. The rapid forces of urbanization and relentless economic development have converged, resulting in the alarming devaluation and irreversible degradation of a substantial portion of this invaluable heritage. Within this disconcerting backdrop, certain remarkable vestiges have managed to endure the ravages of time. One such exemplar is the Marinid Madrasa, an architectural marvel from the 4th century, nestled within the Chellah archaeological site in Rabat, Morocco. Beyond its physical grandeur, the Madrasa plays a pivotal role as a conduit between the past and the future, facilitating the transmission of cultural heritage to generations yet unborn. This paper embarks on a multidisciplinary journey, employing advanced techniques such as terrestrial photogrammetry, numerical modeling, and specialized archaeological characterization, to undertake comprehensive diagnostic study processes. The convergence of these diverse methodologies lays a robust foundation for a holistic diagnostic study. This endeavor serves not only academic curiosity but becomes the cornerstone upon which strategies for compatible conservation and restoration interventions are erected. In the intricate interplay between historical* *preservation and the imperatives of progress, these methodologies form a bridge. This bridge links the architectural magnificence of the Madrasa with the imperatives of safeguarding it in a rapidly changing world. The ultimate aspiration of this multidisciplinary approach is twofold: to ensure the enduring protection of the Marinid Madrasa and other archaeological remnants against the erosive forces of time and urban development, and to forge a narrative that sensitively navigates the challenges posed by preserving cultural heritage in the face of modernity. In this endeavor, advanced technologies are interwoven with a profound recognition of the historical, social, and cultural significance of these sites, ultimately charting a course that not only conserves architectural brilliance but also honors the profound stories they encapsulate across the epochs.*

Keywords: *cultural assets; material analysis; restoration; antiquities; archaeology; 3D technology*

Introduction.

The preservation of archaeological and destroyed heritage holds significant importance in safeguarding tangible cultural artifacts, while also carrying long-term implications by fostering the implementation of sustainable development policies that effectively conserve the past for the benefit of future generations (Mekonnen, Bires, & Berhanu, 2022). Additionally, it is conserved and managed with the aim of benefiting tourists and actively contributing to the utilization of cultural heritage and tourism as powerful tools in fostering a more respectful, inclusive society, and promoting a sustainable future (Almasri & Ababneh, 2021; Jeong, Karimov, Sobirov, Saidmamatov, & Marty, 2023). These considerations are particularly valuable if integrated into the ongoing debates on the future of tourism after Covid-19, specifically regarding how archaeological heritage is managed and the value of cultural tourism to society (Haq, Yasin, & Nair, 2023). The preservation of inherited tangible and intangible assets necessitates the collaboration of various professions, presenting additional challenges in effectively organizing collective conservation efforts in a holistic approach (Nilson & Thorell, 2018). Significant requirements for the choice of materials for the conservation of heritage remains have been gathered from the literature and through consultation with experts working on the preservation of cultural heritage (Choriyev, Shaydullaeva, & Raxmonkulova, 2023).

The protection and valorization of archaeological heritage are mainly promoted through multidisciplinary approaches and the development of new technologies (Di Benedetto et al., 2020). These technologies are available to produce and visualize high-quality 3D models in real-time, considering geometric resolution, textural detail, and large dimensions (Shanoer & Abed, 2018). Several authors have proposed the use of terrestrial and aerial photogrammetry as potential tools for surveying archaeological heritage (Adamopoulos & Rinaudo, 2021; Salagean-Mohora, Anghel, & Frigura-Iliasa, 2023). These techniques have made a significant contribution to the digital conservation and dissemination of these artifacts (Chen, Wu, Sun, Ali, & Zhou, 2023; Simou, Baba, & Nounah, 2022). In this study, the application of 3D laser scanning technology is used for data collection, data processing, and model construction. Surveys have gained significant favor within the scientific community, particularly in the documentation of cultural heritage, as they play a crucial role in capturing and documenting the diverse range of building materials utilized in these contexts (Lu, Wang, Q., Wang, S., & Zhang, 2015; Maté-González, Di Pietra, & Piras, 2022). Survey methods are developed and integrated, providing a textured 3D model (Tsilimantou, Delegou, Nikitakos, Ioannidis, & Moropoulou, 2020). On the other hand, the characterization of building materials is important for the protection of monuments. Many materials such as rammed earth, clay, and stone are used as major building materials in the construction of historical and archaeological buildings in Morocco and worldwide (Sanchez-Calvillo et al., 2021). The purpose of this study is to investigate a multidisciplinary approach by studying architectural, historical, geometric, and documentation data on building materials and their interaction for archaeological building structures. This contributes to the assessment of the current condition of the structure using 3D technology, particularly terrestrial photogrammetry and laser scanning, to provide numerical data for various conservatory analyses and thematic maps, incorporating both qualitative and quantitative information. Furthermore, this approach facilitates the planning and implementation of compatible conservation interventions (Tsilimantou et al., 2020). The selected historical site for the implementation of this procedure is the preserved remnants of the Marinid Madrasa of Abu Al-Hassan, which dates back to the 14th century. This significant historical structure is situated within the Chellah archaeological site in Rabat, Morocco. Originally, it served as a Quranic school designed to fulfill the dual purpose of a college and a student residence, commissioned by the Marinid dynasty.

Materials and Methods.

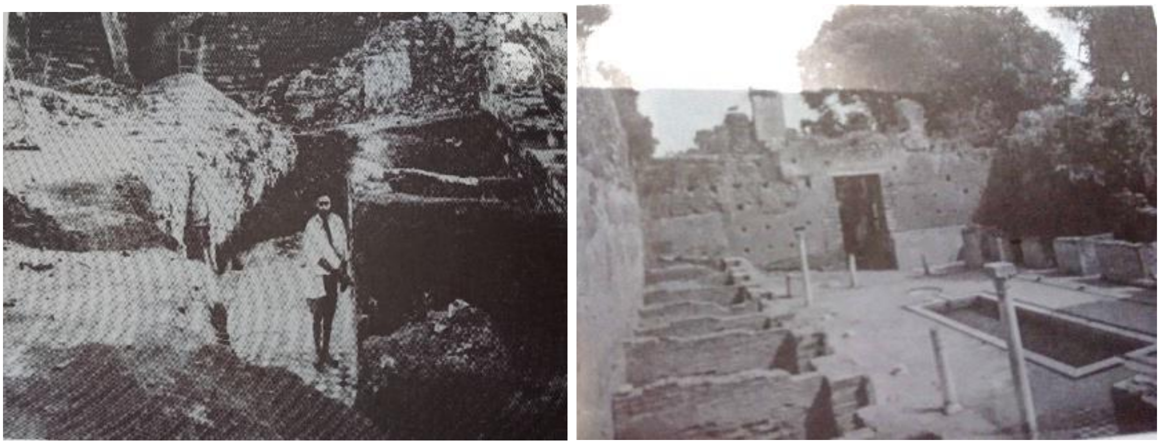
When it comes to archaeological buildings, ensuring structural safety and durability are paramount considerations, with a primary focus on respecting their cultural, historical, and architectural values, thus safeguarding their distinctive characteristics during preservation efforts (Spennemann, 2023). In this paper, we describe the multi-criteria approach aimed at assessing the remains of the Marinid Madrasa (Figure 1), using geometric data from a 3D model generated by terrestrial photogrammetry, which provides important information for physical characterization and numerical analysis.

Presentation of case study.

The presented research was conducted as collaboration between High School of Technology-Salé, Mohammed V University, LAMEREN laboratory, and Region of Rabat-Salé-Kénitra. Through a series of activities, workshops, and conferences, an endeavor was undertaken to promote and disseminate knowledge about the Chellah archaeological site by employing innovative techniques for documenting and conserving its rich cultural heritage.

Figure 1. Location of study area, (a): the map of Rabat city (Google Earth Pro), (b): Chellah archeological site (Google maps), (c): Marinid Madrasa site (UAV- DJI Phantom 4 Pro, taken by Authors).

The site encompasses remnants left by diverse civilizations, including the Phoenicians, Carthaginians, Romans, and Islamic peoples. Specifically, the focus was on the Marinid Madrasa (Figure 2), a remarkable architectural gem constructed by the Marinid dynasty, which held dominion over Morocco and the entire Maghreb region for nearly two centuries, spanning from the mid-13th century to the mid-15th century (Terrisse, 2011).



a b

Figure 2. Documentation of excavations at the Medersa site in 1912 (a), Photographic documentation of the Medersa in 1920 (b) (source: Archive of the Ministry of Culture (Rabat, Morocco)).

In-situ investigations.

Typology of construction.

Many archaeological building monuments have suffered severe damage due to natural weathering processes, pollution influences, insufficient maintenance, utilization, and use of sensitive materials or inappropriate conservation (Theodoridou & Török, 2019). The current archaeological site (Marinid Madrasa) (Figure 3) has suffered these damages, and also the impact of groundwater due to rising aquifers. In (Table 1), the material type is presented as the entry, while the corresponding damage type/state is reported.

Table 1. The material building of Madrasa and the damage type.

Material type	Damage/state
Wood	Mold and fungi growth, gilding degradation, polychrome deterioration, cracks, displacement, deformation, delamination, water stains, and moisture marks.
Stone	Damage caused by water and moisture, moss and lichen growth, cracks, alterations in polychromy, erosion, attrition, and delamination (for limestone).
Rammed earthen	Erosion, stain loss, cracking
Marble	Alteration of gilding, adhesive repairs, staining, chipped paint, changes to polychromy, watermarks, missing fragments, and faded inscriptions.
Zellige	Gaps, tears, soiling, cracks, chips, mold, holes, changes in the pictorial layer, color fading, alterations in the coating, localized dirt accumulation, and delamination of the pictorial layer.

Figure 3. Example of building material and degradations of archaeological assets of Madrasa (Author's figure).

The Ishikawa diagram, Figure 4 interprets the causes of damage of Marinid Madrasa, which is regrouped in three main sections; first the building constitution reason, which is related to the type of materials. Then, People intervention which represents a bad choice of conservation method, and people degradations. Lastly, an environment that encompasses biological aggression, physics-induced issues, and mechanical degradation.

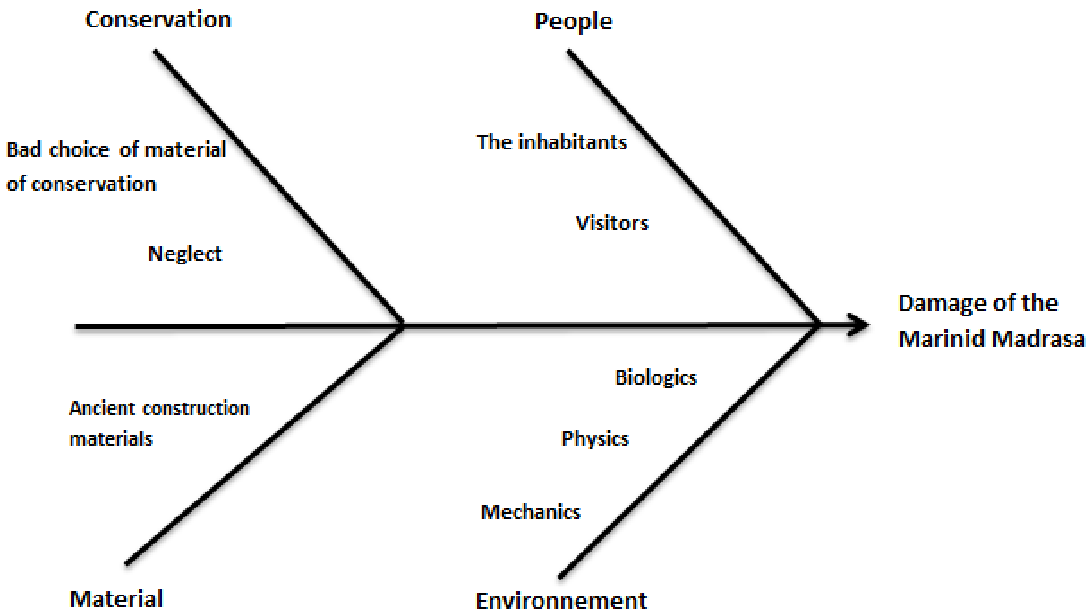


Figure 4. Ishikawa diagram of archaeological assets damage of Marinid Madrasa (Author's figure).

Building materials characterization.

The optimization of diagnostic procedures is an important scientific objective, representing the basis for sustainable monument preservation. The specific objectives of scientific diagnosis include the characterization of stone materials, quantification of stone alterations, and characterization and quantification of weathering characteristics (Theodoridou & Török, 2019). For the documentation and experimental analysis of the building materials of the Marinid Madrasa, a series of mechanical tests were applied to the adobe material extracted from the site. The methodology employed in this study demonstrates encouraging outcomes in enhancing the prediction of mechanical properties for the mix utilized in the construction and restoration of historic monuments, thereby minimizing the need for expensive experimental endeavors. To examine the morphology of a selected surface and provide a preliminary characterization of the construction materials as well as an evaluation of degradation, a scanning electron microscope was used. Specifically, a mini-Scanning Electron Microscope (mini-SEM) HIROX SH 4000M, equipped with SE (Secondary Electron) and BSE (Backscattered Electron) detectors, was employed.

Data acquisition.

The difficulty in surveying the deformation of archaeological buildings lies in finding a measurement method that is reliable, accurate, repeatable, inexpensive, and easy to implement (van Dijk, Gamstedt, & Bjurhager, 2015). Terrestrial laser scanning (TLS) may prove to be a good alternative and supplement for surveying many complex heritage constructions in a fast and safe manner, with high accuracy (Tobiasz et al., 2019). TLS has become increasingly popular for the documentation of cultural heritage due to its availability and the ability to provide dense surface models quickly, with improving accuracy and reliability (Shanoer & Abed, 2018).

In this study, data of the Marinid Madrasa were obtained through TLS, using the Leica ScanStation 2 Laser Scanner (Figure 5), provided by the research team at the Laboratory of Applied Mechanics and Energy Recovery of Materials (LAMERN), Mohammed V University, Rabat. Multiple overlapping scans were acquired from selected positions to capture the surface details of the archaeological site, By achieving an average spatial resolution of 5-6 mm, the dense 3D point cloud acquired enables the generation of a meticulous digital model showcasing the enduring components found within the site, including the Mihrab and the North wall. This detailed representation significantly aids in the documentation of the archaeological assets present.

Figure 5. Laser data setting and capturing using Leica scan (Author's figure).

Results and Discussions.

Data exploration and visualization of numerical models.

The data obtained using TLS allows the creation of orthoimages of many durable types of construction elements in Madrasa site. The accuracy obtained after the correction of the point cloud, and then a 3D models ware produced for Mihrab and north wall of Madrasa site (Figure 6) however, these objects (Figure 7) are used as data for various conservatory analyses for damage and thematic mapping including not only qualitative information but also quantitative data. It is a very useful tool that allows saving the model in the form of virtual copy (Tsilimantou et al., 2020). The acquired models represent the sole available information regarding this archaeological site, serving as an invaluable resource for future research endeavors.

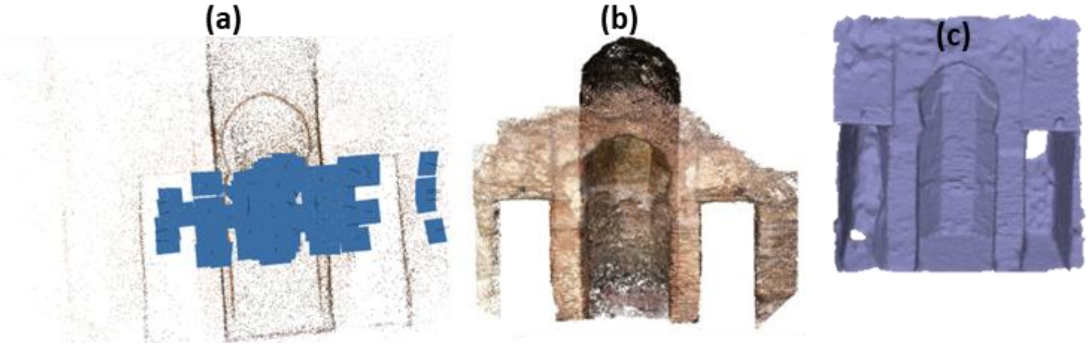


Figure 6. The process involved capturing camera positions for alignment (a), generating a dense point cloud of the Mihrab (b), and creating a 3D mesh to represent its intricate structure (c) (Author's figure).

a b

Figure 7. Orthoimages of (a) the North wall (b) the Mihrab (Author's figure).

The 2D plans corresponding to the Mihrab and the North wall are extracted from the digital models provided by the cloud points using AutoCAD. Each element of the drawing has been classified according to architectural detail, distribution of building material and type of degradation.

Building materials.

The Madrasa is located in the northeastern part of the Chellah archaeological site and comprises a prayer room, an open-air courtyard, a Minaret, and several cells for students. The damaged remains consist of a central courtyard with a beautiful basin at its center, surrounded by a scroll adorned with small columns and marble columns. On the East and West sides, there are a series of rooms. Towards the south, there is a small rectangular prayer hall with two parallel naves along the Qibla wall. In the center, there is a pentagonal Mihrab decorated with stuccoes featuring various motifs. On the opposite side, in the northern area, stands a slender Minaret (Fig. 8.d) that still retains its architectural characteristics from that period. The Minaret is square-shaped and consists of two floors. The first floor is constructed with adobe bricks, embellished with geometric motifs formed by intersecting stone lozenges. The smaller second floor is covered on all four sides with ceramic tiles of different colors.

During the in situ survey, the variations in the building materials for each type of masonry were recorded and analyzed qualitatively and quantitatively. The structural system of each architectural element was documented using thematic maps, thereby validating the architectural and historical research conducted on these elements. On the walls (Fig.8.a), it is evident that there is a higher percentage of Rammed earthen material and a lower percentage of blocks compared to the Mihrab section (Fig.8.c) and the cells (Fig.8.b), indicating the implementation of a rigid partitioned system during their construction.

A comprehensive attribute database was created, encompassing physico-mechanical characteristics data of adobe (Rammed earthen). The investigation revealed that mechanical properties, including tensile strength and modulus of elasticity, can be accurately assessed through bending tensile tests. The adobe material showcased commendable resilience against compression and tensile stress, evident in a bending strength to compressive strength ratio of 40. Furthermore, an SEM test was conducted on the fractured surfaces of the adobe material, revealing a heterogeneous microscopy with the presence of cracks and large pores (Figure 9). The significance of these findings lies in their ability to characterize the adobe material employed in constructing the walls of the Madrasa, providing essential reference values that should be taken into account when undertaking the restoration and rehabilitation of the site's buildings.

Due to the advanced state of degradation of the monument, non-destructive testing (NDT) techniques were employed in the study conducted by S. Belhaj and colleagues (Belhaj, El Ghazali, Bahi, Akhssas, 2019),s to assess the Medersa Marinid site located in Chellah. The objective was to determine the primary cause of these deteriorations by examining the internal and external faces, adobe material within the walls, as well as the chaining stones and bricks. A comprehensive sampling approach was undertaken to cover all the existing structures within the Chellah enclosure, which, combined with the diagnostic process, enabled the identification and characterization of degraded areas within the overall Chellah monument and specifically the Medersa Marinid.

The representation and distribution of building materials at the surface level, particularly on the Mihrab and the minaret, were illustrated using visual inspection, NDT evaluation, and digital models generated through terrestrial photogrammetry. The integration of NDT and visual inspection facilitated the identification of construction materials on the Mihrab's façade, which consists of red bricks interspersed with clay, adobe in the upper part of the Mihrab, and remnants of lime. The minaret's façades feature adobe bricks and persisting zellige patterns.

a b c d

Figure 8. Different archaeological parts of Marinid Madrasa (Author's figure): North wall (a), Remains of chambers (b), The Mihrab (c), The Minaret (d).

For a qualitative and quantitative survey, the distribution of various types of masonry was analyzed, as shown in Figure 10. The wall exhibits a higher percentage of adobe (Rammed earthen) and a smaller proportion of adobe bricks compared to the remaining preserved sections, as it represents the thickest wall within the Medersa building. Conversely, the façades of the Mihrab predominantly consist of adobe brick materials, while the Minaret exhibits a high percentage of red bricks.

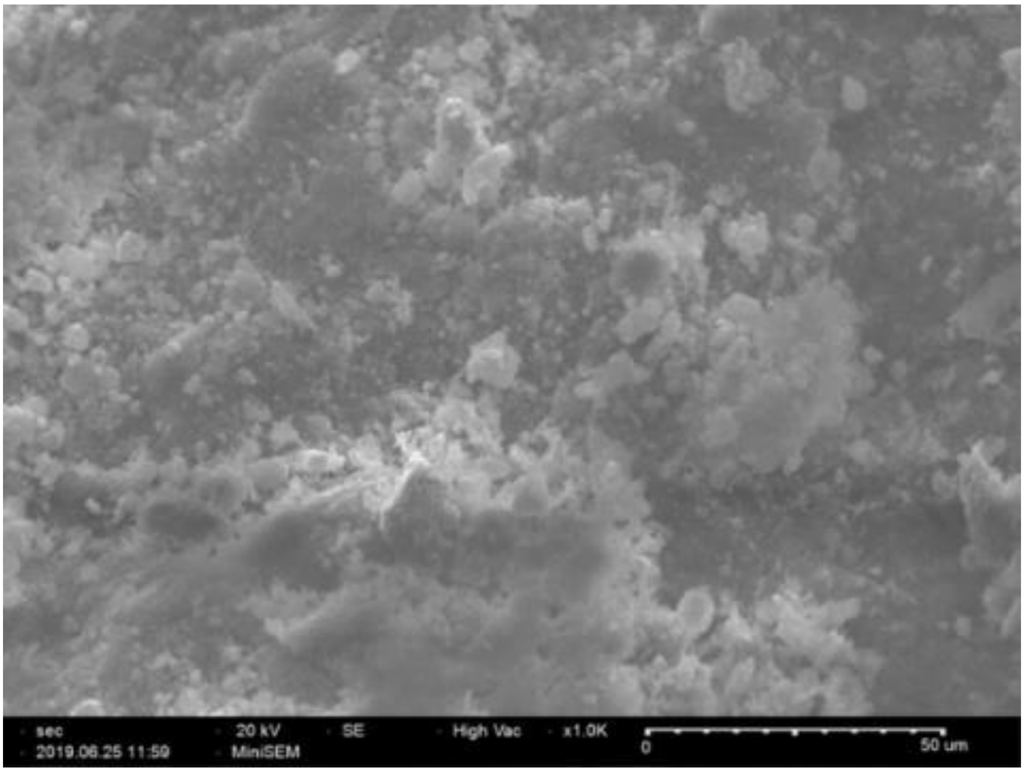


Figure 9. SEM image of fracture surface (50μm) (Author's figure).

In the Marinid stone (Figure 11.a), the percentage of calcium oxide is excessively high, reaching 51%, while clay minerals account for 17%. The loss on ignition is estimated at 30,5%, indicating significant alteration. The rock's alteration is confirmed by both the loss on ignition and observations under the optical microscope. The predominant elements in the rock are carbon, oxygen, and calcium. The Marinid brick (Figure 11.b) is found in the domes of the towers and the Mihrab. The study conducted under the optical microscope revealed that it is a sandstone clay with a low carbonate content and large sandy grains, likely derived from sea sand or Oued Bouregreg. The dispersion of grains indicates a poor element composition and therefore low quality. The composition consists of 10 to 15% of quartz grains measuring 50 to 100μm in diameter, which are sub-rounded in shape, and 5% of joined quartz with a diameter of 0.5 to 1 mm. The matrix is predominantly clayey with occasional patches of calcite. The archaeological monument Madrasa of Chellah includes building materials such as; brick, stone, clay, mud, wood, plaster, zellige, steel and as a method of construction adobe masonry.

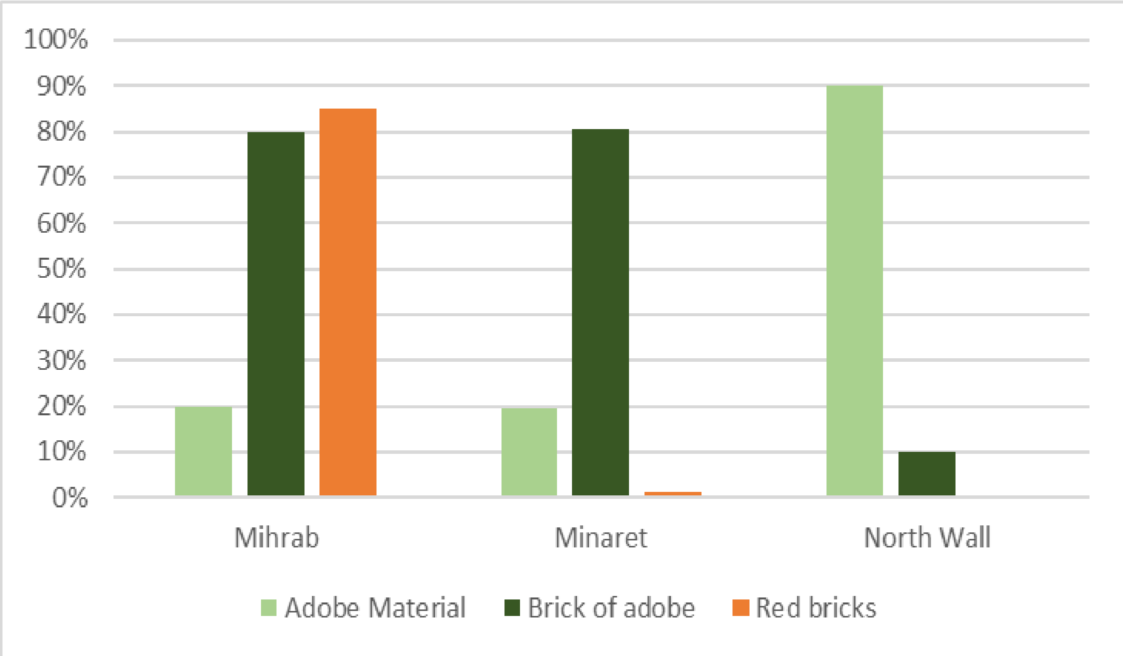


Figure 10. Diagram of the percentage of building materials in North wall, Mihrab, and Minaret (Author's figure).

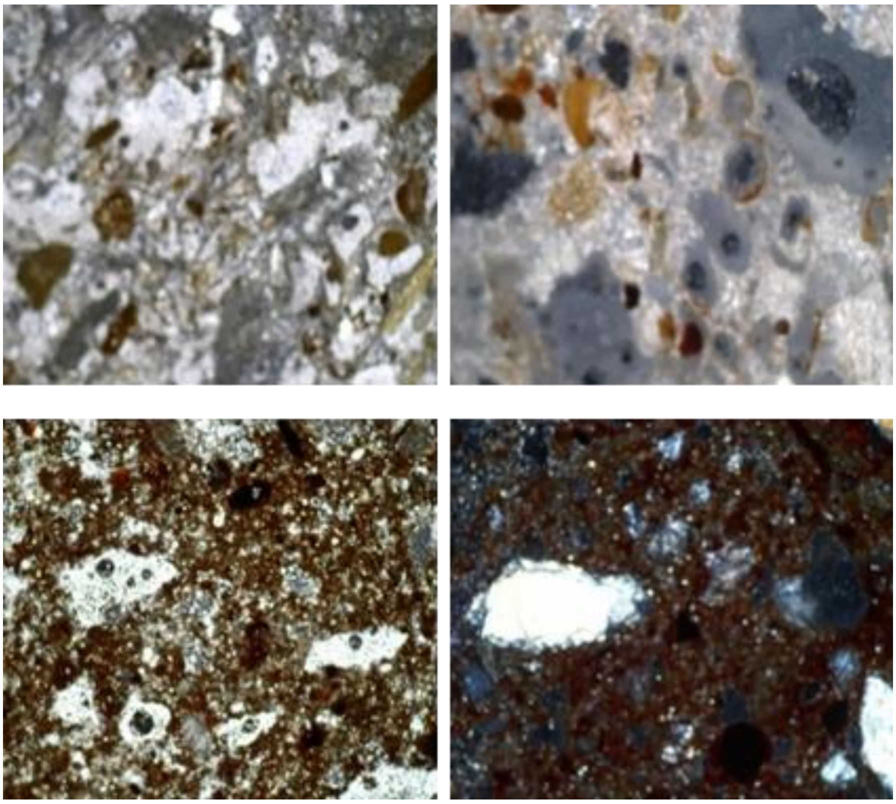


Figure 11. (a) Building stone and (b) The Marinid brick, under white light and polarized under 4X objective. (Author's figure).

The development of lichens (Marked with blue circle) on the wall causes physic-chemical damage because of their metabolic activity (production of oxalic acids) and an aesthetic inconvenience Figure 12-a. The development of lichens causes physic-chemical alterations and aesthetic inconvenience (Minaret of Chellah) Figure 12-b.

a b

Figure 12. (a) North wall and (b) Minaret of Madrasa with the evolution of lichens (Author's figure).

Also, the roots of plants (Marked with the red circle) in addition to the former exert mechanical thrusts causing fractures. The excrements of birds (oxpeckers and storks) also cause chemical degradation (Chellah lichen). The issues encountered on this site are related to humidity, the presence of water, atmospheric pollution, vegetation growth, lack of sanitation inside and outside the site, the primary construction technique and the previous rehabilitation and conservation processes.

Elaboration of thematic maps of decay and building material distribution.

Thematic maps depicting the distribution of building materials in the Madrasa were developed (Figure 13).

The selection of the Mihrab and the North wall was based on their representation of the various building materials and construction phases found throughout the Madrasa. The data pertaining to building materials and decomposition schemes consist of attribute data sets that comprehensively depict the characteristics of the registered spatial features found within the site. To create the thematic maps, GIS tools were utilized, making use of the results obtained from the degradation diagnostics. GIS is capable of recording, aggregating, analyzing and managing large volumes of spatially referenced data and associated attributes. These results form the basis of a database that facilitates the analysis and preservation of the state of the archaeological assets at the Medersa site. Figure 14 represents the thematic map showcasing the decay of building materials in the Mihrab, based on visual inspection, macroscopic tests, and digital models generated by terrestrial photogrammetry.

The decay in the Mihrab is significant, with a noticeable detachment of building materials on the upper part and facade. This detachment indicates rising humidity, although significant structural cracks are not observed. The lime coating has disappeared, revealing the building bricks, which exhibit flaking and material loss. The wood is completely degraded, and a large portion of the plaster decoration has vanished. The most dominant building material observed is red brick (12 cm long and 3 cm wide), intercalated with a layer of clay, with remnants of rammed earth visible in the upper part.

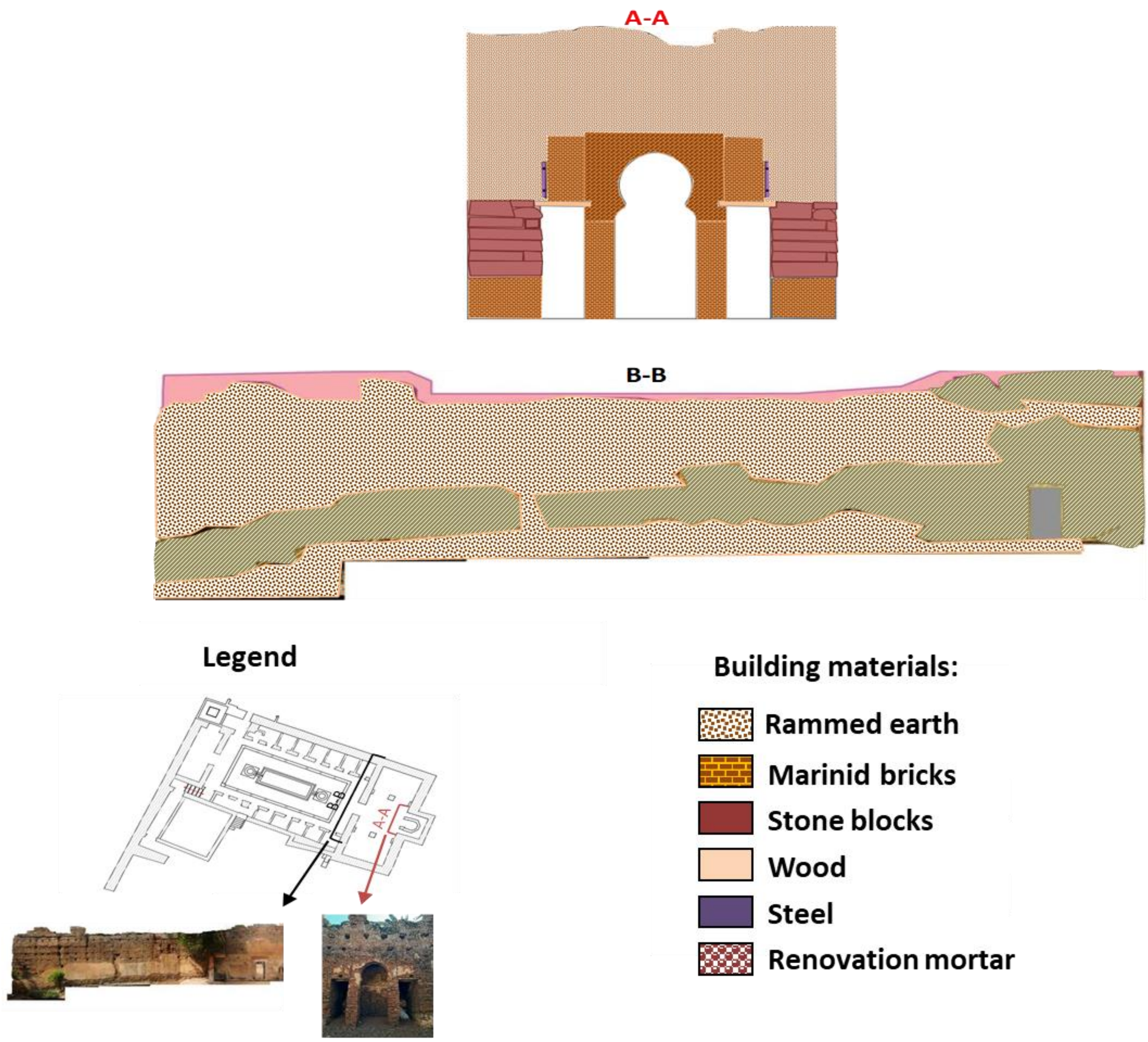


Figure 13. Thematic map of building material distribution on (A-A) the Mihrab and (B-B) North wall (Author's figure).

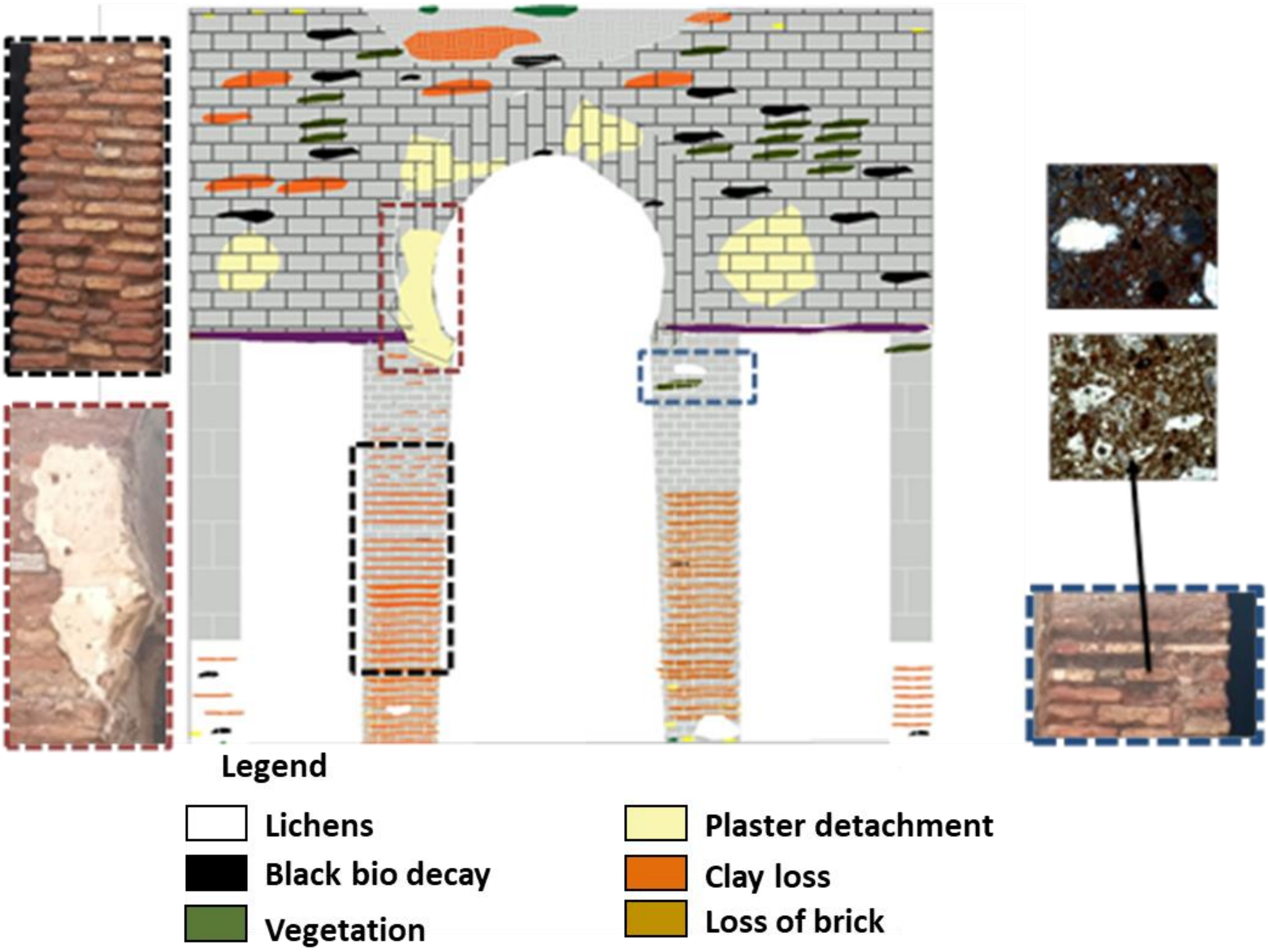


Figure 14. Thematic map of decay on the archaeological Mihrab (Author's figure).

Conclusions.

The multi-criteria approach presented in this paper aims to establish correlations between different data in order to create multidisciplinary thematic maps (Figure 15). This approach relies on in-situ investigations, numerical documentation, and the characterization of building materials in archaeological assets. The first step involves collecting and processing data and information in a careful, balanced, and thoughtful manner to develop a comprehensive action plan. Conservation practices for an archaeological site require a thorough understanding of the structure's characteristics and materials. It is crucial to gather information about the asset in its original and early state, the construction techniques employed, the endured alterations and their effects, the occurred phenomena, and its present condition. The chosen site contains archaeological remains, which poses specific challenges as stabilization must be carried out simultaneously with the excavations while information is still incomplete. A diagnosis was conducted using qualitative and quantitative methods, with historical research relying on structural damage and material decay observations, as well as historical and archaeological investigations. The quantitative aspect involved testing building materials, non-destructive testing (NDT), and geometric data generated through photogrammetry. Based on the obtained data, thematic maps were created, serving as a foundation for restoration efforts and the management of disciplinary information. These maps contribute to the planning and decision-making processes regarding interventions on the site's remains.

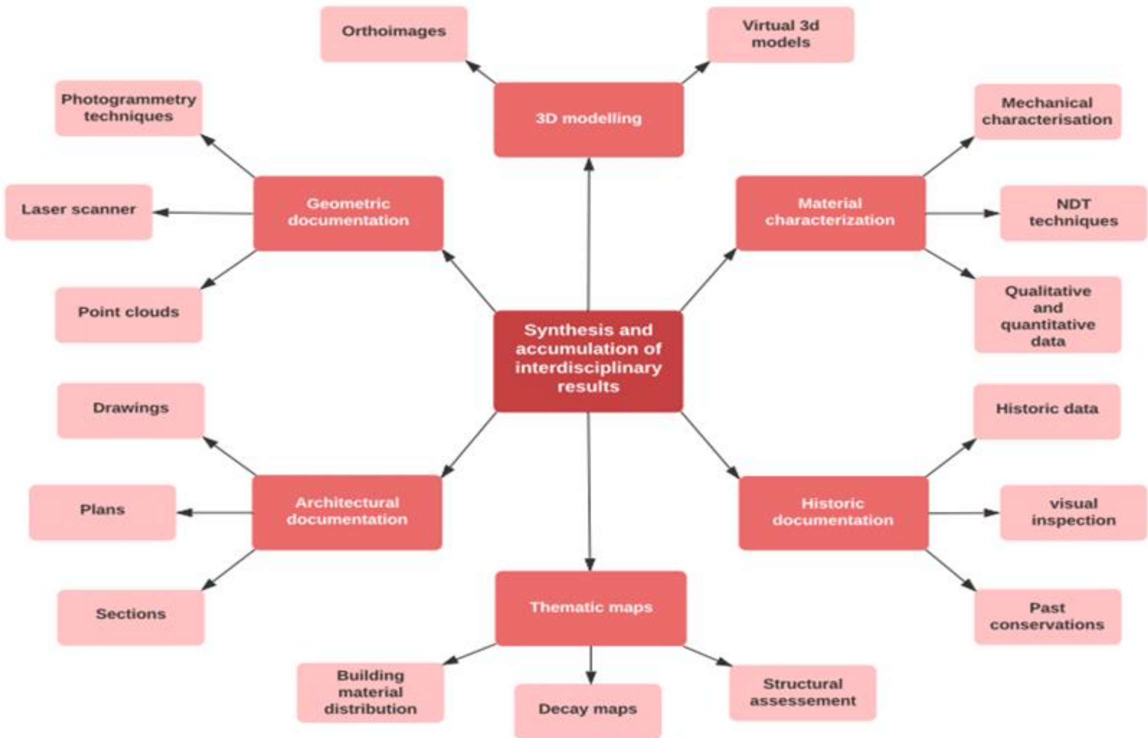


Figure 15. Diagram of the synthesis and accumulation of interdisciplinary results incorporating various data (Author's figure).

Conflicts of interest.

The authors declare no conflict of interest.

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References

Adamopoulos, E., & Rinaudo, F. (2021). Combining multiband imaging, photogrammetric techniques, and FOSS GIS for affordable degradation mapping of stone monuments. *Buildings*, *11*(7), 304. https://doi.org/10.3390/buildings11070304

AlMasri, R., & Ababneh, A. (2021). Heritage management: Analytical study of tourism impacts on the archaeological site of Umm Qais–Jordan. *Heritage*, *4*(3), 2449–2469. https://doi.org/10.3390/heritage4030138

Belhaj, S., El Ghazali, F. E., Bahi, L., & Akhssas, A. (2019, April). *Physico-chemical characterization and studies of the different alterations of the calcarinite stones used in the historical monument Chellah-Rabat*. Paper presented at the meeting of EGU General Assembly, Vienna, Austria. Retrieved from https://presentations.copernicus.org/EGU2019/EGU2019-88_presentation.pdf

Chen, Y., Wu, Y., Sun, X., Ali, N., & Zhou, Q. (2023). Digital documentation and conservation of architectural heritage information : An application in modern Chinese architecture. *Sustainability*, *15*(9), 7276. https://doi.org/10.3390/su15097276

Choriyev, S., Shaydullaeva, G., & Raxmonkulova, Z. (2023). The history of archives in Central Asia : Ancient times. *History of Science and Technology*, *13*(1), 34–51. https://doi.org/10.32703/2415-7422-2023-13-1-34-51

Di Benedetto, C., Gautiero, A., Guarino, V., Allocca, V., De Vita, P., Morra, V., … & Calcaterra, D. (2020). Knowledge-based model for geomaterials in the Ancient Centre of Naples (Italy) : Towards an integrated approach to cultural heritage. *Digital Applications in Archaeology and Cultural Heritage*, *18*, e00146. https://doi.org/10.1016/j.daach.2020.e00146

Haq, F., Yasin, N., & Nair, G. (2023). Envisioning the future of heritage tourism in the creative industries in Dubai : An exploratory study of post COVID-19 strategies for sustainable recovery. *Heritage*, *6*(6), 4557–4572. https://doi.org/10.3390/heritage6060242

Jeong, J. Y., Karimov, M., Sobirov, Y., Saidmamatov, O., & Marty, P. (2023). Evaluating culturalization strategies for sustainable tourism development in Uzbekistan. *Sustainability*, *15*(9), 7727. https://doi.org/10.3390/su15097727

Lu, N., Wang, Q., Wang, S., & Zhang, R. (2015). The application of 3D laser scanning in the survey and measuring of Guyue Bridge of Song Dynasty in Yiwu City. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *II-5-W3*, 185–190. https://doi.org/10.5194/isprsannals-II-5-W3-185-2015

Maté-González, M. Á., Di Pietra, V., & Piras, M. (2022). Evaluation of different LiDAR Technologies for the documentation of forgotten cultural heritage under forest environments. *Sensors*, *22*(16), 6314. https://doi.org/10.3390/s22166314

Mekonnen, H., Bires, Z., & Berhanu, K. (2022). Practices and challenges of cultural heritage conservation in historical and religious heritage sites : Evidence from North Shoa Zone, Amhara Region, Ethiopia. *Heritage Science*, *10*(1), 172. https://doi.org/10.1186/s40494-022-00802-6

Nilson, T., & Thorell, K. (Eds.). (2018). Cultural heritage preservation: The past, the present and the future. *Forskning i Halmstad Nr. 24*. Halmstad: Halmstad University Press. Retrieved from https://www.diva-portal.org/smash/get/diva2:1224014/FULLTEXT01.pdf

Salagean-Mohora, I., Anghel, A. A., & Frigura-Iliasa, F. M. (2023). Photogrammetry as a digital tool for joining heritage documentation in architectural education and professional practice. *Buildings*, *13*(2), 319. https://doi.org/10.3390/buildings13020319

Sanchez-Calvillo, A., Alonso-Guzman, E. M., Martinez-Molina, W., Navarrete-Seras, M. A., Ruvalcaba-Sil, J. L., Navarro-Ezquerra, A., & Mitrani, A. (2021). Characterization of adobe blocks: Point-load assessment as a complementary study of damaged buildings and samples. *Heritage*, *4*(2), 864–888. https://doi.org/10.3390/heritage4020047

Shanoer, M. M., & Abed, F. M. (2018). Evaluate 3D laser point clouds registration for cultural heritage documentation. *The Egyptian Journal of Remote Sensing and Space Science*, *21*(3), 295–304. https://doi.org/10.1016/j.ejrs.2017.11.007

Simou, S., Baba, K., & Nounah, A. (2022). A GIS-based methodology to explore and manage the historical heritage of Rabat city (Morocco). *Journal on Computing and Cultural Heritage*, *15*(4), 74. https://doi.org/10.1145/3517142

Spennemann, D. H. R. (2023). What actually is a heritage conservation area? A management critique based on a systematic review of New South Wales (Australia) planning documents. *Heritage*, *6*(7), 5270–5304. https://doi.org/10.3390/heritage6070279

Terrisse, M. (2011). *Les musées de sites archéologiques appréhendés en tant que vecteurs de développement local à travers trois études de cas préfigurant la mise en valeur opérationnelle du site de Chellah* (These de doctorat, Le Mans). Le Mans. Retrieved from https://www.theses.fr/2011LEMA3006 [in French].

Theodoridou, M., & Török, Á. (2019). In situ investigation of stone heritage sites for conservation purposes : A case study of the Székesfehérvár Ruin Garden in Hungary. *Progress in Earth and Planetary Science*, *6*(1), 15. https://doi.org/10.1186/s40645-019-0268-z

Tobiasz, A., Markiewicz, J., Łapiński, S., Nikel, J., Kot, P., & Muradov, M. (2019). Review of methods for documentation, management, and sustainability of cultural heritage. case study: Museum of King Jan III's Palace at Wilanów *Sustainability*, *11*(24), 7046. https://doi.org/10.3390/su11247046

Tsilimantou, E., Delegou, E. T., Nikitakos, I. A., Ioannidis, C., & Moropoulou, A. (2020). GIS and BIM as integrated digital environments for modeling and monitoring of historic buildings. *Applied Sciences*, *10*(3), 1078. https://doi.org/10.3390/app10031078

van Dijk, N., Gamstedt, K., & Bjurhager, I. (2015). Monitoring archaeological wooden structures : Non-contact measurement systems and interpretation as average strain fields. *Journal of Cultural Heritage*, *17*, 102–113. https://doi.org/10.1016/j.culher.2015.03.011

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Синергія багатокритеріальної діагностики для збереження культурної спадщини та відновлення зниклої спадщини: Історичне дослідження в науці, техніці та археології

Анотація. *Нагальна потреба збереження культурної спадщини на сучасному етапі розвитку суспільства стає надзвичайно важливою, особливо гостро в Марокко, де його багата культурна спадщина стикається з непередбачуваними загрозами. Швидкі сили урбанізації та нескінченного економічного розвитку зіткнулися, що призвело до тривожної депреціації та необоротного погіршення стану значної частини цієї безцінної спадщини. У цьому контексті деяким видатним пам’яткам вдалося витримати плив часу. Одним з таких зразків є Маринідська медресе, архітектурне диво 4 століття, розташоване на території археологічного об'єкту Шелла у Рабаті, Марокко. Поза своєю фізичною величчю, медресе відіграє ключову роль як канал між минулим та майбутнім, сприяючи передачі культурної спадщини нащадкам, які ще народяться. Ця робота розпочинає багатодисциплінарну подорож, використовуючи передові техніки, такі як земельна фотограметрія, числове моделювання та спеціалізована археологічна характеризація, для проведення комплексного діагностичного дослідження. Злиття цих різноманітних методик створює міцну основу для всебічного діагностичного дослідження. Ці зусилля будуть слугувати не лише академічній цікавості, але й стануть кутовим каменем, на якому будуються стратегії сумісних консерваційних та реставраційних втручань. У складній взаємодії між збереженням історичного спадку та імперативами прогресу ці методики утворюють міст. Цей міст зв'язує архітектурну велич медресе з необхідністю збереження її в швидкозмінному світі. Остаточною метою цього багатодисциплінарного* *підходу є: забезпечити довготривалий захист Маринідської медресе та інших археологічних залишків від руйнівних сил часу та міського розвитку, а також сформувати наратив, що чутливо реагує на виклики збереження культурної спадщини перед сучасністю. У цьому зусиллі передові технології переплітаються з глибоким визнанням історичного, соціального та культурного значення цих місць, нарешті, прокладаючи шлях, який не лише зберігає архітектурний блиск, але й вшановує глибокі історії, які вони вміщують через епохи.*

Ключові слова: *культурні цінності; матеріальний аналіз; реставрація; античність; археологія; 3D-технологія*

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On the history of the construction of metal bridges in the 20th century using welding technology

Abstract. *The history of bridge construction is an important part of historical knowledge. Developments in bridge construction technology reflect not only engineering advances, but also social, economic and cultural aspects of society. Engineers and scientists faced unique challenges when designing and building bridges depending on the technological level of the era, available materials and the needs of society. This process may reflect technological progress, changes in transportation needs, and cultural and social changes. The purpose of this article is to briefly review key moments and stages in the history of metal bridge construction using welding technology in the 20th century. The history of the development of the construction of metal bridges using welding goes back a little over 100 years. The short period from the construction of the first welded bridges to their first disasters led to the need to analyze the possible causes of these destructions. As the analysis performed showed, catastrophic destruction most often occurred under the influence of several factors, as well as a combination of external adverse influences and the internal "unpreparedness" of the structure for them. The above examples indicate that an irrational choice of steel could be both an independent cause causing brittle failure of structures, and an aggravating factor in the presence of structural violations, thermal stresses and welding defects. Over the years, bridge manufacturing technologies have been improved in different countries, and new steels and materials for their welding have been developed. Thanks to the use of carbon, low-alloy and alloy steel, designers abandoned the brutal "railroad-type" beam trusses and today metal bridges with graceful and beautiful silhouettes powerfully stride across the water surface, mountains and valleys. They became real attractions of megacities and country landscapes, and builders were able to successfully solve numerous technical and economic problems. An important contribution to the development of global bridge construction using welding technologies was made by the team of the Institute of Electric Welding of the Academy of Sciences of the Ukrainian SSR under the leadership of Academician Evgeny Oskarovych Paton. The team of the Institute of Electric*

Welding of the Academy of Sciences of the Ukrainian SSR, introducing welding into bridge construction, carefully checked the results and monitored the behavior of structures. A new grade of steel was created that was resistant to the formation of brittle and fatigue cracks, its welding technology was developed, a technology for installation welding of vertical sheets with forced formation of a seam was developed, and suitable welding materials were selected. At the time of construction in 1953, the Kyiv Evgeny Paton Bridge across the Dnipro River was the largest all-welded bridge in Europe, all seams of which, including assembly ones, were made for the first time using automatic and semi-automatic welding. In addition, the presence of large similar blocks in the design of the Evgeny Paton Bridge made it possible to mechanize assembly and welding operations and organize an in-line method for their production at the factory and installation, which improved the quality of welding work and reduced its labor intensity.
Keywords: *history of bridge construction; history of metal bridges; welding history; Evgeny Paton Kyiv Bridge; Historical Welded Structure Award; Institute of Electric Welding of the Academy of Sciences of the Ukrainian SSR*

Introduction.

One of the main goals of history as a science is to study the past on the basis of documentary evidence, archaeological finds and other sources. Historians strive to reconstruct the events, trends, and cultural characteristics of different time periods based on available information. It is important to note that historians adhere to certain methodologies and standards of evidence to ensure the integrity of their research. Comparison and analysis of various sources help historians build a more complete and objective understanding of the past. Historical facts and dates are subject to reinterpretation and debate in the light of new research and discoveries, and historians often revise their interpretations and conclusions based on new evidence. This process makes history a dynamic and constantly evolving field.

The history of bridge construction is also an important part of historical knowledge. Developments in bridge construction technology reflect not only engineering advances, but also social, economic and cultural aspects of society. Engineers and scientists faced unique challenges when designing and building bridges depending on the technological level of the era, available materials and the needs of society. This process may reflect technological progress, changes in transportation needs, and cultural and social changes.

Studying the history of bridge construction allows to understand how different civilizations dealt with technical problems, what engineering solutions they created, and how these solutions influenced the development of society. It also highlights the importance of engineering and construction achievements in human history.

The history of the construction of metal bridges is an exciting period in the development of engineering and construction art. An analysis of scientific research devoted to the history of the construction of metal bridges allows to identify several main areas of this work:

1. Evolution of metal bridge construction technology (Pescatore & Borgeot, 2008; Armisén, 2019). This direction is devoted to the study of the history of the development of technologies and methods for constructing metal bridges from their initial introduction to modern trends.

2. The role of metal bridges in infrastructure development (Liegner, Kormos, & Papp, 2015; Statyvka, Kyrychenko, Strelko, & Berdnychenko, 2021; Vůjtěch, Ryjáček, & Matos, 2023). This direction is devoted to the analysis of the impact of the construction of metal bridges on the development of transport infrastructure, urban planning and economics in different regions and eras.

3. Architectural and engineering solutions for metal bridges (Bartlett, Graham, & Camiletti, 2009; Arwade, Schafer, B. W., Schafer, D. F., & Schafer, S. T., 2015; Schueremans, Porcher, Rossi, Wouters, & Verstrynge, 2018). This direction is devoted to the study of the history of the various styles, designs and technical solutions used in the construction of metal bridges, and their impact on the overall landscape.

4. Historical metal bridges as cultural heritage (Bernabeu-Larena, Martín-Caro, Hernández-Lamas, & Plana, 2023).). This direction is devoted to assessing the role and significance of historical metal bridges as part of the cultural heritage and architectural monuments.

5. Problems of maintenance and restoration (Rymsza, Mistewicz, & Tucholski, 2017). This direction is devoted to the study of the challenges and technical aspects associated with the maintenance and restoration of ancient metal bridges, taking into account their preservation for many years.

This work belongs to the first direction. Its purpose is to briefly review key moments and stages in the history of metal bridge construction using welding technology in the 20th century.

Idea, Methodology and Sources of Research.

The author of this article became interested in the topic of constructing metal bridges using welding in connection with well-known information about the 70th anniversary of the Evgeny Oskarovych Paton Bridge in Kyiv in Ukraine. The Paton Bridge was put into operation on November 5, 1953 (Lobanov, Kyrian, & Shumitsky, 2003).

Evgeny Paton Bridge is truly unique. This is an undeniable fact and was specifically recognized in 1995 by the American Welding Society (AWS) with the Extraordinary Welding Awards in the Historical Welded Structure Award category (see Figure 1) (American Welding Society, 2023, p. 52). The AWS website states that (American Welding Society, n.d.): “Nominations for the Historical Welded Structure Award may be submitted by any AWS member for consideration by the Committee of Past Presidents. Nominations for historical recognition are valid for two years, and structures must be at least 35 years old.”

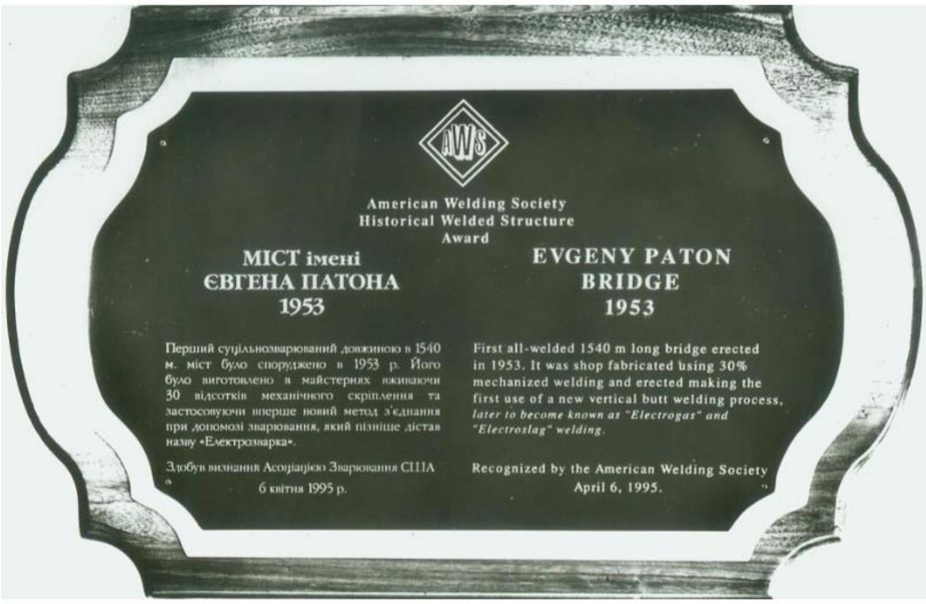

Figure 1. Memorial sign about the Evgeny Paton Bridge Extraordinary Welding Awards in 1995 (Lobanov, Kyrian, & Shumitsky, 2003).

It is worth noting that the Extraordinary Welding Awards were created to recognize and promote the science, technology and applications of welding (American Welding Society, n.d.). The Extraordinary Welding Awards was intended to encourage members of the welding community to recognize their heritage in metal joining; and to convey to the public the fact that the combination of metals has played and continues to play an important role in everyday life. The purpose of the Extraordinary Welding Awards is to recognize the excellence of welding in construction, fabrication and manufacturing, and to recognize those welded structures whose purpose is significant in or influences the history of the world.

As of this writing in 2023, only 42 objects or inventions have been awarded the Extraordinary Welding Awards in two categories: The Historical Welded Structure Award and the Outstanding Development in Welded Fabrication Award (American Welding Society, 2023, p. 52–53). Among them: Tokyo Tower (1997); U.S. Pentagon (2000); Pratt & Whitney F119 Engine (2001); Hoover Dam Penstock Power Plant System (2002); One World Trade Center (2015); Mars Curiosity Rover (2016); Panama Canal (2019).

Evgeny Paton Bridge was awarded the Extraordinary Welding Awards when the award was first presented in 1995, along with three other winners Sludwia River Bridge, Mr. Charlie (Morgan City, LA) and Soviet Combat Tank (American Welding Society, 2023, p. 52). This once again emphasizes the importance of the achievements of welding technologies in the manufacture of the Evgeny Paton Bridge structure.

As can be seen in Figure 1, the AWS award was awarded to the Evgeny Paton Bridge, as the first all-welded bridge, 1540 m long, built in 1953, using new welding processes in the manufacture of vertical butt welds, later called "Electrogas" and

"Electroslag" welding And also for the use of less than 30% mechanical connections in the manufacture of bridge structural elements in factory workshops (Lobanov, Kyrian, & Shumitsky, 2003).

It was in this part of the study that the author had the largest number of questions that required answers supported by documentary evidence of historical documents.

First of all, this concerned terminology. Namely, the use of the term "first". When the Evgeny Paton Bridge was discussed in the Extraordinary Welding Awards, it referred to the "First All-Welded Bridge." First in the world? The first in Europe? The first one this long? The first all-welded one of this length? The first one at the time of construction (put into operation) in 1953?

Finding answers to these questions turned out to be not so simple. The more the author delved into the history of the research question, the more inconsistencies and points there were that required a thorough and verified analysis, as well as a search for verified and reliable information.

For example. In various sources you can find information about Evgeny Paton Bridge, which differs in the degree of "primacy".

The article (Mezenin, 1977) claims that Evgeny Paton Bridge is "the largest all-welded bridge in Europe".

Evgeny Paton Bridge is presented as "the world's first all-welded bridge" in articles (Shumitsky, 1997, p. 240; Korsun, Buyak, & Matsyuk, 2019).

The well-known scientist in the field of bridge construction, Anatoly Viktorovich Perel'muter, proposed an option (Perel'muter, 2012): "The largest all-welded bridge in Europe at the time of construction, for the first time all seams, including assembly ones, were made using automatic welding".

The article (Lobanov, 2014) claims that Evgeny Paton Bridge is "the largest all-welded transport structure in the world at that time".

In articles (Poznyakov, Dyadin, Davydov, & Dmitrienko, 2021; Lobanov, Dyadin, Davydov, & Lytvynenko, 2021) about the Evgeny Paton Bridge, the bridge is shown as "the world's first all-welded road bridge".

Shymanovskyi, Shalinskyi, and Baran (2021), claim that the Evgeny Paton Bridge is "the world's first all-welded bridge with the girder system of such a length".

So, many sources contain the statement that at the time of its construction, Evgeny Paton Bridge was one of the largest all-welded bridges in the world, which for the first time had all seams, including installation ones, made using automatic welding. Today, a large number of overwater bridges are built using this technology, which combines welding and bridge construction. However, in those days, electric welding was still rarely used in bridge construction. And numerous sources reported from time to time that welded bridges were destroyed and fell in different places on the planet. But what could have caused this destruction? What allowed Ukrainian welders to erect such a complex structure without avoiding the mistakes of their predecessors? What does the term "all-welded bridge" mean, and how does it differ from simply a "welded bridge" or "a bridge built using welding technology"? How is welding used in bridge construction? What kind of materials were used at different times in the construction of metal bridges? How relevant is welding technology to modern bridge construction?

The search for answers to these and many other questions formed the basis of this study. During its preparation, a historical and chronological analysis of numerous engineering and scientific studies in the field of bridge construction, construction technologies, materials science and architecture was carried out. This made it possible to offer our own version of the stages in the history of the construction of metal bridges using welding technology in the 20th century.

Results and Discussion.

What materials were used at different times in the construction of metal bridges?

Metal bridges were not known in ancient times. There are only indications that in ancient China and India, around the 1st century AD, iron chains were used for suspension bridges (Bender, 1872; Sedmak, Ković, & Kirin, 2022;).

Any bridge, as we know, consists of one or more spans covered in one way or another. If the spanning parts are suspended from the abutments using a rope or chains, then such a bridge is called a suspension bridge. If the span is covered with wooden beams or wooden trusses (lattice structures of various shapes), or stone slabs, then the bridge is called a beam bridge. Finally, an arched bridge is a bridge in which an arch is thrown across each span, that is, a vault resting on the abutments with its heels. Of course, there are many transitional forms between these main types of bridges. Arch bridges were the highest achievements of ancient bridge construction. Suspension and beam bridges usually had wooden spanning parts. The stone slab could not be suspended, and it was inconvenient to use it as a beam, since it could only cover a very narrow span. The vault retains its strength even with a large span.

Metal bridges could not be developed in ancient times because metallurgy was still at a very low level. Iron was extracted directly from the ore in small pieces in so-called raw furnaces and forged by hand. This took a lot of time and labor. In those days they did not yet know how to cast iron. Therefore, all castings were made of bronze, and large castings could not be made then. After the collapse of the Roman Empire, bridge construction was in decline.

In the 15th century, metallurgy began to develop significantly. In addition to the great successes of bronze foundry, which already produced complex castings (bells, cannons), the production and use of cast iron was mastered. Cast iron was smelted in special high furnaces with increased blast, called blast furnaces. Iron began to be extracted mainly from cast iron in the so-called limit (fresh) forges. These forges were much more productive than cheese forges. Bellows blowers, large forging hammers, drilling machines, etc. began to be driven by water wheels. That is why advanced designers of that period were able not only to improve the types of stone and wooden bridges in every possible way, but also to raise the question of metal bridges.

This idea was first put forward by the Venetian Fausto Veranzio (or Verantius), who lived in the first quarter of the 17th century (Gazzola, 2015, p. 2; Blažević, 2017). At that time, Venice was still a powerful trading republic, although its period of greatest prosperity had passed. Various complex arts and crafts were developed in Venice and the lands under its control. In his work "*Machinae Novae*" (1615 or 1616) (Veranzio, 1968), Veranzio devotes a lot of space to the construction of bridges (Figure 2–4).

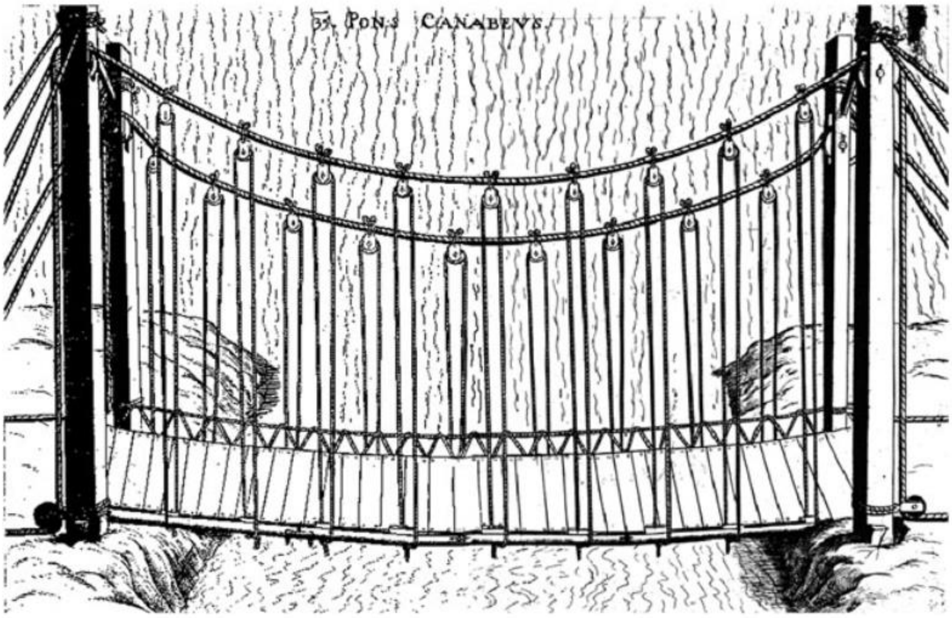

Figure 2. Picture of the Pons Canabeus by Fausto Veranzio (Gazzola, 2015, p. 3).

He puts forward the idea of building a bronze bridge (Pons Arevs) of an interesting design see Figure 3.

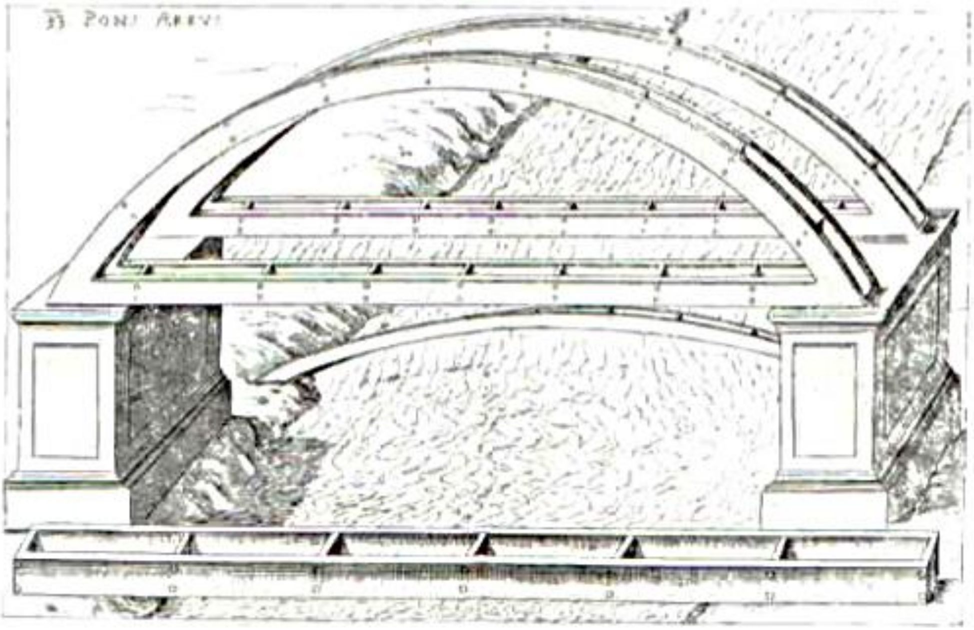

Figure 3. Picture of the Pons Arevs by Fausto Veranzio (Radić, Puž, & Šavor, (2013).

Each of the arches has the appearance of a "bow with a string" or, in geometric language, an arc with a chord, and consists of two bronze, flat arches connected to each other (Figure 3). By its type, such a bridge is transitional from arch to beam. In fact, here the arch is pulled together by a lower, as they say, "belt" and acts on the support in almost the same way as an ordinary truss. Veranzio's main mistake was that he chose bronze as a building material. He not only could not imagine steel castings, but even, apparently, was little familiar with iron foundry, which had already reached a significant level in some countries. Veranzio believed that the bridge's trusses should be cast in bronze, and argued that such a bridge would be cheaper than a stone bridge of equal size. However, bronze, due to its fragility, could not fulfill the tasks that Veranzio assigned to it. A bronze bridge of significant size would collapse on its own. Veranzio's project had only the significance that it prompted later architects to seek materials for bridges.

Even more interesting is another bridge project, which in the text of Veranzio's book is called "Ferrevs" ("*Iron*") (Veranzio, 1968). "We call this bridge," writes Veranzio, "iron, because it is suspended on many iron chains on two towers built along the banks of the river". The bridge deck, i.e. the part along which the path is laid consists of links, apparently of metal (not specified in Veranzio), covered with transverse boards. The links of the canvas are doubly suspended: firstly, to the supporting chains by iron pendants; secondly, additional chains to the towers (Figure 4). Both of Veranzio's projects remained unrealized.

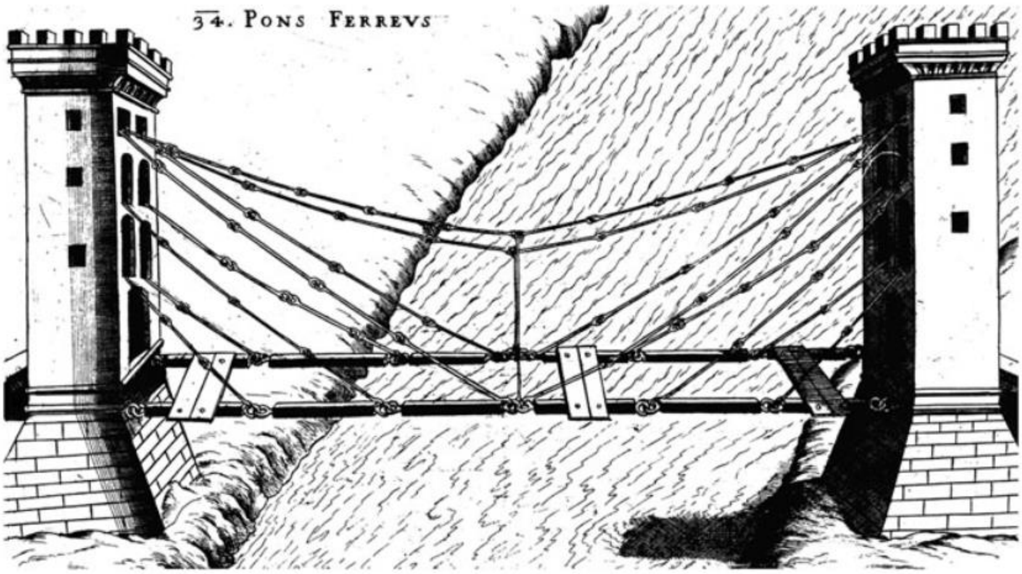

Figure 4. Picture of the Pons Ferreus by Fausto Veranzio (Gazzola, 2015, p. 3).

The first real metal bridge was built in the central industrial region of England, in the county of Shropshire across the river. River Severn (Sedmak, Ković, & Kirin, 2022). On one side of the river was the famous Coalbrookdale works of Abraham

Darby II and Reynolds. On the other are the factories of John Wilkinson. All these names have glorified themselves in the history of technology. Abraham Darby I converted blast furnace smelting to coke in 1709, thereby opening a new chapter in iron foundry (Johnson, n.d.). Reynolds was the first to build a horse track with cast iron rails. John Wilkinson was the largest English metallurgist of that time. The most advanced machines and production methods were introduced at his factories. In particular, Wilkinson was the first to use steam engines for blowers, drilling machines, etc.

As industry grew around the gorge, so did the need for a strong, durable bridge to transport goods across the river. In 1773, Thomas Farnolls Pritchard, an architect from Shrewsbury, came up with a bold idea (English Heritage, n. d.). Combining engineering expertise with new iron casting techniques, he proposed the world's first iron bridge, which would link the parishes of Madley and Benthall across one of the busiest rivers in the country. Pritchard's designs were approved by Act of Parliament and construction began in 1777. Abraham Darby III with Reynolds and Wilkinson jointly created the first metal bridge, which was built from 1777 to 1779 (Siviero & Martini, 2020). The bridge was in the form of a semicircular arch of five parallel cast-iron chords and a 100-feet cross-braced span to support a level mainline 14 feet wide, located 55 feet above the water. Each edge was cast in halves, 70 feet long and weighing 38 tons (Figure 5). They were brought from a nearby foundry on barges, placed in place using a pulley system and connected in the middle with cast iron bolts.

Figure 5. The Cast Iron Bridge near Coalbrookdale (Williams, 1780).

At the same time, the cast iron frames from which the bridge arch was made had a tapering wedge-shaped shape, in imitation of the shape of the stones from which the arched stone bridge arches were erected (Figure 6). Subsequently, the shore supports leaned forward slightly and raised the arch in the central part, but this in no way affected its strength. The coastal abutments of the Coalbrookdale Bridge and the approaches to it were made of brick. Soon a new city grew up near the bridge, called Iron Bridge. The radical new structure, which officially opened on New Year's Day 1781, used a total of 384 tons of iron, costing around 6,000 GBP – significantly more than the original estimate of 3,200 GBP. But if Abraham Darby had wanted to build such a bridge today, he would have to raise in the region of £1.5 million (The Ironbridge Gorge Museum Trust, n. d.). The bridge stands to this day as a monument to the skill of the builders and the efficiency of cast iron. It became a UNESCO World Heritage Site in 1986 and remains an iconic element of Britain's industrial past .

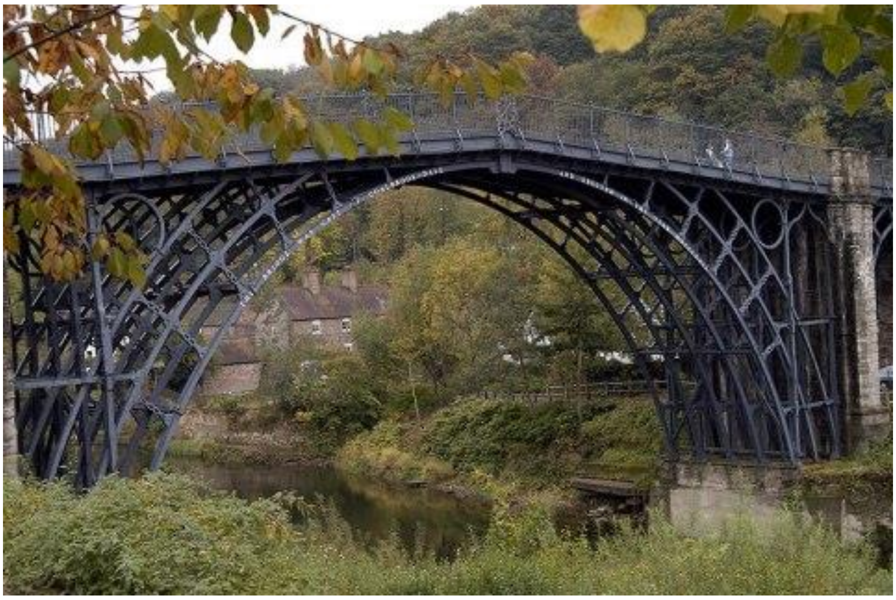

Figure 6. Ironbridge. “Birthplace of the Industrial Revolution” and UNESCO World Heritage Site. (Johnson, n. d.).

Bridge design in the mid-19th century was largely limited to trusses, and wood gradually gave way to iron. The Bavarian Karl Friedrich von Wiebeking (1762–1842) built flat-arch bridges from bolted planks so effectively that his peers credited him with the system's origins, but trusses and iron still dominated (Kahlow, 1995; Booth, 2017; Holzer & Knobling, 2020). Wrought iron's tensile strength, fire resistance, and other beneficial features made the metal the best material for building bridges, especially railroad bridges. While laying the Stockton–Darlington railway, George Stephenson experimented with a small iron bridge in County Durham in 1825 (Kozak-Holland & Procter, 2020; Groote, Ciccarelli, & Giuntini, 2021). The 50-feet long bridge had four lens-shaped spans in a combination of arches and suspended forms, convex at both the top and bottom. There were vertical posts, but no diagonal braces. In 1859, Isambard

Kingdom Brunel built a unique the Royal Albert Bridge over the Tamar River in Saltash (Fougères, 2022). He followed the same principles, but his bridge was much larger and improved by adding diagonal braces. Ten years later, another lenticular bridge was built over the Elbe River in Hamburg, Germany (Mehrtens, 1900a) (Figure 7). However, most builders relied on diagonals to take advantage of the stability inherent in triangles, the only polygons that do not change shape under stress. All designers, whether they realized it or not, acted in accordance with the principles that Simon Stevin formulated back in 1586, defining the "triangle of forces" (Van Dyck, 2020).

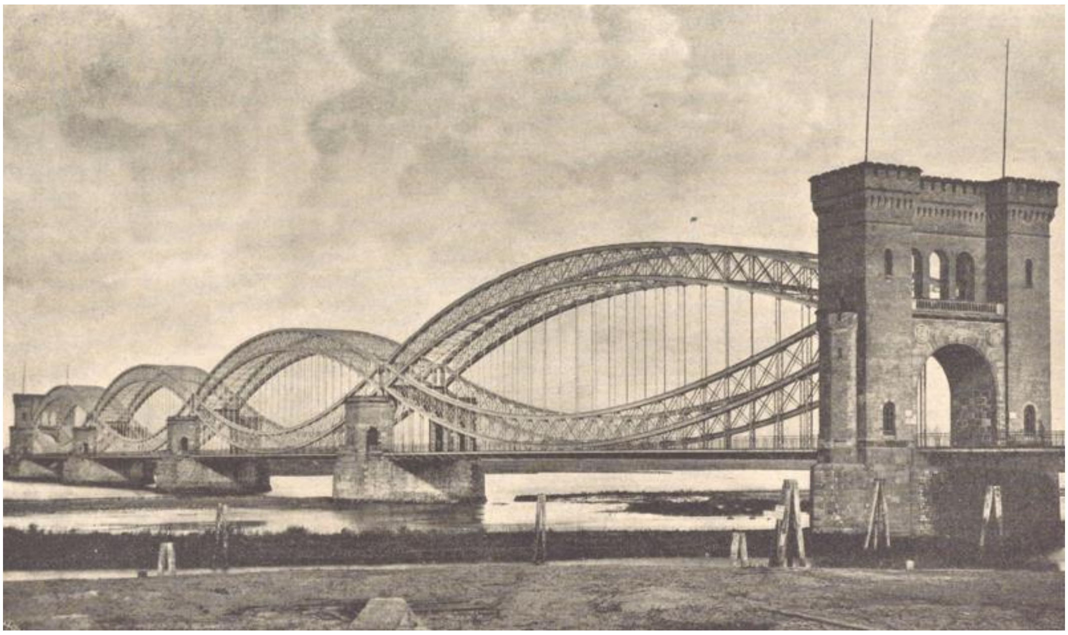

Figure 7. Railway-bridge over Elbe in Hamburg, built 1868–1872 (Mehrtens, 1900b).

Among the large steel bridges built with the rise of railroads in the second half of the 19th century, three were truly outstanding. All three bridges were different in concept and design. James B. Eads chose an arch design for his Mississippi Bridge, opened in the St. Louis area in 1874 (Grimes & Castro, 2020). For the famous Brooklyn Bridge, engineers John A. Roebling and his brother Washington A. Roebling chose a suspension structure that they had succeeded in Niagara (Witcher, 2022). John Fowler and Benjamin Baker, who built the bridge over the Firth of Forth in Scotland, preferred a cantilever design (Rosie, 2018). All builders had experience in underwater work. All three bridges are still in use.

Beginning of the use of welding in bridge construction.

In russian-language Internet sources, the primacy in the use of welding in bridge construction is often mistakenly attributed to Viktor Petrovich Vologdin. His 25-meter bridge was built in Vladivostok in 1928 (Perel'muter, 2012). Various Russian-speaking authors from time to time attribute primacy to this bridge, either in the USSR, then in

Europe, or in the world (Ban'kovskij, 1988; Turmov, 2004; Shevchenko, 2004; Chigarev, Litvinov, 2011; Perel’muter, 2012).

In fact, in 1928, Vologdin built the first all-welded viaduct in the USSR (PrimaMedia.ru, 2023). Four factory welders welded its 25-meter span in 20 days, saving 25% of metal compared to a riveted structure. Later, an urban myth arose in Vladivostok, as if the Kazan Bridge on the Egersheld, thrown across the last meters of the Trans-Siberian Railway, was the very brainchild of Vologdin. In fact, welders under his leadership produced an openwork metal structure of a completely different type and purpose; it has not survived to this day. “The bridge was intended for conveyors and pedestrians between two warehouses on Egerschöld, separated by a road,” recalled one of the first graduates of the Far Eastern Politechnical Institute Welding Department, Candidate of Technical Sciences Ivan Dmitriev.

In the 1920s, bridge designers began preliminary research into the specifics of welding technology and its advantages and disadvantages (Fraser & Roberts, 1994). However, they were in no hurry to fully introduce welding into bridge construction (Figure 8). And instead of building new all-welded spans, they experimented with strengthening existing bridges. The first structure to be reinforced in this manner by welding was the Chicago Great Western Railroad’s swing bridge over the Missouri River at Leavenworth, Kansas. Considered too light for modern locomotives of the time. The bridge was reinforced at critical points over a two-month period in 1927.

Electric Welding Reduces Cost of Strengthening Bridge

Chicago Great Western Avoids Much Drilling and Riveting in Applying Reinforcing Plates to Leavenworth Structure

WHAT is believed to be the first application of electric welding in the reinforcing of a bridge was carried out during the early part of the present year when the superstructure of the Chicago Great Western's bridge over the Missouri river at Leavenworth, Kan., was strengthened by adding cover plates to certain members. This bridge is owned by the Leavenworth Terminal & Railway Bridge Company, a subsidiary of the Great Western, and comprises an important link in the Southern division of that road which extends from Oelwein, Iowa, to Kansas City, Mo.

The Chicago Great Western Bridge Over the Missouri River at Leavenworth, Kan.

The bridge was built in 1893, according to a design of the late George S. Morrison and consists of two fixed through truss spans 330 ft. long and a through truss swing span 440 ft. long. The workmanship on the superstructure was good and it has been maintained in excellent condition, but owing to the extremely low live loading and the comparatively high stresses used in the design, the spans have a limited load-carrying capacity. The spans were designed for a live load of 3,000 lb. per ft. of bridge without any wheel concentration or other allowance for greater weight of locomotive than the following train. The working stresses used in design conformed to a tensile strength of 10,000 lb. per sq. in. for live load and 20,000 lb. per sq. in. for dead load. The main truss members are steel and the floor and lateral system and cross bracing of wrought iron. It is not surprising, therefore, that it was necessary to restrict this bridge to comparatively light locomotives.

For passenger service use of the bridge has been confined to a Pacific type locomotive having a total weight including the tender of 329,280 lb. with 46,400 lb. on each of three driver axles. For freight service power was restricted to a prairie type locomotive having a total weight of 321,480 lb. with 48,250 lb. on each of three driver axles.

Urgent Need for Strengthening

Freight train tonnages based on the rating of the prairie type locomotive, single-headed, placed such limitations on any plans for increased operating economies that it was clear that something had to be done to permit the use of heavier power. Studies were made for a new superstructure for the bridge but the cost of this was such that the project was abandoned. A careful analysis of the old spans was also carried out with a view to ascertaining whether it would be practicable to strengthen the bridge so as to permit of the safe operation of a consolidation locomotive having a total weight of 379,500 lb. with 50,550 lb. on each of four driver axles and followed by a uniform load of 4,000 lb. per ft. of bridge, using the rules for the investigation of old bridges of the American Railway Engineering Association.

This investigation showed that no reinforcing of the draw span trusses was required but that it would be necessary to strengthen the floor beams and stringers of the entire bridge and the end posts, top chords, hip verticals and counters L, U, of the two fixed spans. The failure to apply concentrated locomotive loading in the design readily explains the weakness of the floor system and the hanger verticals, but the need for reinforcement of the end posts and top chords is to be accounted for in part by the faulty make-up of these members. They consist of two webs 22 in. deep with four 5-in. by 3½-in. angles and a cover plate 27½ in. wide by ⅜ in. thick. Therefore, with rivet lines in the cover plates 24½ in. apart and a thickness of only ⅜ in., these cover plates had a slenderness ratio of 1 to 64, whereas good practice limits this to about 1 to 40.

Electric Welding Suggested

It was found that the chord members of the trusses could be reinforced by adding a second cover plate, and that additional or new members would be required for the hip verticals and the inadequate counters, while additional metal would be required in the flanges of the floor beams and stringers.

A request for bids on the reinforcement work resulted in tenders covering the usual method of applying reinforcing materials as well as one in which all cover plates were to be welded in place. The latter bid was so much more favorable that after careful study it was accepted and the work carried out substantially in accordance with the submission made. The strengthening of the hip verticals was carried out by adding two rods 1½-in. in diameter attached at the top to a U-bar over the hip pins and at the bottom to plates riveted to the ends of the floor beams. The counters L, U, were replaced by new members consisting of a 3¼-in. rod attached at the

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Figure 8. The article “Electric welding reduces cost of strengthening bridge” in the journak “Railway Engineering and Maintenance” **(**Railway Engineering and Maintenance, 1927).

The first welded bridge ever built was a pedestrian bridge, erected in 1921 between two buildings of the General Electric plant in Schenectady, New York (McKibben, 1929). In 1921, the Williams Bridge Company of Syracuse, New York, constructed a footbridge over the Delaware & Hudson Railroad tracks at the General Electric plant in Schenectady (Spivey, 2001). This single 35' span, the first all-welded bridge in the U.S. and , began a decade of experimentation with electric arc welding for bridge repair and construction. Until the advent of shielded welding electrodes, which reduced inclusions of slag and therefore improved the ductility of welds, bridge engineers avoided butt welds. They therefore initially kept to the truss form, using fillet welds to join members to the same splice and gusset plates found on those of riveted construction. Footbridges were a more fertile ground for experimentation with welding because they carried lighter loads and were subject to less stringent requirements.

However, the first of any significance was a 53-feet double-girder railroad a bridge constructed using arc welding by the Westinghouse Electric and Manufacturing Company over Thompson Run in Turtle Creek, Pennsylvania (Bissell, 1928). Opened for service on November 5, 1927, the bridge carried railroad traffic between the company's Linhart Works and East Pittsburgh Works (Hess & Hybben, 1989). Interested in promoting virtually any new technology related to electricity, Westinghouse was a leading proponent of electric arc welding. The Turtle Creek Bridge demonstrated what Westinghouse engineer A. G. Bissell called the company's "confidence in arc-welded structures" (Bissell, 1928).

In 1928, Westinghouse also sponsored the construction of the nation's second all-welded railroad bridge as a means of providing access to its plant in Chicopee Falls, Massachusetts (Hess & Hybben, 1989). This, too, was arc welding. To obtain comparative data on welding and riveting costs, Westinghouse based the 134-feet single-span structure directly on the Warren riveted truss originally intended for the site, "the only impediment to a true comparison was the replacement of rolled sections with the precast sections shown in riveted construction". The welded bridge even used regular gussets to connect the panels (Figure 9). Upon completion, Westinghouse claimed "substantial" cost savings: "The welded structure used about two-thirds the amount of steel required for its riveted counterpart, saving most of the joint materials and eliminating holes in tension members and floor stringer continuity" (Fish, 1933).

Highway engineers soon followed the railroads' lead: in 1929, the first all-welded steel highway bridge was built (Fraser & Roberts, 1994). Designed by professor of the Lwow Technical University Stefan Bryla in 1927, the 88-feet truss spans the Słudwia River near Łowicz, Poland (Bryla, 1930). According to design engineer Stefan Bryla, arc welding saved about 21 percent in materials, although the total cost of the project was roughly equivalent to riveted construction – as a result of the need to include the cost of welding equipment in the final accounting.

The construction of a number of welded road bridges followed in the 1930s. Although American civil engineers were reluctant to experiment with the new technology, their European colleagues did not hesitate. “The arc welding process,” wrote Kansas engineer LaMotte Grover in 1934, "has been used quite extensively for the construction of new steel bridges in foreign countries, but it appears to have been indifferent to most American civil engineers" Grover, L. (1934). However, several welded bridges were built in this country during the second half of the decade, including the 397-feet Rancocos River Bridge in New Jersey (Davis, 1935).

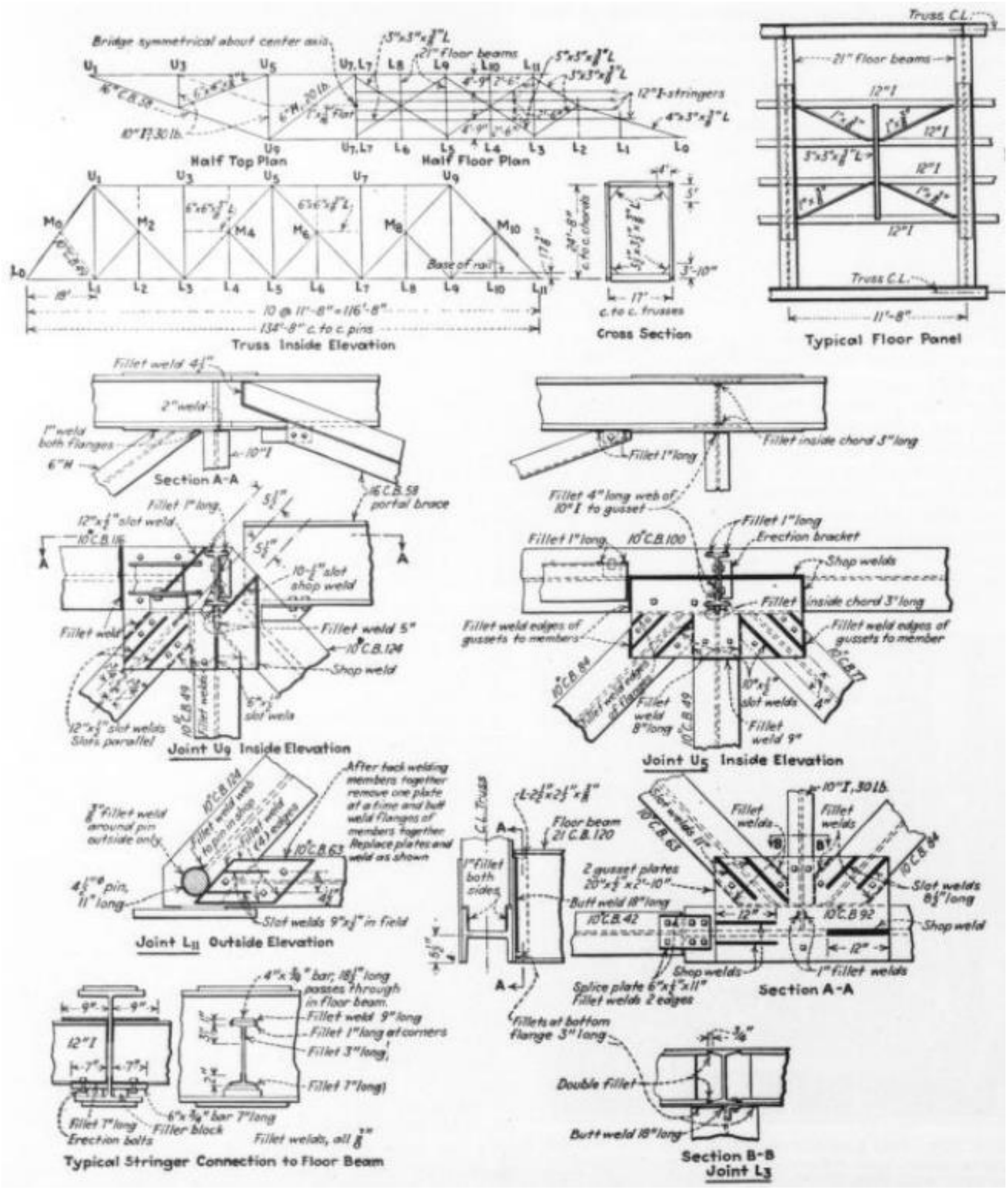


Figure 9. Details of arc-welded Through-Truss Railway Bridge, Chicopee Falls, Massachusetts (Fish, 1933).

In the 1930s, other welded bridges were also built. Thus, in 1934, the first all-welded drawbridge was built in the UK in Middlesbrough (Figure 10).

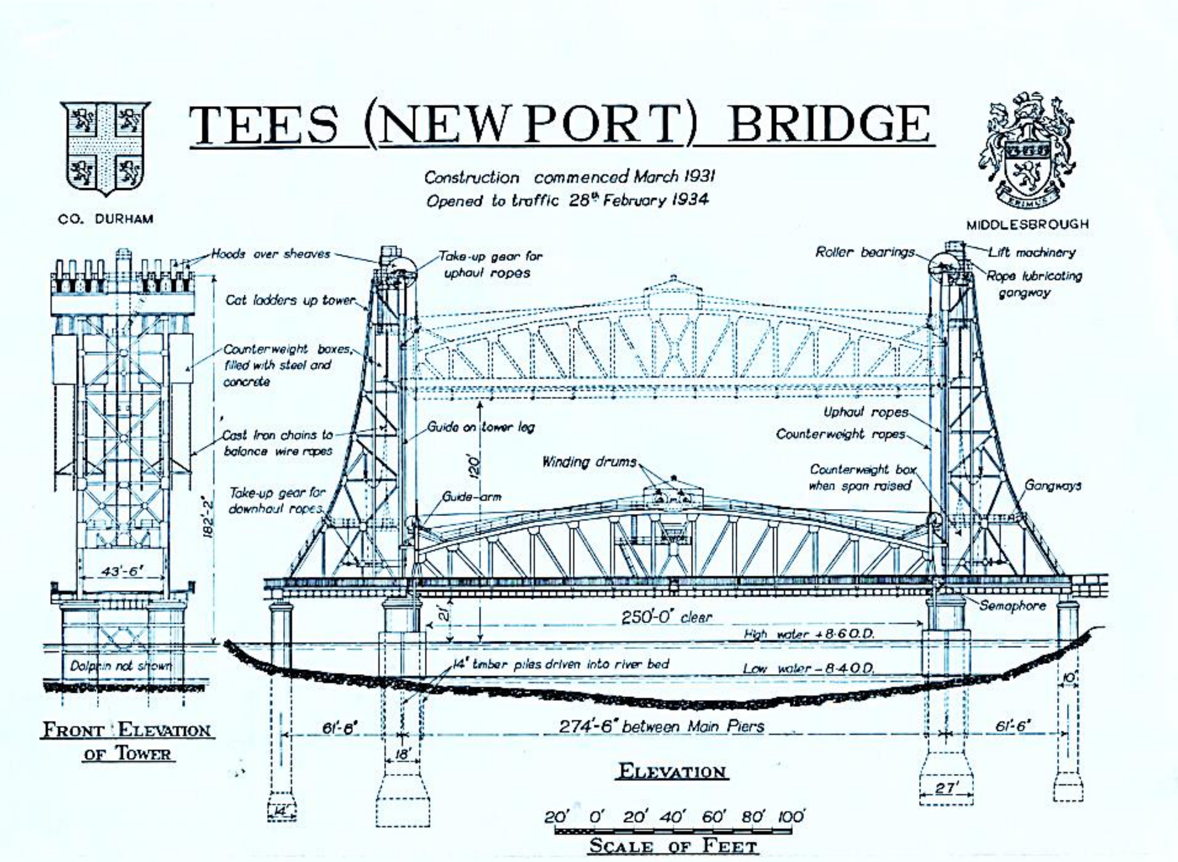


Figure 10. Dorman Long and Newport Bridge. (Tees Valley Museums, n. d.).

The Tees Newport Bridge was the first large vertical lift bridge in Europe, and opened by Prince Albert (later King George VI) on 28 February, 1934 (Figure 10). The bridge connects Middlesbrough to the borough of Stockton-on-Tees and was designed to lift up to 37 m to allow ships to pass under. The bridge was built by the Middlesbrough-based Dorman Long and Co Ltd. (Co-Curate, n. d.). Newport Bridge was a vertical lift bridge, the first of its kind to be built in the UK (Tees Valley Museums, n. d.). It was built specifically so that the main part of the bridge could be lifted to allow ships to pass under it, and then lowered again for people and vehicles to cross. Total length 4,920 feet (1499 m). Weight 8,000 tons. The bridge was fitted with two electric motors and a petrol engine in the event of a power failure. It only took a minute and a half for the bridge to be raised or lowered (Figure 11). It was possible for the bridge to be raised and lowered manually with a winch system, but this would have taken eight hours to do. During its working lifetime between 1934 and 1990, Newport Bridge was raised and lowered twice a day. On average 800 ships a year would pass under it. Gradually the number of ships sailing up the River Tees declined and the bridge was lifted a final time on 18th November 1990.

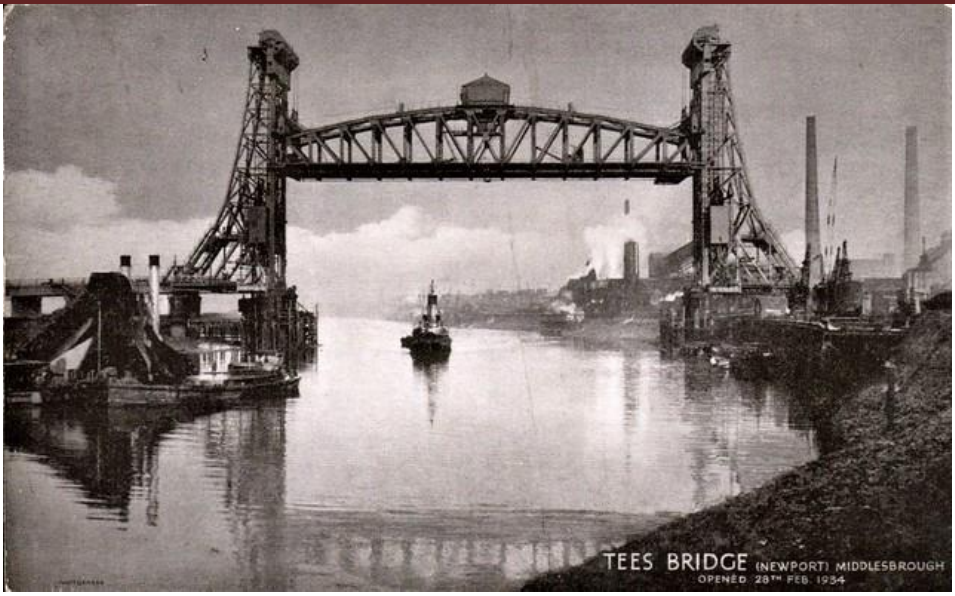


Figure 11. Tees Bridge, Newport. Middlesbrough. (Crombie, 2019).

In the late 40s in the USA, Professor Edward Ashton, who began work on creating an all-welded bridge even before the war, designed an all-welded bridge across the Iowa River (Figure 12). This bridge, called the Benton Street Bridge, had a five-span continuous girder span with a total length of approximately 175 m (Figure 13). The bridge project was completed in 1947, it began operation in 1949 and served well until 1989 – until it was replaced by a wider new bridge (Kallee, n. d.).

Figure 12. View showing welders at work on both the north and south girders, with the old bridge in the background, looking northwest , around 10 May 1949 (Kallee, n. d.).

Figure 13. View of the bridge from the west bank of the Iowa River (Kallee, n. d.).

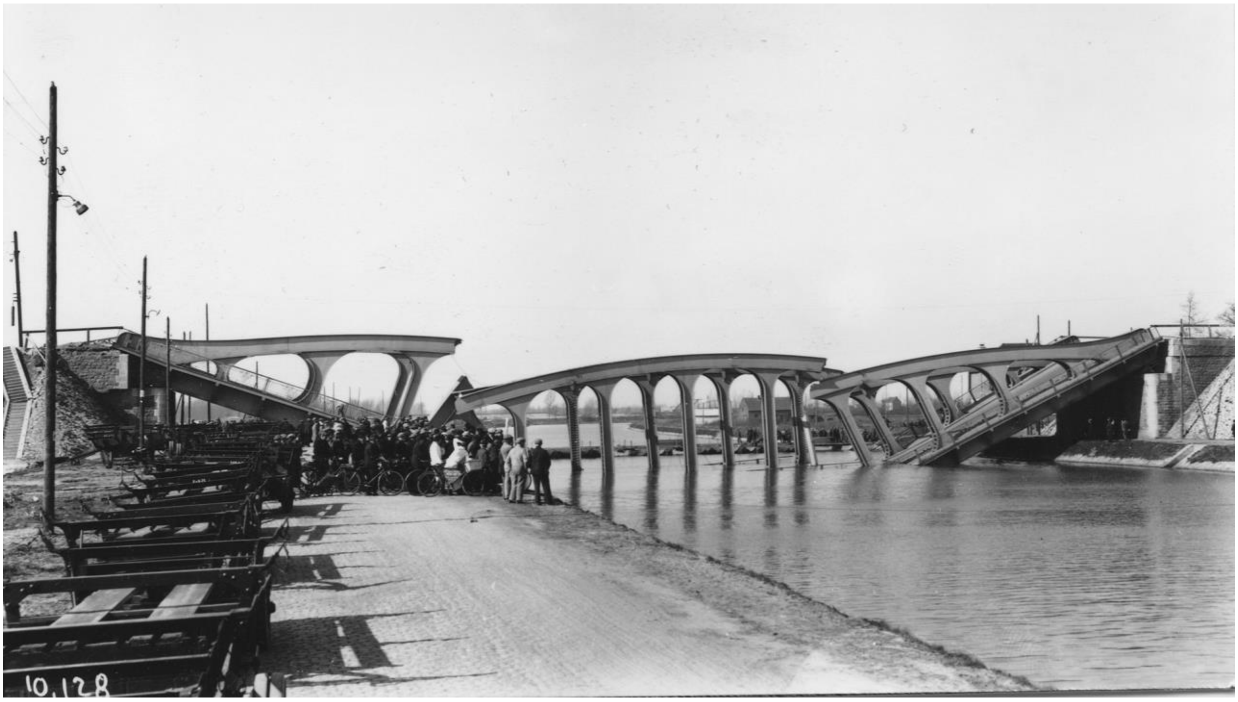
Crossing the Iowa River in the south-central section of Iowa City, the Benton Street Bridge is an all-welded, continuous, five-span, deck, plate-girder highway bridge. Although all-welded bridges appeared in the United States as early as the 1920s, welding was not widely advocated for new bridge construction until immediately after World War II, when a number of state highway departments began preparing all-welded, deck, plate-girder plans. Designed in 1947 and erected in 1949, the Benton Street Bridge introduced all-welded bridge construction to the State of Iowa, and was nationally recognized as one of the most notable examples of the new genre. An early champion of welding, the bridge's designer, Edward (Ned) L. Ashton, had previously engineered several major Mississippi River crossings, and would subsequently be responsible for the world's first welded aluminum highway bridge, completed in Des Moines, Iowa in 1958. Ashton has justifiably been called "the most distinguished bridge engineer in the history of Iowa" (Kallee, n. d.).

So, it can be said that by the beginning of World War II, traffic was carried out on more than a thousand bridges built using arc welding around the world. But this rapid adoption of welding in steel structures came with many challenges that were probably overlooked in the euphoria surrounding bridge construction. Welded bridges in different countries have begun to collapse (Alencar, de Jesus, da Silva, & Calçada, 2019).

What were the main reasons for the destruction of metal welded bridges in the first half of the 20th century?

In March 1938, the Hasselt Bridge suffered a catastrophic failure (Figure 14).

a

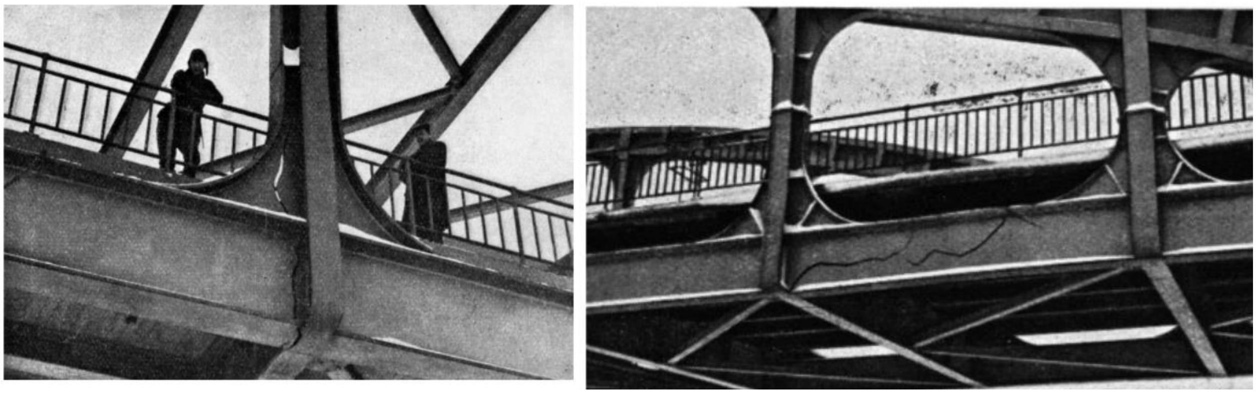


b

Figure 14. Photographs of the Hasselt Bridge over the Albert Canal before destruction (a) and after the disaster (b) on March 14, 1938 (Schuermans, 2018).

This is generally considered the first brittle failure of a large all-welded structure (Espion, 2012) and received much attention at the time. The article by Espion (2012) analyzed the main causes of cracks and failures in welded bridges. Between 1932 and 1937, about 50 welded road bridges of the frame construction type invented by Vierendeel truss were built in Belgium to cross the Albert Canal or the Campine canals. These were the first significant applications of electric arc welding in Belgium, and they account for the majority of large welded bridges built in Belgium at that time. Of the 50 typical Vierendeel road bridges with a parabolic top belt: 25 over the Albert Canal, 23 over the Campine canals. and two in Dudzeel (near Bruges). Five of them were partially welded, and the remaining 45 were fully welded. Twelve steel fabrication contractors and three electrode suppliers were involved in the project: Arcos, Esab and Thermarc. A total of 70 welded bridges were built in Belgium in the late 1930s, of which 60 were considered "large", including 50 Vierendelle spans. By comparison, Germany had about 100 welded railway bridges built by 1935, and an impressive list of 800 welded road bridges and 300 welded railway bridges built by 1939 has been published.

An article by Petrova (2022) shows that in the winter of 1940, cracking problems were reported on at least eight other large welded bridges of the same design. The most notorious cases are damage to bridges in the city of Herental and in the city of Kaulil (Figure 15). These bridges were not completely destroyed, but, as in the case of the Hasselt Bridge, they received cracks in the lower truss: in both cases the air temperature was about -14°C.



a b

Figure 15. Photographs of bridges in Belgium with cracks: (a) Cracks in Herenthals-Oolen Bridge, 1940; (b) Cracks in Kaulille Bridge, 1940 (Espion, 2012).

A generalized analysis of available sources based on the results of the investigation of these cases showed that for all these bridges, non-deoxidized “Thomas” steel of the St-42 grade was used, which contains an increased amount of phosphorus compared to open hearth steel (up to 0.079% P). Independent experts from Germany concluded (Busch & Reuleke, 1946) that the sensitivity of steel to cracks, caused, among other things, by welding defects, could be one of the reasons that provoked or aggravated the destruction. They called for eliminating the use of undeoxidized steel for welded structures greater than 1.5 inches thick.

Disasters of welded bridges have occurred not only in Europe. The collapse of the Duplessis Bridge (1951, Canada) is a typical example of the action of metallurgical factors, namely, the increased content of carbon, oxygen and sulfur in the destroyed steel. The all-welded bridge across the Saint-Maurice River in Quebec collapsed three years after construction. Figure 16 shows a photo of the Duplessis Bridge collapse taken by Milt Loomis (Lambie, 2021).

Figure 16. Duplessis bridge collapse (Lambie, 2021).

On the frosty night of January 31, 1951 (at an air temperature of -34°C, four long spans of the bridge collapsed into the river (Figure 17) (South Clark, 2013). As a result of the disaster, 4 people died in their cars, which fell through the ice.

The local newspaper, The Lethbridge Herald, dated August 29, 1951, wrote (Lethbridge Herald, 1951): "defective and inferior steel blamed for the collapse of the 3,500,000 USD Duplessis Bridge." A construction company spokesman told the newspaper that low quality boiling steel was used. These claims were made against steel plates used to strengthen cracked bridge beams a year before the accident. The plates fastening the damaged areas were ordered from boiling steel CSA S40 (ASTM A7), which, according to technical regulations, was only suitable for thin sheets. The thick plates (2.5 inches) had to be made of calm, deoxidized grade C steel. It was the cold brittleness of the plates reinforcing the truss that led to the collapse of the bridge. Analysis of the destroyed plates showed high local concentrations of carbon (up to 0.4% C) and sulfur (up to 0.116% S), and discovered many string slag inclusions. In his book Fractures and Life, Brian Cotterell concludes (Cotterell, 2010, pp. 205–206): “Obviously, boiling steel was too brittle and almost guaranteed that the bridge would collapse.” He explains: “Molten steel contains dissolved oxygen and other gases that must be controlled during solidification. In boiling steel, the reaction of dissolved oxygen with carbon is accompanied by the formation of gaseous carbon monoxide, which leads to the formation of an ingot with gas bubbles... Boiling steels are the cheapest, but have a high brittle transition temperature... The Charpy impact load for the broken beams of the Duplessis Bridge was only 4–8 J at 38°C. Obviously, the steel rimmed was too fragile and almost guaranteed that the bridge would collapse." Thus, the stresses were too great for a notch-sensitive material: in such a brittle material, any minor defect, combined with permanent stresses, could lead to catastrophic failure at low temperatures.

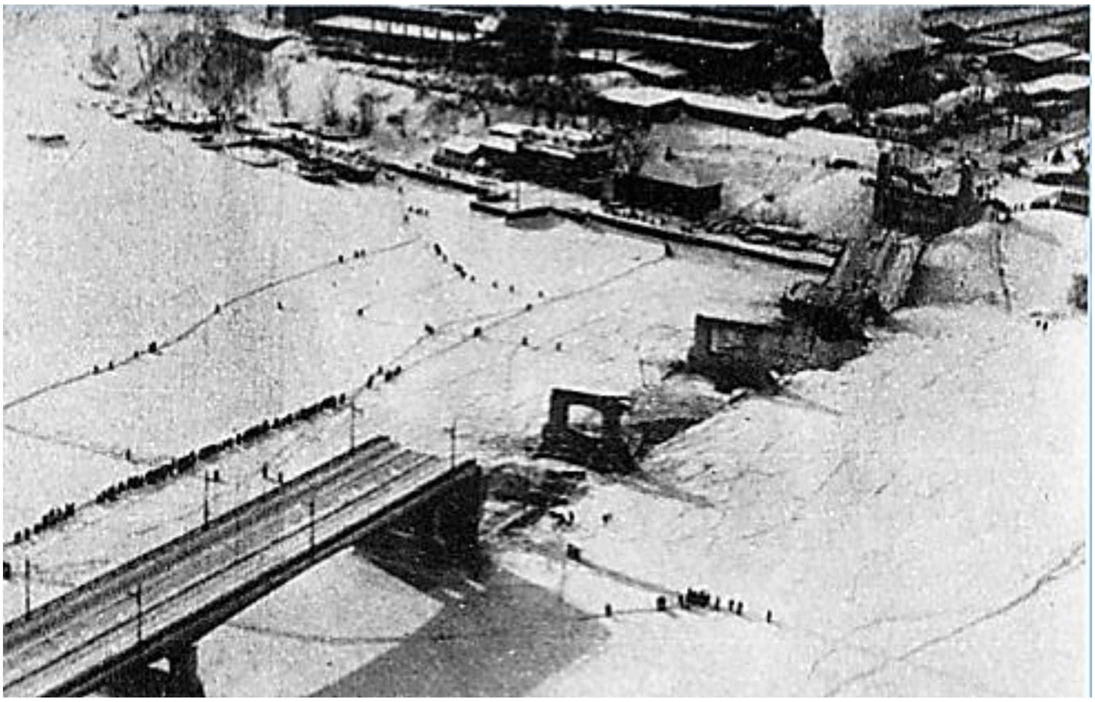


Figure 17. Two remaining spans of the Duplessis bridge in the foreground and four collapsed spans (South Clark, 2013).

As the analysis performed showed, catastrophic destruction most often occurred under the influence of several factors, as well as a combination of external adverse influences and the internal “unpreparedness” of the structure for them. The examples given indicate that an irrational choice of steel could be both an independent cause causing brittle failure of structures, and an aggravating factor in the presence of structural violations, thermal stresses and welding defects.

To the 70th anniversary of the history of the creation of the Evgeny Paton Bridge.

In the Electric Welding Laboratory at the All-Ukrainian Academy of Sciences (Kyiv, Ukraine), transformed in 1934 into the Electric Welding Institute of the Academy of Sciences of the Ukrainian Soviet Socialist Republic (Electric Welding Institute AS USSR), they began to purposefully study the load-bearing capacity of welded joints and structures (Malishevskij, 2003; Strelko, 2021). In this laboratory, organized and headed by academician Evgeny Oskarovych Paton, experimental studies were initially carried out by comparing the test results of identical welded and riveted joints of samples, beams and entire structures under static, variable and impact loading. The tests carried out made it possible to obtain the most visual and convincing evidence of the strength of welded joints and the advantages of welding technology. In these and other comparative tests, welded joints failed from fatigue not in the weld metal, but in the base metal in the joint zone. It became obvious that the main reason for their destruction is the concentration of stresses created by the shape of the joint and seams or technological welding defects.

It was also assumed that the insufficient strength and toughness of the weld metal, its lower homogeneity than the base metal, would reduce the resistance of structures to fatigue failure. In the late 1930s – early 1940s, work was carried out at the Electric Welding Institute AS USSR to find rational design and technological solutions that ensure the specified cyclic durability of welded joints and assemblies. The studies mainly concerned bridges, carriages and cranes. They convincingly showed that welded joints and assemblies can be reasonably used in critical structures that can withstand the effects of alternating stresses. The equal strength of butt joints with the “seam reinforcement” removed and the base metal under variable loads was proven.

The question of the construction of a road bridge across the river in Kyiv the Dnipro was raised before the World War II. At the same time, a technical design of a bridge with a ride on top and split through main trusses spanning spans 58 m long (in the floodplain part) and 87 m long (in the navigable part) was drawn up and approved. Since during this period the Electric Welding Institute AS USSR developed a method of automatic submerged arc welding, which made it possible to obtain high-quality seams, its director, Evgeny Oskarovych Paton, proposed manufacturing bridge spans using welding. The bridge design was based on large blocks and the maximum use of automatic and semi-automatic welding in the manufacture of bridge beams at the factory and during their direct installation.

The construction of this bridge is the result of a collaboration between designers, scientists and builders from Ukrproektstalkonstruktsiya, the Kyiv Bridge Construction Trust of the Ministry of Transport, the Electric Welding Institute AS USSR and Metal Structures Plant named after Babushkin (Dnipro, Ukraine).

The team of the Electric Welding Institute AS USSR, introducing welding into bridge construction, carefully checked the results and monitored the behavior of structures. A new grade of steel was created that was resistant to the formation of brittle and fatigue cracks, its welding technology was developed, a technology for installation welding of vertical sheets with forced formation of a seam was developed, and suitable welding materials were selected.

On November 4, 1953, the Government Commission inspected in situ the constructed road bridge across the river Dnipro in Kyiv, got acquainted with the technical documentation and decided to accept the bridge into permanent operation from November 5, 1953 with the passage of all types of loads provided for by the project, without speed restrictions. The Government Commission gave the main work on the construction of the bridge an "excellent" rating.

On November 5, 1953, the Council of Ministers of the Ukrainian SSR, by its Resolution No. 2348, approved the act of the Government Commission on the acceptance into permanent operation of an all-welded road bridge across the river. The Dnipro in Kyiv and the opening of traffic on the bridge was scheduled for November 5, 1953 (Figure 18). Thus, ended the crucial and most difficult stage in the development of welded bridge construction.

Figure 18. Rally on the Paton Bridge on the day of its opening, view from the right bank of the Dnipro, November 5, 1953 (Central State Audiovisual and Electronic Archive, n. d.).

On December 18, 1953, by Decree of the Council of Ministers of the Ukrainian SSR No. 2644, the newly built bridge was named after Evgeny Paton.

In 1995, the American Welding Association built an all-welded bridge in Kyiv across the river the Dnipro is included in the list of outstanding engineering structures.

After 70 years of operation, the Evgeny Paton Bridge continues to operate reliably with the design load N-10 and a significantly increased traffic intensity (80 thousand vehicles per day with a design value of 10 thousand).

An analysis of numerous documents devoted to the design and construction of this bridge allowed to establish the following. The Kyiv welded road bridge named after Evgeny Paton is unique in a number of its characteristic features not only in Ukraine, but throughout the world (Figure 19).

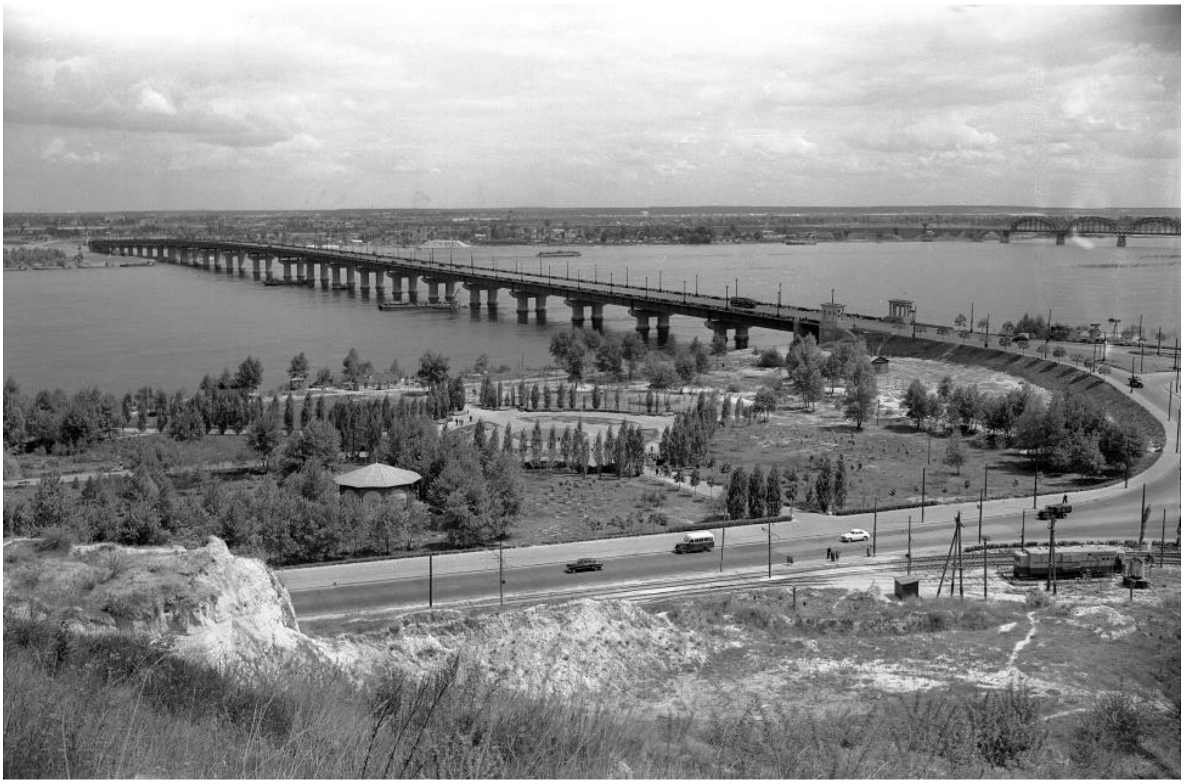


Figure 19. View of the Evgeny Paton Bridge from the right bank of the Dnipro from the place where the monumental sculpture "Motherland" now stands. (Central State Audiovisual and Electronic Archive, 1956).

Its uniqueness lies in the fact that all connections in the bridge spans are made at the factory and installed by welding, i.e. the bridge is all-welded. If we take into account that it has a total length of 1,543 m and that about 10 thousand tons of steel were used for the spans, and the total length of the welds is 10,668 m, then we can say that it is still the largest all-welded bridge in the world (Kornienko & Litvinov, 2008). When manufacturing mounting elements at the factory and making assembly joints, they were carried out mainly using automatic and semi-automatic welding (Lobanov & Kyrian, 2013). Manual welding was used to perform less critical elements of the bridge (braces, transverse beams, etc.). When designing the bridge, the large-block principle was used, which allowed 97% of all factory seams of the main trusses and 88% of all installation seams of the main trusses to be performed using automatic and semi-automatic welding. In addition, the presence of large blocks of the same type made it possible to mechanize assembly and welding operations and organize an in-line manufacturing method at the factory and installation, which improved the quality of welding work and reduced its labor intensity.

The bridge is rightly named after Evgeny Paton (Figure 20), and can be presented as ***the largest all-welded bridge in Europe at the time of construction, in which for the first time all seams, including assembly ones, were made using automatic and semi-automatic welding***.

Figure 20. Evgeny Paton Bridge with night architectural illumination and panorama of the Left Bank (Naumov, 2017).

The Evgeny Paton Bridge has never been closed for major repairs. To improve traffic safety, a semi-rigid decorative and artistic fence was installed on the Paton Bridge in 1968 (for the first time in the USSR) (Figure 21). It was carried out by a company from Donetsk, Remkommunelektrotrans.

In 2019, the bridge was declared unsafe; two outer lanes were closed to traffic due to danger. Design work is currently ongoing on the bridge, after which the first reconstruction in 70 years should begin.

Figure 21. Evgeny Paton Bridge across the Dnipro in Kyiv, 1960s. (Central State Audiovisual and Electronic Archive, n.d.).

How relevant is welding technology to modern bridge construction?

Touran and Ladick (1989) examined the financial aspects of welded bridge construction. Their research found that welding, including consumables, accounted for an average of 14% of the total module manufacturing cost, 38% for material costs, and 48% for additional labor costs.

The construction of metal bridges using welding continues in our time (Markashova, Berdnikova, Bernatskyi, Sydorets, & Bushma, 2019; Poznyakov, Markashova, Shelyagin, Zhdanov, Bernatskyi, Berdnikova, & Sydorets, 2019; Chandramohan, Roy, Taheri, Karpenko, Fang, & Lim, 2022). Welded bridges play an important role in modern infrastructure, ensuring safe and efficient transportation systems. The largest bridge in the world today (Guinness World Records, n.d.), the Danyang-Kunshan Viaduct (Figure 22), was also built in 2011 using welding technologies (iXBT.com, n.d.).

Nowadays, the undisputed favorite of all bridge builders in the world is steel, which has good mechanical properties under various operating conditions under load and is perfectly amenable to processing. It is carbon and low-alloy steels that are the most popular and cost-effective materials, widely used for the construction of small, medium and simply gigantic bridge structures of our time (Bazaras, Cesnavicius, Ilgakojyte-Bazariene, & Kersys, 2017; Lenner, Ryjacek, & Sýkora, 2020; Tkachenko, Tsegelnyk, Myntiuk, & Myntiuk, 2022).

Figure 22. Danyang-Kunshan Viaduct (iXBT.com, n.d.).

The use of high-strength and high-strength steels and the use of welded structures helps reduce metal consumption, so a steel bridge is often a cheaper and more practical alternative to other options.

Conclusions.

The history of the development of the construction of metal bridges using welding goes back a little over 100 years. The short period from the construction of the first welded bridges to their first disasters led to the need to analyze the possible causes of these destructions. As the analysis performed showed, catastrophic destruction most often occurred under the influence of several factors, as well as a combination of external adverse influences and the internal "unpreparedness" of the structure for them. The examples given indicate that an irrational choice of steel could be both an independent cause causing brittle failure of structures, and an aggravating factor in the presence of structural violations, thermal stresses and welding defects. Over the years, bridge manufacturing technologies have been improved in different countries, and new steels and materials for their welding have been developed.

Thanks to the use of carbon, low-alloy and alloy steel, designers abandoned the brutal "railroad-type" beam trusses and today metal bridges with graceful and beautiful silhouettes powerfully stride across the water surface, mountains and valleys. They became real attractions of megacities and country landscapes, and builders were able to successfully solve numerous technical and economic problems.

An important contribution to the development of global bridge construction using welding technologies was made by the team of the Institute of Electric Welding of the Academy of Sciences of the Ukrainian SSR under the leadership of Academician Evgeny Oskarovych Paton. The team of the Institute of Electric Welding of the

Academy of Sciences of the Ukrainian SSR, introducing welding into bridge construction, carefully checked the results and monitored the behavior of structures. A new grade of steel was created that was resistant to the formation of brittle and fatigue cracks, its welding technology was developed, a technology for installation welding of vertical sheets with forced formation of a seam was developed, and suitable welding materials were selected.

At the time of construction in 1953, the Kyiv Evgeny Paton Bridge across the Dnipro River was the largest all-welded bridge in Europe, all seams of which, including assembly ones, were made for the first time using automatic and semi-automatic welding. In addition, the presence of large similar blocks in the design of the Paton Bridge made it possible to mechanize assembly and welding operations and organize an in-line method for their production at the factory and installation, which increased the quality of welding work and reduced its labor intensity.

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Conflicts of interest.
The author declare no conflict of interest.

References

Alencar, G., de Jesus, A., da Silva, J. G. S., & Calçada, R. (2019). Fatigue cracking of welded railway bridges: A review. *Engineering Failure Analysis, 104,* 154–176. https://doi.org/10.1016/j.engfailanal.2019.05.037

American Welding Society. (2023). *AWS National Awards Package 2022. Award Descriptions and Past Winners.* Retrieved from https://aws-p-001-delivery.sitecorecontenthub.cloud/api/public/content/a6a0971a52a6451397245c2cbfa695e9?v=fa3002b1

American Welding Society. (n. d.). Extraordinary Welding Awards. *American Welding Society*. Retrieved from https://www.aws.org/About/Awards/Outstanding-Achievement-Awards/

Armisén, J. M. (2019). Puentes que me ayudaron a entender y diseñar. *Informes de la Construcción, 71*(553), e279. http://dx.doi.org/10.3989/ic.67502 [in Spanish].

Arwade, S. R., Schafer, B. W., Schafer, D. F., & Schafer, S. T. (2015). Modern Examples of Structural Art in Metals. In *Structures Congress 2015* (pp. 714–729). https://doi.org/10.1061/9780784479117.062

Ban'kovskij, L. (1988). *Sozidayushchee Plamya [Creative Flame].* Perm: Perm Book Publishing House. Retrieved from https://books.google.co.uk/books/about/%D0%A1%D0%BE%D0%B7%D0%B8%D0%B4%D0%B0%D1%8E%D1%89%D0%B5%D0%B5_%D0%BF%D0%

BB%D0%B0%D0%BC%D1%8F.html?id=ptQMAQAAIAAJ&redir_esc=y [in Russian].

Bartlett, F. M., Graham, J. M., & Camiletti, J. (2009). 1870s innovation in London Canada's Blackfriars Bridge. *Proceedings of the Institution of Civil Engineers-Engineering History and Heritage*, *162*(2), 111–117. https://doi.org/10.1680/ehh.2009.162.2.111

Bazaras, Z., Cesnavicius, R., Ilgakojyte-Bazariene, J., & Kersys, R. (2017). Investigation of the probabilistic low cycle fatigue design curves at stress cycling. *Mechanics*, *23*(2), 176–181. Retrieved from https://pdfs.semanticscholar.org/237e/2c710d299130436854ef6465bdea48a7c8a7.pdf

Bender, C. (1872). Historical sketch of the successive improvements in suspension bridges to the present time. *Transactions of the American Society of Civil Engineers*, *1*(1), 27–44. https://doi.org/10.1061/TACEAT.0000003

Bernabeu-Larena, J., Martín-Caro, J. A., Hernández-Lamas, P., & Plana, Á. G. (2023). Technical heritage of Madrid's bridges, Spain. *Proceedings of the Institution of Civil Engineers-Engineering History and Heritage*, *176*(3), 113–126. https://doi.org/10.1680/jenhh.23.00012

Bissell, A. G. (1928). An arc welded railroad bridge. *Journal of the American Welding Society*, *7*(4), 42–46. Retrieved from https://archive.org/details/sim_welding-journal_1928-04_7_4/page/42/mode/2up?view=theater

Blažević, Z. (2017). Faust Vrančić (1551–1617) and intellectual culture of his age. *Povijesni Prilozi*, *36*(52), 53–66. https://doi.org/10.22586/pp.v52i0.2 [in Croatian].

Booth, L. G. (2017). The development of laminated timber arch structures in Bavaria, France, and England in the early nineteenth century. In *The Development of Timber as a Structural Material* (pp. 291–304). Abingdon: Routledge. Retrieved from https://books.google.com.ua/books?hl=uk&lr=&id=glsPEAAAQBAJ&oi=fnd&pg=PA291&dq=Wiebeking+Bridge&ots=ZZ8DMSwdhP&sig=P0ABiy2eSWkpAUpu5QNhRudivMA&redir_esc=y#v=onepage&q=Wiebeking%20Bridge&f=false

Bryla, S. (1930). The first arc-welded bridge in Europe. *The Journal of the American Welding Society*, *9*(5), 71–74. Retrieved from https://archive.org/details/sim_welding-journal_1930-05_9_5/page/70/mode/2up?view=theater

Busch, H., & Reuleke, W. (1946). Investigation of failures in a welded bridge. *Welding Journal*, *25*(8), 463s–466s. Retrieved from https://archive.org/details/sim_welding-journal_1946_25_index/page/n5/mode/2up?view=theater

Central State Audiovisual and Electronic Archive. (n. d.). *Tsentralnyi Derzhavnyi Audiovizualnyi ta Elektronnyi Arkhiv [Central State Audiovisual and Electronic Archive]*. Retrieved from https://tsdaea.archives.gov.ua [in Ukrainian].

Chandramohan, D. L., Roy, K., Taheri, H., Karpenko, M., Fang, Z., & Lim, J. B. P. (2022). A state of the art review of fillet welded joints. *Materials*, *15*(24), 8743. https://doi.org/10.3390/ma15248743

Chigarev, V. V., & Litvinov, A. P. (2011). Razvitie elektrodugovoj svarki [Development of electric arc welding]. *Visnyk Natsionalnoho Tekhnichnoho Universytetu «Kharkivskyi Politekhnichnyi Instytut». Zbirnyk Naukovykh Prats. Seriia "Istoriia nauky i tekhniky" – Bulletin of the National Technical University "Kharkiv Polytechnic Institute". Collection of Scientific Works. "History of Science and Technology" Series*, (20), 176–181. https://repository.kpi.kharkov.ua/handle/KhPI-Press/14062 [in Russian].

Co-Curate. (n.d.). Tees Newport Bridge. *Co-Curate*. Retrieved from https://co-curate.ncl.ac.uk/tees-newport-bridge/).

Cotterell, B. (2010). *Fractures and Life*. London: Imperial College Press. Retrieved from https://books.google.co.uk/books?hl=uk&lr=&id=nznICgAAQBAJ&oi=fnd&pg=PR9&dq=Cotterell+2010+Fractures+and+Life&ots=Nj4chYIycX&sig=SSJZg-AbAZJzEbR3F0KV9k6aqis&redir_esc=y#v=onepage&q=Cotterell%202010%20Fractures%20and%20Life&f=false

Crombie, M. (2019, April 11). Middlesbrough. Tees Bridge, Newport. Opened 1934. Yorkshire. *Flickr*. Retrieved from https://www.flickr.com/photos/147645911@N08/32644218697/

Davis, A .F. (1935). Largest all-welded bridge completed in New Jersey. *The Journal of the American Welding Society*, *14*(8), 2–4. Retrieved from https://archive.org/details/sim_welding-journal_1935-08_14_8/page/2/mode/2up?view=theater

English Heritage. (n. d.). History of Iron Bridge. *English Heritage*. Retrieved from https://www.english-heritage.org.uk/visit/places/iron-bridge/history/

Espion, B. (2012). The Vierendeel bridges over the Albert Canal, Belgium–their significance in the story of brittle failures. *Steel Construction*, *5*(4), 238–243. https://doi.org/10.1002/stco.201210029

Fish, G. D. (1933). Arc-welded steel frame structures. *Engineering News-Record*, *101*(4), 120–123. Retrieved from https://archive.org/details/sim_enr_1928-07-26_101_4/page/120/mode/2up?view=theater

Fougères, D. (2022). Le pont Royal-Albert, 1875–1876: Histoire d'une Bérézina sur fond de rivalités ferroviaires. *Revue D'histoire de l'Amérique Française, 75*(3), 3–34. https://doi.org/10.7202/1092169ar [in French].

Fraser, C. B. & Roberts, J. J. (1994). 86th Street Overpass. *Historic American Engineering Record.* Retrieved from https://tile.loc.gov/storage-services/master/pnp/habshaer/ia/ia0400/ia0410/data/ia0410data.pdf

Gazzola, F. (2015). Brief History of Suspension Bridges. In: *Mathematical Models for Suspension Bridges. MS&A – Modeling, Simulation & Applications, 15,* 1–41. Cham: Springer. https://doi.org/10.1007/978-3-319-15434-3_1

Grimes, N., & Castro, J. J. (2020). The less imperial path: the Mississippi Valley, US expansionism, and engineer James B. Eads' failure to build a ship railway. *The Historian, 82*(2), 156–181. https://doi.org/10.1080/00182370.2020.1747842

Groote, P. D., Ciccarelli, C., & Giuntini, A. (2021). The history of rail transport. In R. Vickerman (Ed.), *International Encyclopedia of Transportation, 5* (pp. 413–426). London: Elsevier. https://doi.org/10.1016/B978-0-08-102671-7.10461-0

Grover, L. (1934). Arc welding for bridge construction. *Civil Engineering, 4*(7), 360–364. Retrieved from https://archive.org/details/sim_civil-engineering-1930_1934-07_4_7/page/360/mode/2up?view=theater

Guinness World Records. Longest bridge. (n. d.). *Guinness World Records.* Retrieved from https://www.guinnessworldrecords.com/world-records/longest-bridge

Hess, J. A. & Hybben, R. (1989). Benton Street Bridge. *Historic American Engineering Record.* Retrieved from https://tile.loc.gov/storage-services/master/pnp/habshaer/ia/ia0100/ia0198/data/ia0198data.pdf

Holzer, S. M., & Knobling, C. (2020). The laminated arch in the first half of the 19th century: A status report from Switzerland. In *Iron, Steel and Buildings: Studies in the History of Construction. The Proceedings of the Seventh Annual Conference of the Construction History Society, Cambridge, United Kingdom, April 4–5, 2020* (pp. 389–404). Cambridge: Construction History Society. https://doi.org/10.3929/ethz-b-000449543

iXBT.com. (n.d.). Most dlinoj 164 kilometra: kak vyglyadit neveroyatnyj kitajskij viaduk [A bridge 164 kilometers long: what the incredible Chinese viaduct looks like]. *iXBT.com.* Retrieved from https://www.ixbt.com/live/offtopic/most-dlinoy-164-kilometra-kak-vyglyadit-neveroyatnyy-kitayskiy-viaduk.html [in Russian].

Johnson, B. (n. d.). Ironbridge. "Birthplace of the Industrial Revolution" and UNESCO World Heritage Site. *Historic UK.* Retrieved from https://www.historic-uk.com/HistoryMagazine/DestinationsUK/Ironbridge/

Kahlow, A. (1995). French influence on the development of applied mechanics in Germany in the nineteenth century. *History and Technology, an International Journal, 12*(2), 179–189. https://doi.org/10.1080/07341519508581883

Kallee, St. (n. d.). Benton Street Bridge in Iowa. The First All-welded Steel Bridge in Iowa, and One of the First in the USA. *AluStir.* Retrieved from https://www.alustir.com/english/did-you-know/benton-street-bridge /

Kornienko, A. N., & Litvinov, A. P. (2008). Transition to integrated development of welding production. *The Paton Welding Journal,* (3), 37–40. Retrieved from https://patonpublishinghouse.com/tpwj/pdf/2008/tpwj200803all.pdf

Korsun, I. V., Buyak, B. B., & Matsyuk, V. M. (2019). Contribution of Ukrainian scientists to the development of technology. *Science and Innovation, 15*(6), 94–102. https://doi.org/10.15407/scin15.06.099

Kozak-Holland, M., Procter, C. (2020). Chapter Case Study 1: The Stockton and Darlington Railway. In: *Managing Transformation Projects: Tracing Lessons from the Industrial to the Digital Revolution* (pp. 27–46). Cham: Palgrave Pivot. https://doi.org/10.1007/978-3-030-33035-4_3

Lambie, G. (2021, January 31). Looking back on the Duplessis bridge collapse 70 years later. *The Sherbrooke Record*. Retrieved from https://www.sherbrookerecord.com/looking-back-on-the-duplessis-bridge-collapse-70-years-later/

Lenner, R., Ryjacek, P., & Sýkora, M. (2020). Resistance models for semi-probabilistic assessment of historic steel bridges. In *1st IABSE Online Symposium Wroclaw 2020: Synergy of Culture and Civil Engineering – History and Challenges, Wroclaw, 7–9 October 2020,* (pp. 1061–1068). https://doi.org/10.2749/wroclaw.2020.1061

Lethbridge Herald. (August 29, 1951). Poor quality steel blamed for bridge crash. *Lethbridge Herald*. Retrieved from https://digitallibrary.uleth.ca/digital/collection/herald2/id/20998

Liegner, N., Kormos, G., & Papp, H. (2015). Solutions of omitting rail expansion joints in case of steel railway bridges with wooden sleepers. *Periodica Polytechnica Civil Engineering*, *59*(4), 495–502. https://doi.org/10.3311/PPci.8169

Lobanov, L. M. (2014). Do 60-richchia mostu imeni Ye. O. Patona [To the 60th anniversary of the bridge named after E. O. Paton]. *Budivelni Konstruktsii – Building Structures,* (81), 119–128. Retrieved from http://irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/cgiirbis_64.exe?C21COM=2&I21DBN=UJRN&P21DBN=UJRN&IMAGE_FILE_DOWNLOAD=1&Image_file_name=PDF/buko_2014_81_16.pdf [in Ukrainian].

Lobanov, L. M., & Kyrian, V. I. (2013). The E. O. Paton all-welded bridge is sixty years old. *The Paton Welding Journal*, (12), 33–38. Retrieved from https://patonpublishinghouse.com/tpwj/pdf/2013/pdfarticles/12/7.pdf

Lobanov, L. M., Dyadin, V. P., Davydov, E. O., & Lytvynenko V. A. (2021). Vybir neruinivnykh metodiv kontroliu shchodo otsinky tekhnichnoho stanu metalevykh konstruktsii holovnykh balok mostu im. Ye.O. Patona cherez r. Dnipro u m. Kyiv [Selection of nondestructive testing methods for evaluation of the technical condition of metal structures of the main beams of E.O. Paton bridge across the Dnipro in Kyiv]. *Tekhnichna Diahnostyka i Neruinivnyi Kontrol – Technical Diagnostics and Non-Destructive Testing*, (4), pp. 47–53. https://doi.org/10.37434/tdnk2021.04.05 [in Ukrainian].

Lobanov, L. M., Kyrian, V. I., & Shumitsky, O. I. (2003). Fifty years of the E.O. Paton bridge. *The Paton Welding Journal*, (10–11), 12–20. Retrieved from https://patonpublishinghouse.com/tpwj/pdf/2003/tpwj200310all.pdf

Malishevskij, I. (2003, October 31). Den' rozhdeniya mosta. 50 let tomu nazad v Kieve byl otkryt Most Patona. Birthday of the bridge. 50 years ago the Paton Bridge was opened in Kyiv. *Zerkalo Nedeli – Mirror of the Week*. Retrieved from https://zn.ua/SOCIUM/den_rozhdeniya_mosta_50_let_tomu_nazad_v_kieve_byl_otkryt_most_patona.html [in Russian].

Markashova, L., Berdnikova, O., Bernatskyi, A., Sydorets, V., & Bushma, O. (2019). Crack resistance of 14KhGN2MDAFB high-strength steel joints manufactured by laser welding. *IOP Conference Series: Earth and Environmental Science*, *224*(1), 012013. https://doi.org/10.1088/1755-1315/224/1/012013

McKibben, F. P. (1929). *Evidence that welding is being adopted for fabricating steel bridges and buildings*. Boston: General Electric Company. Retrieved from https://archive.org/details/EvidenceThatWeldingIsBeingAdoptedForFabricatingSteelBridgesAnd/page/n1/mode/2up?view=theater

Mehrtens, G. C. (1900a). *A hundred years of German bridge building*. Berlin: Springer. Retrieved from https://archive.org/stream/hundredyearsofge00mehr/hundredyearsofge00mehr_djvu.txt

Mehrtens, G. (1900b, May 1). *Eisenbahnbrücke über Elbe, Eisenkonstruktion mit Lohse-Trägern, erbaut 1868–1872. Der deutsche Brückenbau im XIX jahrhundert.* Retrieved from https://commons.wikimedia.org/wiki/File:HH-EisenbahnBr%C3%BCckeLohse_Mehrtens1900.png

Mezenin, N. (1977). Bridges, welding, and metallurgy. *Metallurgist*, *21*(12), 845–848. https://doi.org/10.1007/BF01087567

Naumov, R. (2017, August 5). *Most Patona s Nochnoj Arhitekturnoj Podsvetkoj i Panorama Levogo Berega [Evgeny Paton Bridge with Night Architectural Illumination and Panorama of the Left Bank].* Retrieved from https://ru.wikipedia.org/wiki/%D0%A4%D0%B0%D0%B9%D0%BB:%D0%9C%D1%96%D1%81%D1%82_%D0%9F%D0%B0%D1%82%D0%BE%D0%BD%D0%B0_%D0%B7_%D0%BD%D1%96%D1%87%D0%BD%D0%BE%D1%8E_%D0%B0%D1%80%D1%85%D1%96%D1%82%D0%B5%D0%BA%D1%82%D1%83%D1%80%D0%BD%D0%BE%D1%8E_%D0%BF%D1%96%D0%B4%D1%81%D0%B2%D1%96%D1%82%D0%BA%D0%BE%D1%8E_%D1%82%D0%B0_%D0%BF%D0%B0%D0%BD%D0%BE%D1%80%D0%B0%D0%BC%D0%BE%D1%8E_%D0%9B%D1%96%D0%B2%D0%BE%D0%B3%D0%BE_%D0%B1%D0%B5%D1%80%D0%B5%D0%B3%D0%B0.jpg

Perel'muter, A. V. (2012). Pervyj cel'nosvarnoj most [The first all-welded bridge]. *Promyslove Budivnytstvo ta Inzhenerni Sporudy – Industrial Construction and Engineering Structures*, (1), 33–35. Retrieved from https://urdisc.com.ua/rl/info/1_12.pdf [in Russian].

Pescatore, J.-P., & Borgeot, J.-H. (2008). Chapter 10. Welding Steel Structures. In R. Blondeau (Ed.), *Metallurgy and Mechanics of Welding: Processes and Industrial Applications*, (pp. 359–374). London, Hoboken, NJ: ISTE Ltd., John Wiley & Sons, Inc. https://doi.org/10.1002/9780470611272.ch10

Petrova, L. G. (2022). Metallovedcheskaya ekspertiza razrushenij konstrukcij po prichine hladnolomkosti: istoricheskij obzor [Metallurgical examination of structural failures due to cold brittleness: a historical review]. *Problemy Ekspertizy v Avtomobil'no-Dorozhnoj Otrasli – Problems of Examination in the Automobile and Road Industry,* (2(3)), 29–46. Retrieved from https://disk.yandex.ru/i/es-Yxsv_EhO-MQ [in Russian].

Poznyakov, V. D., Dyadin, V. P., Davydov, Y. O., & Dmitrienko, R. I. (2021). Evaluation of damage of all-welded longitudinal main beams of the E.O. Paton bridge across the Dnipro river. *The Paton Welding Journal*, (7), 30–38. https://doi.org/10.37434/tpwj2021.07.06

Poznyakov, V. D., Markashova, L. I., Shelyagin, V. D., Zhdanov, S. L., Bernatskyi, A. V., Berdnikova, O. M., & Sydorets', V. M. (2019). Cold cracking resistance of butt joints in high-strength steels with different welding techniques. *Strength of Materials, 51,* 843–851. https://doi.org/10.1007/s11223-020-00132-7

PrimaMedia.ru. (2023, July 27). Duga sud'by professora Vologdina [The arc of fate of Professor Vologdin]. *PrimaMedia.ru.* Retrieved from https://primamedia.ru/news/1544555/?from=37 [in Russian].

Radić, J., Puž, G., & Šavor, Z. (2013). Arch bridge development in Croatia in the international context. In *4th Chinese-Croatian Joint Colloquium* (pp 1–22). Retrieved from https://www.researchgate.net/profile/Goran-Puz-2/publication/262159643_ARCH_BRIDGE_DEVELOPMENT_IN_CROATIA_IN_THE_INTERNATIONAL_CONTEXT/links/00b7d536caaba719cd000000/ARCH-BRIDGE-DEVELOPMENT-IN-CROATIA-IN-THE-INTERNATIONAL-CONTEXT.pdf

Railway Engineering and Maintenance. (1927). Electric welding reduces cost of strengthening bridge. *Railway Engineering and Maintenance, 23*(7), 279–281. Retrieved from https://archive.org/details/sim_railway-track-structures_1927-07_23_7/page/278/mode/2up?view=theater

Rosie, G. (2018). Double Crossings: The Tangled Tale of the Forth Road Bridges. *Scottish Affairs*, *27*(3), 342–360. https://doi.org/10.3366/scot.2018.0247

Rymsza, B., Mistewicz, A., & Tucholski, Z. (2017). Kierbedź Bridge: A history of the first permanent bridge across the Vistula river in Warsaw, Poland. *Icon, 23,* 145–166. Retrieved from https://www.jstor.org/stable/26454979

Schueremans, L., Porcher, H., Rossi, B., Wouters, I., & Verstrynge, E. (2018). A study on the evolution in design and calculation of iron and steel structures over the mid 19th century in western and central Europe. *International Journal of Architectural Heritage, 12*(3), 320–333. https://doi.org/10.1080/15583058.2017.1323244

Schuermans, D. (2018, March 5). Expo over de Kempische brug die in het water viel. *Bad Republic.* Retrieved from https://www.badrepublic.be/lokaal/2018/03/expo-over-de-kempische-brug-die-in-het-water-viel/ [in Dutch].

Sedmak, A., Ković, M., & Kirin, S. (2022). Structural Integrity-Historical Context. *Tehnički vjesnik, 29*(5), 1770–1776. https://doi.org/10.17559/TV-20220321074430

Shevchenko, V. G. (2004). *Svarshchik Viktor Vologdin [Welder Viktor Vologdin].* Vladivostok: Far Eastern State Technical University. Retrieved from https://proza.ru/2010/12/28/899 [in Russian].

Shumitsky, S. I. (1997). Welded structures and their optimization. *Welding and Surfacing Reviews, 8*(1), 239–47. Retrieved from https://books.google.com.ua/books?hl=uk&lr=&id=JDKUSCqRreQC&oi=fnd&pg=PA239&dq=Paton+Bridge+1953&ots=JGJyFz40Mu&sig=SAhnw16wRNE3ogWHvZlYtY3Govs&redir_esc=y#v=onepage&q=Paton%20Bridge%201953&f=false

Shymanovskyi, O., Shalinskyi, V., & Baran, W. (2021). Peculiarities of reconstruction work as a result of possible terrorist attacks on out-of-class bridges. In Z. Zembaty, D. Beben, Z. Perkowski, A. Rak, G. Bosco, & P. Solanki (Eds.), *Environmental Challenges in Civil Engineering. ECCE 2020. Lecture Notes in Civil Engineering, 122* (pp. 15–30). Cham: Springer. https://doi.org/10.1007/978-3-030-63879-5_2

Siviero, E., & Martini, V. (2020). Bridges in the world heritage list between culture and technical development. In *1st IABSE Online Symposium Wroclaw 2020: Synergy of Culture and Civil Engineering – History and Challenges, Wroclaw, 7–9 October 2020*, (pp. 157–180). https://doi.org/10.2749/wroclaw.2020.0153

South Clark, N. (2013). The Duplessis Bridge Collapse – January 31, 1951. *An Engineer's Aspect.* Retrieved from http://anengineersaspect.blogspot.com/2013/04/the-duplessis-bridge-collapse-january.html

Spivey, J. M. (2001). Passerelle in Lincoln Park. *Historic American Engineering Record.* Retrieved from https://historicbridges.org/illinois/lincolnpark/haer-il-155.htm

Statyvka, Y., Kyrychenko, H., Strelko, O., & Berdnychenko, Yu. (2021). Control of technological processes using a fuzzy controller of the system for management of cargo delivery by railway. *Acta Scientiarum Polonorum Administratio Locorum, 20*(3), 241–251. https://doi.org/10.31648/aspal.6808

Strelko, O. (2021). Stages of development, improvement and application of equipment for welding in space, created with the participation of Ukrainian scientists. *Studia Historiae Scientiarum, 20*, 263–283. https://doi.org/10.4467/2543702XSHS.21.010.14041

Tees Valley Museums. (n.d.). Dorman Long and Newport Bridge. *Tees Valley Museums.* Retrieved from https://teesvalleymuseums.org/blog/post/newport-bridge/

The Ironbridge Gorge Museum Trust. (n. d.). The Iron Bridge. *The Ironbridge Gorge Museum Trust.* Retrieved from https://www.ironbridge.org.uk/about-us/the-iron-bridge/

Tkachenko, D., Tsegelnyk, Ye., Myntiuk, S., & Myntiuk, V. (2022). Spectral methods application in problems of the thin-walled structures deformation. *Journal of Applied and Computational Mechanics, 8*(2), 641–654. https://doi.org/10.22055/JACM.2021.38346.3207

Touran, A., & Ladick, D. R. (1989). Application of robotics in bridge deck fabrication. *Journal of construction engineering and management, 115*(1), 35–52. https://doi.org/10.1061/(ASCE)0733-9364(1989)115:1(35)

Turmov, G. P. (2004). *Ognyom Svarki i Plamenem Serdca. Istoricheskij Ocherk [With the Fire of Welding and the Flame of the Heart. Historical Essay].* Vladivostok: Far Eastern State Technical University [in Russian].

Van Dyck, M. (2020). Causality and the Reduction to Art of Simon Stevin's Mechanics. In C. A. Davids, F. J. Dijksterhuis, I. H. Stamhuis, & R. H. Vermij (Eds.), *Rethinking Stevin, Stevin Rethinking* (pp. 155–181). Leiden, The Netherlands: Brill. https://doi.org/10.1163/9789004432918_008

Veranzio, F. (1968). *Machinae Novae. Facsimile of the Printed Edition: Venetiis, [1615-1616?].* Milano: Ferro [in Latin].

Vůjtěch, J., Ryjáček, P., & Matos, J. C. (2023). Dealing with defects and strengthening historical steel bridges. *Structural Engineering International*, *33*(1), 195–205.

Williams, W. (1780). *The Cast Iron Bridge near Coalbrookdale.* Retrieved from https://comestepbackintime.files.wordpress.com/2013/04/5-iron-bridge-william-williams-painting.jpg

Witcher, T. R. (2022). Bridge of the Century. *Civil Engineering Magazine Archive*, *92*(4), 26–29. Retrieved from https://ascelibrary.org/doi/pdf/10.1061/ciegag.0001622

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До питання історії будівництва металевих мостів у 20 столітті з використанням технології зварювання

Анотація. *Історія будівництва мостів є важливою частиною історичного знання. Розвиток технології будівництва мостів відбиває як інженерні досягнення, так й соціальні, економічні та культурні аспекти суспільства. Інженери та вчені, проектуючи та будуючи мости, стикалися з унікальними викликами залежно від технологічного рівня епохи, доступних матеріалів та потреб суспільства. Цей процес може бути відображенням технологічного прогресу, змін у транспортних потребах, а також культурних та соціальних змін. Метою цієї статті є короткий огляд ключових моментів та етапів історії будівництва металевих мостів з використанням технології зварювання у 20 столітті. Історія розвитку будівництва металевих мостів із застосуванням зварювання налічує трохи більше 100 років. Невеликий період від будівництва перших зварних мостів, до перших катастроф, призвів до необхідності аналізу можливих причин цих руйнувань. Як показав виконаний аналіз, катастрофічні руйнування найчастіше відбувалися під дією кількох факторів, а також при поєднанні зовнішніх несприятливих впливів та внутрішньої «неготовності»* *конструкції до них. Наведені приклади свідчать про те, що нераціональний вибір сталі може бути як самостійною причиною, що викликає крихке руйнування конструкцій, так і погіршуючим фактором за наявності конструктивних порушень, термічних напружень і дефектів зварювання. За ці роки у різних країнах було вдосконалено технології виготовлення мостів, розроблено нові сталі та матеріали для їх зварювання. Завдяки використанню вуглецевої, низьколегованої та легованої сталі проектувальники відмовилися від брутальних балкових ферм «залізничного типу» і сьогодні металеві мости з витонченими та красивими силуетами потужно крокують через водну гладь, гори та долини. Вони стали справжніми визначними пам'ятками мегаполісів та заміських ландшафтів, а будівельники змогли успішно вирішити численні технічні та економічні завдання. Важливий внесок у розвиток світового мостобудування із застосуванням технологій зварювання зробив колектив Інституту електрозварювання Академії наук УРСР під керівництвом академіка Євгена Оскаровича Патона. Колектив Інституту електрозварювання Академії наук УРСР, впроваджуючи зварювання у мостобудування, виконував ретельну перевірку результатів та вів спостереження за поведінкою конструкцій. Було створено нову марку сталі, стійку до утворення крихких і втомних тріщин, відпрацьовувалась технологія її зварювання, розроблялася технологія монтажного зварювання вертикальних листів із примусовим формуванням шва, підбиралися відповідні зварювальні матеріали. На момент побудови у 1953 році, київський Міст імені Євгена Патона через річку Дніпро був найбільшим у Європі цільнозварним мостом, усі шви якого, включаючи монтажні, вперше виконали за допомогою автоматичного та напівавтоматичного зварювання. Крім того, наявність великих однотипних блоків у конструкції Моста імені Євгена Патона дозволило механізувати складально-зварювальні операції та організувати потоковий метод їх виготовлення на заводі та монтажі, що підвищило якість зварювальних робіт та знизило їх трудомісткість.*

Ключові слова: *історія будівництва мостів; історія металевих мостів; історія зварювання; Київський Міст імені Євгена Патона; Нагорода за Історичні Зварні Конструкції; Інститут електрозварювання АН УРСР*

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