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EDITORIAL

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PREFACE

This issue of the journal begins with an article by Gennadiy V. Bulavko that provides an in-depth exploration of organic photovoltaics, a key green energy technology. The article traces its development from early theoretical concepts to its current status as a promising option for sustainable energy production. The research thoroughly examines the series of milestones in converting solar energy into electrical power, focusing on the evolution, technological advancements, and inherent challenges of organic solar cells. It reviews the foundational aspects of organic photovoltaics, including the initial discoveries and subsequent material science enhancements that have significantly improved the efficiency and practicality of organic solar cells.

Skepticism and critical inquiry are essential in the scientific process, serving as protections against the "ad verecundiam" fallacy, where claims are accepted merely based on authority. The next article thoroughly investigates Augustin-Jean Fresnel's challenge to Newton's corpuscular theory with his innovative wave theory of light. By examining how Fresnel overcame challenges, it offers lessons on constructing scientific knowledge, highlighting the need to avoid accepting theories based solely on authority and instead focus on empirical evidence and theoretical coherence. Fresnel's case serves as a valuable example for teaching the history of science and understanding the evolution of complex scientific concepts.

The article by Iryna Humenna focuses on the national, cultural, educational, and scientific activities of Ukrainian student societies in Eastern Galicia from the late nineteenth century to 1939, examining their cooperation with Metropolitan A. Sheptytskyi. Using chronological, historical-comparative, retrospective, and interdisciplinary methods, including the structural method, the author analyzes historical evidence. The study investigates the functioning of Ukrainian student societies in difficult and unfavorable conditions and demonstrates that their primary aim was the consolidation of society and the realization of national and cultural aspirations of the Ukrainian people. This was achieved by catalyzing processes in the educational and scientific spheres through active interaction with A. Sheptytskyi.

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During the period covered, students collaborated with various political parties, participated in the First World War, and fought for the establishment of the Ukrainian University as a center of higher education and a Ukrainian scientific school.

The article by authors from Yaroslav Mudryi National Law University of Ukraine examines the development of the problem-solving method in the history of pedagogy, both in theory and practice. The research findings show that problem-solving teaching and learning is viewed as a process in which students solve cognitive and practical problems, stimulating their creative and mental activity and promoting active participation in learning. The significant potential of the problem-solving teaching method has been extensively utilized in higher education. The ideas and accumulated pedagogically valuable experiences of implementing problem-solving teaching in higher education offer a valuable theoretical framework and teaching tools for ensuring and enhancing the intellectual and professional competence of future specialists, thereby improving the quality of higher education.

The next article discusses a study on the role of natural knowledge in organizing agricultural research in Ukraine's forest-steppe zone. It provides insights based on available sources about efforts to establish an agricultural experimentation framework in the Forest-Steppe region during the first quarter of the 20th century, following a regional approach. This initiative included the operation of two regional agricultural research centers in slightly different areas of the Forest-Steppe. In the right-bank area, agricultural experimentation was conducted by the Kyiv Agricultural Research Station, along with various district institutions. In contrast, the left-bank area was served by the Kharkiv Agricultural Research Station, along with district and specialized research institutions. The natural science experience accumulated in the early 20th century significantly contributed to developing the theoretical and methodological foundations for advancing agricultural science and research in Ukraine.

Pantelis Zoiopoulos's detailed study offers a comprehensive evaluation of the national and international career of the eminent Greek agriculturist Ioannis Papadakis. The study highlights how Papadakis, primarily working as a plant breeder since 1923, addressed the major challenge of achieving wheat self-sufficiency in Greece by developing new, high-yielding varieties that adapted well to the country's adverse soil and climatic conditions. In 1947, after being invited by Argentina to create its ecological map, Papadakis permanently moved there. He had published the pioneering book "Agricultural Ecology" in French in 1938 and was invited to write the "Soils" entry for the Encyclopaedia Britannica. Papadakis worked for the Food and Agriculture Organization of the United Nations and researched agricultural issues in South America, West Africa, Southeast Asia, and other regions. He authored numerous research and review papers on various agricultural topics, including field crops, plant breeding, biometry, soil science, agricultural ecology, and rural economy and policy.

The article by authors from the Research Center for Prehistoric and Historical Archaeology of the National Research and Innovation Agency of Indonesia investigates how municipalities managed wastewater in the Dutch East Indies in the early 20th century. The focus is on Bandung, one of the most significant cities in the Dutch East Indies, which evolved into a modern residential area, economic hub, and

government seat. This research uses historical-archaeological methods, combining primary data from written sources and field observations. The study reveals that Bandung faced environmental issues, such as the local population's habit of defecating in rivers and open spaces, which spread diseases and polluted river water.

The next article is devoted to the study of the history of the emergence and development of additive technologies in world artistic ceramics. The article analyzes information on the history of the emergence of additive technologies. The principle of operation of 3D printing equipment, features of its use, the most common areas of use and materials used in 3D printing have been considered.

The article by authors from Kharkiv State Academy of Culture of Ukraine examines the carved support beams from the homes of Cossack elder families and Orthodox clergy in the Hetmanate during the last quarter of the 17th century to the end of the 18th century. The creation of these elaborately ornamented support beams served as a confirmation of the homeowners' social status and artistic tastes, as well as a demonstration of the master carvers' skill level of that era.

The next article presents a comprehensive review of Prussian Blue, a pigment with a rich history and diverse applications. It explores the pigment's origins, artistic uses, and chemical properties. The review emphasizes the wide-ranging applications of Prussian Blue, demonstrating its enduring relevance and evolution beyond its historical beginnings.

The next article examines how the socio-economic conditions in Bukovyna influenced the formation and development of the railway network in the region. It explores whether these processes aligned with the global trends of the time. The article also analyzes the impact of railway construction on the social aspects of life in Bukovyna.

The authors from Ternopil Volodymyr Hnatiuk National Pedagogical University made an attempt to explain the evolution of architectural styles of theater buildings from ancient times to modern times. It helps to understand the influence of cultural, technological and social factors on architectural decisions. The article analyzes the relationship between the development of theater architecture and social aspects, such as changes in audience tastes, the role of theater in society, and the reflection of political and cultural trends in buildings.

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Organic photovoltaics: A journey through time, advancements, and future opportunities

Abstract. *This comprehensive study explores the realm of organic photovoltaics, a pivotal green energy technology, tracing its journey from early theoretical concepts to its current status as a promising avenue for sustainable energy production. The research meticulously examines the series of developmental milestones in the conversion of solar energy into electrical power, with a specialized focus on the evolution, technological advancements, and the inherent challenges faced by organic solar cells. Delving into the foundational aspects of organic photovoltaics, this paper reviews the initial discovery and subsequent enhancements in material science that have significantly influenced the efficiency and practicality of organic solar cells. It provides a detailed analysis of the various organic materials used over the years, including small molecules and polymers, discussing their light-absorbing capabilities, charge transport properties, and the innovative engineering behind the architectures of organic photovoltaic devices. A substantial portion of the study is dedicated to highlighting the unique advantages of organic photovoltaics, such as their lightweight nature, flexibility, and potential for low-cost production through roll-to-roll processes. These benefits are juxtaposed with the current limitations of organic photovoltaic technology, including comparatively lower efficiency and lifespan issues, to present a balanced perspective on the current state of organic photovoltaic development. Furthermore, the paper explores the environmental impact of organic solar cells, emphasizing their role in reducing carbon footprint and dependency on fossil fuels. It assesses the lifecycle analyses of organic photovoltaics, from manufacturing to disposal, to underscore their potential as an eco-friendly alternative to traditional photovoltaic technologies. In addressing the future prospects of organic photovoltaics, the research outlines the ongoing efforts in material innovation, device engineering, and scalability challenges. It discusses the role of interdisciplinary collaboration in*

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overcoming the technical hurdles and enhancing the commercial viability of organic photovoltaics. The potential for integration of organic photovoltaics s into the urban landscape, wearable technology, and portable power sources is also explored, highlighting the versatile applications of organic solar cells in meeting the diverse energy needs of the modern world. In conclusion, this paper not only provides a thorough historical overview and current state analysis of organic photovoltaics but also forecasts the exciting advancements on the horizon. By identifying the critical factors for the success of organic photovoltaics and proposing strategic directions for future research, this study contributes valuable insights into the ongoing quest for renewable energy solutions. It calls for increased investment and research focus on organic photovoltaics as a key player in the global transition towards a sustainable and energy-efficient future.

Keywords: *renewable energy; solar cell efficiency; material science; sustainable technology; energy conversion; environmental impact*

Introduction.

The significance of green energy has increasingly come to the forefront of global discussions on sustainable development and climate change mitigation. As societies grapple with the urgent need to reduce greenhouse gas emissions and transition away from fossil fuel dependency, renewable energy sources emerge as vital components of an environmentally friendly future. Among these, photovoltaic (PV) technology, which converts sunlight directly into electricity, stands out for its potential to harness the most abundant and widespread renewable energy source – the sun.

The concept of energy transition – the shift from non-renewable sources of energy such as coal, oil, and natural gas to renewable energy sources like solar, wind, and hydro – is crucial for achieving long-term sustainability goals. This transition is not merely a technical challenge but also an economic and social one, requiring significant innovations in technology, infrastructure development, and policy frameworks. The role of photovoltaics in this transition is paramount. PV technology offers a clean, inexhaustible source of power that can significantly reduce carbon emissions and lessen the environmental impacts associated with traditional energy generation (Bulavko, Davidenko, Derevyanko, Ishchenko & Kulinich, 2015).

Photovoltaics, at its core, involves the use of solar cells to convert light into electricity through the photovoltaic effect, a process that generates electrical power by converting solar radiation into direct current electricity using semiconductors. The development and optimization of PV technology have been subjects of extensive research and innovation, leading to significant improvements in efficiency, durability, and production costs. Today, photovoltaics is not just a theoretical possibility but a practical tool in the global energy mix, contributing to the growing share of renewable energy in power generation.

However, the journey of photovoltaics from a niche technology to a cornerstone of renewable energy has not been without challenges. Issues such as efficiency, stability, and the environmental impact of PV production processes are areas of ongoing research and development. The quest for sustainable, efficient, and cost-

effective solar energy solutions continues to drive innovation in materials science, engineering, and policy-making.

The primary objective of this research is to perform a comprehensive historical and technological analysis of organic photovoltaics. This includes exploring their developmental milestones, evaluating their current applications, and forecasting future technological potentials. Our goal is to assess how organic photovoltaics (OPVs) can serve as a sustainable alternative in the global energy mix, focusing on their environmental impacts, efficiency improvements, and integration into existing and future energy systems. By doing so, we aim to contribute to the broader dialogue on renewable energy adoption and its implications for sustainable development.

Research Methods.

This study employs a mixed-methods approach to comprehensively understand the evolution and impact of organic photovoltaics. Our methodology includes a systematic literature review of peer-reviewed articles, patents, and industry reports to gather data on the historical development and technological advancements in OPVs. We complement this with a qualitative analysis of expert interviews and case studies to gauge the practical applications and market readiness of these technologies. Additionally, quantitative methods, such as statistical analysis and trend forecasting, are used to evaluate the performance metrics of OPVs and predict future trends. This holistic approach allows us to integrate diverse perspectives and provide a thorough analysis of the state of OPV technology and its potential trajectory.

The foundational concept of solar technology, the photovoltaic effect, was first identified by French physicist Alexandre-Edmond Becquerel in 1839 during electrolyte solution experiments. This discovery set the stage for future innovations, highlighting pivotal moments and figures in the evolution of solar energy technologies. While conducting experiments involving metallic electrodes immersed in an electrolyte solution, Becquerel observed the unexpected generation of electricity under light exposure. Several decades later, in 1883, Charles Fritts took a significant step forward by developing a photovoltaic cell made of selenium plates, achieving an efficiency of approximately 1%. These early explorations, although groundbreaking, were largely empirical and lacked a solid theoretical foundation to fully explain the photovoltaic phenomena observed, limiting their immediate impact on the advancement of solar energy conversion technology (Bulavko et al., 2017).

The landscape of photovoltaic research underwent a transformative change with the methodical investigations into the photoelectric effect by Aleksandr Stoletov in the late 1880s and the seminal work by Albert Einstein in 1905, which elucidated the fundamental laws governing the photoelectric effect. Einstein's theoretical insights, for which he was later awarded the Nobel Prize, provided a deeper understanding of the interaction between light and matter, laying the groundwork for the modern field of photovoltaics. These pivotal developments paved the way for the breakthrough in the mid-20th century at Bell Labs in New Jersey, USA, where researchers unveiled the first silicon solar cell with an efficiency of around 6%, heralding the dawn of practical photovoltaic technology. This milestone was not just a technical achievement but also

a conceptual leap that sparked the rapid evolution of photovoltaic cells, leading to the dynamic and ever-expanding field of solar energy research we see today (Heeger, 2014).

While detailed technical metrics assess photovoltaic cell efficiency, their broad implications on renewable energy adoption and economic impact are of paramount importance, influencing global energy policies and market dynamics. Therefore, for the purposes of this discussion, we will focus primarily on the most universally comprehensible and widely recognized metric: the efficiency percentage. This singular parameter effectively encapsulates the performance of a photovoltaic cell, providing a straightforward and intuitive measure of how efficiently a cell converts sunlight into electrical energy.

In the nascent stages of photovoltaic technology, the devices that first demonstrated a significantly high level of efficiency, approximately 6%, were those constructed using crystalline silicon (c-Si). This material, along with germanium-based counterparts, forms the cornerstone of what is known as the first generation of solar cells. Today, these crystalline silicon devices command the lion's share of the commercial solar cell market, boasting an impressive efficiency rate of up to 24.4% and constituting about 90% of the global production. Despite their widespread adoption and high performance, the manufacturing processes for these devices are marked by their complexity and high demand for resources, leading to considerable costs. The price point for crystalline silicon photovoltaic modules hovers around $2.50 for each watt of capacity installed, reflecting the expensive nature of their production (Bulavko et al., 2017).

The limitations associated with the first generation of photovoltaic devices, such as their hefty production costs and the extensive resources required for their creation, have spurred an intensive search for alternative materials that could be used in the construction of photovoltaic devices. This search has culminated in the advent of second-generation photovoltaic devices, characterized by their thin-film construction. These include a diverse array of materials such as microcrystalline (μc-Si), amorphous (a-Si), and polycrystalline silicon (multi-cSi), alongside III-V semiconductors (InP, GaP, GaAs), chalcogenides (CdTe, $CuInS_2$, $CuInxGa(_{1-x})Se_2$), and other multifaceted semiconductor compounds. A significant advantage of these second-generation devices lies in their manufacturing process, which, thanks to the thin-film approach, has become markedly simpler and less energy-intensive compared to their crystalline silicon counterparts (Rehman et al., 2023).

Moreover, the flexibility and malleability inherent to most thin-film materials enable their application over surfaces with complex geometries and varied textures, opening up new possibilities for integrating photovoltaic technology into unconventional settings. This adaptability, combined with reduced production costs and decreased energy requirements for manufacturing, positions second-generation thin-film solar cells as a promising alternative to traditional photovoltaic technologies. Their development not only signifies a stride towards more economical and environmentally friendly solar energy solutions but also enhances the functional

versatility of solar technology, allowing for its integration into a broader range of applications and environments (Bulavko et al., 2017).

A significant drawback of second-generation solar cells is their relatively lower efficiency. For instance, photovoltaic devices based on CdTe exhibit efficiency rates of 15-20%. However, this limitation is substantially offset by the lower production costs associated with these devices. It has been reported that the average cost of electricity generated by batteries using second-generation photovoltaic cells does not exceed $0.9 per kWh. Despite this economic advantage, the transition to second-generation solar batteries has not been entirely successful, mainly due to the high toxicity of the production process, challenges associated with disposal, and the significant impact of environmental conditions on the operation of these devices. These disadvantages, combined with their relatively low efficiency, have led to a marked decline in their market share since the early 2010s, a trend that continues to the present day (Scarpulla et al., 2023).

Moreover, the performance of second-generation solar cells is heavily influenced by external conditions, such as temperature and lighting, which can vary widely depending on geographic location and time of year. This variability can affect the consistency and reliability of power output, further complicating their integration into the broader energy grid.

The introduction of third-generation solar cells not only marks a technological shift but also a significant economic breakthrough. These advancements have catalyzed substantial industrial growth, creating new markets and reducing dependency on traditional energy sources, thus reshaping national economies and enhancing global energy security. This generation is distinguished by its embrace of both organic and hybrid materials, merging the realms of organic chemistry with inorganic photovoltaic principles to unlock new potential in solar energy conversion. Moreover, this category broadens its horizon by integrating photovoltaic devices that utilize quantum dots and employ multijunction or tandem configurations. These sophisticated designs feature a series of thin, sequentially connected solar cells, each fine-tuned to absorb a distinct segment of the solar spectrum, thereby optimizing the capture and conversion of sunlight into electrical energy (Shah et al., 2023).

The core of third-generation photovoltaic innovation lies in its foundational materials - organic and hybrid compounds. These materials offer a significant reduction in manufacturing complexities and costs when juxtaposed with traditional inorganic solar cells. One of the standout features of organic photovoltaic (OPV) devices is their exceptional capacity for creating nanocomposites, which affords unparalleled flexibility in adapting to the physical contours and dimensions of various end-use products. This adaptability is further enhanced by the inherent versatility of organic materials, whose molecular architecture can be precisely engineered to optimize light absorption, charge transport, and overall photovoltaic performance tailored to specific application requirements (Panagoda et al., 2023).

The ease of processing organic materials into solar cells contributes to their economic appeal, with production costs projected to plummet to between $40 and $60 per square meter in the near future. This cost-efficiency, coupled with the

environmental benefits of using less toxic materials, presents a compelling case for the wider adoption of OPVs (Kalowekamo & Baker, 2009). The field of synthetic organic and polymer chemistry stands as a fertile ground for the development of innovative materials designed specifically for organic photovoltaics. This strategic synthesis approach not only expands the repertoire of available photovoltaic materials but also enhances the functional characteristics of solar cells, such as their efficiency, stability, and lifespan.

The origins of organic photovoltaic technology are traced back to the 1980s, marking a significant leap in the pursuit of alternative energy sources. At the heart of these initial OPV cells was a layered structure comprising a p-type semiconductor, exemplified by materials like tetraazabenzoporphyrin, coupled with an n-type layer, with rhodamines or triphenylmethanes serving as notable examples.

In a notable study conducted in 1984, Harima and his team shed light on the mechanisms of charge carrier photogeneration within OPV cells, employing a photoactive layer that included zinc-based phthalocyanines and a porphyrin variant, showcasing the potential of these materials in solar energy conversion. This research underscored the importance of selecting appropriate materials to facilitate efficient light absorption and charge separation (Harima, Yamashita, & Suzuki, 1984).

Building upon these foundational studies, in 1986, Tang introduced a breakthrough in OPV design, utilizing copper phthalocyanines as the p-type layer and pairing it with an n-type material derived from perylene. This innovative cell configuration, marked a milestone by achieving an efficiency rate close to 1% (Tang, 1986). This achievement not only demonstrated the viability of organic materials in photovoltaic applications but also highlighted the critical role of material composition and structure in optimizing the performance of OPV cells.

While an efficiency of 1% was modest, even by the standards of that era, especially when compared to their inorganic counterparts, the notion of commercializing these early organic photovoltaic cells seemed premature. However, the successful demonstration of using organic materials for solar energy conversion ignited further research in the field (Hoppe & Sariciftci, 2004). This initial success underscored the potential of organic compounds in photovoltaic applications, setting the stage for a wave of innovation that would seek to harness the unique properties of organic materials for energy conversion (Bulavko, Davidenko, Derevyanko, Ishchenko & Kulinich, 2015).

A landmark moment in the advancement of organic photovoltaics came with the discovery of fullerene in the late 20th century. This novel carbon-based material, characterized by its unique cage-like molecular structure, revolutionized the field of organic electronics, including photovoltaics (Spanggaard & Krebs, 2004). Fullerenes quickly became a focal point of research due to their exceptional electron-accepting properties, making them ideal candidates for use as acceptor materials in OPV cells.

The integration of fullerenes into organic photovoltaic cells marked a significant evolution in the design and efficiency of these devices. Their ability to facilitate efficient charge separation and transport within the solar cell significantly enhanced the performance and reliability of OPVs (Machín & Márquez, 2024). This

breakthrough not only improved the efficiency of organic solar cells but also broadened the understanding of material interactions at the molecular level, paving the way for the design of more sophisticated and efficient photovoltaic systems.

The design innovations of organic solar cells trace back to the early attempts by pioneers in the field, who first conceptualized and implemented these designs in a lab setting before moving towards industrial applications. These historical milestones reflect the significant contributions of numerous researchers and their enduring impact on the renewable energy landscape.

Photovoltaic cells of the type described above, where the photoactive components (p-type and n-type semiconductors) are layered in sequence, are referred to as bilayer cells or cells with a planar heterojunction (Fig. 1.a).

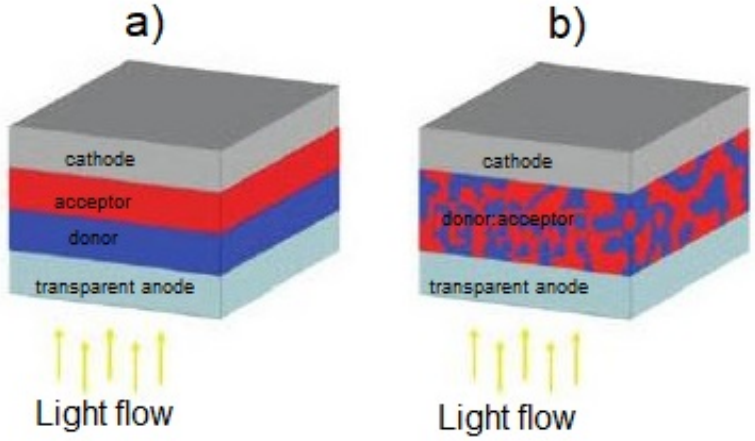

Figure 1. Schematic illustration of photovoltaic devices: bilayer type (a) and bulk heterojunction (b) (Koul & Hakim, 2018).

By the early 1990s, it became evident that the use of the planar heterojunction concept in the creation of organic photovoltaic systems was somewhat inefficient, primarily due to the limited contact area between the donor and acceptor phases in such devices. This limitation was a significant barrier to enhancing the efficiency of organic solar cells because it restricted the extent of photogeneration—the process by which light is converted into electrical energy. In planar heterojunction cells, the interface where this crucial photogeneration occurs is confined to a narrow layer. This means that only a small fraction of the incoming sunlight can effectively contribute to generating electricity, as the rest of the light passes through or is absorbed without contributing to the electrical output.

The recognition of this limitation prompted researchers to explore new architectures and configurations for organic photovoltaic cells. The goal was to increase the interfacial area between the donor and acceptor materials, thereby maximizing the opportunities for photogeneration and improving the overall efficiency of the solar cells.

The challenge of creating such layers was successfully addressed through the concept of the bulk heterojunction (Fig. 1.b), proposed in 1992 by A. Heeger and N. S. Sariciftci (Sariciftci, Smilowitz, Heeger, & Wudl, 1992) . In devices utilizing a bulk heterojunction, the active layer consists of a thin film made from a blend of donor

and acceptor molecules. This mixture creates numerous contact points throughout the volume of the active layer, significantly increasing the total area of the interface between the n-type and p-type semiconductors. As a result, this architecture facilitates a more efficient generation of charge carriers compared to the bilayer cells.

This innovation marked a pivotal shift in the field of organic photovoltaics. By interspersing the donor and acceptor materials throughout the active layer, the bulk heterojunction approach maximizes the interface where the photogeneration process occurs. This increased interface area ensures that a larger portion of the incident light is utilized for generating electricity, enhancing the cell's overall efficiency. The blend of donor and acceptor molecules in a finely intermixed network enables the effective separation and transport of charge carriers, significantly improving the performance of organic solar cells.

The introduction of the bulk heterojunction concept not only addressed the limitations of planar heterojunctions but also opened new avenues for the design and development of highly efficient organic photovoltaic systems. This breakthrough laid the foundation for subsequent advancements in the field, driving research towards optimizing the composition and morphology of the active layer to achieve even higher efficiencies in organic solar cells (Park et al., 2009).

The introduction of the bulk heterojunction concept in the early 90s marked a significant advancement in organic photovoltaic technology. This innovative approach, involving the creation of the first solar cell that utilized a bulk heterojunction, demonstrated a marked improvement in efficiency over the traditional bilayer configurations. Despite this leap forward, bulk heterojunction cells also presented unique challenges. The critical issue revolved around the limited exciton diffusion length in organic semiconductors, typically ranging from 10 to 30 nm. To effectively facilitate the dissociation of excitons into free charge carriers at the "donor-acceptor" interface, the photoactive layer within these cells needed to adopt a nanocomposite structure. This structure would have to feature nanoclusters or domains whose dimensions were on par with the exciton's average diffusion length, ensuring efficient charge generation and separation.

As a result, bulk heterojunction technology has become a cornerstone of modern organic photovoltaics, continuously evolving with new material discoveries and morphological innovations to harness solar energy more effectively.

After Ch. Tang's pivotal work, the focus turned towards metal phthalocyanines and perylene derivatives as the go-to materials for bilayer photovoltaic cells. Yet, surpassing a 1% conversion efficiency barrier with these materials proved to be a formidable challenge, prompting a continued quest for innovative materials suitable for the active layers in photovoltaic devices. The 1985 discovery of fullerenes marked a watershed moment in this search.

The exceptional electron-accepting qualities and notable conductivity of fullerenes C_{60} and C_{70} (Fig. 2) positioned them as superior n-type materials in the realm of photovoltaics. Their unique spherical configuration hindered the recombination of photogenerated charges more effectively than planar acceptors such as tetracyanoquinodimethane, despite similar electron-accepting attributes. This

innovative approach of integrating fullerene C_{60} as an acceptor in bilayer cells, especially those with ZnPc and CuPc donors, significantly enhanced device efficiency to 2.5%. Moreover, substituting metal phthalocyanines with subphthalocyanine boron (SubPc) further propelled the conversion efficiency to 3% in a device featuring a SubPc/C_{60} active layer configuration.

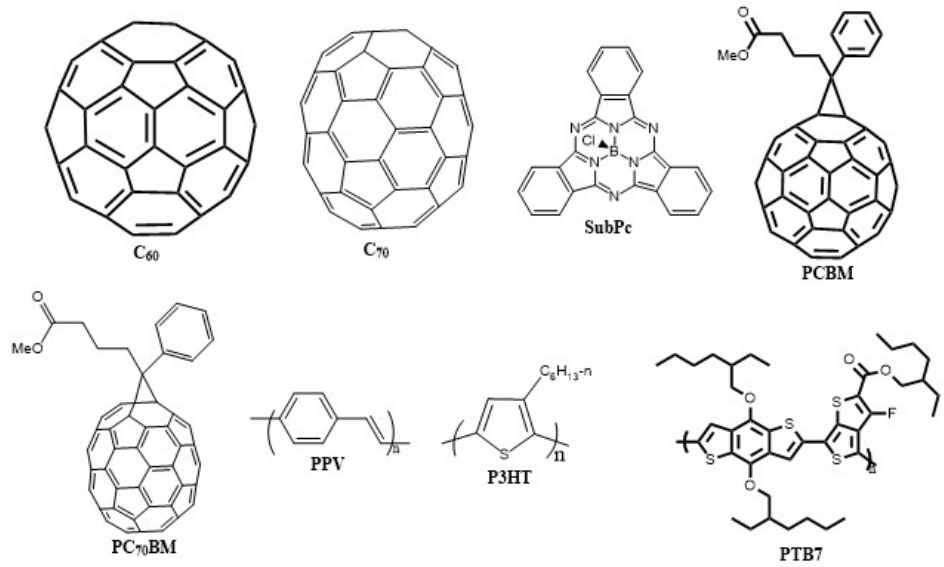

Figure 2. Chemical formulas of some donor and acceptor materials mentioned in this article (Author's source).

This shift towards new material combinations underscored the critical role of molecular architecture and electron-accepting properties in the development of more efficient photovoltaic cells. The introduction of fullerenes not only expanded the possibilities for active layer composition but also set a new benchmark for the performance of organic photovoltaic devices.

While pure fullerenes boast a multitude of benefits, they also present a significant drawback: their practical insolubility in organic solvents. This characteristic necessitates their application through labor-intensive and energy-consuming vacuum sublimation processes, prompting researchers to seek out materials that combine fullerenes' electron-accepting properties with improved solubility in organic solvents. This quest led to the development of methanofullerenes, organic derivatives of C_{60} and C_{70} fullerenes. Among these, the methyl ester of [6,6]-phenyl-C61-butyric acid (PCBM) and its counterpart, the methyl ester of [6,6]-phenyl-C_{71}-butyric acid ($PC_{70}BM$) (Fig.2), became particularly prominent. These fullerene derivatives showed good solubility in chlorobenzene and moderate solubility in toluene, enabling their application from solution.

Bulk heterojunction photovoltaic cells have demonstrated significantly higher efficiency compared to their bilayer counterparts, revolutionizing the field of organic solar energy conversion. The manufacturing process for these devices has also become notably more straightforward. The enhanced solubility of the materials used has facilitated quick and easy application through cutting-edge printing technologies. Among the pioneering bulk heterojunction systems were those utilizing PCBM as the

acceptor and various soluble derivatives of poly(para-phenylenevinylene) (PPV), such as MEH-PPV, MDMO-PPV, and CN-PPV, as donor materials. For several years, PCBM:PPV (Fig. 2) derivative mixtures served as benchmark systems for a vast majority of organic solar cells. Devices based on these combinations achieved efficiencies around 2.6%, approaching the theoretical limit for PCBM:PPV derivative-type bulk heterojunction cells. This marked progress underscores the potential of novel material combinations and manufacturing techniques in enhancing the performance and scalability of organic photovoltaic systems.

The relatively low efficiency of materials based on PPV derivatives is primarily due to their narrow spectral sensitivity range. Essentially, the broader the range of light wavelengths a material can absorb, the higher the efficiency of the solar cell. However, for PPV derivatives, this range is limited to between 360 and 550 nm (Fig. 3). This means that photons with wavelengths longer than 550 nm are not absorbed by this material, thus not contributing to the generation of photocurrent and, in turn, limiting efficiency. Figure 3 shows the absorption spectra, or spectral sensitivity, of some common materials used as donors in the manufacture of organic photovoltaic cells, along with the emission spectrum of a solar simulator. As evident from Figure 3, the majority of solar photons fall in the near-infrared (NIR) and infrared spectrum, i.e., wavelengths of 750 nm and longer. Consequently, it became clear that enhancing the device's efficiency necessitates the development of new materials with a broader absorption range, especially in the NIR region of the spectrum.

In simpler terms, for a solar cell to be more efficient, it needs to be like a net that can catch a wider range of light waves. Currently, materials like PPV derivatives are like nets that only catch small fish (short wavelengths) and miss the big fish (longer wavelengths). To make our net catch more and bigger fish, we need to design new materials that can absorb light across a wider spectrum, especially catching those big fish in the near-infrared region, where a lot of solar energy lies waiting to be harnessed.

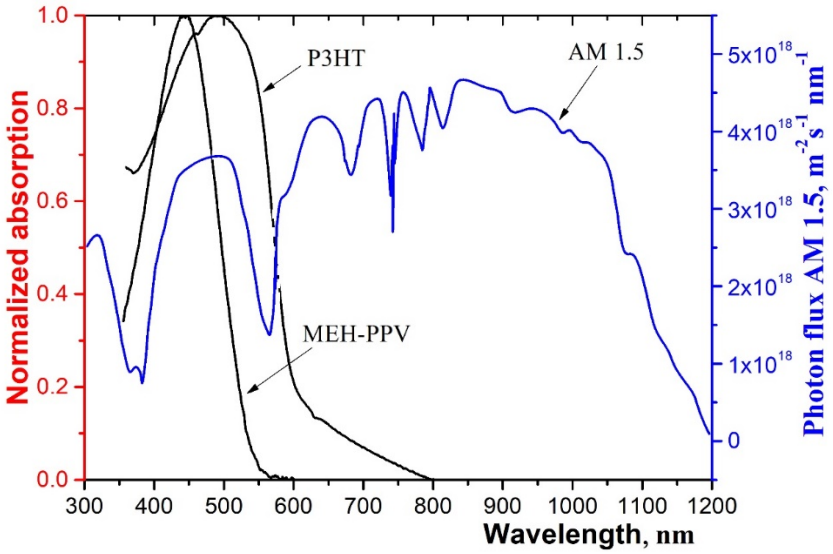

Figure 3. Normalized absorption spectra of MEH-PPV and P3HT polymer films, alongside the emission spectrum of an AM 1.5 source (Bulavko et al., 2017).

The search for materials capable of capturing a wider range of light wavelengths heralded the introduction of the P3HT polymer. Notably broader in its absorption spectrum compared to PPV derivatives, P3HT extends its reach up to 800 nm in the long-wavelength region, as illustrated in Figure 3. This broad spectrum of light absorption, combined with P3HT's impressive ability to transport charge, led to efficiencies surpassing 4%. Estimates suggest that the peak efficiency achievable with P3HT:PCBM systems could range between 4.5% and 5%, according to various studies. As a result, devices utilizing the P3HT:PCBM combination have set a benchmark in the industry, becoming a classic model extensively explored for their composition and structural properties. Today, the P3HT:PCBM framework continues to serve as a reference point or standard in the development and comparison of new organic photovoltaic materials, highlighting its significance in the progression of solar cell technology.

To further enhance the efficiency of organic photovoltaic cells, it became necessary to achieve strong light absorption in the wavelength range above 700 nm. This led to the development of so-called narrow-bandgap polymers for organic photovoltaics. Examples of such polymers include those developed by Leclerc in the mid-2000s, with commercial names like PBDTTT, PTB7 (Fig. 2), among others (Blouin, Michaud, & Leclerc, 2007). These polymers are distinguished by their intense absorption in the near-infrared region of the spectrum - around 800 nm, enabling the immediate attainment of high efficiency levels of 7.7 % and even up to 9 % for the photoactive layer based on the PTB7:fullerene derivative. However, these polymers also exhibited a drawback: low stability, which significantly limits their application. For instance, devices with an active layer of PTB7:PCBM experienced a reduction in efficiency by more than half after just one and a half hours of operation.

Further experimental exploration and, particularly, theoretical calculations have revealed that to continue increasing the efficiency of photovoltaic cells, there needs to be a more nuanced control over the semiconductor and spectral properties of polymers. Achieving this can be done by constructing the polymer chain from not just one type of monomer, but several. Polymers constructed from multiple monomers are known as copolymers. This led to the development of donor-acceptor copolymers, which have emerged as the next generation of donor materials for organic photovoltaic cells and represent the most promising avenue for current research.

These donor-acceptor copolymers allow for a tailored approach to adjusting the electronic and optical properties of the material, enabling more efficient light absorption and charge separation. By combining different monomers, scientists can fine-tune the energy levels and absorption spectrum of the copolymer, optimizing it for specific wavelengths of light. This level of customization is crucial for developing more efficient photovoltaic cells, as it ensures that a broader spectrum of sunlight can be converted into electrical energy. As such, donor-acceptor copolymers stand at the forefront of organic photovoltaic research, heralding new possibilities for solar energy conversion.

A significant milestone was achieved in 2012 with the creation of transparent photovoltaic cells. Until then, numerous attempts had been made to develop devices

that are transparent in the visible spectrum using electron-conducting polymers, graphene, and other materials. However, these devices often suffered from either low transparency in the visible range or poor efficiency. To overcome this challenge, a copolymer was designed that primarily absorbs light in the near-infrared range. When this copolymer was combined with PCBM, which predominantly absorbs in the UV spectrum, a significant level of transparency was achieved 66% at 550 nm, the peak sensitivity of the human eye. The active layer of such devices is sandwiched between two electrodes that must also be transparent. These transparent cells have successfully reached efficiencies over 4 %.

Transparent photovoltaic cells present a host of advantages, opening up exciting possibilities for integrating renewable energy into everyday life. One of the most promising applications is their integration into windows, allowing for the generation of electricity without obstructing visibility. This innovative approach can transform buildings into self-sustaining energy producers, reducing dependency on external power sources. Furthermore, transparent photovoltaic technology can be applied to the surfaces of electronic devices, providing an inconspicuous power generation solution. The development of transparent photovoltaic cells marks the beginning of a new era, where solar energy can be harnessed in more places than ever before, seamlessly blending into our surroundings and contributing to sustainable living.

While PCBM-based acceptors have long dominated the landscape of organic photovoltaics due to their reliable electron-accepting capabilities and compatibility with a broad range of donor materials, their inherent limitations have increasingly become apparent, highlighting a need for innovation beyond their scope. The primary challenge with PCBM and similar fullerene derivatives lies in their energetic mismatch with many promising donor materials, which can significantly hinder optimal charge transfer processes, crucial for high device efficiency. Additionally, the spectral absorption of PCBM is not sufficiently broad or well-matched to the solar spectrum, resulting in underutilization of available solar energy and consequently limiting the photocurrent and overall device performance.

Another critical aspect is the complex, resource-intensive production process of PCBM, which not only adds to the cost but also raises concerns about the environmental impact and scalability of organic photovoltaic manufacturing. This complexity, coupled with the relatively narrow absorption spectrum and suboptimal energy level alignments, has spurred the search for alternative materials that could overcome these hurdles.

The advent of non-fullerene acceptors has been a response to these challenges, marking a significant evolution in the field of organic photovoltaics. These innovative materials are designed with versatility in mind, featuring customizable molecular structures that allow for precise tuning of energy levels and absorption characteristics. This flexibility enables a more harmonious integration with a wide array of donor materials, enhancing charge separation efficiency and enabling the capture of a broader spectrum of solar light.

Non-fullerene acceptors have shown to dramatically expand the design space for organic photovoltaic cells, offering enhanced thermal stability and a better blend

morphology with donor polymers, which contributes to the longevity and performance consistency of solar cells. Their synthesis routes are generally more straightforward than those of their fullerene counterparts, potentially leading to reduced production costs and a lower environmental footprint. The design and development of these materials have leveraged advanced computational modeling and high-throughput screening techniques, accelerating the discovery of highly efficient non-fullerene acceptors (Sonar, Fong Lim, & Chan, 2011).

Remarkably, the integration of non-fullerene acceptors into organic solar cells has led to breakthrough efficiency levels, with some configurations surpassing 15% a milestone that seemed elusive with fullerene-based systems. These high-performance cells also exhibit improved photochemical stability and mechanical durability, addressing longstanding concerns that have impeded the commercialization of organic photovoltaics.

As the quest for the ideal photovoltaic material continues, non-fullerene acceptors stand out as a pivotal development in organic solar cell technology, embodying the principles of adaptability, efficiency, and sustainability. Their rise heralds a new era for organic photovoltaics, one that promises to bring solar energy closer to becoming a ubiquitous, cost-effective source of renewable energy.

Another significant milestone in the evolution of organic photovoltaic technology has been the integration of organic dyes to enhance the efficiency of solar cells. These dyes can be introduced either as a third component in the photoactive layer to broaden the spectral sensitivity range or as a standalone component, acting either as a donor or an acceptor within the cell structure (Ishchenko, 2008).

The strategic incorporation of organic dyes into the photovoltaic matrix allows for a more comprehensive capture of the solar spectrum, addressing one of the fundamental limitations of many organic photovoltaic materials — their narrow absorption bands. By selecting dyes with absorption characteristics complementary to the existing photoactive components, it's possible to significantly extend the range of light wavelengths that the cell can convert into electrical energy. This approach effectively turns previously unused parts of the solar spectrum into valuable energy sources, enhancing the cell's overall efficiency.

Choosing the right dye involves careful consideration of its photophysical properties, such as its absorption spectrum, photostability, and energy levels, to ensure it harmonizes with the other materials in the solar cell. The dye's molecular structure can also be tailored to improve its solubility and compatibility with the photovoltaic blend, optimizing the morphology of the photoactive layer for efficient charge transport and extraction.

One of the remarkable outcomes of incorporating organic dyes into solar cells has been the achievement of higher power conversion efficiencies. In some instances, the addition of dyes has led to notable efficiency improvements, bringing organic solar cells closer to their inorganic counterparts in terms of performance. Moreover, the use of dyes opens up new avenues for the aesthetic customization of solar panels, allowing for the creation of visually appealing energy-generating surfaces that can be integrated into a variety of applications, from building facades to wearable devices.

The application of organic dyes in photovoltaic cells exemplifies the ongoing innovation in material science aimed at optimizing solar energy conversion. By expanding the spectral range of light absorption and enhancing the aesthetic appeal of solar technologies, organic dyes contribute to the development of more efficient, versatile, and consumer-friendly photovoltaic solutions. This progress underscores the potential of organic photovoltaics to play a significant role in the transition towards sustainable energy sources, highlighting the importance of material innovation in achieving a greener future (Kurdiukova, Kulinich, & Ishchenko, 2012).

As of today, the efficiency of organic solar cells has reached a remarkable milestone, surpassing 17 %. This achievement not only highlights the rapid progression of organic photovoltaic technology but also showcases its growing competitiveness with inorganic counterparts. The journey from the first organic solar cells with an efficiency of around 1 % to the current state where efficiencies exceed 17 % is a testament to the relentless innovation and research within the field.

This evolution underscores the potential of organic solar cells to offer a viable alternative to traditional inorganic solar technologies. With advantages such as flexibility, lighter weight, and the potential for lower production costs, organic photovoltaics are carving out a significant niche in the renewable energy landscape. The progress to date suggests that the efficiency ceiling for organic solar cells has yet to be reached, with ongoing advancements in material science, device architecture, and processing techniques continuing to push the boundaries of what's possible.

The achievement of efficiencies over 17 % also signals a shift in the perception of organic solar cells from a niche, experimental technology to a serious contender in the solar energy market. This marks a crucial step towards realizing the vision of integrating photovoltaic technology into everyday surfaces, from building materials to wearable devices, thereby contributing to the widespread adoption of sustainable energy sources.

Results and Discussion.

Up to this point, the discussion has primarily revolved around organic solar cells as laboratory specimens, showcasing their potential through controlled experiments and theoretical models. However, for these innovative devices to truly impact our daily lives, a transition from laboratory-scale prototypes to commercially manufactured models is imperative. The commercialization of organic solar cells is not just a matter of technological achievement but also a crucial step towards integrating renewable energy solutions into the global energy mix.

The importance of commercializing organic photovoltaic technology cannot be overstated. It represents the bridge between the theoretical potential of organic solar cells and their practical application, making sustainable energy more accessible to a broader audience. In this context, we will explore some of the most successful examples of organic solar cell commercialization, highlighting the strategies employed to bring these technologies to market.

One key aspect of commercialization is the reduction of production costs. As organic solar cells advance towards commercial viability, innovative manufacturing

processes and material optimizations that lower the overall cost are essential. Techniques such as roll-to-roll printing and solution processing have shown promise in scaling up production while maintaining the efficiency and reliability of the solar cells.

Moreover, further development prospects within the organic photovoltaic industry are vast. Continuous research is focused on improving the efficiency, stability, and lifespan of organic solar cells to make them competitive with traditional solar technologies. The exploration of new materials, such as non-fullerene acceptors and novel polymer donors, is part of this ongoing effort to enhance performance and reduce costs.

Additionally, our analysis extends the discussion presented by Lizin et al. (Lizin et al., 2013) on the environmental impact of OPVs. While they reported minimal reduction in carbon footprint compared to traditional photovoltaic technologies, our data suggest that newer organic materials could enhance the eco-friendliness of OPVs, aligning with the global push for more sustainable energy solutions. These discrepancies underscore the importance of continued research and development in the field of organic photovoltaics.

Sustainability is another critical factor driving the commercialization of organic solar cells. Their potential for low environmental impact, combined with the ability to be printed on flexible substrates, opens up new applications that were previously unattainable with conventional photovoltaics. From integrating solar cells into building materials to developing portable and wearable solar-powered devices, the possibilities are endless.

The commercial production of organic solar cells has been a reality for over a decade, with various companies pioneering the field and bringing these innovative technologies to market. For instance, as early as 2011, Mitsubishi Chemical launched an organic solar cell model that boasted an impressively high efficiency of 10% (Bian, Zhu, Tang, Tang, & Zhang, 2012). This milestone was akin to breaking the four-minute mile in athletics—a feat that not only showcased the potential of organic photovoltaics but also marked a significant step forward in the quest for renewable energy solutions.

The findings of this study contribute to the existing body of knowledge on organic photovoltaics by highlighting several key advancements and challenges. In comparison to the recent study by Solak & Irmak (Solak & Irmak, 2023), which focused on the efficiency limits of OPVs, our results indicate similar trends in efficiency improvements but also suggest potential breakthroughs in material innovation that could surpass these current limitations.

One of the most successful examples of transitioning from laboratory production to industrial-scale manufacturing of organic solar cells is Heliatek (Germany) (Kaienburg et al., 2023). This company stands out for its innovative approach to organic photovoltaic technology, emphasizing the significance of intellectual property with an extensive portfolio of over 450 patents. These patents cover a range of innovations, from unique absorber molecules to the specialized cell designs crucial for optimizing solar energy conversion.

Heliatek's approach to solar cell manufacturing employs a distinctive thermal vacuum evaporation process in a roll-to-roll method, a technique developed and perfected within their own research and production facilities. This method allows for the creation of ultra-thin, flexible, and lightweight solar films, characteristics that make Heliatek's products highly versatile and environmentally friendly. Such properties enable the integration of solar cells into a variety of applications where traditional photovoltaic technologies might not be suitable due to weight, flexibility, or installation constraints.

Another exemplary case of commercial application in the organic photovoltaic field is the project undertaken by Konarka Technologies Inc (Camaioni et al., 2023). The company made headlines with the largest installation of OPV systems at its headquarters in New Bedford, Massachusetts. Konarka installed OPV panels on seven windows. This initiative marked a significant shift towards adopting building-integrated photovoltaic systems, moving away from traditional practices like post-construction rooftop solar installations.

Konarka's organic photovoltaic panels are notable for their production process, which closely resembles roll-to-roll newspaper printing. This innovative approach results in flexible panels, a stark contrast to the rigid crystalline silicon panels prevalent in the market. The semi-transparent nature of Konarka's OPV panels allows for application directly onto window glass, leveraging commercial buildings' vertical surfaces for solar energy generation – a valuable advantage over conventional silicon-based panels that require significant rooftop space.

A laboratory report attributed to Konarka's panels boasts a conversion efficiency of 8.3%, demonstrating the practical viability and efficiency of OPV technology in commercial settings. Projects like Konarka's installation underscore the growing potential and applicability of organic photovoltaic systems in the renewable energy sector, highlighting the transition towards more integrated, efficient, and flexible solar energy solutions.

As we stand today, the field of organic solar cells (OSCs) has seen a multitude of industrial-scale production examples, underscoring a significant shift from experimental research to tangible, market-ready solutions. This transition has been facilitated by the development and adoption of new application methods, among which inkjet printing has emerged as a standout technique for depositing organic photovoltaic materials.

Inkjet printing, alongside other methods such as slot-die coating and roll-to-roll processing, has revolutionized the manufacturing landscape for OSCs. These techniques share several advantages crucial for the commercial viability of organic solar technology. Firstly, they allow for precise control over the deposition of photovoltaic materials, ensuring uniformity and quality across large areas. This precision is vital for achieving the high efficiency and performance consistency required for commercial applications.

Speed and cost-effectiveness are among the primary benefits of these modern manufacturing techniques. Unlike traditional methods that often involve high temperatures, vacuum environments, and complex procedures, inkjet printing and

similar processes can be performed at room temperature and do not require expensive equipment or extensive energy consumption. This reduction in production costs and complexity makes OSCs more accessible and appealing to a broader market.

Scalability is another critical advantage. The adaptability of these methods to continuous, roll-to-roll manufacturing processes enables the production of large quantities of OSCs, meeting the growing demand for renewable energy solutions. This scalability is essential for driving down costs further and making solar energy a more competitive alternative to fossil fuels.

The development and use of flexible substrates represent another breakthrough in the OSC field. Unlike rigid panels, flexible OSCs can be integrated into a wide range of surfaces and applications, from wearable electronics to building facades. This flexibility opens up new avenues for solar energy harvesting, allowing for the generation of clean power in scenarios previously deemed unsuitable for solar installations.

Flexible substrates also offer significant advantages in terms of installation and transportation. Lightweight and easy to deploy, they reduce the logistical challenges and costs associated with traditional solar panels. Moreover, the aesthetic versatility of flexible OSCs enables them to blend seamlessly into various architectural designs, enhancing their appeal for both commercial and residential applications.

Despite the significant advantages offered by organic solar cells, such as their flexibility, lightweight nature, and potential for low-cost production, they are not without their challenges. Two of the most pressing issues are their relatively short lifespan, typically ranging from 5 to 7 years, and their lower efficiency compared to traditional silicon-based solar cells. These limitations are critical areas of focus for ongoing research and development within the field of organic photovoltaics.

The limited lifespan of OSCs is primarily attributed to the organic materials' susceptibility to degradation when exposed to environmental factors such as oxygen, moisture, and sunlight. This degradation not only diminishes the cell's performance over time but also impacts the long-term reliability and cost-effectiveness of OSC installations. Addressing this challenge requires the development of new materials that are more resistant to environmental stressors, as well as the implementation of advanced encapsulation techniques to protect the cells from external conditions.

Efficiency is another area where OSCs have traditionally lagged behind their silicon counterparts. While significant strides have been made, with record efficiencies now exceeding 17% under laboratory conditions, the average efficiency of OSCs in practical applications remains lower than that of silicon-based cells. Bridging this gap is essential for making OSCs a competitive option in the broader solar market. This will involve not only the discovery of new high-performance organic materials but also the refinement of device architectures and manufacturing processes to maximize the conversion of sunlight into electricity.

The quest to overcome these challenges is driving an intensive research effort focused on both innovating new materials and optimizing existing ones. Scientists are exploring novel organic semiconductors, non-fullerene acceptors, and hybrid materials that combine organic and inorganic components to enhance stability, efficiency, and

spectral absorption. Parallel to material development, advancements in nanostructuring, interface engineering, and scalable printing technologies are being pursued to improve the fabrication quality and performance of OSCs.

Furthermore, interdisciplinary collaboration between chemists, physicists, material scientists, and engineers is crucial for translating these material and technological innovations into practical improvements in OSC performance and durability. By fostering a holistic approach to problem-solving, the field can accelerate the pace of advancement and more effectively address the complex challenges facing organic solar cells.

In summary, while organic solar cells present a promising path toward sustainable and versatile solar energy solutions, significant hurdles related to lifespan and efficiency remain. Overcoming these obstacles requires a concerted effort in material innovation and process optimization, highlighting the importance of continued research and development. With a dedicated focus on enhancing material stability and device performance, the future of organic photovoltaics looks bright, offering the potential for wide-scale deployment in a diverse range of applications.

It's important to note, incidentally, that Ukrainian scientists have also made significant contributions to the development of organic solar cells. The work of scientific groups led by academician A. A. Ishchenko, S. L. Studzinsky, V. G. Syromyatnikov, and A. Yu. Kolendo deserves particular mention in this context. These researchers have significantly advanced the creation of new photoactive layers for organic photovoltaic cells, utilizing carbazole-containing polymers, polymethine dyes, and other materials. Their efforts have facilitated the development of innovative and promising organic solar cells, including transparent models.

The contributions of these Ukrainian research teams extend beyond the national scientific community, offering valuable insights and advancements to the global effort in renewable energy research. By focusing on novel materials that enhance the performance and versatility of organic photovoltaic cells, these scientists are helping to push the boundaries of what's possible in solar energy technology. Their work on carbazole-containing polymers and polymethine dyes, for example, has opened up new avenues for increasing the efficiency and application range of organic solar cells, making significant strides toward the realization of highly efficient and even transparent solar energy solutions.

The progress made by these Ukrainian research groups underscores the importance of international collaboration and knowledge exchange in the field of renewable energy. As we move toward a more sustainable future, the contributions of scientists from around the world, including Ukraine, will continue to play a critical role in developing the technologies needed to harness the power of the sun more effectively. The development of new materials for organic solar cells by Ukrainian scientists represents a valuable piece of the puzzle in our ongoing quest for renewable energy solutions that are both efficient and environmentally friendly.

Conclusions.

The evolution of organic solar cells represents a dynamic and transformative chapter in the quest for sustainable energy solutions. Progressing from early-stage laboratory prototypes to the brink of commercial viability, OSCs embody the collaborative spirit and innovative drive of the global scientific community. This journey, characterized by both challenges and breakthroughs, has propelled OSCs into the spotlight as a promising alternative to traditional solar technologies.

Significant advancements have been achieved in enhancing the efficiency of OSCs, with state-of-the-art developments pushing performance beyond 17%. This milestone not only showcases the potential of organic photovoltaics but also narrows the gap with their inorganic counterparts, underscoring the progress made in harnessing organic materials for energy conversion.

The commercialization phase has introduced scalable and cost-effective manufacturing techniques, such as inkjet printing and roll-to-roll processing. These methods have revolutionized the production of OSCs, offering a path to widespread adoption by enabling large-scale fabrication while maintaining high efficiency and material quality. Moreover, the development of flexible substrates has expanded the application possibilities for OSCs, allowing for their integration into a variety of new and existing surfaces, thereby broadening the scope of solar energy harvesting.

Despite these promising developments, OSCs continue to face challenges that must be addressed to fully realize their potential. The quest for longer lifespan and higher efficiency remains at the forefront of research efforts. Addressing these issues requires a relentless pursuit of new materials and continuous refinement of device architectures. The contributions of scientists worldwide, including innovative approaches to photovoltaic materials and enhancements in spectral sensitivity, highlight the collective endeavor to overcome these obstacles.

In conclusion, the goals outlined at the onset of this research have been comprehensively achieved. The study has documented the historical evolution, current status, and future prospects of organic photovoltaics through a rigorous methodological framework. Our findings reveal that while OPVs hold promising potential for sustainable energy solutions, challenges in efficiency, durability, and cost remain. The technological advancements we have identified indicate a positive trajectory, with significant opportunities for improvement and wider adoption. The methodologies employed enabled a deep dive into both the technological aspects and socio-economic impacts of OPVs, highlighting their role in the transition towards a more sustainable energy landscape. These conclusions underscore the need for ongoing research and targeted policy support to enhance the scalability and integration of OPVs into the global energy market.

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Органічна фотовольтаїка: Подорож у часі, досягнення та майбутні можливості

Анотація. *Це комплексне дослідження присвячене сфері органічної фотовольтаїки, ключової технології зеленої енергії, простежуючи її шлях від ранніх теоретичних концепцій до її поточного статусу перспективного шляху для сталого виробництва енергії. Дослідження прискіпливо вивчає низку етапів розвитку перетворення сонячної енергії в електричну, зосереджуючись на еволюції, технологічному прогресі та внутрішніх проблемах, з якими стикаються органічні сонячні елементи. Заглиблюючись у фундаментальні аспекти органічної фотовольтаїки, у цій статті розглядаються початкові відкриття та подальші вдосконалення в матеріалознавстві, які суттєво вплинули на ефективність і практичність органічних сонячних елементів. Вона містить детальний аналіз різноманітних органічних матеріалів, які використовувалися протягом багатьох років, включаючи малі молекули та полімери, обговорюється їх здатність поглинати світло, властивості транспортування носіїв заряду та інноваційні технології, що лежать в основі архітектури пристроїв органічної фотовольтаїки. Значна частина дослідження присвячена висвітленню унікальних переваг органічної фотоелектричної енергії, таких як їхня легкість, гнучкість і потенціал для недорогого виробництва за допомогою процесів «рулон-на-рулон». Ці переваги поєднуються з поточними обмеженнями технології органічної фотовольтаїки, включаючи порівняно нижчу ефективність і проблеми зі строком експлуатації, щоб представити збалансовану перспективу поточного стану розвитку органічної фотовольтаїки. Крім того, у статті досліджується вплив органічних сонячних елементів на навколишнє середовище, підкреслюється їхня роль у зменшенні викидів вуглецю та залежності від викопного палива. Вона оцінює життєвий цикл органічної фотовольтаїки, від виробництва до утилізації, щоб підкреслити їхній потенціал як екологічної альтернативи традиційним фотоелектричним технологіям. Вирішуючи майбутні перспективи органічної фотовольтаїки, дослідження окреслює поточні зусилля в області інновацій матеріалів, розробки пристроїв і викликів масштабованості. У ньому обговорюється роль міждисциплінарного співробітництва в подоланні технічних перешкод і підвищенні комерційної життєздатності органічних фотовольтаїчних пристроїв. Також досліджується потенціал для інтеграції органічної фотовольтаїки в міський ландшафт, переносні технології та портативні джерела живлення, підкреслюючи різноманітність застосування органічних сонячних елементів для задоволення різноманітних енергетичних потреб сучасного світу. На завершення, ця стаття не лише надає ретельний історичний огляд та аналіз*

поточного стану органічної фотоелектричної енергії, але й прогнозує захоплюючі досягнення на горизонті. Визначаючи критичні фактори успіху органічної фотовольтаїки і пропонуючи стратегічні напрямки для майбутніх досліджень, це дослідження вносить цінний внесок у постійні пошуки рішень для відновлюваних джерел енергії. Воно закликає до збільшення інвестицій і зосередженості на дослідженнях органічної фотоелектричної енергії як ключового гравця в глобальному переході до сталого та енергоефективного майбутнього.

Ключові слова: *відновлювана енергетика; ефективність сонячних батарей; матеріалознавство; сталі технології; перетворення енергії; вплив на навколишнє середовище*

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The epistemological impact of Augustin-Jean Fresnel and his wave theory of light in the 19th century

Abstract. *Skepticism and critical inquiry play crucial roles in the scientific process, acting as safeguards against the "ad verecundiam" fallacy, where claims are accepted solely based on authority endorsement. This study thoroughly investigates Augustin-Jean Fresnel's challenge to Newton's corpuscular theory with his innovative wave theory of light. Supported by precise measurements and the "Fresnel integrals," Fresnel earned the Paris Academy of Sciences Prize in 1819. Despite staunch opposition from corpuscular theory proponents, his theory's validity was confirmed with Poisson's point paradox, where light waves from two sources interfere to create a bright spot in the center of a shadow, providing compelling evidence for the wave nature of light. This successful resolution of the paradox confirmed the validity of Fresnel's wave theory and contributed significantly to the acceptance of wave optics over the corpuscular theory. This conflict transcended a mere clash of explanatory models in the physics of light, prompting reflections on the nature of light, reality, and*

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epistemological issues. Examining how Fresnel overcame challenges offers lessons on constructing scientific knowledge, emphasizing the importance of avoiding theory acceptance based solely on authority and focusing on empirical evidence and theoretical coherence. The case of Fresnel serves as a valuable example for teaching the history of science and understanding complex scientific evolution. Analyzing how Fresnel navigated challenges and opposition provides valuable insights into the development of scientific knowledge, emphasizing the intricate nature of scientific progress characterized by debates and efforts to gain acceptance. This study on Fresnel's groundbreaking wave theory of light not only illuminates the historical clash between competing scientific paradigms but also aims to contribute to modern science by emphasizing the enduring significance of empirical evidence and theoretical coherence in knowledge construction. Through an insightful exploration of Fresnel's triumph over challenges, we anticipate offering valuable insights that resonate with contemporary scientific methodologies, fostering a deeper understanding of the dynamic evolution of scientific thought.

Keywords: *Fresnel; corpuscular theory of light; Prize of the Paris Academy of Sciences; Poisson's point; diffraction*

Introduction.

The first theories to explain the nature of light date back to the 17th century. The initial one was the 'Cartesian Theory' in the 1630s, postulating that light was transmitted instantaneously through the matter of space with infinite speed (Descartes, 1633). This theory was discarded by Roemer in 1676 when he demonstrated that the speed of light was finite by observing Jupiter's moons, particularly Io. Roemer noticed that the eclipses of Io varied as the Earth moved away from or towards Jupiter in its orbit around the Sun. These variations in the eclipse times could be explained only if light has a finite speed, and Earth moves around the Sun (Roemer, 1676). Following this theory, the 'Wave Theory of Huygens' emerged in 1678, asserting that light consisted of waves emitted from a luminous body propagating through the elastic particles of the ether, which were emitters of spherical waves (Huygens, 1678). Subsequently, in 1699, Malebranche postulated that light was transmitted through the contraction and expansion of the particles composing the ether (Silliman, 1967)

In 1687, Newton published the Universal Law of Gravitation in his work titled 'Philosophiæ Naturalis Principia Mathematica,' which gained widespread acceptance in the scientific community of the time for its simplicity and universality. The Universal Law of Gravitation provided an explanation for the attraction between two masses anywhere in the universe. It enabled the precise mathematical prediction and calculation of the behavior of celestial bodies. The triumph of Newton's law of universal gravitation led the scientific community to contemplate the possibility of explaining all natural phenomena, such as electricity, magnetism, and reflection, among others, through the interaction of particles subject to forces of attraction and repulsion.

Seventeen years later, in 1704, Newton published the Corpuscular Theory of Light. According to Newton's corpuscular theory, the interaction between the ether and

light provided a comprehensive explanation for all-optical phenomena, including refraction and reflection. These phenomena arose due to density variations in the ether caused by the presence of material bodies. Additionally, Newton introduced the concept of inflexion, which occurred when the attraction or repulsion of bodies curved light particles. Robert Hooke's work supported this theory by proposing that light behaves similarly to sound waves, bending when encountering obstacles (Hooke, 1665). With the notable acceptance of Newton's Universal Law of Gravitation, the Corpuscular Theory gained wide recognition, especially in countries like Holland and the United Kingdom (Newton, 1833; Newton, 1704; Fitz Gerald, 1889). In contrast, in France, the adoption of Newtonian theory did not occur until 1720 and 1730, following the publication of Voltaire's "Elemens de la Philosophie du Newton" (Pimentel, 2015). Although there were notable detractors, such as Leonhard Euler, who expressed skepticism about the propagation of light without a particle medium (Euler, 1746), the Corpuscular Theory remained the predominant explanation of light behavior for over 100 years. Finally, with the definitive rejection of Cartesian and Wave theories (Cantor, 1983), the Corpuscular Theory became established.

The present article focuses on a comprehensive review of the pioneering work of Augustin-Jean Fresnel in the development of the wave theory of light. The epistemological relevance of his contribution is particularly addressed as he challenges the prevailing corpuscular theory of light proposed by Newton. The main objective of this research is to analyze how Fresnel's innovative work not only revolutionized the understanding of light and optics in his time but also provided fundamental lessons on the construction of scientific knowledge by questioning and overcoming established paradigms.

Research Methods.

Literature Search: A systematic exploration was undertaken on Google Scholar, employing Boolean operators to refine the search query: ("Augustin-Jean Fresnel" OR "Fresnel") AND ("wave theory of light" OR "light theory" OR "optics") AND ("corpuscular theory of light" OR "Newtonian theory of light").

Inclusion and Exclusion Criteria: The search encompassed primary sources, scholarly articles, and historical documents about Augustin-Jean Fresnel's contributions to the wave theory of light and its impact on challenging Newton's corpuscular theory. Non-academic sources, duplicate publications, and studies diverging from the research focus were excluded. Studies in both English and French were included to capture the historical significance of Fresnel's work within the context of French scientific literature.

Quality Assessment: The credibility and reliability of selected sources were rigorously evaluated, considering the reputation of journals, authors, and the coherence of presented arguments. A critical examination of the literature identified gaps, contradictions, and controversies in the historical narrative of Fresnel's contributions to the wave theory of light.

Ethical Considerations: Stringent adherence to copyright laws and meticulous citation practices were employed to ensure ethical handling of the literature, respecting intellectual property rights and acknowledging the origin of all extracted information.

Results and Discussion.

Historical Context in France in the 19th Century.

At the end of the 19th century, France experienced a tumultuous period due to the French Revolution of 1789, a key event that marked the end of the Old Regime. This revolution ushered in a new era that culminated in a coup led by Napoleon Bonaparte in 1799. During this time, France was embroiled in conflicts with several nations, including Austria, Prussia, Russia, Spain, and England. Amidst this constant belligerence, Napoleon recognized the importance of science in current and future conflicts. As part of his ambition to establish a vast empire, he promoted the study of applied science, instituting awards such as the annual prize for the most innovative work in electricity starting in 1802. This connection between Napoleon and science was reflected in the fact that two scientists, Chaptal and Laplace, held the position of Minister of the Interior in France (Lentz, 2013).

In the decades of the 1770s and 1780s, science in France progressed thanks to Lavoisier, who conducted research without government financial support. Subsequently, scientific organizations with government backing emerged, such as the Institute of France, established in 1795, with the participation of notable scientists like Lagrange, Laplace, Berthollet, and Guyton (Crosland, 2002). This institute brought together various French academies, including the Academy of Sciences, focused on physical and mathematical sciences. At the beginning of the 19th century, the Arcueil Society was formed in 1806, a group of French scientists who gathered in Arcueil on Sundays to discuss and analyze publications from the Academy of Sciences. The meetings were often held at the homes of Laplace and Berthollet. Prominent members included Laplace, Berthollet, Malus, Gay-Lussac, Biot, Pyramus de Candolle, Collet-Descotils, Humboldt, Thénard, Arago, Bérard, Chaptal, Dulong, and Poisson. For the most part, they shared the Newtonian view of light, influenced by Laplace and Berthollet. Laplace admired Newton, while Berthollet argued that chemical reactions depended solely on the masses of the reactants, similar to Newtonian mechanics, where the force between two objects depends on their masses (Buchwald, 1989).

Fresnel's Early Investigations.

In this historical context, Augustin Fresnel was born in Broglie, France, in 1788. Fresnel studied at the École Polytechnique and worked as an engineer until 1814 when he lost his job due to Napoleon's return to power. It was at this time that Fresnel began his investigations in the field of optics. Fresnel aimed to demonstrate the wave nature of light, contrary to the prevailing Corpuscular Theory of his time (Cooper, 1970; Boutry, 1948).

In 1815, Fresnel investigated the diffraction of light. The experiments were conducted with sunlight directed through a window into a darkened room, where it was projected onto a white screen. Diffraction was observed by placing a narrow diffractor

(an obstacle or aperture) in front of the screen, causing the sunlight to disperse. These experiments required heliostats to keep the focused sunlight, compensating for the sun's movements (Fresnel, 1866). This allowed for prolonged experiments without constant adjustments. Although heliostats were not common, limiting the research, Fresnel used a powerful lens at the window as an alternative to create a unidirectional beam of light and overcome the lack of heliostats in his diffraction experiments.

The key innovation in Fresnel's measurement method was to add a lens to the conventional screen for observing diffraction patterns (Fig. 1) (Shetty & Bingi, 2020). This improvement offered significant benefits: scientists no longer had to worry about blocking rays with their bodies while measuring diffraction fringes, and they could track these fringes back to their point of origin more easily. With this new technique, Fresnel achieved a precision of 1/40 mm in his measurements, a milestone none of his predecessors had reached. To measure the position of the diffraction fringes, Fresnel improvised in the absence of a micrometer; he used two silk threads knotted at one end (forming a "V") and a piece of cardboard as a slider (Fresnel, 1866).

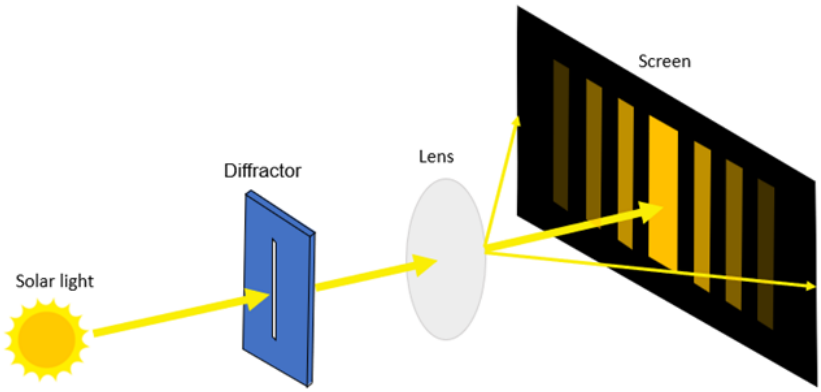

Figure 1. Fresnel Diffraction Experiment. Sunlight passes through the diffractor and creates diffraction patterns captured on a screen after being magnified by a lens. (Own elaboration).

Initially, Fresnel studied diffraction, focusing on the region near the diffractor, where attractive and repulsive forces were stronger. According to Newton's universal law of gravitation, these forces depend on the mass of the involved objects, such as the diffractor and light particles. Examining the diffraction fringes near the diffractor, Fresnel observed that they seemed to emanate directly from the corners of the diffractor, contradicting Newtonian theory. This observation marked his first experimental evidence of the inaccuracy of Newton's theory. As a result, Fresnel decided to investigate this phenomenon under the assumption that the nature of light was wave-like.

Rediscovering Interference.

The results of Fresnel's research on diffraction directed him towards the study of the wave nature of light. His understanding was clarified with the rediscovery of the principle of interference. In discussions with Arago about Young's works, there was no reference to Young's most significant discovery: the interference phenomenon.

Fresnel's lack of prior knowledge about these works led him to dedicate time to an already established phenomenon. Young demonstrated interference through the double-slit experiment detailed in Fig. 2a (Beléndez, 2015; Geesink & Meijer, 2018).

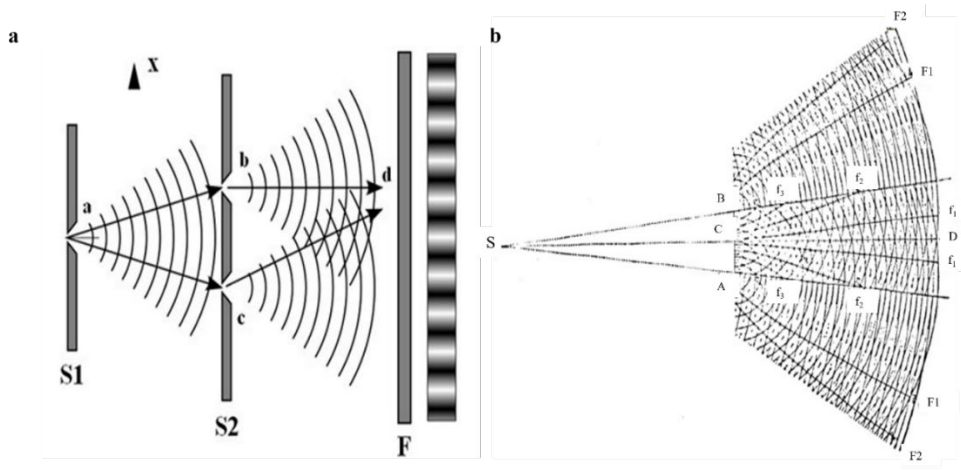

Figure 2. Fresnel Interference Experiments. (a) Fresnel's double-slit interference experiment. The waves from the sources (b) and (c) interfere, resulting in the diffraction pattern on screen F. Adapted from (Geesink & Meijer, 2018).
(b) Interference of waves emitted from the source S as they pass through obstacle AB. S is the light source, A and B are the ends of the diffracting body, C is the midpoint between A and B, and D is the geometric shadow of point C. Circles are drawn from points S, A, and B as centers, continuously increasing the radius by half a wavelength. Modified from (Fresnel, 1866).

By placing a narrow slit in front of a source of sunlight (a), the light beam impinged on an opaque screen with two narrow and closely spaced slits (b and c). The waves passing through these slits, with a wavelength λ and separated by a distance ab, create two new focal points of waves. These waves interact, generating a diffraction pattern on the screen F. Constructive interference produces bright fringes (maxima), while destructive interference creates dark fringes (minima). The intensity of light at a point d on the screen is determined by the difference in the distance traveled by these two waves.

Later, Fresnel further investigated by adding a sheet of black paper to one corner of the diffractor as an obstacle (Fig. 2.a), observing the disappearance of the inner fringes. He concluded that these fringes depended on the intersection of divergent rays from both edges of the diffractor, while the outer fringes seemed to arise from an intersection of direct rays from the light source and the reflection from the edges of the diffractor. These results were not explainable by the principles of corpuscular theory but fit well with wave theory. Fig. 2.b shows a diagram that Fresnel created to explain this experiment, with lines representing the inner fringes (f1, f2, and f3) and the outer fringes (F1 and F2) of destructive interference.

Fresnel validated his theory by comparing experiments and formulas, achieving a maximum error of 7%. A notable consequence was the formation of curved fringes when modifying the distances between the diffractor and the screen, contradicting

corpuscular theory. Despite initial progress, Fresnel still needed to address details, such as the discrepancy between the theoretical and experimental positions of the outer fringes. To tackle this, he proposed that rays from the edge of the diffractor experienced a half-wavelength delay $\left(+\frac{\lambda}{2}\right)$, considering that it did not affect the general validity of the theory.

Fresnel's report presented in October 1815.

Fresnel presented his research in the field of optics on October 15, 1815, before the Academy of Sciences, which included his discoveries on diffraction and the hyperbolic propagation of waves. He apologized for potential writing errors due to the rush to be the first to present his findings. Despite his results, he noted that "Newton's theory was generally accepted" (Fresnel, 1815).

However, Fresnel was unaware of the prior work by the English physicist Thomas Young in 1801, which addressed similarities in the behavior of light and sound (Young, 1802; Robinson, 2023). According to Young, light deviates less than sound when propagating in a straight line, due to the greater elasticity of the ether compared to air. Based on these observations, Young discovered the principle of light interference. According to this principle, the resulting light wave from the interaction of two or more waves is a combination of their effects, known as the principle of wave superposition. These resulting waves have maxima and minima based on the phase difference between the interacting waves (Gbur & Visser, 2022).

The Academy of Sciences commissioned Arago to review the paper presented by Fresnel, and he concluded that it contained "a great number of interesting experiments, some of which have already been conducted by Dr. Thomas Young, treating this phenomenon in a similar manner" (Fresnel, 1866). However, Arago supported the innovative idea of the hyperbolic propagation of diffraction fringes. Arago encouraged Fresnel to continue his work on diffraction to strengthen his theory.

In 1816, Fresnel learned that Young was investigating diffraction. Following Arago's suggestion, he decided to refocus on the topic, drafting a new paper published in Annales de chimie, excluding what had already been published by Young. Upon reading it, Young informed Fresnel that he had already disclosed those findings. Although Fresnel initially claimed priority, he later acknowledged Young's precedence. Fresnel wrote to Young expressing his joy in supporting the latter's theory. Thus, Young gained recognition after a decade of being ignored, and Fresnel secured independent confirmation of his work.

Double Mirror Experiment.

Fresnel sought to demonstrate interference with his experiments, but Newtonian theory followers could still attribute the results to attraction and repulsion caused by the edges of the diffractor. To refute this argument, he conducted the double mirror experiment, eliminating the diffractor. He placed two mirrors forming an angle slightly less than 180 degrees and a light source at point S in front of them, isolated by a plate. The rays reflected by the mirrors and reaching the screen could be considered as originating from the virtual sources S1 and S2. In conducting the experiment, Fresnel

observed bright fringes on the screen, a result of interference between the rays reflected by both mirrors. Using the analogy between the width of the diffractor and the distance between the virtual sources S1 and S2, he calculated the path difference and estimated the values for the fringe positions with previously obtained formulas (Fig 3.a). The results demonstrated that the theoretical values matched the experimental ones, ruling out the explanation of inflection as the cause of the fringes (Rossi, 1978).

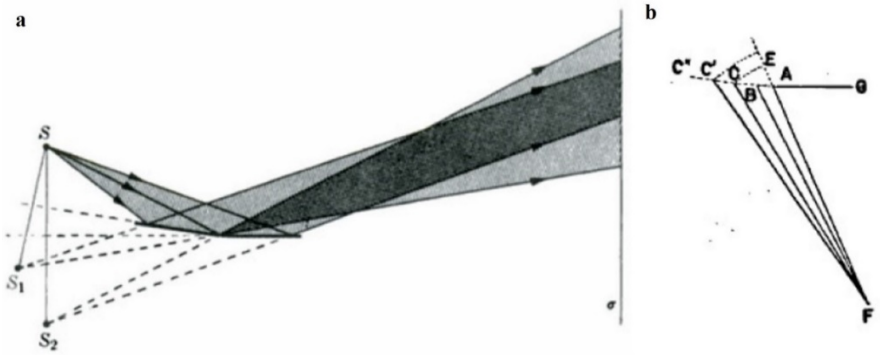

Figure 3. Fresnel's Double Mirror and Effective Rays Experiment. (a) Double mirror experiment. Rays originate from the light source S and reflect off both mirrors, reaching the screen σ. S1 and S2 are the virtual sources of the reflected rays. Taken from (Rossi, 1978). (b) Diffraction analysis at point F (within the geometric shadow), with A as the edge of the diffractor AG. To trace different points (B, C, C', and C''), representing each point of emission of a secondary wave, multiples of λ/2 are added to the distance AF (EF = CF = AF + EA). Taken from (Fresnel, 1866).

With the Double Mirror Experiment, Fresnel departed from his original idea that the center of inflected light was at the edges of the diffractor. Instead, he proposed that the inflected rays could originate at a certain distance from the diffractor, thus solving the problem of fringe inversion by introducing additional differences in the path length between interfering rays on the screen. Fresnel argued that when spherical waves (primary waves) intercepted light, new spherical waves (secondary waves) were generated at each point of interception. These secondary waves, when interfering, were only perceptible in directions where they mutually reinforced, providing a robust explanation based on the wave paradigm, albeit requiring complex mathematics.

Effective Rays Experiment.

In the summer of 1816, Fresnel began developing the mathematical framework to formalize his theory, exploring the concept of "effective rays." Fresnel analyzed diffraction at point F, where secondary waves arrive at different phases after interacting with the obstacle AG, which intercepts the wavefront of the primary wave (AC´´). From point F and taking a radius equal to AF plus half the wavelength (λ/2), he described the arc EC, which intersects the wavefront at C. Rays CF and AF differ by λ/2, and C'F is equal to CF plus λ/2: $\left(C'F = CF + \frac{\lambda}{2}\right)$. The secondary waves from CC' destructively interfere with those from AC due to a path difference of λ/2. Except for AC, secondary waves from other arcs will mutually destroy each other. Thus,

considering half of arc BC as an effective contribution, where B is the midpoint of AC, the "effective ray" BF covers λ/4 more than the edge ray A (Fig. 3.b). Although the hypothesis of "effective rays" mitigated the discrepancy between theory and experimental observation, it lacked mathematical precision by simplifying the influence of all rays to those in arc AB. Aware of this limitation, Fresnel requested the Academy of Sciences to frame his results within a more comprehensive theory that was under development.

Paris Academy of Sciences Award in 1819.

Fresnel's submission to the Paris Academy of Sciences summarized his research over the past three years. It began with a general overview of diffraction phenomena and their contradiction with the theory of inflection, then introducing the principle of interference as the most natural explanation. The second section presented his new theory with relevant mathematical considerations and addressed the problem of interference, determining the intensity of light at convergence points of multiple waves. He then focused on the concept of "effective rays," combining the interference principle with Huygens' concept of elementary waves. He innovated by using λ/4 phase-shifted waves to generalize intensity across the entire wavefront, grouping contributions into two large sets through Fresnel integrals. He solved these integrals through series of partial integrals and documented the results in his submission. Subsequently, he concentrated on comparing theoretical and experimental values of first-order maxima and minima for various configurations of obstacles and rectangular geometry openings. Fresnel compiled 125 experimental measurements, showing a discrepancy of 5/100 mm in one measurement, 3/100 mm in three measurements, 2/100 mm in six measurements, and 1/100 mm or less in the remaining 115 measurements, forming the basis of the submission for the 1819 award.

In 1817, the commission formed by Laplace, Biot, Berthollet, and Charles of the Academy of Sciences selected the topic for the upcoming Physics prize. On February 10, 1817, Biot proposed diffraction as the prize topic. The commission members were announced on July 27, 1818: Laplace, Biot, Poisson, Arago, and Gay-Lussac. The first three believed in corpuscular theory, causing apprehension in Fresnel about an unfriendly reception. Arago, on the other hand, supported Fresnel's wave theory, and Gay-Lussac, with no interest in optics, was expected to maintain an impartial stance. Candidates remained anonymous through an epigram. After the submissions, they had the freedom to persuade the jury about the merit of their research. Fresnel seized the opportunity to persuade the three members of the jury who supported corpuscular theory. In the meetings, the outcomes were varied: Laplace showed no interest, while Biot and Poisson were willing to discuss optical phenomena as they had some doubts about corpuscular theory (Silliman, 1967).

In the initial verdict of the Academy of Sciences jury, two submissions were considered as potential winners. The first lacked the necessary precision and did not satisfactorily analyze optical phenomena when light passed through obstacles or openings, also appearing to be unaware of the works of Young and Fresnel. As for the second submission, Fresnel's under the epigram "*Natura simplex et fecunda,"* it was

more precise and provided a more detailed explanation of some luminous phenomena, although it was noted to have conceptual errors due to its non-corpuscular approach.

During the review of the submission, Poisson suggested that Fresnel's experiments could be applied to additional situations, such as the case of a circular obstacle. Poisson proposed that, according to Fresnel's theory, directing light towards an opaque circular obstacle should result in the observation of a bright point in the center of the screen, known as Poisson's Spot. Fresnel faced the challenge of demonstrating the existence of such a point to win the prize. In the preliminary report of the jury, the value of Fresnel's submission was recognized due to the extensive series of calculations and experiments performed. The commissioners pointed out Poisson's inference about the Poisson's Spot. The decision on the prize was postponed until Poisson could perform the theoretical calculations and Arago could experimentally verify them. After Poisson completed the calculations, Arago demonstrated the existence of the spot. With this demonstration, any opposition from the jury to Fresnel's theory lacked a basis. The final report of the commission, without explicitly mentioning the word "wave," emphasized the accuracy of Fresnel's results and acknowledged the utility of Fresnel integrals for diffraction, although it omitted their foundation in the wave theory of light.

On March 15, 1819, Arago read the final resolution and awarded the prize to Fresnel, whose submission was highlighted as the best. Augustin Fresnel was honored with the 1819 Academy of Sciences prize, marking a milestone in modern physics by surpassing Newton's corpuscular theory. Despite the recognition, Fresnel faced indifference from his colleagues, such as Laplace, Biot, and Poisson, who resisted accepting his theory. Over the following decades, new generations of physicists, including Airy, Ampère, and Cauchy, gradually embraced Fresnel's wave theory, solidifying it in the 1830s through mathematical advances. Despite the lasting impact of his theory, Fresnel did not live to witness its widespread acceptance.

Conclusions.

Fresnel's work marked a paradigm shift in the understanding of light, as the acceptance of his wave theory over the corpuscular theory had a significant impact on optics and laid the groundwork for the subsequent development of the electromagnetic theory of light. The contemporary relevance of Fresnel's wave theory is undeniable, playing a fundamental role in fields such as quantum optics and the theory of electromagnetic waves. Analyzing how Fresnel overcame challenges and resistance in his time provides valuable insights into the construction of scientific knowledge, highlighting the complexity of scientific evolution through debates and struggles for acceptance.

The case of Fresnel illustrates the importance of avoiding the "*ad verecundiam*" fallacy (appealing to authority, Newton in that era) in the historical context of resistance to the wave theory, offering valuable lessons for critical thinking today. It also emphasizes the importance of factors such as empirical evidence, theoretical coherence, and the ability to explain observable phenomena in shaping scientific

theories. Furthermore, it underscores the interaction between theory and experimentation in scientific progress.

Studying how Fresnel developed his theory and overcame obstacles provides an enriching example for teaching the history of science, inspiring students to understand the complex and often nonlinear dynamics of scientific evolution.

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Conflict of interest.
The authors declare no conflict of interest.

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Епістемологічний вплив Огюстена-Жана Френеля та його теорії хвиль світла в XIX столітті

Анотація. *Скептицизм та критичне дослідження відіграють важливу роль у науковому процесі, діючи як засоби захисту від логічної помилки, коли твердження приймаються виключно на підставі авторитетного підтвердження. Це дослідження ретельно вивчає виклик Огюстена-Жана Френеля корпускулярній теорії Ньютона за допомогою його інноваційної теорії хвиль світла. Підтриманий точними вимірюваннями та "інтегралами Френеля", Френель отримав Премію Паризької академії наук в 1819 році. Незважаючи на тверду опозицію прихильників корпускулярної теорії, валідність його теорії була підтверджена парадоксом точки Пуассона, де світлові хвилі з двох джерел взаємодіють, щоб створити яскраву точку в центрі тіні, надаючи переконливі докази про хвильову природу світла. Це успішне рішення парадоксу підтвердило валідність хвильової теорії Френеля та внесло значний вклад у прийняття хвильової оптики над корпускулярною теорією. Цей конфлікт перейшов далеко за межі простого зіткнення пояснювальних моделей в фізиці світла, спонукаючи до рефлексій над природою світла, реальністю та епістемологічними питаннями. Дослідження того, як Френель подолав виклики, пропонує уроки з конструювання наукових знань, акцентуючи важливість уникання прийняття теорії лише на підставі авторитету та акцентуючи на емпіричних даних та теоретичній узгодженості. Справа Френеля слугує цінним прикладом для викладання історії науки та розуміння складного наукового розвитку. Аналіз того, як Френель долав виклики та опозицію, надає цінні інсайти в розвиток наукових знань, акцентуючи складну природу наукового прогресу, що характеризується дискусіями та зусиллями отримати прийняття. Це дослідження про проривну хвильову теорію світла Френеля не лише проливає світло на історичний конфлікт між конкуруючими науковими парадигмами, але також має на меті сприяти сучасній науці, акцентуючи вічне значення емпіричних доказів та теоретичної узгодженості у конструкції знань. Шляхом проникливого дослідження перемог Френеля над викликами, ми очікуємо надати цінні інсайти, які резонують з сучасними науковими методологіями, сприяючи глибшому розумінню динамічного розвитку наукової думки.*

Ключові слова: *Френель; корпускулярна теорія світла; Премія Паризької академії наук; точка Пуассона; дифракція*

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National, cultural, educational and scientific activities of Ukrainian student societies in Eastern Galicia (from the late nineteenth century to 1939) through the prism of cooperation with Metropolitan A. Sheptytskyi

Abstract. *In the latter half of the 19th century, students of Eastern Galicia, who were destined to become scientists, engineers and cultural figures, had joined together in societies to advocate for their right to receive education in their native language. Additionally, they endeavored to advance the concept of developing a distinct «national science». The aim of the study is to analyze a new stage of nationally oriented, cultural, educational and scientific activities of Ukrainian student societies in Eastern Galicia from the late 19th century to 1939 which began due to active cooperation with Metropolitan A. Sheptytskyi. The author has used chronological, historical-comparative, retrospective, and interdisciplinary methods, including the structural method, to analyze historical evidence. The specificity of functioning of Ukrainian student societies in difficult and unfavorable conditions has investigated and has proved that the dominant direction of their activity was consolidation of society and realization of national and cultural aspirations of the Ukrainian people, catalyzing processes in the educational and scientific sphere through active interaction with A. Sheptytskyi. In the time period covered by this study, students collaborated with parties of various persuasions, took part in the fighting of the First World War and fought for the establishment of the Ukrainian University as a center of higher education and a Ukrainian scientific school. In the absence of opportunities and their own scientific institutions, student societies carried out their applied, fundamental, search and methodological research during participation in summer schools, applying their results in the publication of student periodicals, speeches at student congresses and studios, which were mostly organized and supported by intellectuals, including A. Sheptytskyi. To achieve this goal, Ukrainian student societies used a range of methods, from writing research papers and proclamations to boycotts. And the vision of the idea of state-building united Ukrainian students with well-known public and spiritual figures, scholars and artists of Eastern Galicia.*

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Keywords: *Eastern Galicia; Ukrainian student society; «Akademichna hromada»; scientific and educational events; Ukrainian University; intelligentsia; A. Sheptytskyi*

Introduction.

Students were one of the most active parts of Ukrainian society in the latter half of the 19th and early 20th centuries. In Eastern Galicia, students were organizers and participants in the national cultural movement, collaborating with Ukrainian intellectuals and clergy. Students' ideas of their basic educational needs, first attempts at scientific research, analytical discourses, most of which became the basis for national concepts of Ukrainian political movements and parties, could been found in the speeches of students or in their periodicals. Ukrainian student societies contributed to the formation of the mentality of a national intellectual state by participating in all spheres of life in Eastern Galicia, justifying non-violent methods of state-building, and helping to form the foundations of national Ukrainian culture, education, and science.

The Ukrainian intelligentsia of Eastern Galicia was not numerous and acted mainly in the context of the ethnographic and cultural stages of the national revival. Students at that time were characterized by a craving for radicalism and actively entered the ranks of the fighters for the national idea and sometimes led the national and cultural movement. The student societies of Eastern Galicia in their pursuit of national, cultural, educational and scientific activities received support from the most prominent figure of the Ukrainian Greek Catholic Church (UGCC), a representative of the House of Lords of the Austrian Parliament and a member of the Galician Seimas Metropolitan A. Sheptytskyi.

Among the Ukrainian researchers this issue was analyzed in general by such scientists as V. Lenyk in his work «Ukrainian Organized Youth (Youth Organizations from the beginning to 1914)» (Lenyk, 1994) and I. Andrukhiv in his study «Ukrainian Youth Societies of Galicia 1861–1939» (Andrukhiv, 1995). Generalized information about the emergence and characteristic activities of Ukrainian student societies in Eastern Galicia from the time of their inception to the beginning of World War II is contained in these works. A complex vision of the role of student organizations in the national, political, and cultural life of Western Ukraine was also presented by R. Kovaliuk in his monograph «Ukrainian Student Movement in Western Ukraine in the 19th – 20th centuries» (Kovaliuk, 2001).

B. Savchuk carried out a thematic study of Ukrainian students in his work «The student movement in Western Ukraine in the 1920s and 30s: a chronicle of organizational and ideological formation» (Savchuk, 1999). Researcher Yu. Shumskyi covered the ideological directions of the student movement in Western Ukraine in his work «Western Ukrainian Student movement of national democratic orientation in the early 20s of the 20th century» (Shumskyi, 2003). T. Plazova's article «Socio-political activity of youth associations in 1894–1939 in Western Ukraine» requires special attention in the study of the formation and socio-political activities of societies (Plazova, 2011) and S. Tserkovnyk's «The development of student societies in Eastern Galicia from the second half of the XIX century to the first half of the XX century in the

historical and legal context» (Tserkovnyk, 2023). An aspect of the activity of cultural and educational societies such as «The Society of Supporters of Ukrainian Literature, Science, and Crafts» is analyzed in B. Yanyshyn's work «Organization and activity of the Ukrainian literature, science and crafts society in Lviv» (Yanyshyn, 2018).

The article by V. Vyzdryk's «On the formation of the Ukrainian Secret University in Lviv» raises the issue of the struggle for the formation of its own scientific center, including among Ukrainian students (Vyzdryk, 2009) as well as in V. Melnyk and V. Kachmar's work «Contribution of T. Shevchenko Scientific Society to the founding of Ukrainian University in Lviv (the end of the 19th century – Mid-1920s)» (Melnyk & Kachmar, 2023). The interaction of students with local authorities to establish the Ukrainian University was studied by N. Mysak in the article «Ukrainian student societies in Eastern Galicia in the late 19th century: on the issue of interaction with provincial authorities» (Mysak, 2012).

Special attention is paid to the works that show the relations between Ukrainian student societies of Eastern Galicia and A. Sheptytskyi. For example, O. Kekosh focuses on the educational activities of the head of the UGCC and his support of Ukrainian students in his work «Educational projects of Metropolitan A. Sheptytskyi and the education of youth» (Kekosh, 2014). O. Tychovska and V. Basarab in their article «Educational Initiatives of Metropolitan Andrey Sheptytskyi as a crucial prerequisite for the Ukrainian State creation (based on Pastoral messages)» conducted a scientific analysis of the national and educational activities of Metropolitan A. Sheptytskyi through the study of materials from his speeches, letters, and spiritual messages (Tykhovska & Basarab, 2023).

Modern research on the topic of the article is represented by the scientific work of M. Rohde «Ukrainian popular science in Habsburg Galicia 1900–1914» (Rohde, 2020) and the work of L. Korzh-Usenko, O. Sydorenko, H. Dovgopolova «Development of the Ukrainian Free University: national identity and dialogue of cultures» (Korzh-Usenko, Sydorenko, & Dovhopolova, 2021). The above article makes it possible to compare the peculiarities of student education in Eastern Galicia and in Munich where the Ukrainian Free University operated and around which representatives of the Ukrainian emigration gathered. Student societies were also supported by representatives of the Galician intelligentsia, for example, a public figure, professor at Lviv University S. Dnistryanskyi, whose contribution to the scientific life of Eastern Galicia was analyzed by W. Macierzyński, Yu. Glado i L. Tarasenko in their article «Stanislav Dnistryanskyi and Lviv University: the prosopographic research» (Macierzyński, Glado, & Tarasenko, 2020). The cooperation of students with such a representative of the Ukrainian intelligentsia as M. Hrushevskyi is shown in the study by V. Telvak «M. Hrushevskyi's student audience at Lviv University: quantitative dynamics, ethnic composition, didactic preferences» (Telvak, 2023).

Information on the declared research topic can be obtained not only from historiographical developments but also through the analysis of archival sources. Certain issues of the student movement and the role of members of student societies are covered in the collection of the Central State Historical Archives of Ukraine in Lviv: f. 146 «Galician Governorate in Lviv», f. 201 «Greek Catholic metropolitan consistory, Lviv»,

f. 309 «Taras Shevchenko Scientific Society in Lviv», f. 358 «Andrey Sheptytskyi (1865–1944) count, Metropolitan of Halych of the Greek Catholic Church, Archbishop of Lviv, Bishop of Kamianets-Podilskyi, cultural and church figure, philanthropist, full member of the Scientific Society», f. 399 «Regional council of Ukrainian students in Western Ukraine», f. 400 «Ukrainian Student union», f. 408 «Greek Catholic Metropolitan Ordinaries, Lviv», f. 750 «Ukrainian National museum, Lviv».

This study covers and systematizes information about the national, cultural, educational and scientific activities of Ukrainian student societies in Eastern Galicia from the late 19th century to 1939 and their cooperation with the Metropolitan of the UGCC A. Sheptytskyi on the basis of analyzed historiographical and archival sources.

The opportunity to evaluate the peculiarities of the formation and activity of Ukrainian student societies in Eastern Galicia in the context of the youth movement in Western Ukraine comes after the study of a broad historiographical and source base. However, the educational, scientific and cultural activities of student societies were not analyzed sufficiently convincingly certifying the relevance of the problem and requires further scientific study.

The aim of the study has analyzed the national, cultural, educational, and scientific activities of Ukrainian student societies in Eastern Galicia from the late 19th century to 1939 through the prism of interaction with the Metropolitan of the UGCC and a member of the Galician Sejm and the Austrian Parliament in Vienna A. Sheptytskyi.

The author has considered the main features of the activity of Ukrainian student organizations in Eastern Galicia from the end of the 19th century to 1939 in this study. It also researcher has analyzed the peculiarities of the cooperation of Ukrainian student societies of Eastern Galicia during this period with Metropolitan A. Sheptytskyi. Furthermore, author has highlighted the role of Ukrainian student societies in the national, cultural, educational, and scientific life of Eastern Galicia from the late 19th century to 1939.

Research Methods.

This research is based on the complex use of scientific methods, especially historical and logical. Using the historical method, in particular, the historical-comparative, historical-typological, historical-system allowed us to show the genesis of national-cultural, educational and scientific activities of Ukrainian student societies of Eastern Galicia on the basis of the facts obtained from the work with the primary sources. Chronological, retrospective and interdisciplinary structural methods have been used to analyze historical facts.

Justification of the research time frame which covers the period from the late 19th century to 1939 was possible using the chronological method. The lower boundary is the period of high activity of Ukrainian student societies in Eastern Galicia. The upper boundary is the beginning of World War II which led to the decline of the societies and their transformation into other organizations and movements. The cooperation of Ukrainian student societies with Metropolitan A. Sheptytskyi is correlated within the period 1900–1939, that is, from the time of his election as metropolitan to the decline of Ukrainian student societies.

The complex of general scientific methods, in particular, analysis and synthesis, description of event character and explanation has applied in the implementation of this study. The historical and genetic method is also has used in the study which makes it possible to analyze the causal regularities of the historical process and to distinguish significant factors of influence on the typical behavior of participants of Ukrainian student societies and their requirements.

Results and Discussion.

The national and cultural activities of Ukrainian student societies in Eastern Galicia from the late 19th century to 1939 and their interaction with A. Sheptytskyi.

The Ukrainian student society's national-oriented activities were driven by a desire to play a significant role in the life of Eastern Galicia, to develop its higher education and science and to help restore their own state.

In the second half of the 19th century Ukrainian students began active social and political activities and united in social, educational, scientific, and loan societies, such as «Osnova», «Akademichne tovarystvo» («Academic Society»), «Pravovyi kruzhok» («Legal Group»), «Druzhnii lykhvar» («Friendly Loan») and others in Lviv, Chernivtsi, Stanislaviv, the University of Vienna and Lviv Polytechnic. Some societies were formed by students who found themselves in emigration. According to V. Kondratiuk's statistics presented in the work «Galician youth and student movement for the development of national education» about 70% of Ukrainian students who studied at the universities of the Austro-Hungarian Empire and later in higher education institutions of the Second Polish Republic were covered by societies (Kondratiuk, 2007, p. 2).

It is important to note that students were often unified in thematic-oriented organizations, such as medical societies, philological, legal, philosophical, and society-loan sharks. However, they were engaged in the national and cultural life of Eastern Galicia, regardless of the practical orientation of the group or society. For example, members of the «Akademichna hromada» («Academic Community») society were actively involved in educational activities and contributed to the protection of university students and were involved in the political life of Eastern Galicia giving speeches and cooperating with Ukrainian parties. Reports by members of the «Akademichna hromada» («Academic Community») and other student societies that centered on political issues were mostly announced at regular meetings of the societies, starting in the fall of 1904 as evidenced by historical sources.

Thus, on November 26, 1904, the «Hurtok suspilnykh nauk» («Circle of Social Sciences») which conducted in-depth studies of the history of the Ukrainian people in the context of world history organized a discussion on «Ukrainian-Polish relations» (chaired by M. Lozynskyi). On February 1, 1905, the society joined the organization of a rally of Ukrainian students in response to the revolutionary events in the Naddnipranshchyna (Kovaliuk, 2001, p. 136).

Despite the swift response of students to foreign policy developments, those belonging to student societies in Eastern Galicia increasingly focused their attention on

domestic policy issues. The decision to implement electoral reform, which was substantiated not only by law students but also by Galician intelligentsia was one of the top priorities. The struggle for universal, equal, direct and secret suffrage, especially through labour and peasant movements, became significant. Therefore, students could not remain indifferent to the solution of this issue (Kovaliuk, 2001, p. 136). Thanks to the election law, it would be possible to realize one's desire to solve certain Ukrainian questions, in particular, the issues of education and science.

In work the «Essays on the History of Ukraine: the formation of the modern Ukrainian nation in the 19th and 20th centuries» Ya. Hrytsak confirms that universities in the Ukrainian territories were the driving force for the formation of revolutionary cadres. The Ukrainophile, cultural, and academic phase of the national revival radicalized in the late 19th century and was represented mainly by university youth. The first student nationalist organizations originate from the 1920s from a scientist's point of view (Hrytsak, 2000, p. 198). The organizations were established mainly in Lviv, Prague, Podebrady, Stanislav and other cities where Ukrainian youth studied. However, they often expanded to include areas where their participants were born. The nationalist movement of the early 1930s also consisted largely of students. One of the largest Ukrainian student centers was located in Lviv in a hostel known as the «Akademichnyi dim» («Academic House»). This facility was funded by various Ukrainian organizations and aid funds as well as by student contributions.

Student associations cooperated with political parties, but their statutes often emphasized non-partisan and purely cultural activities (Request from the founders, 1870–1891, p. 3). For example, the «Akademichna hromada» («Academic Community») cooperated with the Russian-Ukrainian Radical Party (RURP) which was founded by I. Franko and M. Pavlyk in 1890. By the decision of the Council, on December 3–4, 1905 in the house where the students of the «Akademichna hromada» («Academic Community») gathered the members of the party and the party meetings were held on December 22–26, 1906 (Kovaliuk, 2001, p. 136). The society supported the actions of the Russian-Ukrainian Radical Party (RURP) in Eastern Galicia as the party supported the struggle for the rights of workers and peasants and expressed clear nationally oriented positions.

It is important to note that student organizations, in their activities, did not always comply with the law and often did not inform the police about meetings or peaceful protests held outside the university. This caused discontent among Polish pro-government circles (Mytsyk, 2012, p. 42). The active political speeches, meetings, conferences, and congresses of Ukrainian student societies were perceived negatively by Polish local authorities, who repeatedly appealed to Vienna for permission to carry out preventive measures to separate the student movement from politically actions.

In response to the Polish policy of electoral fraud, Ukrainian students employed radical tactics. For example, on April 12, 1908, Ukrainian student Myroslav Sichynskyi intentionally killed Governor A. Potockiy (Lenyk, 1994, p. 87). Prior to this event, the University of Lviv experienced frequent aggravation between Ukrainian and Polish students, but the use of extreme radical methods intensified them again. The conflicts were characterized by disputes over the language of instruction, access to educational

facilities, the ability to conduct academic and research activities, and the possibility of national self-determination. In 1910, Ukrainian student Adam Kotsko was killed in one of the clashes between Ukrainian and Polish students.

Researcher L. Krupa (Krupa, 2006, p. 162) asserts that Metropolitan of the UGCC A. Sheptytskyi explicitly expressed his intention to establish a Ukrainian state and provided support to Ukrainian student societies in this endeavor. However, as a spiritual leader, he did not endorse the use of violence or other methods that would result in the harm of others. Instead, he espoused the view that the establishment of a state should be based on Christian principles, which would be founded upon legality and patience. A. Sheptytskyi was also aware that the causes of student radicalization were limited access to education, the socioeconomic situation of Ukrainians and condemned the containment processes directed against Ukrainian student societies through the «pacification» campaign and forced Catholicism.

Such societies as the «Ukrainska akademichna pomich» («Ukrainian academic assistant») or the «Druzhnii lykhvar» («Friendly Loan») along with political actions did not leave work in the social and economic spheres. In particular, they made numerous appeals to the people of Eastern Galicia, requesting the collection of funds for the Ukrainian Students' Fund (Letters from students, 1899, p. 1). Ukrainian student societies which study economic theories and market characteristics often collaborated with cooperatives or their participants, created credit cashiers and auditing commissions. The students collected scrap metal, organized fairs, theater evenings, lectures, and used all available legal means of fundraising to generate more money.

Preparation for the First World War did not pass Ukrainian student societies and militaristic processes caused quarrels in the student camp. There were sports societies that contributed to the physical and military training of students, for example, «Sokil» («Falcon»), «Sich», «Plast».

There was considerable debate among the parties involved as to which side they should align themselves with or pursue an independent course of action. On December 7, 1912, a meeting of representatives of all Ukrainian political parties and organizations was convened in Lviv to address the issue of the position of Ukrainian students during the war. At the meeting, a unanimous decision was reached that «in the event of a war between Austria and Russia, Ukrainian citizens should unanimously and strongly support Austria …» (Andrukhiv, 1995, p. 47). At the meeting, it was determined that given the prevailing military atmosphere in the world, it was extremely important to organize military units in the youth societies «Sokil» («Falcon») and «Sich». This would allow the Ukrainian youth to gain a fundamental understanding of military affairs, search operations, and tactical medical care. In addition to the youth societies «Sokil» («Falcon») and «Sich» in early 1913, such work began in student societies «Akademichna hromada» («Academic Society») and «Osnova». The organizing committee of these societies was headed by one of the leaders of «Plast» I. Chmola.

During the First World War, Metropolitan Andrey continued to believe in the creation of a Ukrainian state in the future, as well as Ukrainian students, and even developed a detailed plan for its development. In 1914, the Metropolitan substantiated

his thoughts about the future state in the «Memorandum to the Austrian Government on the future system of the Ukrainian State».

Ukrainian student societies continued to engage in political activities following the conclusion of the First World War. They began to study the peculiarities of negotiation and the processes inherent in world politics. For example, the Ukrainian student movement's members frequently participated in international political events, including the International Congress in Prague (March 22 – April 4, 1921) which brought together students from 13 countries. Ukrainian students were represented by a delegation from the «Akademichnoi hromady» («Academic community») which included I. Fedova, S. Lopatynskyi, S. Slabchenko. The congress accepted the Ukrainian Student Union to the International Student Organization (Shumskyi, 2003, p. 109).

In the fall of 1918, it became apparent that the Austro-Hungarian Empire had been defeated and Eastern Galicia could become part of another state. In response to the unfolding political situation, intellectuals, student societies and other interested parties initiated the process of formation of their own state and joined the establishment of the West Ukrainian People's Republic (Western Ukrainian National Republic or ZUNR). A. Sheptytskyi also joined this process. As a member of the Austrian Parliament in Vienna, he represented the interests of Ukrainians including students and participated in negotiations regarding the future of the Ukrainian people following the war. He also joined the Ukrainian National Council (Hladka, 2018, pp. 252–254) which in November 1918 proclaimed ZUNR. For a period of one month, the Metropolitan engaged in correspondence with the representatives of the Entente countries, advocating for the preservation of Ukrainian statehood and the right of the Ukrainian people to self-determination.

In July 1921, Ukrainian student societies participated in the National Student Congress in Lviv where the decision was proclaimed to revive the Ukrainian Independent State by uniting all ethnic Ukrainian territories. The period of active cooperation with Ukrainian students from Naddnipryanshchyna has commenced.

In addition to political affairs, students continued to create the Ukrainian University. After the unsuccessful secession, a secret «Committee of Ukrainian Youth» (Committee of Ukrainian Youth or KUM) was created to protect the university. It was decided to reduce the exit for studying at German or Czech universities to those students who could get an education at the Ukrainian University to preserve the future Ukrainian intelligentsia and skilled workers.

The Ukrainian Student Congress and the General Congress of Ukrainian Students were held in Lviv between 1909 and 1913. During this period, the «Ukrayinskiy Studentskyi Sojuz» (Ukrainian Student Union) was established. It's task was to unite student organizations in all the territories where Ukrainians lived (Plazova, 2011, p. 45).

About 600 Ukrainian students arrived west of the Bug River at the beginning of the Second World War. These territories became part of the German Governor-General's provinces. As for the above-mentioned students, they were Ukrainians who studied at the universities of Germany, as well as refugees from the territories seized

by the Soviet troops. There were few young people who could continue studying at German universities because of financial difficulties. It is important to note that the «Natsionalnyi Soiuz Ukrainskykh Studentskykh Orhanizatsii u Nimechchyni» (National Union of Ukrainian Student Organizations in Germany or NaSUSON) and Ukrainian student societies in exile played a pivotal role in assisting Ukrainian students who wished to pursue their studies abroad.

World War II initiated a new phase of organized student life and most of the societies were eliminated by the Soviet authorities. Most of the students of Eastern Galicia found war in prisons, in particular in the Bereza Kartuzka, since in March 1939 they were arrested during the 7th Regional Conference of the Union of Ukrainian Student Organizations.

The onset of persecution and repression in September 1939, following the capture of Eastern Galicia, compelled Ukrainian student societies to either go underground or emigrate. At this juncture, A. Sheptytskyi provided support to the participants of Ukrainian student societies and denounced the actions of the totalitarian regime. In his letter to Cardinal Tisseran, A. Sheptytskyi gives a detailed account of the events of this period: «Having come to «liberate and save Ukrainians» which in their terminology means to conquer and destroy [...]. In Lviv, having confiscated the premises of the Great and Small Seminaries, the authorities organized a Ukrainian university, promising 35 departments for the philosophical academy alone, and closing the theological faculty [...]. Institutions that were created and supported by people's donations (cooperatives, «Prosvita», etc.) were either liquidated or declared state-owned by the authorities one by one» (Kravchuk, 1999, pp. 893–894).

In conclusion, it is important to note that the student movement in Eastern Galicia was characterized by a high degree of diversity in its organizational structure. The existence of local academic and professional societies in Eastern Galicia testify to this diversity. A number of student organizations have been structured in such a way that it reflected the influence of political parties and their own statehood ideas. B. Savchuk argued that the above-mentioned characteristics of student societies contributed to the transformation of students into the driving force of nationalist Ukrainian formations (Savchuk, 1999, p. 54).

In summary, I have to note that Ukrainian student societies participated in state-building activities and sought to gain an opportunity to study in their own higher educational institutions and to join the creation of the scientific base of their state. Members of Ukrainian student societies in Eastern Galicia demonstrated a profound respect for national ideals and a willingness to fight for their goals, even to the point of engaging in combat. Ukrainian Greek-Catholic Metropolitan A. Sheptytskyi supported the members of Ukrainian student societies in their quest for an independent state created by non-violent means.

The educational and scientific activities of Ukrainian student societies in Eastern Galicia from the late 19th century to 1939 and their interaction with A. Sheptytskyi.

As a progressive segment of society, students played a distinctive role in the political lives of Ukrainian lands, including Eastern Galicia, at that time. It was of great importance to the students that they engage in educational and scientific activities. One such activity was the dissemination of Ukrainian education. Additionally, the students established their own scientific school, and they endeavored to safeguard the learning process from negative influences.

The student societies of Eastern Galicia were established and technical knowledge was disseminated. They subsequently formed their own scientific school at Lviv Polytechnic, in particular, around the Ukrainian student society «Osnova». Despite its relative smallness, the society actively engaged in the dissemination of natural, mathematical, and technical knowledge. This not only facilitated the advancement of science but also contributed to the economic and technological development of Eastern Galicia and the acceleration of the industrial revolution.

The students of the «Osnova» Society established a library that primarily comprised technical literature and they also initiated a publishing business due to the dearth of textbooks in Ukrainian for technical and natural-mathematical disciplines. As observed by S. Tserkovnyk, the «Osnova» Society conducted lectures during which they disseminated their scientific discoveries through reports. Additionally, the company hosted professional discussions, during which renowned Ukrainian scientists and technologists were invited to participate (Tserkovnyk, 2023, p. 91).

Legal education also spread in Eastern Galicia and was represented by the «Kruzhok pravnykiv» («Circle of Lawyers»). The latter included participants who studied the peculiarities of legislative processes, studied normative and legal acts, conducted legal education among the population.

One of the individuals who fostered an interest in law among Ukrainian students was the renowned scientist S. Dnistrianskyi. He worked at the Department of Austrian Law, where he taught in the Ukrainian language. Additionally, he served as a deputy of the Austrian Parliament in Vienna and provided support to Ukrainian students in their efforts to establish the Ukrainian University and to achieve universal suffrage (Macierzyński, Glado, & Tarasenko, 2020, p. 84–86).

The «Ukrayinskiy Studentskyi Sojuz» (Ukrainian Student Union) which had been inactive during the period preceding the First World War, resumed its activities in early 1920. The Union's General Government produced an action plan that called for «students preparing politically for the final pinnacle of our political liberation» as stated in the document. On May 1, 1921, the Union's General Government addressed the Ukrainian students who were studying at Polish universities with a proposal to enter the Ukrainian University in Lviv (Vyzdryk, 2009, pp. 117–118).

It is evident that the establishment of an indigenous educational infrastructure, the infusion of Ukrainian-language materials into academic libraries and the recruitment of highly qualified scientific personnel were pivotal in the development of Ukrainian education. In matters relating to the establishment of Ukrainian educational

institutions, exhibitions, schools, museums, and other cultural events, Metropolitan A. Sheptytskyi provided significant financial support to student societies in Eastern Galicia. He advocated for non-violent methods of achieving their objectives.

The students played a pivotal role in the advancement of art and culture in Eastern Galicia, particularly through their involvement in the «Tovarystvo prykhylnykiv ukrainskoi literatury, nauky, remesla» («Society of supporters of Ukrainian literature, science and crafts»). The members of the Society provided financial and moral support to young artists, thereby facilitating the dissemination of their work to a wider audience. Also, supporters of literature, science and crafts collected folklore, researched ethnography and ethnology, concluded regional intelligence and produced numerous scientific and popular scientific publications (Yanyshyn, 2018).

However, Ukrainian students held the conviction that the most crucial aspect of their endeavor should be the establishment of an educational and scientific center for Ukrainians. Archival materials indicate that the actions of the struggle for their own university were planned by student societies not only in the 1920s, but also in the period preceding the war. They proposed to gather for meetings and publish a press. When peaceful methods of achieving the goal were unsuccessful, the students initiated a boycott campaign (Appeal of student organizations, 1902–1914, p. 17–21).

The intellectual community held disparate opinions regarding the establishment and operation of higher education for Ukrainian students. For instance, the perspectives of M. Hrushevsky and O. Kolessa diverged. The historian posited that the university should be publicly accessible and open, without restrictions on the education of applicants and the involvement of a wide range of specialists. O. Kolessa was attracted to the European standards of higher education, academic freedom, and clear requirements for entrants and present teachers of scientific degrees and titles (Korzh-Usenko, Sydorenko, & Dovhopolova, 2021, p. 301). The objective of these discussions was to create a scientific environment for Ukrainian students to pursue higher education.

Members of the Shevchenko Scientific Society who collaborated with Ukrainian students and advocated for the educational process in Ukrainian language and the establishment of the educational and scientific center of Ukrainian and have been instrumental in establishing the Ukrainian University (Melnyk & Kachmar, 2023).

A. Sheptytskyi also discussed the significance of educating Ukrainian students and young people through educational institutions and organizations that would foster the growth of national consciousness and patriotism. The Metropolitan underscored the necessity for an independent state to possess its own educational institutions, including a Ukrainian University, a Ukrainian curriculum, and textbooks and handouts. Furthermore, he emphasized the importance of fostering a conscious citizenry through the establishment of museums and scientific centers.

The Metropolitan expressed his support for and shared the desire of students to learn. In his pastoral instructions, he emphasized that no wealth can replace the knowledge and wisdom that a person has. A. Sheptytskyi posited that knowledge, skills, and wisdom are intrinsic to the human condition. He also underscored the necessity for the establishment of a Ukrainian high school, citing the longstanding

tradition of Ukrainian intellectualism and the apt designation of this trait as a «valuable sign of our people» (Tykhovska & Basarab, 2023, p. 119–122).

The above generalizations are corroborated by his words: «Turn your desire and willingness to what is the basis of wealth and power of the people. Let young children learn to love their land, let children learn to work on it, let future generations take over the trade and fishing, because society is always weak, which has no industry; poor society, which sells strangers...» (Kravchuk, 1999, p. 11).

A. Sheptytskyi provided support to Ukrainian students engaged in the campaign for the establishment of the Ukrainian University in a number of ways. The Metropolitan has repeatedly appealed to the government authorities to prioritize the demands of Ukrainian students to open a university: «Although the issue of establishing an independent university in Lviv has been the subject of discussion for several years […] no tangible progress has been made to date. However, this matter, gentlemen, is of profound importance for many reasons...» (Kekosh, 2014, p. 239).

Evidence of A. Sheptytskyi's active cultural position can be found in his material support of Ukrainian schools of all degrees, the funding of cultural and scientific events, educational societies and organizations, the establishment in Lviv of the Scientific Institute of Studies and the «Akademichnyi dim» («Academic House»). The Metropolitan also provided scholarships for Ukrainian students who had emigrated to study abroad, assisted pupils of orphanages, and supported printing houses and public societies (Rybchyn, 2015, p. 43).

The Metropolitan posited that in order for a country to achieve its goal of state-building, it was necessary to investigate and understand its own history. Notably, the renowned historian M. Hrushevsky also played a pivotal role in the dissemination of knowledge on the history of Ukraine and Ukrainian studies. As indicated by the data presented by V. Telvak, the professor's lectures were attended by approximately 84% of Ukrainian students, representing the majority of the total student population and 12% of Polish students also participated (Telvak, 2023, p. 293). These figures demonstrate not only the interest in the history of the Ukrainian people, but also the widespread interest in the Ukrainian national revival among representatives of other peoples who were also engaged in the process of restoring their statehood.

Additionally, A. Sheptytskyi provided assistance to students enrolled in medical schools. He also facilitated the establishment of the «Narodna Lichnytsia» (People's Hospital) which was a charitable initiative aimed at providing free healthcare services to the impoverished population of Eastern Galicia. Ukrainian medical students had an organization known as the «Likarske tovarystvo» (Medical Society) which provided an opportunity for students to enhance their knowledge. At the end of 1911 or at the beginning of 1912, with the assistance of the Metropolitan, the students established a sanatorium for their exclusive use.

The Metropolitan also facilitated the education of Ukrainian students and the research activities of Ukrainian scientists through access to the library resources of the Studio in the Lviv Student Lavra, the book collection in the libraries of Lviv and its own archive (Kekosh, 2014, p. 239). The head of the UGCC demonstrated support for

the publishing industry. Given that almost every student society of Ukrainians in Eastern Galicia had its own publication, Andrey frequently served as their patron.

Student society the «Osvitnii hurtok» (Educational Circle), which united Ukrainian students with the objective of disseminating educational and scientific knowledge among the villagers and on weekends, held a number of events for the Ukrainian population. These events included lectures, practical work, and joint training. The curriculum included instruction in the history of Ukraine, geography, natural science, jurisprudence, and German. The courses were provided with books or support from the Metropolitan's funds.

Ukrainian student societies also played an active role in the advancement of Ukrainian science. In order to disseminate information about the Ukrainian scientific school and to familiarize the public with its achievements, the Summer Courses were organized. Some of these courses were held in 1904 by the «Tovarystvom prykhylnykiv ukrainskoi nauky, literatury ta mystetstva Halychyny» («Society of Supporters of Ukrainian Science, Literature, and Art of Galicia»).

In addition to participating in various scientific events, members of student societies joined the «Tovarystva ukrainskykh naukovykh vykladiv im. P. Mohyly» («Society of Ukrainian Scientific Presentations Named After P. Mohyla») which was established in 1909 with the objective of familiarizing the population of Eastern Galicia with the latest scientific discoveries and showcasing the contributions of Ukrainian scientists to the global scientific community. Notable Ukrainian figures such as literary critic O. Kolessa, geographer S. Rudnytsky, and mathematician V. Levytsky were active participants in the society's activities (Rohde, 2020, p. 153).

In addition to political student societies, there were also non-political student societies. One such society was «Proforus» (Professional Organization of Ukrainian Students). Its stated purpose was to spread education and scientific knowledge among the population of Galicia, Volyn lands, Northern Bukovina and Bessarabia. It later expanded its influence to Transcarpathia. The Society was comprised of a substantial number of students, with a membership exceeding two thousand (Vyzdryk, 2009, p. 119).

This is a mere fragment of the extensive array of cultural, educational, and scientific activities undertaken by Ukrainian student societies in Eastern Galicia. These include the creation of lectures, the organization of training courses, evenings of poetry and music, the publication of newspapers and magazines, the establishment of societies for economic assistance, sanatoriums, exhibitions of young artists and sculptors, the organization of the Ukrainian museum and various libraries, and, most notably, the struggle for the creation of the Ukrainian University. During the course of these events, Ukrainian student societies in Eastern Galicia were the beneficiaries of the patronage of A. Sheptytskyi.

Conclusions.

The author has demonstrated that the Ukrainian student associations of Eastern Galicia engaged in a range of activities, including national-oriented, socio-political, cultural and educational-scientific pursuits in the article. They collaborated with

political parties and representatives of the Ukrainian intelligentsia such as O. Kolessa, M. Hrushevskyi and S. Dnistrianskyi. Additionally, they participated in the fighting of the First World War, fought for the establishment of their own Ukrainian University, popularized Ukrainian education, and contributed to the development of their own scientific school. In order to achieve their objective Ukrainian student societies employed a range of methodologies, including educational initiatives, petitions, proclamations, appeals and boycotts.

In all instances of peaceful, legal and moral struggle for the establishment of their own state, the creation of the Ukrainian University and scientific achievements, Ukrainian student societies in Eastern Galicia received the support of the head of the UGCC, A. Sheptytskyi. He considered it a virtue to be a patriot of his homeland, yet he condemned violence as befitting a spiritual leader.

Concurrently, the Metropolitan denounced the discriminatory actions of the pro-government forces that targeted Ukrainian student associations, not only for their social and political activities, but also for their cultural activities, their desire to pursue education in their native language and their efforts to establish their own scientific centers. In the realm of cultural activities, Ukrainian student societies played a pivotal role in supporting the Ukrainian population of Eastern Galicia. They facilitated the dissemination of knowledge, organized leisure activities and contributed to the advancement of national-patriotic education.

An analysis of the socio-political, cultural, educational, and scientific activities of Ukrainian student societies in Eastern Galicia from the late 19th century to 1939 has revealed that students at the time were one of the most active social and active groups. Furthermore, the active support of Metropolitan A. Sheptytskyi not only gave the societies the opportunity to function and continue their activities, but also served as a moral benchmark during the everyday state-building struggle.

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Національно-культурницька та освітньо-наукова діяльність українських студентських товариств Східної Галичини (з кінця XIX ст. до 1939 р.) крізь призму співпраці з митрополитом А. Шептицьким

Анотація. *Студенти Східної Галичини, майбутні науковці, інженери та культурні діячі ще з другої половині XIX ст., підтримуючи погляди української галицької інтелігенції, об'єднувались в товариства, які боролись за право здобувати освіту рідною мовою та поширювали ідею розвитку власної «національної науки». Метою дослідження є аналіз нового витка національно-орієнтованої, культурницької та освітньо-наукової діяльності українських студентських товариств Східної Галичини з кінця XIX ст. до 1939 р., який розпочався завдяки активній співпраці з митрополитом А. Шептицьким. Для аналізу історичного фактажу було використано хронологічний, історико-порівняльний, ретроспективний, міждисциплінарний методи, зокрема структурний метод. Досліджено специфіку функціонування українських студентських товариств у складних і несприятливих умовах, доведено, що*

панівним напрямком їх діяльності була консолідація суспільства та реалізація національно-культурницьких прагнень українського народу, каталізація процесів в освітньо-науковій площині через активну взаємодію з А. Шептицьким. В окресленому рамками дослідження проміжку часу студенти співпрацювали з партіями різного спрямування, брали участь у бойових діях Першої світової війни, боролися за створення Українського Університету як осередку вищої освіти та при ньому української наукової школи. За відсутності можливостей та цілком власної наукової установи студентські товариства здійснювали свої прикладні, фундаментальні, пошукові та методичні наукові дослідження під час участі у літніх школах, застосовуючи їх результати при випусках студентської періодики, виступах на студентських з'їздах та студіях, які здебільшого організовувались й підтримувались інтелігенцією, зокрема, А. Шептицьким. Для досягнення мети українські студентські товариства використовували цілий спектр методів від написання наукових розвідок та прокламацій до бойкотів. А бачення ідеї державотворення об'єднували українських студентів з відомими громадськими й духовними діячами, науковцями та митцями Східної Галичини.

Ключові слова: *Східна Галичина; українське студентське товариство; «Академічна громада»; науково-освітні заходи; Український Університет; інтелігенція; А. Шептицький*

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History of problem-solving teaching and learning evolution

Abstract. *The article focuses on the development of the problem-solving method in the history of Pedagogy both in theory and practice. The manuscript purpose is to characterize the history of problem-solving teaching and learning ideas development and instigate and inform their progress and implementation in higher education teaching practice in the second half of the 20th century. The methods used during the research were 1) methods of the theoretical level (analysis, synthesis, generalization) for clarifying the definition of the notion, singling out the shifts in the underlying ideas of the problem-solving method throughout human history, specifying the application of the problem-solving teaching method at universities in the second half of the previous century; 2) methods of historical research (historiographical, chronological, logical-historical, historical-typological) for characterizing the development of problem-solving teaching ideas in historical aspect, and determining their essential manifestations. The research results have revealed that problem-solving teaching and learning is perceived as the process of solving cognitive and practical problems by students stimulating their creative and mental activity and promoting their active participation in learning. The problem-solving teaching method that originated in*

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ancient Greece was based on the ideas of famous historical figures and pedagogical practice of progressive educators and has made a long way in its advancement. The paper novelty lies in presenting the generalization of the problem-solving teaching and learning ideas historic evolution in education, in determining the problem-solving method ideas development stages based on the key elements of the given method, covering the structure of thought processes, stages of cognitive development, the significance of the problem situation in thinking and learning, the impact of problem-solving on one's intellectual potential, in tracing the problem-solving method use in higher education in the second part of the last century. The great potential of problem-solving teaching method was extensively exploited in higher education training practice. Problem-solving teaching and learning ideas and accumulated pedagogically valuable experience of their implementation in higher education provide a valuable theoretical framework and teaching means for future specialists' intellectual and professional competence ensuring and raising higher education quality.

Keywords: *history of pedagogy; problem-solving; teaching method; higher education; students*

Introduction.

The history of education worldwide reflects the desire to improve methods of teaching, raise quality of education, promote learners' interest, search for and introduce the most successful pedagogical methodologies and teaching tools. In fact, the history of Pedagogy is the history of striving for better and effective teaching theories and practice and teaching methods in particular. One of the greatest results of this search and developments in the sphere of education is represented by the implementation of problem-solving (the term has a number of synonyms such as: problem-based, inquiry-based, problem-oriented) teaching method.

A *problem* in education is viewed as a case that demands exertion and the application of existing knowledge and experience on the part of the learner to be solved (Felmer Perdomo-Díaz, Giaconi, & Espinoza, 2015). Accordingly, *problem-solving* deals with an individual's capacity to manage a challenge and means navigating the process of bridging the gap between the desired outcome and the present circumstances in a context influenced by variables encountered, whether previously experienced or not (Huitt, 1992; Min, Kim, & Yoo, 2021). Problem-solving requires learners to construct knowledge and use specific strategies to cope with difficulties (Ince, 2018; Karpushyna & Bloshchynsky, 2022).

In the era of modern challenges, the solution of educational problem situations is also introduced in modern computer learning (including interactive), which develops the creative ability, critical thinking and independence of the student (Abuzagha & Tabieh, 2021; Holubnycha, Besarab, Pavlishcheva, Kadaner, & Khodakovska, 2022; Iyagba, 2020; Mykytiuk, Sv., Lysytska, Chastnyk, & Mykytiuk, S., 2023). Therefore, this type of learning does not only gain audiences, but also is actively used by students for independent work (both interactive and receptive) facilitating both quality of education and soft skills of students.

The priorities of *problem-solving teaching and learning* (PSTL) make up the theories, concepts and practices suggested by some of the outstanding thinkers of the past, whose ideas have proved their relevance and effectiveness and are the attributes of this form of training. The study of the problem-solving teaching method development in historical aspect is topical as it helps to understand advantages and avoid mistakes when using it, sets the stage for further pedagogically significant findings.

Thanks to the research of historians of pedagogy, modern didactic practice has already been enriched by a number of pedagogically important provisions for the activation of students' educational and cognitive activities, organization of students' independent work, development of students' creativity; these all are facilitated by the use of PSTL method.

Recent literature review has confirmed that a lot of data have been accumulated on the theoretical aspects and practical cases of applying PSTL. However, rather few studies deal with the retrospective scrutiny of the given pedagogical phenomenon. Such studies tend to focus on specific areas of problem-based teaching implementation like the history of development of problem-solving competence (Posamentier, Kose, Virgadamo, & Keefe-Cooperman, 2019; Servant-Miklos, 2019b), problem-based teaching in medical universities (Servant-Miklos, 2019a, 2020; Servant-Miklos, Norman, & Schmidt, 2019), history of problem-solving use in teaching specific disciplines (Li, Song, Hwang, & Cai, 2020; Csachová, 2021), on presenting the developments in PSTL within brief historical periods (Alimova, 2022; Hudha et al., 2023; Zakaria, Maat, & Khalid, 2019) and practising it in different countries (Xiong, 2021).

Meanwhile, further analysis of the history of theoretical foundation and teaching techniques of PSTL development worked out by the pedagogical thought in different countries and presented in the paper, sheds the light on the PSTL history lacunas, brings forth and complements the data on the factors that influenced its evolution and priorities, deepens the level of historical analysis of the given approach and opens new perspectives on creative use of the problem-solving method in teaching, facilitating working out more effective strategies of problem-solving skills development as its principles have proved their effectiveness at all levels of education. Such findings are of both theoretical and practical value and allow for learners' intellectual development which has become the priority in the 21st century.

The **purpose** of the paper is to characterize the history of PSTL ideas development and instigate and inform their evolution and use in higher education teaching and learning practice (in the second half of the last century) in order to single out the most significant of them for modern teaching practice.

The **tasks** are 1) to specify the concept of PSTL; 2) to trace the history of PSTL ideas worked out by advocates of inductive reasoning and teaching practices; 3) to highlight the peculiarities of PSTL application at the tertiary level in the second half of the 20th century.

Methodology.

The stated purpose demanded the following set of methods to be used:

1) general methods of theoretical study such as analysis, synthesis, generalization of special literature in pedagogical history, pedagogical periodicals, and didactic sources. They were applied in order to clarify definition of the concept under research, to single out valuable PSTL ideas in the history of education, and to characterize the real application of PSTL at the tertiary level in the second half of the 20th century when it became an inseparable training process component at the tertiary level;

2) methods of historical research, namely: historiographical, chronological, logical-historical, and historical-typological. These methods allowed us to characterize the development of PSTL ideas in historical aspect and generalize them, to determine the essential components and features of the pedagogical phenomenon under study.

Results and Discussion.

1. Concept of PSTL.

Since in the early history of education PSTL did not exist in its present form, in order to find out pre-PSTL ideas, we need to single out specific components of the concept under study. For this purpose, we analysed modern definitions of PSTL. The most general of them define it as:

1) an established student-centred pedagogical approach wherein intricate real-life challenges serve as the conduit to foster students' comprehension of principles and concepts, contrasting with the straightforward presentation of facts and ideas (Duch, Groh, & Allen, 2001);

2) "an instructional method by which students learn through simplified problem-solving" (Nirchi, 2015, p. 1);

3) "an activity in which a learner perceives a discrepancy between a current state and a desired goal state, recognizes that this discrepancy does not have an obvious or routine solution, and subsequently tries to act upon the given situation in order to achieve that goal state. It is accompanied by a number of mental and behavioural processes that might not necessarily take place in sequential order but can run in parallel" (Hesse, Care, Buder, Sassenberg, & Grifn, 2015, p. 37).

So, according to the above definitions, the following specific components of PSTL have been determined: it is *student-centred* in nature. It is *directed at students' intellectual development* and their assimilation of knowledge by *involving* them *in active creative thinking*. In contrast to traditional explanatory and illustrative teaching, PSTL *focuses* not only on the assimilation of the results of scientific cognition, but also *on the cognition paths* and *methods of creative activity*.

2. PSTL in History of Teaching.

In the European educational context posing questions that cause difficulty in finding answers to them (method of enquiry) is associated with ancient Greek philosophers Socrates (470–399 BC) and his Socratic method and Plato (428/427 or 424/423–348/347 BC). They believed that mental activity could contribute to memory improvement and deeper penetration into the essence of objects, processes and

phenomena. In the new history, the desire to promote active learning dates back to the philosophical views of F. Bacon (1561–1626), who being called the father of empiricism, argued that acquisition of scientific knowledge has to be based only upon inductive reasoning and careful observation of events in nature (Compayré, 1886).

Since that time the long-running disputes between two trends in pedagogical theory and practice have begun – between those who supported material education with the focus on the content of education and supporters of formal education who highlighted the development of cognitive abilities of learners.

The ideas of active learning, of mobilizing learners' cognitive abilities by involving them in independent search activity associated with progressivism are reflected in the works of J. A. Comenius (1592–1670), J. J. Rousseau (1712–1778), W. Gilpin (1724–1804), D. Manson (1726–1792), J. H. Pestalozzi (1746–1827), A. V. Disterweg (1790–1866), and others, who were against dogmatic memorization of knowledge and supported active teaching methods.

J. A. Comenius who is known as one of the first supporters of active teaching of schoolchildren wrote about the need to arouse in pupils the thirst for knowledge and an ardent zeal for learning in contrast to the verbal and dogmatic teaching. J. J. Rousseau maintained that the teacher's task was to make a child interested and make him ask questions (Trotsko, 2008, pp. 145–147).

The study confirms that almost in every state there were political and public officials, educators and teachers who tried to implement unorthodox pedagogical ideas believing that they could provide for better quality of education and better results in teaching and learning.

For example, in England in the 50s of XVIII century two personalities who did not know each other – W. Gilpin (the artist, Anglican cleric, schoolmaster and author) and D. Manson (an Irish schoolmaster) introduced and carried out a number of creative transformations in teaching in order to exclude "drudgery and fear" and promote 'uprightness and utility" (Stewart, 1972, pp. 152–157).

They both wanted to change the traditional for that period of time forms and methods of teaching. They were against corporal punishment for pupils and pioneered the use of play and peer tutoring in schooling. Nevertheless, in general that was the time when the task of schools was to develop obedient and patient young people (Barnard, 1947, pp. 212–215).

However, in the second half of XVIII century pedagogical theory and practice began to polarize around the traditional classical Christian and the "new" one, based on natural sciences, trends in education in England and later in the middle of XIX century several innovative proactive pedagogical trends were formed.

One of them was connected with the ideas of European Enlightment and Jean-Jacques Rousseau's theory. In England one of its followers was D. Williams (1738–1816), who argued that if a child grew up in accordance with his/her natural inclinations in the natural environment, then he/she would grow up healthy and would have a healthy and active mind (Stewart, 1972, pp. 161–164).

Similar ideas were advocated by the Swiss educator J. H. Pestalozzi. He believed that mental education should be carried out in accordance with the natural way of

child's cognition following the principle of conformity to nature and child's self-activity (Trotsko, 2008, p. 148).

Another trend was represented in the ideas and activities of R. Owen (1771–1858), who, trying to make education more attractive and interesting for children, believed that: there was no room for corporal punishment in school education; teachers had to be kind to their pupils; the best forms of teaching were conversations and discussions; alternation of lessons and games had to be observed; attention had to be paid to the development of children's thinking abilities (Stewart, 1972, pp. 169–171).

F. A. Disterweg argued that the teaching method was good if it activated the student's cognitive activity, but if it only made learners memorize the material under study, then this teaching method was bad (Trotsko, 2008, p. 149).

The next trend followed the ideas of Pestalozzi and was represented by philanthropists Lady Byron (1792–1860) and James Kay-Shuttleworth (1804–1877). They wanted to create conditions in schools allowing pupils to reveal their own initiative in learning and providing for their independent activities in the educational process. They applied their ideas in practice in teaching pupils Geography, History and other disciplines (Kuznetsova, 1990).

Although we cannot claim all the outstanding philosophers and educators mentioned above to be the theorists of real PSTL ideas, their thoughts were advanced and innovative for their time, close to child-centred concepts in education, directed at cognitive development through problem-solving and became predecessors for the current PSTL framework.

The creative ideas and efforts directed at improving the process of teaching and learning, creating schools for all social groups of children and developing new active methods of teaching appeared in the pedagogical activities of public personalities and teachers in the pedagogical history of almost every state. However, ideas and activities of some of them influenced theoretical pedagogical thought and school practice developments all over the world. So, J. Dewey (1859–1952), the American philosopher, psychologist, and educator is the one whose contribution to PSTL is a vivid example of the case. Due to his outstanding innovative ideas and pedagogical activities the early 20th century marked a special stage in the development of theory and practice of PSTL. This was he, who launched a new didactic system, the priority method of teaching and learning in which was problem-solving one (Jagger, 2023).

J. Dewey rejected the dominance of traditional learning and insisted on the value of active self-learning of students through their solving problems. Thus, learners' self-activity and self-learning based on the interests and real needs of schoolchildren became the focus of his innovative activity in Chicago schools in 1895. Besides, his theory of learning highlights the idea of "complete act of thinking" elaborated by him, pointing to the fact that a student begins thinking when he faces challenges, the overcoming of which holds significant importance for him. In the work "How We Think" (1909), he defined thinking as the solution of problems, rejected traditional dogmatic teaching and contrasted it with the active practical activities of learners solving problems. He argued that students' ability to solve problems was based on their inborn mental characteristics. Emphasising the importance of critical thinking and the

vital role education should play in this process, he believed that the thought of an individual moved naturally through several stages to the point at which all aspects of the problem became clear (Dewey, 1910).

Besides, the ideas of another American psychologist J. Bruner (1915–2016) also played a significant role in the development of the theory of discovery (problem-solving) learning. His approach deals with organizing education materials and emphasizes the primary role of intuitive thinking in the acquisition of new knowledge, serving as the foundation of heuristic thinking. J. Bruner focused on: the importance of the knowledge composition in the organization of training; students' readiness to study as a factor of learning; intuitive thinking as a basis for the development of mental activity; motivation for learning (Bruner, 1960).

Alongside the efforts of educators and practicing teachers, the contribution of psychologists into PSTL ideas evolution who maintained that intellectual development is defined not solely by the quantity and calibre of acquired knowledge, but also by the configuration of cognitive processes, encompassing the array of logical operations and intellectual manoeuvres that the learner masters, and believed that each student moved through certain stages in their cognitive development (S. Rubinshtein (1889–1960), J. Piaget (1896–1980)) was made. Besides, the psychologists elaborated on the significance of the problem case in the processes of cognition and learning (Gutiérrez et al., 2018).

A number of other outstanding educators and scholars analysed the problem-solving method principles and allowed for other pedagogical concepts to be developed on their basis during the 20th century. So, V. Sukhomlynskyi (1918–1970) stressed the importance of applying the problem-solving method of teaching and learning developing his theory of humane didactics, according to which a person is of the highest value, so the task of education is to create conditions for the development of personality, its creative potential, natural inclinations and abilities, to help in one's life self-determination. The educator highly valued the development of intellectual activity in the organization of independent cognitive activity of students. He believed that the problem-solving method of learning ensured organizing, managing and intensifying learners' cognitive activity and contributed to education quality improvement. Thus, V. Sukhomlynskyi developed a technology of PSTL use for effective development of children and raising the quality of education (Sukhomlynskyi, 1981).

Significant attention to PSTL was paid by a great number of researchers of the second half of the 20th century. Stewart (1950) was proving that problem-solving method of teaching and learning was an effective one; Krebs (1967) was looking for essential elements necessary for more effective teaching with problem-solving method; Newell and Simon (1972) as well as Gubitz (1984) were considering the relations between human problem solving and development of the students' potential in intellectual sphere; Barrows and Neufeld (1974) coined the term "problem-based learning" that is synonymous to PSTL; Flavell (1976) was discovering metacognitive aspects of problem solving in the organization of learning activities, focused on shaping their intellectual abilities, cognitive activity, self-sufficiency and cognitive interests; Polya (1973) and Mayer (1983) revealed the best way to develop students'

intellectual abilities through solving educational problems; Moore G. E. & Moore B. A. (1984) were trying to investigate the problem solving as a holistic approach to teaching: its content, principles, organizational forms; Van Gundy (1987) prepared a guide for trainers presenting a great number of creative problem solving tasks.

It is important to point out that the PSTL issues were studied not only by individual scholars and educators but also by Scientific Didactic Schools. A. Zilberstein's Kharkiv Scientific Didactic School was an example of such joint efforts of researchers to further promote PSTL theory and practice. Thus, current issues of problem-solving learning were considered by the scientist and his followers in the early 1970s. This group of scholars studied how problem questions and tasks could help to test student's knowledge (Lozovaya, 1972), use of visual aids in problem-solving activity of students (Evdokimov, 1973, 1988, 1989), individual approach to students carrying out problem-solving activity (Barabash, 1975), organization of mental work of students (Evdokimov, Lozova, & Mozhayeva, 1985) and other PSTL concerned aspects.

Another evidence of the further development of the problem under study was the creation of the problem laboratory of experimental didactics. The authors of this investigation managed to find it under the direction of I. Fedorenko in H. S. Skovoroda Kharkiv State Pedagogical Institute (1966–1982) (Lozova & Trotsko, 2001).

Active work of the given didactic school and the problem laboratory of experimental didactics facilitated a significant increase in the number of publications on PSTL. In addition, there was deepening of the level of research ranging from the study and generalization of learning experience to the development of various aspects of the theoretical framework of the didactic problem under study. As a result of the efforts of numerous scholars, PSTL goals (acquisition of competences, knowledge, skills and abilities; mastering methods of independent cognitive activity; development of cognitive and creative abilities) were specified, methods for creating problem situations in various educational disciplines were developed, problem-solving teaching methods (e.g. heuristic method of presentation, of problem presentation, of partial search, of search-simulation, reasoning teaching method, research method etc.) were investigated and criteria for assessing the problem intellectual assignment complexity were identified. The search for ways to increase the effectiveness of teaching and optimization of learning and mental activities contributed to the development of various aspects of problem-based learning (content and structure specific, methodological and technological ones).

Thus, on the basis of theoretical and practical developments accumulated as a result of research efforts of many generations of educators a number of fundamental findings on different aspects of PSTL were amassed by the end of the 20th century. Summarized PSTL ideas of outstanding thinkers and educators are presented in Table 1.

Table 1

Development of PSTL ideas suggested by outstanding philosophers and educators

Developers	Ideas
"Intuitive" PSTL development	
Socrates	developed the argumentative dialogic method that leads to the "birth" of truth (knowledge)
Plato	claimed that mental activity contributes to memory improvement and deeper penetration into the essence of objects, processes and phenomena
Bacon	put forward the idea that acquisition of scientific knowledge has to be based only upon inductive reasoning and careful observation of events in nature
Comenius	● launched and advocated active teaching of schoolchildren ● advocated the necessity to arouse the desire for getting knowledge in pupils
Rousseau	believed that the teacher's task is to make a child interested and make them ask questions
Gilpin **Manson**	insisted on changing traditional methods of teaching and recommended using playing activities and peer tutoring in schools
Williams	held that children should grow up in accordance with their natural inclinations in the natural environment
Pestalozzi	asserted that mental education should be carried out in accordance with the natural way of child's cognition following the principle of conformity to nature and child's self-activity
Owen	● propagated conversations and discussions as the best teaching forms ● argued that attention should be paid to the development of children's thinking abilities
Disterweg	claimed that the teaching method was good if it activated the student's cognitive activity
Lady Byron	

Kay-Shuttleworth	advocated creating conditions allowing pupils to reveal their own initiative in learning and providing for their independent activities in the teaching process
PSTL development based on theoretical findings	
Dewey	● instigated modern PSTL, strongly recommending replacing traditional learning with active self-learning through problem solving ● considered thinking as the solution of problems ● believed that students' ability to solve problems is based on their inborn mental characteristics
Rubinshtein	elaborated the theory of activity, establishing that activity is a powerful means of a thinking process
Piaget	created the developmental theory, stating that a child comes through certain stages in cognitive development
Bruner	● pointed to the importance of structuring knowledge in the organization of training ● emphasised the value of motivation and intuitive thinking as a basis for the development of mental activity
Sukhomlynskyi	● developed the theory of humane didactics, focusing on the creation of conditions for the development of personality, important part of which is intellectual development ● claimed that PSTL ensures intensifying learners' cognitive activity
Stewart	asserted the efficiency of PSTL
Krebs	elaborated on essential elements necessary for more effective PSTL
Newell & Simon, Gubitz	determined relations between human problem solving and development of the students' intellectual potential
Barrows & Neufeld	coined the term "problem-based learning" that is synonymous to PSTL
Flavell	discovered metacognitive aspects of problem solving in the organization of PSTL focusing on the formation of students'

	mental abilities, cognitive activity, independence and cognitive interests
Polya, Mayer	revealed the effective way to develop students' intellectual abilities through PSTL
Moore G.E. & Moore B.A.	generalized the problem-solving as an approach to teaching
Van Gundy	prepared a guide for trainers presenting a considerable number of creative problem-solving tasks
Zilberstein's Kharkiv Scientific Didactic School	investigated: ● how problem questions and tasks can help to test student's knowledge ● how to use visual aids in PSTL ● individual approach to students in PSTL ● how to organize students' mental work in PSTL
problem laboratory of experimental didactics	● specified PSTL goals ● developed methods for creating problem situations in various educational disciplines ● probed for problem-solving teaching methods ● identified the criteria for assessing the problem intellectual assignment complexity

3. PSTL Application at the Tertiary Level (the second half of the 20th century).

While numerous researchers elaborated on theoretical aspects of PSTL, teaching expert mentors and teaching professionals creatively developed and implemented in the practice of higher education various methodological strategies and techniques based on the PSTL ideas to improve the quality of future professionals' training at higher education institutions.

Different didactic sources testify that in the second half of the 20th century PSTL was applied widely at the tertiary level during lectures, seminars, laboratories and other types of classes, as one of the key tasks of higher education was defined as the purposeful development of an active, creative and free personality, based on the conception providing that one's views and beliefs, as well as their abilities are best developed in active setting, the nature of which determines the development level of these qualities (Oksa, 1997). The development of creative abilities occurs only during

the search activity, the organization of which is the essence of problem-solving teaching method (Maheshwari, 2017).

In the course of didactic investigation Viktorov (1964) fixed significant experience of a higher education institution lecturer (D. Gordevskyi). So, those problem-solving lectures presupposed a number of small problems (10–12 situations per a lecture) that were being solved in the course of dialogic interaction with the students. As soon as the lecturer was a strong supporter of encouraging students' independent cognitive activity and creativity, he stimulated his students to propose their own definitions as well as to draw conclusions. Thus, the information acquired by the students in an active manner in close interaction with their teacher was perceived by them as personally valuable and essential.

Nizamov (1970) gave an account of his own efforts to improve a problem-solving lecture. In this case, students were asked questions and given problem situations that stimulated them to work independently and intensified their cognitive activity. However, provoking students' independent learning, he believed that the problem questions encouraged students' cooperation pointing to the importance of both aspects for effective learning.

Offering his real practice with four inquiry projects Knowles (1975) perceived the role of the teacher as that of a facilitator of learning rather than a traditional instructor, emphasizing guidance in procedures rather than transmission of content.

Organization and management of students' intellectual activity with PSTL assistance included not only methods of problem presentation of the teaching material at lectures but also were used during practical classes where students' attention and thinking were inspired by using problem-solving practical tasks. Palant (1982) described his experience in designing banks of tests and tasks of problem-solving character.

Moreover, our investigation proves that considerable attention was paid to PSTL because of its potential to promote the development of creativity and independence of future professionals. As during the 1980s the priority was given to students' independent work, measures were taken to improve the organization of such work in higher education institutions. PSTL was given priority in the higher education teaching process as a means to achieve the goals set and a didactic strategy ensuring and stimulating active independent cognitive and exploratory activity, independent problem solving, search and identification of constructive solutions, overcoming problem situations, etc. (Rybalko, 1987).

Historiographical research of Holubnycha & Moshynska (2020) established that the pedagogical press of the second half of the last century tended to cover the urgent issues of PSTL in higher education, proving that at that time it was already regarded as a valuable asset of university pedagogical experience. Especially actively PSTL practice was discussed in the 1980s, as evidenced by numerous works. The authors reported on the use of problem-solving learning elements in lectures and practical classes (Kholodova, Sirotenko, & Petrova, 1980), problem-solving lectures (Shtelmakh, 1981), ways of activating students' mental activity in lectures (Stashys, 1986), promoting students' activity in practical classes (Yushchenko, 1981),

intensification of students' creativity in group classes (Omelchenko, 1981), problem-solving learning in laboratory classes (Rybalko, 1987), use of visuals in problem-solving learning (Urbanskyi, 1986).

Problem-solving lectures presented educational material on the curriculum themes as a problem considered from differing perspectives. Considering the distinctive features of problem-solving cognition and the enhancement of students' intellectual engagement, heuristic methods became predominant as an approach to presenting lecture material based on problem-solving principles (Holubnycha & Moshynska, 2020).

The research data suggest that PSTL application in higher education is also strongly associated with the practical activities of individual academics and lecturers who were advocates of the given educational strategy. In this context useful material is presented by Honchar (2011). The author collected the memories of students of the late 1980s and early 1990s. As evidenced by them, the most successful were the classes of those lecturers who moved away from traditional authoritarian teaching methods. For example, the lecturer of Lexicology (L. Pelepeichenko) chose the order of presenting scientific facts in her lectures in such a way that the objective contradictions of the teaching material content were highlighted, causing the cognitive interest of students and the desire to solve the discrepancy. Although the teacher asked questions, they did not necessarily require an accurate answer; they were used by the lecturer to engage the audience in analysis of imaginary problem situations. This method of teaching required from the teacher and students an in-depth analysis of the teaching material.

Another case example is the method of a problem lecture organization with the use of so-called stencils (M. Yakymenko). The entire text of the lecture was presented with a number of intentional omissions. The absence of a certain piece of the text signalled its special importance for the assimilation by students, as well as the fact that its completion required students to process certain information and make generalizations. This stencil-based form of presentation of lecture material freed up time for problematic discussions of other important teaching issues, intensified students' thinking, and at the same time provided for encouraging a pedagogically valuable working dialogue of students and lecturers. This method of organizing teaching activities ensured a high level of students' readiness for the lectures, adherence to the stencil pattern facilitated the assimilation of the lecture material, helped to focus students' attention on the lecture content, encouraged their active learning and intensified their intellectual skills as well as their independent work.

During the 1990s, to enhance students' independent work using PSTL, lecturers involved students in joint discussion and solving educational issues, stimulated student youth to solve problems independently (Blumenfeld et al., 1991). At the stage of setting hypotheses, teachers directed their efforts to ensure that students learn to offer their vision of the problem, to "reflect-in-action and reflect-on-action" (Schön, 1991), to prove their rightness, to choose the most adequate solutions to the problem (Gerzhod, 1992).

Another trend of the 1990s was a rather broad application of case-study. Academic staff were training their students to effectively communicate and utilize knowledge adaptively for addressing professional challenges. Within the framework of PSTL, team members articulated their existing knowledge and identified areas for further learning, facilitating the cultivation and adaptable application of knowledge in problem-solving endeavours. Consequently, this fostered collaborative interactions within communities of practice, providing the students with a productive platform for problem-solving and meaningful dialogue (Lave & Wenger, 1991). Dealing with case-study students encountered numerous intricate challenges necessitating collaboration with their peers. They engaged in activities such as framing the problems, considering diverse perspectives, deliberating solutions, contemplating outcomes, and reflecting on their decisions (Harrington, 1995).

Thus, in the second part of the 20th century PSTL proved to be an essential element of university education due to the accumulated data on its intensified students' cognitive activity fostering. However, the limitations of the study are certain aspects of essential difficulties in the organization of PSTL such as: staff qualification and readiness to design educational problems as they need to be tailored to students' prior knowledge, carefully formulated and relevant to the identified learning outcomes; awareness of the peculiarities of each stage of the problem-solving process; work overload and time it takes to plan teaching procedure and prepare course materials and necessary resources.

Conclusions.

Thus, the results of the study provide useful insights into the history of PSTL that allowed us to characterize its development in educational history through essential ideas of outstanding thinkers and educators, and determine its specifics at the tertiary level teaching and learning practice in the second part of the 20th century.

1. The analysis of modern scholarly ideas on the definition of PSTL has allowed us to single out the following specific components of this concept: student-centred nature, directed at students' intellectual development, involvment in active creative thinking, focused on the cognition paths and methods of creative activity.

2. Summarising the research data on the evolution of PSTL ideas in the history of Pedagogy, the conclusion has been drawn that 1) PSTL ideas advancements were strongly linked with the efforts of individual outstanding thinkers, educators, public personalities and teachers of different historic periods; 2) PSTL evolution may be divided into two periods: I. Intuitive PSTL ideas development; II. PSTL ideas development based on theoretical findings; 3) intuitive PSTL ideas were close to child-centred concepts, directed at intellectual development as a reaction to dogmatic methods of teaching and became predecessors for the current PSTL framework; 4) the period II of PSTL ideas development is characterized by a significant increase in the number of studies; 5) researchers of the period II delved into the structure of knowledge, the structure of thought processes, stages of cognitive development, the significance of the problem case in thinking and learning, effectiveness of PSTL, the impact of problem-solving on one's intellectual potential; 6) PSTL ideas development

based on theoretical findings were suggesting teaching that could both activate students' learning and develop their cognitive abilities.

3. The research data on peculiarities of PSTL application at the tertiary level in the second half of the 20th century suggest that: 1) PSTL became an essential teaching approach in higher education institutions; 2) PSTL were being implemented in all kinds of classes: lectures, practical and laboratory classes as well as students' individual work; 3) PSTL aimed to develop the existing teaching methodologies and techniques, to work out teaching models allowing students to reveal their own initiative and engagement in learning, critical thinking, knowledge retention and providing for their independent learning; 4) the pedagogical success of PSTL nevertheless was associated with the individual aspirations of university staff for arranging the educational setting promoting students' active participation in the process of teaching and learning.

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Історія еволюції проблемного методу викладання та навчання

Анотація. *У статті розглядається розвиток проблемного методу в історії педагогіки як у теорії, так і на практиці. Метою рукопису є охарактеризувати історію розвитку ідей проблемного викладання та навчання, а також з'ясувати та проаналізувати їх впровадження й використання в практиці викладання у закладах вищої освіти у другій половині XX століття. При проведенні дослідження використано методи: 1) теоретичного рівня (аналіз, синтез, узагальнення) для уточнення визначення поняття, виділення змін в основних ідеях проблемного методу протягом історичного суспільного*

розвитку, висвітлення застосування методу проблемного навчання в університетах у другій половині минулого століття; 2) методи історичного дослідження (історіографічний, хронологічний, логіко-історичний, історико-типологічний) для характеристики розвитку ідей проблемного навчання в історичному аспекті, визначення їх сутнісних проявів. Результати дослідження виявили, що проблемне навчання сприймається як процес розв'язання студентами пізнавальних і практичних задач, що стимулює їх творчу та розумову діяльність, сприяє активній участі у навчанні. Проблемний метод навчання, що виник в Стародавній Греції, був розроблений на основі наукових розвідок і педагогічної практики відомих історичних діячів і прогресивних педагогів і пройшов довгий шлях у своєму розвитку. Новизна роботи полягає в узагальненні історичної еволюції ідей проблемного викладання та навчання в освіті, запропонованій періодизації їх розвитку на основі ключових положень методу, що охоплюють структуру мисленнєвої діяльності, важливість проблемних ситуацій у процесах мислення і навчання, вплив вирішення навчальних проблем на інтелектуальний розвиток, у висвітленні досвіду впровадження проблемного методу у вищій освіті другої половини XX ст. Великий потенціал проблемного методу широко використовується у викладацькій та навчальній практиці вищої освіти. Ідеї проблемного викладання та навчання та накопичений педагогічно цінний досвід їх реалізації у вищій освіті створюють цінну теоретичну базу та засоби навчання для формування інтелектуальної та професійної компетентності майбутніх спеціалістів, що забезпечує та підвищує якість вищої освіти.

Ключові слова: *історія педагогіки; вирішення проблем; навчальний метод; вища освіта; студенти*

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Development of natural knowledge as a basis for the organization of agricultural research in the forest-steppe zone of Ukraine (1st quarter of the 20th century)

Abstract. *The use of innovations and information technology approaches in the agricultural sphere of Ukraine under conditions of global influence has been based on the results of multifaceted long-term research. Our goal was to reveal the peculiarities of the formation of Ukrainian natural science knowledge in historical retrospect using problem-chronological and comparative-historical methods. The analysis of the development of agricultural zoning of the territory of Ukraine has been justified by its theoretical and methodological content, which has served as the scientific basis for the organization and formation of agricultural science and research in the first decades of the 20th century. Attention has been focused on the need for an in-depth study of the peculiarities of different territorial parts of the Russian Empire of the country in connection with the problem of geographical division and the growing demands of economic development. The first developments of geographers and soil scientists regarding the division and mapping of the soil cover of Ukraine on maps have been disclosed, among which is the work of V. V. Dokuchaev, as the author of the mapping technique and theoretical justification of the phenomenon of natural zoning. The work of his follower G. I. Tanfilieva became one of the first attempts at a comprehensive characterization of Ukrainian lands, taking into account zonal and provincial differences. The works of P. A. Tutkovskyi, K. G. Vobloh and other scientists, developers of agro-soil, agro-climatic, geobotanical, geomorphological and physical-geographical zoning of the territory of Ukraine. Based on the gathered sources, data*

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regarding the attempt to establish an agricultural experimentation structure during the first quarter of the 20th century in the Forest-Steppe zone of Ukraine, according to the regional principle, are provided. This initiative involved the operation of two regional agricultural research structures in slightly different areas of the Forest-Steppe. In the right-bank part, agricultural experimentation was carried out by the Kyiv Agricultural Research Station with a number of district institutions, while the left-bank part was served by the Kharkiv Agricultural Research Station, district and specialized research institutions. Accumulated in the first decades of the 20th century natural science experience contributed to the development of theoretical and methodological tools for the further development of agricultural science and research in Ukraine.

Keywords: *history of science; natural conditions of Ukraine; zonal division of the territory; natural and agricultural zoning; marginal principle; agricultural experimentation*

Introduction.

Natural conditions and regional natural-climatic features play a predominant role in the functioning and scientific-technical support of the agricultural sector in every country worldwide. Global changes in average temperatures, and consequently in the accumulation of heat, have a noticeable impact on established classification markers. According to some sources, a 1°C increase in temperature in Ukraine leads to a shift of the agro-climatic zone boundary towards the north by 100 km (Ivaniuta, Kolomiiets, Malynovska, & Yakushenko, 2020, p. 17). Further potential climate changes due to global warming by 1.5°C and their consequences for the world's ecosystems are outlined in the report of the Intergovernmental Panel on Climate Change (2018), the main conclusion of which emphasizes the urgent need for a global reduction in anthropogenic greenhouse gas emissions (Rogelj et al., 2018). In the absence of adaptation to the consequences of climate change, things like human health, access to water, and food security are becoming the most vulnerable. The agriculture of countries worldwide, including Ukraine, undergoes fundamental changes in the assortment of agricultural crops and, overall, in the innovation and technological processes of agricultural production. In this context, there is a need to refer to the historical roots of global experience and the modern mechanism of providing production processes in the agricultural sector of Ukraine with innovative technologies.

The establishment of agricultural science and research in leading countries occurred several decades earlier than in Ukrainian territories. The emergence of research institutions networks in the USA and Europe was primarily facilitated by agronomic needs based on centuries-old practical experience with soils and plants. The application of agronomic techniques depending on natural conditions was first mentioned in ancient Roman works by Marcus Varro, Lucius Columella, and others. The main impetus for the development of natural sciences, including soil science and plant science, came from the fundamental research of German chemist Justus von Liebig, Swiss botanist Jean Senebier, French scientist Jean-Baptiste Boussingault, and others (Mykhailychenko, 2013). According to the natural-climatic conditions of a particular country, specialization in agricultural production and its scientific support

was formed through private initiative based on private property. By the end of the 19th century, agricultural research had emerged from higher sectoral education and become an integral part of natural sciences.

The development of agricultural science in the USA and Europe had a significant impact on the emergence of agricultural experimentation in Ukraine. At the end of the 19th and the beginning of the 20th century, research institutions established on Ukrainian territory received equipment and scientific literature from European countries, seed materials from the USA and Canada, and talented youth, upon completing university education, were sent abroad to deepen their knowledge and enrich their experience. Overall, until the 1920s, Ukraine did not face issues regarding the compatibility of methodological approaches and statistical data processing in research with global scientific standards. Therefore, by 1914, through the efforts of scientists, the gap had been bridged, overcoming several decades of lagging behind.

The system of scientific support for the development of the agricultural sector of Ukraine has undergone a complex path of transformations, overcoming political, socio-economic barriers at various stages of its development, with the transient influence of external and internal factors. In different periods of the formation of the theoretical-methodological and scientific-organizational foundations of this system, various natural factors or components of the process that exerted a generating influence on its development played a leading role (Zubets, 2004). Modern researchers argue that in the first decades of the 20th century, which marked a stage of formation for most of its natural science directions, including agricultural science and research in Ukrainian territories, considerable attention was paid to studying the issues of natural-historical and natural-agricultural zoning of the territory (Verhunov, 2021; Shchebetiuk, 2017). The materials collected at that time and their analysis contributed in many aspects to the construction or even laid the groundwork for agricultural experimentation in Ukraine, subsequently influencing the creation of new technologies, innovative models, and more.

The problem of territorial zoning in Ukraine has an interdisciplinary nature, and therefore, the current state of its scientific development is characterized by a diversity of expertise. Specifically, the analysis conducted by modern researchers of publications during Ukraine's independence era indicates the absence of a unified and widely accepted scheme of economic zoning, which is constantly evolving and improving, like other types of zoning (Chmyrova & Fediai, 2013). Primarily, the analysis and priorities of the scientific foundations of agro-industrial production in Ukraine are conducted within the framework of three zones (Polissia, Forest-Steppe, Steppe) corresponding to the natural-climatic conditions (Zubets, 2004). Generally, natural-agricultural zoning based on agro-climatic features in the form of taxonomic units (belts, zones, regions, districts, etc.) is applied (Martyn, Osypchuk, Chumachenko, 2015). Among the scientific works on this issue in the context of historical perspectives, in addition to those mentioned, there are also studies by researchers (Demuz & Borodai, 2022) with partial coverage of specific theoretical-methodological and scientific-organizational aspects of the establishment and activities of scientific institutions in the

first decades of the 20th century in Ukrainian territories and specifically in the Forest-Steppe zone.

The aim is to highlight the peculiarities of the initiation and further development of natural-agricultural zoning of Ukrainian territories through the contributions of prominent scientists. Additionally, to elucidate the regional principle of organizing agricultural experimentation in accordance with the contemporary zoning system, using the Forest-Steppe zone of Ukraine as an example.

Research Methods.

This historical research is grounded in the application of overarching scientific principles such as objectivity, systematicity, historicism, comprehensiveness, and others. Pursuing the goal of impartially generalizing the results of studying the peculiarities of creating agricultural zoning in Ukraine, the works of scientists from the Soviet period were analyzed, avoiding political expediency and ideological bias. Additionally, the study involves incorporating the scientific contributions of scholars from the Russian Empire who made contributions to the development of physical-geographical zoning of Ukrainian territories within the empire during its initial stages. The accumulated natural science knowledge facilitated the theoretical justification of the relationships between various components of climatic and natural zonality and the directions of agricultural production. Working in related fields, scientists designed a system of scientific support for agricultural management based on zonal division.

The most weight is given to the subject-chronological and comparative-historical methods that we have applied. Their synthesizing role in reflecting the progressive development of natural knowledge has contributed to understanding individual phenomena, events, and processes in dynamics. The use of the problem-chronological method has allowed studying phenomena in temporal spatiality, highlighting finer aspects in chronological order according to historical background, as well as generalizing the whole picture and its individual components. By tracing the process from the theoretical substantiation of zonality to the identification of natural zones, we come to conclusions about specific soil-climatic conditions that interact with zonal soil types, and ultimately with the directions and forms of agricultural research and production.

The comparative-historical method allows us to identify or clarify the essence of little-studied phenomena, particularly those not yet confirmed. Therefore, its application by us is evident and has allowed us to delineate and characterize the features of accumulating natural knowledge, their development within the framework of a scientific-organizational approach to agricultural experimentation in the first decade of the last century in the territories of Ukraine, particularly in the Forest-Steppe zone.

Tracing the development of natural knowledge through the analysis of scientists' scientific contributions allowed the application of the principle of personification and the biographical method. The identification of creative achievements and scientific heritage confirms the step-by-step overcoming of scientific problems, the

implementation of new scientific developments into practice, and the acquired scientific knowledge gains signs of individuality, uniqueness.

Results and Discussion.

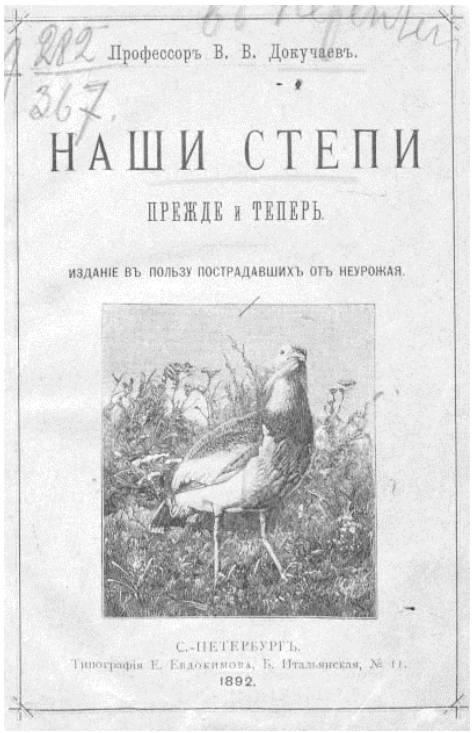
In the second half of the 19th century, conditions for the initiation of agricultural research were historically established on the territory of modern Ukraine. Among these, we note private initiative through the activities of societies and subsequent state support in the form of various legislative initiatives. There were many interacting factors contributing to the emergence of theoretical-methodological factors in the development of agricultural science and research. The formation of scientific-organizational foundations occurred almost simultaneously with the accumulation of natural knowledge. At the beginning of the 20th century, in Soviet Ukraine, an attempt was made to create a structure for agricultural research based on the so-called regional principle, which was based on the natural-historical zoning of the territory. It is noteworthy that the latter has always served as the basis for the structured placement of agricultural production, assessment, and rational use of land resources, etc.

Natural-agricultural zoning is based on agroecological principles, reflecting all the bioclimatic natural resources of specific territories with a prioritized interpretation of land resource utilization in the agricultural sector. Its characteristic features are filled with a unified content, which lies in the absorption of solar energy by various agricultural crops. Scientific knowledge about natural conditions and available resources complements natural-agricultural zoning, considering the need for scientific support in managing the agricultural sector. Therefore, this zoning combines administrative-territorial boundaries with natural-climatic regions, administrative formations according to local natural conditions, etc.

For over a century, scientists have been studying the issue of natural-agricultural zoning, the prerequisites for which began to emerge after the abolition of serfdom in 1861. Increasing demands for economic development and a pressing need for clear administrative management brought to the fore the problem of geographical division of the territory of the Russian Empire. The already accumulated scientific knowledge and experience were actively supplemented by a deepened understanding of the characteristics of various territorial parts. The initial schemes of agricultural zoning in the European part of the Russian Empire delineated the chernozem, southern non-chernozem, and northern non-chernozem latitudinal agricultural belts. Soil maps by geographers-economists such as K. S. Veselovsky (1819–1901) (1851) and V. I. Chaslavsky (1834–1878) (1879) reflected the soil cover of Ukraine with predominance of chernozems (Dokuchaev, 1879). The characteristic sandy soils, loams, and sandy loams for the north, and loamy, loamy chernozems for the south of Ukraine were also noted. The theoretical-methodological content for the aforementioned maps was developed by renowned soil scientists such as V. V. Dokuchaev (1846–1903), G. I. Tanfilyev (1857–1928), M. M. Sibirtsev (1860–1900), and others.

V. V. Dokuchaev not only developed a methodology for mapping soil cover based on field research but also theoretically substantiated the phenomena of natural zonality

by generalizing existing materials at that time (Dokuchaev, 1879, 1892). Publishing the results of research on the close relationships between "climate, soils, animal and plant organisms" and nature zones, the scientist initiated the process of zonal study and division of the natural space of Ukraine (Fig. 1, a, b). Subsequently, researchers such as G. N. Vysockij, O. I. Voieikov, and others continued to investigate and develop Dokuchaev's zonal approach, adhering to a single indicator (the ratio of heat and moisture) in assessing biological productivity. The establishment of natural-agricultural zoning of Ukraine was facilitated by organized expeditions of the Poltava, Chernihiv, and Podillia zemstvo expeditions from 1882 to 1916. The results obtained during that time laid the groundwork for the development of soil science and other directions, including landscape studies, physiographic zoning, and so on.


Профессоръ В. В. Докучаевъ.

НАШИ СТЕПИ

ПРЕЖДЕ и ТЕПЕРЬ.

ИЗДАНІЕ ВЪ ПОЛЬЗУ ПОСТРАДАВШИХЪ ОТЪ НЕУРОЖАЯ.

С.-ПЕТЕРБУРГЪ.
Типографія Е. Евдокимова, Б. Итальянская, № 11.
1892.

Figure 1, a. The work of V. V. Dokuchaev, 1892.

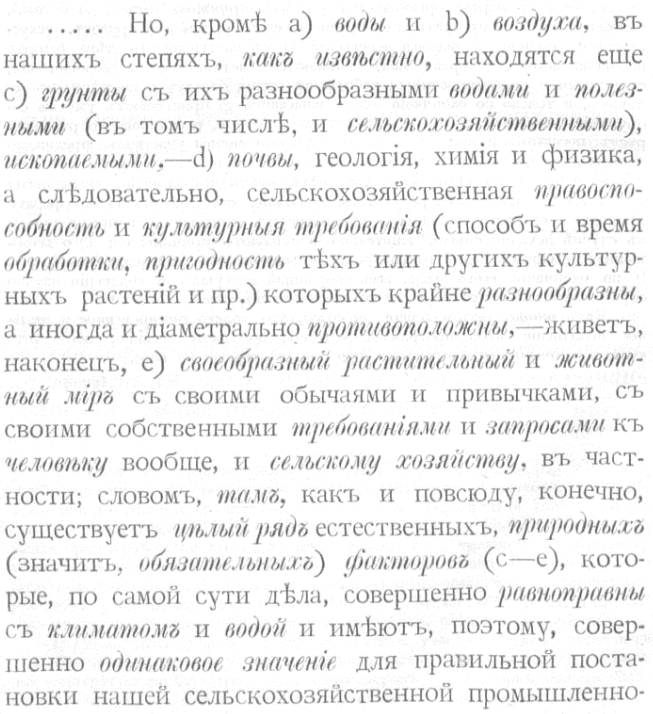
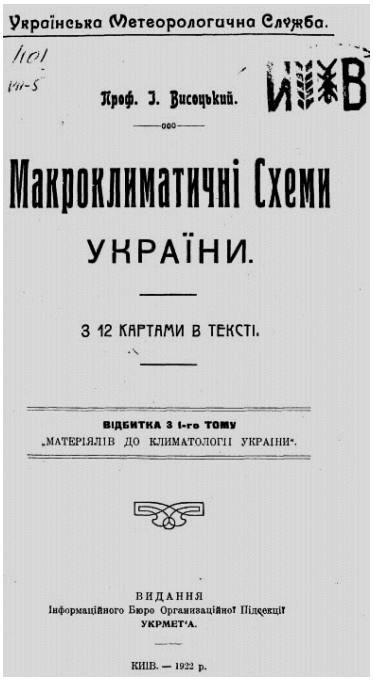

..... Но, кромѣ a) *воды* и b) *воздуха*, въ нашихъ степяхъ, *какъ извѣстно*, находятся еще c) *грунты* съ ихъ разнообразными *водами* и *полезными* (въ томъ числѣ, и *сельскохозяйственными*), *ископаемыми*,—d) *почвы*, геологія, химія и физика, а слѣдовательно, сельскохозяйственная *правоспособность* и *культурныя требованія* (способъ и время *обработки*, *пригодность* тѣхъ или другихъ культурныхъ растеній и пр.) которыхъ крайне *разнообразны*, а иногда и діаметрально *противоположны*,—живетъ, наконецъ, e) *своеобразный растительный* и *животный міръ* съ своими обычаями и привычками, съ своими собственными *требованіями* и *запросами* къ *человѣку* вообще, и *сельскому хозяйству*, въ частности; словомъ, *тамъ*, какъ и повсюду, конечно, существуетъ *цѣлый рядъ* естественныхъ, *природныхъ* (значитъ, *обязательныхъ*) *факторовъ* (c—e), которые, по самой сути дѣла, совершенно *равноправны* съ *климатомъ* и *водой* и имѣютъ, поэтому, совершенно *одинаковое значеніе* для правильной постановки нашей сельскохозяйственной промышленно-

Figure 1, b. A fragment from the work of V. V. Dokuchaev on natural conditions (Dokuchaev, 1892, p. 118).

Climatologist and geographer O. I. Voieikov (1842–1916) also contributed to the study of chernozems and other types of soils, but among his main works is the theoretical justification of climatic zonality alongside natural zonality and directions of agricultural production. Engaged in the problems of agriculture and forestry, the eminent forest scientist G. N. Vysockij (1865–1940) worked on theoretical aspects of physiographic zoning, taking into account the relationships between different components and substantiating zoning schemes based on quantitative indicators of moisture conditions and the relationship of other zonal factors. He proposed a statistical method of grouping territorial units into integrated natural regions, introduced the concepts of locality, microrelief, microclimate, etc. (Vysockij, 1941, pp. 27–30). Subsequently, G. N. Vysockij became a proponent of the idea of geographic

(landscape) zonality, distinguishing four regions (moist forest, transitional forest-steppe, moderately dry steppe, southern dry steppe) (Fig. 2, a, b).


Українська Метеорологічна Служба.

Проф. І. Висоцький.

Макроклиматичні Схеми України.

З 12 КАРТАМИ В ТЕКСТІ.

ВІДБИТКА З І-го ТОМУ „МАТЕРІЯЛІВ ДО КЛИМАТОЛОГІЇ УКРАЇНИ".

ВИДАННЯ Інформаційного Бюро Організаційної Підсекції УКРМЕТ'А.

КИЇВ. — 1922 р.

Figure 2, a. Work by G. N. Vysockij, 1922.

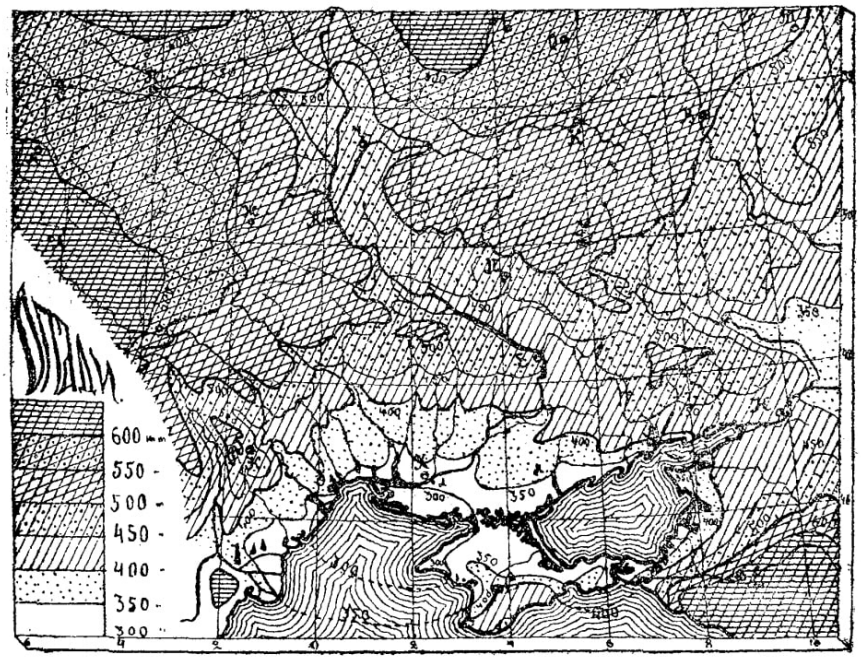


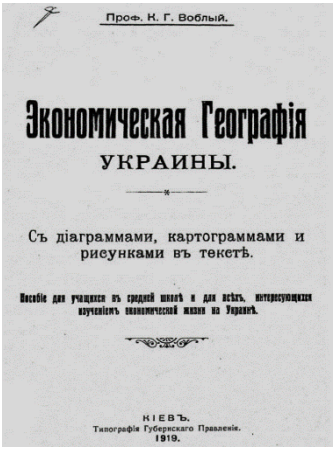
Figure 2, b. The scheme of precipitation distribution taking into account the main features of the relief of Ukraine (Vysockij, 1922, p. 18).

One of the first attempts at a comprehensive characterization of Ukrainian lands, taking into account both zonal and provincial differences, was made by the soil scientist and geographer H. I. Tanfiliev. He justified the division of the East European Plain into "regions," "belts," and "districts" according to the features of zonal distribution of soils and vegetation based on the assertion of the continuity of changes in the composition and physical properties of soils, which in turn affects vegetation (Tanfiliev, 1897). Further application of the hypothesis of the evolutionary path of landscapes proposed by H. I. Tanfiliev served as confirmation, as it was applied in studying the relationship between soils and vegetation of different natural-climatic zones.

Further development of the natural zoning system of Ukraine occurred in the early 1920s with the emergence of natural-geographical works by prominent geologists B. L. Lichkov (1888–1966) and P. A. Tutkovskyi (1858–1930). Based on geological and geomorphological features, B. L. Lichkov identified seven regions (forest, sandy, terminal moraine, moraine, island mountains, loess, and granite) considering their genesis (Lichkov, 1922). It is noteworthy that P. A. Tutkovskyi referred to the identified units as "landscapes" and directly linked their types (forest, sandy, terminal moraine, moraine, drumlin, loess, granite landscapes, landscapes of Devonian ridges, and denudation island mountains) with human activity, primarily everyday life and culture (Tutkovskyi, 1922). In the 1920s, a more refined and still relevant scheme of Ukrainian land division was substantiated by Ukrainian geographer S. L. Rudnitsky (1877–1937), described in two parts of the work "Foundations of Ukrainian Land Studies" (Rublov, 2018). The scholar firmly believed in aligning natural zoning with

physical-geographical and especially ethnographic principles, as well as historical and political boundaries.

Approximately during the same period, the economist and geographer K. G. Voblyj (1876–1947), in a brief characterization of the general geographical conditions of Ukraine, distinguished three natural-historical regions (Voblyj, 1919, p. 16) (Fig. 3, a, b).


Проф. К. Г. Воблый.

Экономическая Географія
УКРАИНЫ.

Съ діаграммами, картограммами и рисунками въ текстѣ.

Пособіе для учащихся въ средней школѣ и для всѣхъ, интересующихся изученіемъ экономической жизни на Украинѣ.

КІЕВЪ.
Типографія Губернскаго Правленія.
1919.

Figure 3, a. Textbook by K. G. Voblyj, 1919.

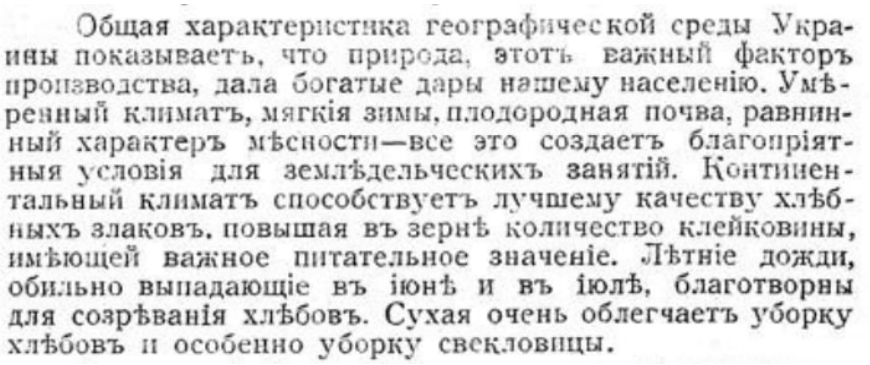

Общая характеристика географической среды Украины показываетъ, что природа, этотъ важный факторъ производства, дала богатые дары нашему населенію. Умѣренный климатъ, мягкія зимы, плодородная почва, равнинный характеръ мѣстности—все это создаетъ благопріятныя условія для землѣдельческихъ занятій. Континентальный климатъ способствуетъ лучшему качеству хлѣбныхъ злаковъ, повышая въ зернѣ количество клейковины, имѣющей важное питательное значеніе. Лѣтніе дожди, обильно выпадающіе въ іюнѣ и въ іюлѣ, благотворны для созрѣванія хлѣбовъ. Сухая очень облегчаетъ уборку хлѣбовъ и особенно уборку свекловицы.

Figure 3, b. Fragment from the work of K. G. Voblyj (1919, p. 18).

Given the importance of the present aspect of economic opportunities, let us delve deeper into the main points of K. G. Voblyj's description. Thus, the Ukrainian Polissia region (northwestern and northern district) was attributed by the scholar to the northern and northwestern part of Volyn Governorate, Radomysl County of Kyiv Governorate, northern parts of Kyiv, Skvyra, and Vasylkiv Counties, and northern parts of Chernihiv Governorate. Polissia was characterized by high humidity, small temperature fluctuations, a large number of rivers, lakes, and swamps, with predominance of loam. The economy mainly relied on animal husbandry, forestry, and timber rafting. Due to the low productivity of agriculture, grain had to be imported from other governorates. The transition zone from forest to steppe, which encompassed the southern parts of Volyn, Podillia, and Kyiv Governorates, Poltava and Kharkiv Governorates (excluding the southern part of Starobilsk County), was called the Forest-Steppe. The region was characterized by diverse relief, a sufficient number of rivers, and soils predominantly consisting of dark gray loam and degraded chernozem. Agriculture developed through crop farming with a specialization in sugar beet and wheat. The plain part of Ukraine, which also included a part of the Baltsky County of Podillia Governorate, Starobilsk County of Kharkiv Governorate, and the entire territory known as New Russia, was called the Steppe. The plain stretched along the shores of the Black and Azov Seas, with almost no forests but numerous navigable rivers. Coal and ore deposits facilitated industrial development, and the presence of chernozem allowed for successful cultivation of wheat, barley, and vegetable crops. It's worth noting that unlike in Polissia, the Forest-Steppe and Steppe regions were dominated by the population of large cities. However, overall, the moderate climate, mild winters, fertile soil, and flat terrain created conditions for successful agriculture. The continental climate

contributed to the improvement of the quality of grain crops, increasing the amount of gluten, which has important nutritional value. Summer rains allowed grains to ripen in time, and dry autumns facilitated harvesting. The natural conditions of the southern part favored horticulture and viticulture.

The above-mentioned studies of the natural-geographic character indicate the formation of the natural-historical zoning of Ukraine during the first quarter of the 20th century. Somewhat later, a series of Soviet works on comprehensive zoning of the former USSR emerged, where the territory of Ukraine's East European Plain was divided into four zones (forest, forest-steppe, steppe, and arid-steppe) with a characterization of their natural resources in terms of agricultural needs. Directly agricultural zoning of the territory of Ukraine was first presented in the early 1970s in general Soviet works, and in separate publications in 1985 authored by R. G. Derevyanko, D. S. Dobryak, O. P. Kanash, B. S. Noska, and other Ukrainian naturalists. Subsequently, there was an improvement in the methodology of zoning and clarification of the boundaries of natural-agricultural and administrative districts, their coordination, and so on.

Based on the analysis of natural conditions using materials from agro-soils, agro-climatic, geobotanical, geomorphological, as well as physical-geographical zoning of the territory of Ukraine, a unified system of taxonomic units was eventually adopted – zone (5), province (19), district (31), and sub-district (196) (Martyn, Osypchuk, Chumachenko, 2015, p. 28). These taxonomic units of natural-agricultural zoning of the territory of Ukraine serve as a scientific basis for the differentiation of the agricultural sector, its priorities, innovations, and prospects for further development (see Figure 4).

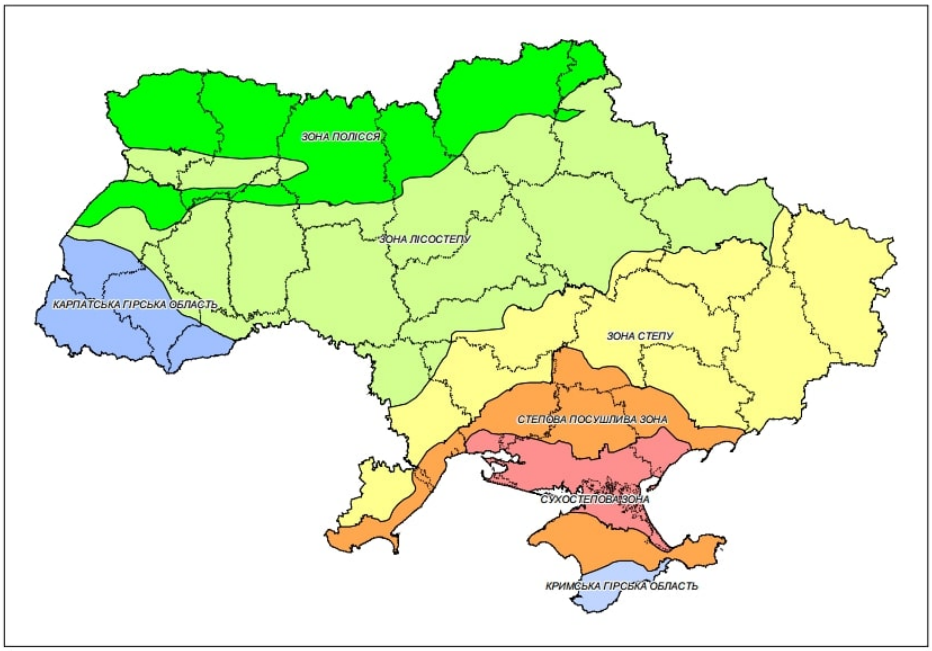


Figure 4. Natural-agricultural zones and mountainous regions of Ukraine (Martyn, Osypchuk, Chumachenko, 2015, p. 62).

In addition to the Land Code of Ukraine (2001), legislative support for natural-agricultural zoning has been provided by the regulatory framework formed in the last decade, mostly through subsequent laws of Ukraine such as "On Land Management," "On Land Valuation," "On Land Protection," "On Environmental Protection," and others. These legislative acts are aimed at fulfilling obligations regarding the rational use of land areas and their responsible protection within various types of agricultural formations, taking into account zoning, or regional division.

The term "zones" or "regions" refers to designated territories based on specific soil-climatic conditions, which in turn shape zonal types of soils, agricultural production, and consequently, systems of agrotechnical and land improvement measures. In this context, examining the scientific and organizational development of agricultural research in the Forest-Steppe zone of Ukraine during the first quarter of the 20th century, we note its conditional division into the right-bank (Kyiv) and left-bank (Kharkiv) Forest-Steppe regions. Overall, as noted by the eminent soil scientist H. H. Makhov (Makhov, 1924) (Fig. 5.a), the results of comparative analysis of natural-historical and natural-agricultural zones not only indicate their correspondence but also genetic zoning, which was conducted through the study of basic natural conditions (Makhov, 1925) (Fig. 5.b). Thus, it can be argued that there were already existing natural knowledge within the framework of zonal characteristics of the territory of Ukraine, which served as the basis for the active development of agricultural research.

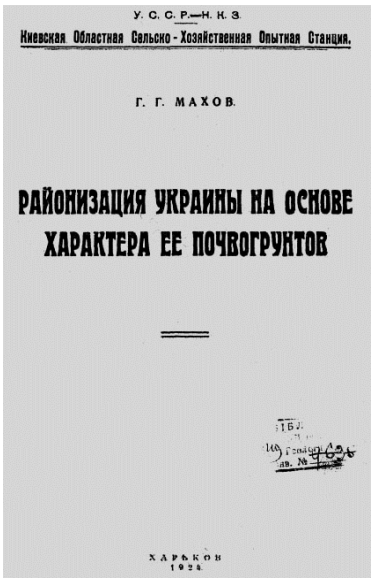

У. С. С. Р.—Н. К. З.
Киевская Областная Сельско-Хозяйственная Опытная Станция.
Г. Г. МАХОВ.
РАЙОНИЗАЦИЯ УКРАИНЫ НА ОСНОВЕ ХАРАКТЕРА ЕЕ ПОЧВОГРУНТОВ
ХАРЬКОВ
1924.

Figure 5, a. Work by H. H. Makhov (1924).

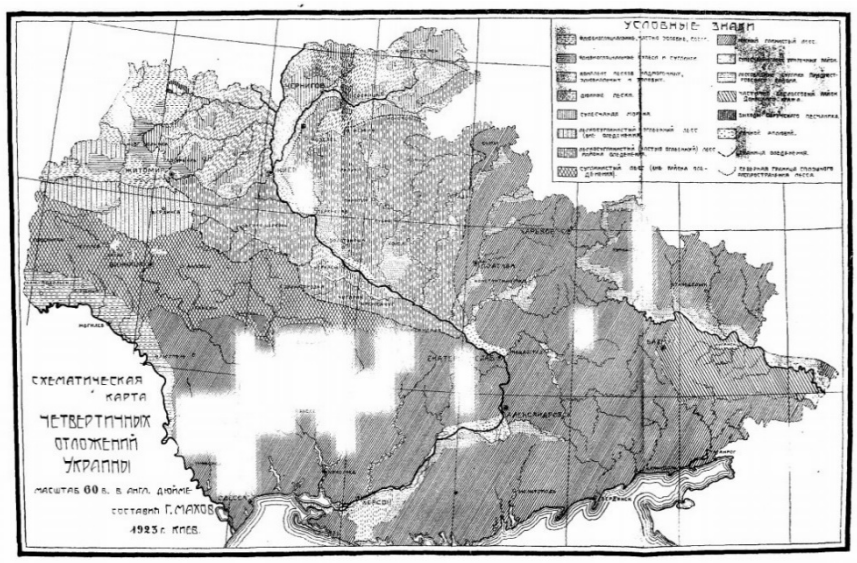
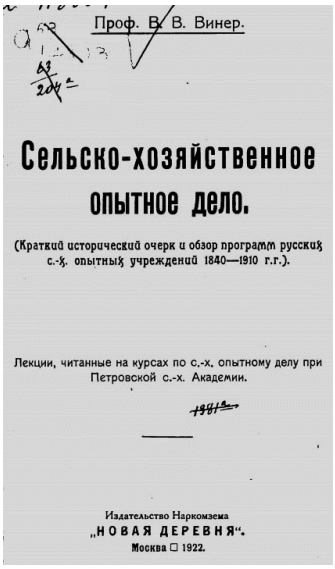


Figure 5, b. Schematic map of soils by H. H. Makhov (1925, p. 57).

Before delving into the specifics of forming the system of agricultural experimentation in the Forest-Steppe zone of Ukraine, it is also worth mentioning the experience of other countries, particularly the practice of organizing comprehensive agricultural research stations in the United States. In each state, a large scientific research institution operated successfully, subordinate to it, with financial support from the Department of Agriculture in accordance with the Adams-Hatch-Parnell Act

(Fig. 6, a, b). Borrowing the experience from the USA and establishing regional agricultural research stations in all natural-climatic zones (Forest-Steppe – Kharkiv, Kyiv; Polissia – Polisska; Steppe – Dnipropetrovska, Odeska) on Ukrainian territories took a considerable amount of time and did not bring the expected results in the long run.


Проф. В. В. Винер.

Сельско-хозяйственное опытное дело.

(Краткий исторический очерк и обзор программ русских с.-х. опытных учреждений 1840—1910 г.г.).

Лекции, читанные на курсах по с.-х. опытному делу при Петровской с.-х. Академии.

Издательство Наркомзема „НОВАЯ ДЕРЕВНЯ". Москва □ 1922.

Figure 6, a. Work by V. V. Viner (1922).

Напомним, впрочем, что и в Европе и в Соединенных Штатах Сев. Америки быстрый рост опытных учреждений относится тоже только ко второй половине восьмидесятых годов, Франция заимствовала план строительства опытного отдела из Германии (под влиянием профессора Грандо, изучавшего перед этим опытное дело в Германии) и могла приступить к осуществлению нового государственного плана только с 1885 года, когда успела оправиться от разгрома 1871 года. Соединенные Штаты имели в то время всего 6 станций, число которых после проведения закона Хатча (в 1887 г.) быстро возросло до 54 (к концу XIX века).

Figure 6, b. Fragment from the work of V. V. Viner (1922, p. 14).

However, it is worth noting that the basis for the developed projects of the network of agricultural research stations by P. A. Kostychev (1894) and V. V. Viner (1908) was the physical and geographical zoning of the territory of the Russian Empire into edges and districts (Shchebetiuk, 2017, p. 110). As V. V. Viner pointed out, its foundation consisted of "…recognized plant regions corresponding to botanical-geographical, soil, and climatic regions," followed by division into districts according to "natural-historical conditions, statistical data characterizing the distribution of land use and field crops, and economic principles" (Viner, 1921, p. 14). Despite the fact that the project of V. V. Viner, which was taken as a basis, was coordinated with the professional communities of researchers in Kharkiv, Kyiv, Odesa, and other cities of Ukraine, state planning of agricultural experimentation based on the regional principle was attempted to be implemented or adapted over almost two decades.

As of the mid-1920s, the organization of agricultural research already had a certain structure, built on a regional (zonal) principle. The Forest-Steppe zone of Ukraine stretched south of the glacial deposits boundary, covering an area of 20.291.100 thousand hectares. The Dnipro River conventionally divided the territory into two parts with different relief, subsoil, soil cover, and vegetation. During this period, the Kyiv part included the southwestern part of Volyn, Podillya, and a significant part of the Kyiv governorate. The area was situated at an altitude of 150–400 meters above sea level, with gray forest soils, degraded black soils, and so on. The main functions of scientific support for agriculture in the right-bank Forest-Steppe zone were entrusted to the Kyiv Regional Agricultural Research Station named after

Ya. M. Dudnyk, established in 1914 (Domrachov, 1927, p. 136). Various departments (agronomy, agrochemistry, breeding, meteorology, entomology, phytopathology, animal husbandry, economics, and adaptation) worked on different issues, including soil fertility, plant protection, fodder production, etc. Prominent scientists such as agronomist K. K. Gedroits (1872–1932), who developed the basics of colloid chemistry of soils and principles of their classification based on exchangeable cations composition, theory of salinity reclamation, and others; agronomist and plant physiologist O. I. Dushechkin (1874–1956), author of rational fertilization methods and the necessity of early spring nitrogen fertilization for plants, among others; agrarian scientist S. P. Kulzhynskyi (1880–1947), organizer of agricultural research, developer of the method of forced propagation of breeding potato varieties by buds, and others; agronomist O. K. Filipovskyi (1889–?) – author of the first textbook for higher agricultural institutions "Agricultural Research" (1928), among others, worked fruitfully at the institution. Research activities in this area were also conducted by district agricultural research stations with different soil types, such as Nosivska, Mokiyivska, Umanska, Chortoryiska, Vinnytska, as well as Mliivska fruit and vegetable research station.

The territory of the Kharkiv region (left-bank Forest-Steppe) was situated at an elevation of 60–250 meters above sea level, with a conditional division into the lower Dnieper region with the near-Dnieper area, the western part of Poltava region, and elevated terrain, which included part of the Poltava region and the entire Kharkiv region. The responsible function of scientific support for agricultural production in this region was entrusted to the Kharkiv Regional Agricultural Research Station. Departments (agronomy, agrochemistry, meteorology, breeding, animal husbandry, entomology and phytopathology, horticulture, gardening, economics, and adaptation) worked on issues such as soil cultivation and fertilization, investigated agrochemical properties of soil and plants, crop rotations, varieties of agricultural crops, and so on. They studied pests, diseases of agricultural plants, and developed methods for their protection, as well as specific issues of horticulture, gardening, economics, etc. It is worth noting that scientific staff of district agricultural research stations, located on different types of soil (Sumy, Poltava, Chervonograd, Drabiv), and individual specialized research stations (Kharkiv Beekeeping, Lubny Medicinal Plants, Lokhvitsa Tobacco) were actively involved in agricultural experimentation in the region. Among the most significant achievements of this period, the breeding and successful testing of new varieties of winter and spring wheat on the territory of Poltava and Kharkiv regions can be mentioned, such as Bilozerna 0676, Yuriivka, etc. (Domrachov, 1927, p. 139). These mentioned varieties of winter wheat, particularly Bilozerna 0676, became widespread throughout the territory of the Ukrainian Republic.

Overall, in the territory of both right-bank and left-bank Forest-Steppe, as well as in the rest of Ukraine, district agricultural research stations developed and implemented scientific programs according to the specific needs of various sectors of agriculture in the region. Conducting various analytical work, elaborating on theoretical and methodological aspects of agricultural experimentation, such as determining natural

and agricultural factors in a given zone within districts, fell within the prerogative of regional stations.

The organization of scientific support for the development of the agricultural sector was carried out centrally, and accordingly, management structures also developed their own framework. In 1918, the coordinating body, the Agricultural Scientific Committee of Ukraine (ASCU), began its scientific and organizational activities. In 1921–1922, under the People's Commissariat of Agriculture of the Ukrainian Soviet Socialist Republic (PCA USRR), a research department was established under the leadership of D. V. Domrachov. Additionally, in the previous two years, the All-Ukrainian Bureau of Research Affairs, the Bureau of All-Ukrainian Congresses, and the All-Ukrainian Committee for Agricultural Research Affairs (1921) were created. Besides these central bodies, regional administrations of agricultural research affairs began operating in 1921. Thus, the principle of zoning territories was extended to the management apparatus of the agricultural experimentation system. By 1922, the network of research institutions had reached about fifty, but the scale and the discursive format of the organizational process, as well as numerous economic difficulties, hindered the establishment of effective operations (Shchebetiuk, 2017).

In the late 1920s, increasing demands of the socio-economic situation, taking into account the low level of material provision, led to a reassessment of the existing regional organization of agricultural experimentation and the search for a more rational structure that could avoid previous shortcomings, particularly of a methodological nature. For many debating parties, the gradual institutionalization of scientific and organizational forms for conducting agricultural research affairs, which eventually occurred, served as a guiding principle.

According to the project of the PCA USRR and various additions from state institutions, by the end of the 1920s, a system of scientific support for the agricultural sector was being established. Its basis comprised research institutes of various types and levels of subordination. Looking at the situation in the focus zone of the Forest-Steppe of Ukraine, we can mention republican-level institutes such as soil science, plant protection, fodder, forestry, mechanization and electrification, scientific-practical veterinary medicine, organization and economics of socialist agriculture, and animal husbandry. Among the specialized institutes of all-Union significance were those for grain farming, dairy farming, medicinal and aromatic plants, fruit and berry production, pig farming, sugar beet farming, and sugar-bearing plants. The structure of agricultural research was complemented by zonal stations, including in the Forest-Steppe zone such as those for beekeeping, vegetable production, hemp and flax production, fodder production and fodder plants, rabbit breeding, onions and pastures, dairy farming, meat animal husbandry, poultry farming, sericulture, and sugar beet farming. Furthermore, supporting points and research farms were also established, mostly based on institutions that did not fit into the general structure. The entire process of institutionalization, which lasted almost a decade, contributed to the transition of agricultural research to an academic form, formally confirmed in 1931 by the establishment of the All-Ukrainian Academy of Agricultural Sciences. In subsequent

years, the Soviet model of the structure of scientific support for the agricultural sector of Ukraine underwent constant contradictory reorganizations under the influence of centralization and ideological trends. In contrast, the global natural science and its coordinating links within university education successfully developed based on scientific and organizational principles built on private initiative and private ownership.

Conclusions.

In the face of global changes in natural habitat conditions, there is a heightened demand for a reassessment of the evolutionary progress of natural sciences knowledge and its application in ensuring food security. The establishment of theoretical and practical foundations for scientific support of the agricultural sector's development in leading countries occurred in the second half of the 19th century and reflects a systematic process of successful implementation of state policy under conditions of private ownership.

The scientific basis for the differentiation of the agricultural sector and the implementation of technological solutions in Ukraine was the accumulation of experience in agro-soil, agro-climatic, geobotanical, geomorphological, and physico-geographical zoning of the territory. Natural-agricultural zoning occupied a leading position in the variable structure of the scientific-methodological support of state agriculture in Ukrainian territories. However, the adoption of American experience during the establishment of scientific-organizational forms of agricultural experimentation in the first decades of the 20th century, along with attempts to achieve maximum profitability of farms under state ownership, proved unproductive for various reasons. Nevertheless, the achievements of Ukrainian scientists have demonstrated the ability of science to accumulate experience, the regularities of natural science knowledge movement, and socio-cultural changes, as well as produce new knowledge about the mechanisms of new technological approaches in various spheres of development in Ukraine, including in the direction of innovative scientific methodology.

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Розвиток природничих знань як основа організації аграрного дослідництва у зоні Лісостепу України (І чверть ХХ ст.)

Анотація. *Використання інновацій та інформаційно-технологічних підходів в аграрній сфері України за умов глобального впливу ґрунтується на результатах різнобічних довготривалих досліджень. Розкрити особливості становлення українських природознавчих знань в історичній ретроспективі за допомогою застосування проблемно-хронологічного і порівняльно-історичного методів і стало нашою метою. Аналіз розвитку сільськогосподарського районування території України аргументовано його теоретико-методологічним наповненням, що слугувало науковим підґрунтям організації й становленню у перші десятиліття ХХ ст. аграрної науки і дослідної справи. Акцентовано увагу на посталій тоді потребі поглибленого вивчення особливостей різних територіальних частин Російської імперії у зв'язку з проблемою географічного поділу і зростаючими запитами економічного розвитку. Розкрито перші напрацювання географів і ґрунтознавців щодо поділу й відображення на картах ґрунтового покриву України, серед яких вирізняється доробок В. В. Докучаєва, як автора методики картографування і теоретичного обґрунтування явища природної зональності. Праця його послідовника Г. І. Танфільєва стала однією з перших спроб комплексної характеристики*

українських земель з урахуванням зональних і провінційних відмінностей. Виокремленню єдиної системи таксономічних одиниць (зона, провінція, округ, район) природно-сільськогосподарського районування посприяли праці П. А. Тутковського, К. Г. Воблого та інших учених, розробників агроґрунтового, агрокліматичного, геоботанічного, геоморфологічного та фізико-географічного районувань території України. Розглянуто спробу створення впродовж першої чверті ХХ ст. структури аграрного експериментаторства в зоні Лісостепу (правобережний і лівобережний краї) України за крайовим принципом, який передбачав функціонування двох крайових сільськогосподарських дослідних структур у дещо відмінних краях Лісостепу. У правобережній частині аграрне експериментаторство здійснювала Київська сільськогосподарська дослідна станція з низкою районних установ, а лівобережну обслуговувала Харківська сільськогосподарська дослідна станція, районні та спеціалізовані дослідні установи. Накопичений у перші десятиріччя ХХ ст. природознавчий досвід сприяв виробленню теоретико-методологічного інструментарію подальшого розвитку аграрної науки й дослідної справи в Україні.

Ключові слова: *історія науки; природні умови України; зональний поділ території; природно-сільськогосподарське районування; крайовий принцип; аграрне експериментаторство*

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The national and ecumenical career of the eminent Greek agriculturist Ioannis Papadakis

Abstract. *This article reviews in depth life, works and spirit of the eminent Greek agriculturist Ioannis Papadakis. Primarily, it shows the way Papadakis, working mainly as a plant breeder from 1923, tackled the major problem of Greek agricultural history, namely the accomplishment of Greece's wheat self-sufficiency, by inventing new, high-yielding, varieties of great adaptability to the adverse soil and climatic conditions of the country. The solution to this problem is regarded as an outstanding achievement of agricultural research and policy in Greece. However, today, judging in the comfort of time-distance from the events of the Mid-war period and in an effort to interpret the outcome of this exercise and its implications on the development of Greece's agricultural economy, one could say that the pursued single-cultivation of wheat with a simultaneous decrease in the area devoted to growing of certain crops destined for forage or other animal feed resources, this had a negative effect as regards the imbalanced evolution of the various branches of agricultural production in favor of wheat. Therefore, this partial approach brought about a dramatic delay in the development of the animal production sector, contributing to the huge exchange deficit for importing animal products in contemporary Greece. Nevertheless, Ioannis Papadakis had received the mandate by the Hellenic State for achieving the country's wheat self-sufficiency and in this respect was successful and worked for it impeccably. Furthermore, in 1947, after having been invited by Argentina to construct its ecological map, he emigrated permanently to that country. Papadakis had published (1938) in French the first of its kind book worldwide "Agricultural Ecology". He was also invited to write the entry "Soils" in Encyclopaedia Britannica. He worked for Food and Agriculture Organization of the United Nations and studied agricultural questions in South America, West Africa, South-East Asia and elsewhere. He wrote research and review papers on several aspects of agriculture, including field crops, plant breeding, biometry, soil science, agricultural ecology as well as rural economy and policy. This article concludes with some of Papadakis' thoughts, stemming from*

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his own wisdom of experience, accumulated from his long service in Greece, Argentina and elsewhere in the world.

Keywords: *Greece; wheat self-sufficiency; Argentina; soil mapping; world agricultural ecology*

Introduction.

Greece has a long and eventful history (Clogg, 2002). Being a mountainous country, with Mediterranean climate, could not nourish large population, so that, since ancient times, big cities, like Athens, imported considerable part of wheat required from abroad. This lack of wheat turned Greeks to the sea, reached naval supremacy, made colonies round the Mediterranean basin, and the Black Sea, thus giving the Hellenic civilization to the humanity. Later on, in Byzantium, the torch was taken by Thessaloniki and Constantinople, which were distinguished in the roads of international sea trade.

The lack of wheat was the most crucial question to be answered in Greek agricultural history. Even if it seems oxymoron, starting-point for a brave uplift for Greece in this sector, was the most tragic year of its modern history, i.e. 1922. When one refers to Greece of the beginning of twenties, he talks about a country which did not have any possibilities for increase of production. Greece in 1922 was coming out from the catastrophe in Minor Asia, which had followed a ten year period of continuous wars. This poor country of 5.5 million people, with dominant problem that of the need for wheat self-sufficiency, had to nourish 1.3 million of ragged refugees from Minor Asia, who had to share the little cultivated land with the local peasants who produced mainly for self-maintenance and the landless ones who were still waiting for settlement, in the framework of agrarian reforms which took place in 1910s. One could not imagine worse combination of adverse conditions for Greece, than those of 1922 (Eddy, 1931; Mazower, 1987, 1991). It was in this tragic scene, where, as an expression of contradiction which characterizes the Hellenic race, the great agricultural epic of the Inter-war period was born. Following the Parliamentary Law for the creation of "Central Agricultural Co-operatives Administration" and the establishment of Ministry of Agriculture during WWI, at that period, the landless peasants and refugees settlement was completed, Agricultural Bank was established and land reclamation works started, but, especially, the dragged-on question for wheat self-sufficiency was tackled and the foundations were put for solving this major problem. Here another paradox happened. The man, who took the solution of the most difficult problem of Greece's wheat self-sufficiency upon his shoulders, was a 20 years old agriculturist, just having graduated from Belgium. His name, Ioannis Papadakis.

The purpose of the present article is to lighten the relevant historiography so that make known to a broader readership the life and works of the eminent Greek agriculturist Ioannis Papadakis. This man proved to be a versatile genius who, as distinguished plant-breeder and statistician solved Greece's biggest problem namely that of wheat self-sufficiency, but on the other hand he was the founder of Agricultural Ecology on a worldwide basis.

Methodology.

The present study tries to put past events composing Papadakis' life and works in a chronological order. It necessitated the use of archive material taken from various sites throughout Greece, mainly the library of the Academy of Athens of which Ioannis Papadakis was an elected member. Additionally, the author by researching this issue, made use of further sources, including dissertations, books, symposia proceedings, or scientific journals. Finally, the author used also a narrative approach by interviewing various people who knew and worked with Papadakis at various stages of his life.

The achievement of Greece's wheat self-sufficiency.

Ioannis (John) S. Papadakis (1903–1997) was born in the largest of the islands forming the Cyclades complex of the Aegean Sea, namely Naxos (Dianelidis, 1983; Sfakianakis, 1997). Because no university level in agricultural education was provided at the time in Greece, since the first agricultural university was established after 1920 at Athens (Panayotopoulos, 2004), he went to study agriculture at the 'Institute Agricole des Gembloux' part of the University of Liege, in the French speaking region of Belgium (Wallonia). Studying in a foreign tongue (Greek is brotherless language) he graduated in 1922 'avec grande dinstinction' coming off with flying colours. Just after his graduation, Papadakis spent several months in France, specializing on plant improvement and seed propagation, in the famous, at the time, commercial firm of "Vilmorin, Andreux et Cie", as well as the "State Seed Control Station" near Paris (Karamanos, 1994). In the meantime, he never stopped being acquainted with the output of the work of agricultural research Stations worldwide, like the one of Beltsville at Maryland, USA, and particularly, the oldest in the field, Rothamsted at the Harpenden, England.

As regards Rothamsted, Papadakis had great affection for the history of agricultural science and made special reference himself to developments of experimentation there (Papadakis, 1984a). British being more pragmatic, proceeded with extensive experimentation. Thus 140 years ago, the Rothamsted Agricultural Station was founded by Sir John Bennet Lawes. Lawes invited as co-worker Sir John Henry Gilbert and since, the Station became famous all over the world. In the end of 1890s, USA decided to establish experimental Stations in every State and invited Gilbert to organize this exercise. Gilbert, before he left, wrote a book published by USDA. Papadakis wrote for that: " You cannot imagine how much I was impressed when I read it. The book was not only full of most important observations, experiments and ideas, but also I read it with great pleasure, written in a literary style. Gilbert, at the end of 1890s, was viewing the fundamental questions of agricultural science with greater insight than the scientists, not only of 1930s but also of 1980s. Gilbert's successor in Rothamsted E. J. Russel wrote later another book, also very important, but less than Gilbert's one. It had started coming into fashion, we scientists, to say what other people did, but avoiding the responsibility of saying our opinion".

Papadakis had also been influenced by the work of Sir Ronald Aylmer Fisher, an eminent geneticist and statistician, who had joined Rothamsted Station in 1919, and whose experiments were related to plant improvement. Papadakis was impressed by

Fisher's work in planning experiments, particularly the introduction of random selection, and focusing on the multifactorial nature of the questions emerging and the analysis of variance (Fisher, 1925). Papadakis exploited these findings, and deepened later our knowledge in the area of field experimental error calculation and minimization; something will be referred to later on.

Ioannis Papadakis returned to Greece in September 1923. He was appointed at the Ministry of Agriculture and immediately was transferred to the newly established Agricultural University of Athens, to serve as lecturer in the subject of "Field Crop Science" and help with the teaching of Introduction to Agriculture, in other words, *Elements of Agriculture* (Robinson, 1962). There, on the latter, lies the "happy coincidence" for Papadakis. Professor of "Introduction to Agriculture" was Spyridon Chasiotis, rector of the University, regarded as the "father of Greek agriculture". Chasiotis was pioneer in organizing the primary and university agricultural education of Greece, the establishment of Ministry of Agriculture and the Agricultural Bank of Greece, the latter with Socrates Iasemides. Papadakis (2003) quotes: "Agricultural University at the time did not have the required means or money but it was privileged to have Chasiotis". Chasiotis taught students "Introduction to Agriculture" in first year. In fact, the man who knew the problems of Greek agriculture better than anybody else, introduced students to the nature, difficulty and possibility of tackling those problems. It is not surprising, therefore, that among the five students that graduated in 1924, were Basilios Christides and Socrates Kalogereas, later worldwide authorities in cotton production (Christides & Harrison, 1955) and the technology of agricultural products together with environmental pollution, respectively. Chasiotis initiated Papadakis to the acute problems of Greek agriculture by hierarchying and giving priorities to their solution.

It should be noted at this point that for increasing a country's wheat production, by plant breeding, one has two choices. First, to use foreign varieties, evaluating their yield, quality and adaptability in different areas for at least 2 years. Then selects the best and propagates this or them (seed production lasts for 5 yearly periods). In this respect, Papadakis imported certified seed of certain varieties (Mentana, Canberra) which used for seed production. He also made selection from local wheat populations which he used also for seed production (e.g. Lemnos). However, yield improvement of wheat is influenced by other parameters, namely better technical support (fertilizers, pesticides e.t.c.), as well as social and economic conditions of the area. In addition, the selection of foreign varieties cannot be by itself a permanent and safe solution for a country, because it includes the dependence on other countries' production, and it does not secure a stable wheat production, under the specific Greek conditions. Thus, the second step is the development of agricultural research for the creation of new varieties with distinct potential for adaptability and performance (yield) under Greek conditions of the arid climate, particularly in the months April and May. Papadakis did exactly this second step, and he did it correctly and successfully. He started with cross-breeding between foreign ones. In turn, using different selection methods, and in order to speed up procedures, he proceeded with varieties evaluation in "pots" and "pockets", aiming at creating and selecting the best genotypes.

Due to Chasiotis' backing, Papadakis started four trials in a network of experimental fields throughout Greece, for the introduction of certain foreign wheat varieties of high productivity. Papadakis, by choosing to study the potential of foreign wheat varieties and test their productivity, yield and adaptation under the adverse Greek soil and climatic conditions, he made the right thing, simple and clever, since the creation of a new variety is an extremely time consuming job and the country's wheat self-sufficiency problem was pressing. This network was supplemented by the "Plant Improvement Station" which started operating on 1st February 1925 in Larissa, Thessaly, traditionally the granary of Greece (Papadakis, 1983). Based on these experiments, Papadakis suggested in summer 1926 the importation to Greece of big quantities (thousands of tons) of certified seeds from certain varieties. Later, in 1927, the "Plant Improvement Station" was transferred to Thessaloniki (Salonica), the country's second largest city, where it received the support of "Refugees Settlement Commission" in Macedonia, directed by Ioannis Karamanos. It should be underlined at this point that the social problem of refugees' rural settlement was strongly linked to that of wheat self-sufficiency in view of the need for nourishing the increased Greece's population, after 1.3 million refugees' arrival from Minor Asia (Kribas, 2007). Karamanos in 1928 was appointed Director General of the Ministry of Agriculture during Eleftherios Venizelos' Government and by assisting further financially the Station, enabled Papadakis to introduce an original system of experimentation using 'pots', which contributed greatly towards, either the carrying out of basic theoretical research or the creation of new better wheat varieties. The same year, the certified wheat seed production started in large scale. In 1931, again due to Karamanos' vision, the Station was promoted to "Plant Improvement Institute" and its certified seed production was legalized by the State.

Since 1937, the cultivation of certified seeds of three varieties reproduced in the institute occupied two thirds of the land sown with wheat in Greece. These were the foreign ones, Italian "Mentana" and Australian "Canberra" –the latter exhibited hardiness in early blown hot winds– as well as "Lemnos" the indigenous wheat variety grown in the homonym island of the Aegean Sea. Furthermore, Papadakis, pushed also by State's choice for autarky (Mazower, 1987), worked on the creation of new wheat varieties of high productivity, good adaptability in the adverse soil and climatic conditions of the country, and making better quality of bread. His works led to the creation in 1934 of the variety Γ-38290 (Eucarpia I), known to the peasants as "numero" (number), a cross-breeding between Italian variety "Rieti" and the Australian "Quality". This wheat variety which entered seed production in 1942, and for which Greek agricultural research is proud of, is considered a milestone. It was sown, after 1950 and for 20 years in 70% of the land cultivated with wheat in Greece. The Greek national production of wheat had almost a 3-fold increase, i.e. from 300000 tons before 1930 up to 850000 tons in 1940. In any case, Papadakis' contribution to plant propagation falls within what one of the greatest satiric writers of the English language ever, the Irish Jonathan Swift, wrote in "Gulliver's Travels" back in 1726: "…Whoever would make two ears of corn or two blades of grass grow upon a spot of ground where only one grew before, would deserve better of mankind and do more

essential service to his country, than the whole race of politician put together" (Swift, 1994).

Increasing wheat production was a very difficult task in Greece. Even the otherwise great agriculturist Nikolaos Anagnostopoulos had stated publicly that Greece, although can improve wheat production to some extent after employing better cultivation techniques, however, it will never reach self-sufficiency (Anagnostopoulos, 1930). In addition, certified seed production of a new variety and its release into the market is by definition an awkward job, calling for time consuming procedures up to 15 to 17 years. One should bear in mind that till 1941 the use of fertilizers for wheat production was negligible in Greece. The same can be said for pesticides. Herbicides did not exist at the time.

In addition, Papadakis knew well that, although improvement of wheat production is mainly a task of technical character, however, this possesses a strong political element as well. He was aware that his efforts will fail if he did not manage to secure a reasonable income for wheat producers to enable them to afford to pay for the certified seeds and other agricultural supplies, so that the propagation of the new varieties is not delayed. Therefore, in 1927, at the age of 24(!), along with Ioannis Karamanos, he tried hard, requested, and managed to convene a meeting with two inspired and influential people of public life in Greece, namely Alexandros Papanastasiou, an ex-Prime Minister and Minister of Agriculture at the time, and Alexandros Koryzis, Vice-Governor of the National Bank of Greece at the time, who later, as acting-Prime Minister, committed suicide as a mark of supreme integrity and sacrifice, the day when Germans occupied Greece in April 1941. Papadakis managed to convince these people to establish "ΚΕΠΕΣ" ("CCPIW" in English, from the initials of "Central Commission for the Protection of the Income of Wheat-producers").

The two issues, that of wheat production and the other of wheat producers' income protection, were supplementing one another. Without securing centrally a reasonable price for wheat producers by State intervention, the latter would have been, as they were till then, a prey to usurers' mercy. In fact Papadakis in his inauguration as Member of the Athens Academy 40 years ago expressed his view explicitly that it will constitute almost committing suicide for a political party if ever abolished wheat protection in Greece. Unfortunately, soon after its accession to the EEC, where different, more demanding for Member-States, harmonized mechanisms of product protection function, and this is not EEC to blame, Greece lost the greatest agricultural achievement of the twentieth century, namely wheat self-sufficiency, by importing in recent years more than 80% of wheat required for bread production from abroad, Canada, Russia and especially Ukraine. Of course, this is another chapter of agricultural history of Greece, the second part of an affair could have been titled 'The rise and fall of wheat production in Greece'.

It should be noted at this point, that country's increase in wheat production, apart from the creation of improved varieties, and the protection of farmers' income, had also been benefited, as already mentioned, by the work of "Refugees Settlement Commission", in the framework of the agrarian reforms in Greece. Two further efforts were made with the expansion of arable area through land reclamation and allocation

of more land, otherwise used for other crops, to wheat production. This, particularly in the Northern districts of the country was, in part, the case, but one should bear in mind that, land reclamation demands heavy earthworks machinery, too costly for an almost bankrupted country like Greece at the time. In addition, drought lands converted to irrigated ones, by big State's loan capital investment, were not frittered away for the low-price sold wheat, but to more profitable crops such as fruits and vegetables. As regards unrestricted allocation of more arable land to wheat-production, at the expense of other crops, this had two disadvantages. First, mono-cultural wheat operation would have an adverse effect on flora biodiverstity, and second, it would be, and in fact it was, at the expense of the exported Greek products (tobacco, cotton, raisins), but also of animal production due to the restriction of land for the cultivation of the other cereals used for animal feeding (maize, barley, oats, rye, sorghum), as well as forage producing legumes, particularly the rich in nitrogen content, high yielding lucerne, which suits to the Greek environmental conditions with abundant daylight for photosynthesis. That is why if one wants to find the origin of Greece's nowadays big exchange deficit of more than 2 billion euros imports of animal products, he has to study this particular Mid-war period and the tendency towards mono-cultural wheat operation at the time. Therefore, among the various parameters influencing the country's rise of wheat production, plant improvement together with producers' income protection, were the principal factors and according to Papadakis do not cost anything. That is why Papadakis' contribution was dominant.

Another thing Papadakis was credited with, is his contribution to propagating the use of chemical fertilizers. Just after the War in 1946 the Chemical Engineering branch of the "Technical Chamber" of Greece asked Papadakis to undertake a study with a view to proposing the actual amount of nitrogenous fertilizers in thousands of tons, farmers would require annually in Greece and what would be the expected demand for nitrogen in Greece for the next ten years. Papadakis had found in his experiments that the nutrient content of Greek soils, particularly nitrogen was not enough to support the yield promised by the potential of the new varieties of wheat. Therefore, he proposed 40000 tons. Other specialists on this field opposed his opinion arguing that, before the War, consumption of fertilizers was only 6000 tons, and that could not see any increasing trend. Nevertheless, the FAO Mission for Greece (Anonymous, 1947) in 1946 took his part and eventually the "Technical Chamber" supported Papadakis' proposal. Before the lapsing of ten years, the demand for nitrogenous fertilizers had exceeded the amount of 50000 tons annually. Nowadays, this is of the order 450000 tons per year. Actually, Greece in 1957 attained wheat self-sufficiency, with an annual production of the order of 2700000 tons. This necessitated the building of a new big factory for fertilisers production, particularly nitrogenous ones, using the geothermic energy derived from the deposits of brown coal (lignite) in the area of Ptolemais in Northern Greece.

In addition, Papadakis carried out theoretical (fundamental) research. In this respect, he studied the phenomenon of antagonism (competition) between plants, mainly due to root excretions. These works were extremely laborious and time consuming so that Papadakis, in order to speed up procedures, introduced the

experimentation for a series of years by using "pots" and "pockets", the latter located in far distance between one another. In the area of "Statistics in Biology", Papadakis paid particular attention to soil heterogeneity. He proposed in 1937 the adjustment of plot yields in field experimentation, on the basis of contiguous plots with a view to minimizing error. This procedure which was known as "Papadakis' method"(Papadakis, 1937) remained in obscurity for approximately 40 years. However, from the end of 1970s, a rapid recognition of the significance of this method appears internationally by some high-sounding names in the field, like Bartlett and Dagnelie. Here is how Papadakis at the age of 80, describes this phenomenon: "My statistical method was known internationally after Barlett placed himself on it in 1938 (Bartlett, 1938). After 40 years, researchers realized the conventional methods lead nowhere. So they searched a solution in my own method (Bartlett, 1978). More than ten works were published on my method in the British and Australian literature in the last few years. Dagnelie, in his paper, gives abundant bibliography of 92 references on my method (Dagnelie, 1987). In addition, the British ARC employed three mathematicians especially for studying my method. In fact they thought I had died! I was informed recently what is going on and I am preparing to participate in the debate by presenting a perfected version of my method in the meantime".

With his work in Greece, Papadakis showed he was a haeretical scientist, if one considers his persistence on the feasibility of Greece's wheat self-sufficiency, contrary to other agriculturists' views. He released fiery articles in the press to defend his view. He was also an iconoclast by researching on something unexpected, i.e. the potential beneficial effects of untillage, obviously under certain conditions, and the parallel use of herbicides. Overall, the pursuing of wheat self-sufficiency, together with the success on the epic of refugees' and landless peasants' rural settlement, the latter in the framework of agrarian reforms, made distinguished people talk about the 'Greek agricultural miracle of the Mid-war period'(Alivizatos, 1939).

In the meantime, Papadakis published several papers on the outcome of theoretical and fundamental studies. One should quote at this point his interest on answering the question: "Which factors limit plant yield?" In this respect, after ruling out, by research, the possibility of the competition (antagonism) of plants for nutrients being the critical factor, he tested Pickering's hypothesis (Pickering, 1917), in that this can be attributed to the excretion of toxins by living plants' roots and he proposed the "spacing theory" as limiting factor of plant yield (Papadakis, 1940, 1968). Papadakis decided to publish his work in the "spacing theory" in an authoritative journal across the Atlantic, namely *Soil Science*. It was also the first time Papadakis released information to a broader readership on his innovative work of field experimentation by using "pots" (Papadakis, 1935a) and "pockets" (Papadakis, 1935b). It is an important piece of experimental work. A synopsis of what he had done in the Thessaloniki Institute for a period of approximately 15 years. It is evident there that he possesses a large "arsenal of mathematical supplies", in his effort to quantify matters. At the same time also he studied the effect of soil colloids and soil reaction on wheat yield and adaptation (Papadakis, 1941a), whereas he published a new method for soil testing (Papadakis, 1941b).

But one would ask: What was the future in Greece of Ioannis Papadakis, the man mainly responsible for the solution of Hellenic race's major agricultural problem of wheat self-sufficiency? Papadakis, just after World War II, during a very delicate period politically (Woodhouse, 1947), was put under pressure in his work, because other people coveted his position. This was unfair for him. Generalising, of course, is a rather superficial approach. One should dissect and stir up each case, so that concealed truth comes out to the surface. However, in Greek public life, frequently, meritocracy is put aside. That is why in recent years Greece paid the price, experiencing an unprecedented economic recession, following an irrational uninterrupted borrowing, exceeding its potential to settle.

Later in 1946, while being for a private visit in Belrsville Maryland USA, Argentina approached and invited Papadakis to construct the country's ecological map. It should be mentioned at this point that Papadakis in 1938 had published in French the first globally of its kind book 'Agricultural Ecology'. It should be underlined also that Papadakis had submitted for a professorship in Greece but, him, the greatest Greek agriculturist of the twentieth century, did not manage to be elected. Therefore, Papadakis, during the Greek Civil War, fed up, he resigned with a bang, packed his luggage, accepted Argentina's invitation and in 1947 emigrated permanently there.

Discussion on limitations governing the single-cultivation of wheat.

It should be made clear that, while the adoption of wheat self-sufficience as a target for the autarky of a country's economy constitutes a political action, the achievement of this target is mainly a technical procedure, since, apart from the allocation of more land to wheat production at the expense of other crops, it calls for the creation of new higher yielding wheat varieties. And in the technical side of this issue, Ioannis Papadakis proved to be an outstanding researcher.

There is no adverse criticism for the way Papadakis handled scientifically the issue of increasing wheat yield. The first who wrote about Papadakis after his return to Greece in 1983 was Karamanos (1994), whereas after Papadakis' death in 1997 several researchers praised his scientific skills as wheat varieties improver (Korpetis et al., 2023; Ploumidis, 2021; Tsompanoglou, 2024; Xynias et al., 2020; Zoiopoulos, 2015, 2020). In addition, Arapostathis (2017) commented upon Papadakis' contribution to calculating Greece's needs for fertilizers, whereas Carmona-Zabala and Panagiotopoulos (2021) give emphasis on Papadakis' capacity as agro-ecologist.

On the contrary, on the issue on imposing a generalized single-cultivation of wheat in the country, in other words wheat should be the sole crop cultivating in Greece, this direction found great opposition. In fact, a debate took place in Greece between two groups: one in favor (pro) led by Ioannis Papadakis and the other against (anti) the single-cultivation of wheat in Greece led by George Kyriakos (1934). Papadakis' view was shared by other well-known Greek agriculturists as Ioannis Karamanos, Epaminontas Kypriades, Stavros Papandreou, Aristides Mouratoglou. On the other hand, at Kyriakos' side stood the agriculturists researching in the area of forage production, i.e. Demetrios Panou, Nikolaos Anagnostopoulos, Ioannis Tsoumis and the veterinarian Vasilios Hatziolos. The eminent agriculturist Chrysos Evelpides

stood somewhere in the middle of these two groups, in that, on the one hand supported the improvement of wheat production but on the other advocated that this has not to be done at the expense of the cultivation of other crops (Ploumidis, 2024).

First reference to the above debate in the post WWII era was made by Zoiopoulos (2003) while commenting on Mazower (1987) book about pursuing autarky as a measure of Greece's recovery from crisis in Mid-war period. There, the author calls George Kyriakos as an undistinguished conservative agriculturist for the reasons he quotes. However, George Kyriakos was a distinguished Greek agriculturist and he had exceptional contribution to the improvement of agriculture in his country. The fact that Kyriakos opposed Papadakis on the issue of self-sufficiency of wheat does not necessarily mean that his reasoning was unstable, deprived of a concrete base. Simply, Kyriakos believed that the single-cultivation of wheat would be at the expense of the exported Greek agricultural products, like tobacco, cotton and resin, as well as of animal production after limiting the cultivation of other cereal crops used as forages for animals like maize, barley, oats, rye but also of legume seeds (field beans, lupins, peas, vetch) but also lucerne hay, the later being favored by the exceptional Greek conditions of sunlight.

These facts eventually vindicated Kyriakos with the observed delay in development of Greek animal production. Nowadays, Greece is characterized by a big deficit of exchange in its international trade of the order of 2 billion euros for the importation of farm animal products for which Greece is showing this big deficit, due to the lack of forages, in other words feeds for animals. In addition, emphasis put on single-wheat cultivation has adverse effects on biodiversity of the flora in a country. Nevertheless, one could well say overall that Papadakis took the mandate from the Hellenic State to achieve the country's wheat self-sufficiency and in this respect he proved to be an eminent scientist of great caliber.

The ecumenical I. Papadakis through agricultural ecology.

With settling down to Argentina, the Ecumenical, the far from Greece, career of Ioannis Papadakis, started. In 1951, Papadakis released the "Ecological Map of Argentina" which was reissued several times since. It is characteristic that Papadakis' suggestions for the cultivation of sorghum and soya bean, in the suitable areas for that purpose, were substantial, so that today these two crops are grown in very large acreage in Argentina. In 1954 Papadakis was invited by the "International Labour Bureau" of the UN (United Nations) and took part at "Mission Andina" to study for three years the agricultural development of Peru and Bolivia, where he worked at very high altitudes, like the upland Puno of mountain Andes at 4000 m. From 1958 and for five years worked at INTA (Institute National of Technology in Agriculture) with main subject the study of Argentine soils.

While Ioannis Papadakis was known as John in English and Jean in French, from the beginning of 1960s he appears as Juan. In this respect, he published in "Soils and Fertilisers" (1969), Harpenden, on the formation of clay (Papadakis, 1960a) and bleached (Papadakis, 1960b) horizons and in "Soil Science" (1963) something showing his caliber as great pedologist. In fact, in 1962, USDA published its official report on

the so-called 7th approximation comprehensive system for soil classification (Anonymous, 1960). Papadakis exerted discreet critic on this and proposed amendments (Papadakis, 1962), letter "p" in particular, which incorporated into his publication for the soils of Argentina (Papadakis, 1963).

In 1963, FAO (Food and Agriculture Organisation) of the UN (United Nations) assigned to Papadakis the ecological study of West Africa countries. Then at the age of 60, he visited and worked, at some of the most inconvenient parts of the world for that era, with fragile and volatile political regimes, like Liberia, Ivory Coast, Ghana, Togo, Dahomey (now Benin) and Nigeria. In 1964 and for 4 years, Papadakis was invited by FAO and, staying at the Rome headquarters, visited several developing countries in the framework of the 'World Indicative Plan' to study the production possibilities for food and other non-edible agricultural products.

Among these countries Papadakis visited and studied the agriculture of India, Pakistan and Bangladesh, and in turn published a series of monographs related to the subjects of his studies. He visited also Egypt. Furthermore, Papadakis, continuing his participation at FAO missions, in 1968, and for approximately 2 years, worked in Chile, where he drew the country's ecological map and lectured at the Agricultural University of Chile.

In 1970 Papadakis returned to Argentina and for 2 years was member of the governing body of INTA. During this period, he was invited to lecture on Agricultural Ecology as Regular Professor at the University of Buenos Aires, first at the Chair of Forages Cultivation and then at General Crop Science. It is also important one to note that Papadakis was elected Professor at the age of 70 and retired at 75, whereas the upper limit of retirement for University staff was 65 years of age, and this is indicative of Papadakis' fame and recognition in Argentina. Finally, in 1988 Papadakis was elected Corresponding Member of the Academy of Sciences in Buenos Aires.

It is difficult to accurately appraise all Ioannis Papadakis' published work. This consists of over 100 exercises, including about 70 research and review papers, whereas 33 monographs have also been reported. Papadakis touched upon numerous subjects of agricultural sciences including plant physiology, plant improvement (breeding), soil science (pedology), biometry (statistics), agricultural ecology, rural economy, sociology and policy, as well as the combination of plant and animal production. Despite its versatility, all Papadakis' research work is of high level, something very uncommon in the scientific community, but it is indicative of man's excellence, culture and competence. Some examples of his work are given below.

It is wise one to start from an apparently humble book titled *General and Special Agronomy: For Primary School Teachers* (Papadakis, 1929). It was in 1928 when, due to efforts by Alexandros Papanastasiou, an ex-Prime Minister and Minister of Agriculture at the time, further education tuition courses for the agricultural initiation of primary school teachers started operating in Greece in order to attract students to become servants of the land. At the end of the first year of teaching in 1929, Papadakis composed an important reference book for teachers, where simplified complex things, while at the same time maintained the scientific 'weight' of the information presented. It is something which falls within what the former Director of the Rowett Research

Institute at Aberdeen late Sir Kenneth Lyon Blaxter called "The art and science of Agriculture"(Blaxter, 1976). Papadakis' book for teachers is a 2 volume book, 400 pages overall, where the 25 years old Papadakis finds the opportunity to draw the two axes across which is going to move scientifically in the future. He has included a chapter titled "Can Greece become self-sufficient in wheat?" and another on "Agricultural Climatology".

As regards experimental research works, Papadakis started publishing in Greek at the Thessaloniki's Station Bulletin he had created, first with his results in testing foreign imported wheat varieties for adaptation in Greece. Then he published in English in the French Bulletin of the "International Association for Plant Selection" on techniques of field experiments (Papadakis, 1931a), while showing the first sign of his talent in agricultural ecology (Papadakis, 1931b). Furthermore, he published the observed effects of ecological variability on plant productivity (Papadakis, 1931c), the effect of temperature on plant yield (Papadakis, 1931d), evaluation of plants' resistance to drought (Papadakis, 1933a), while emphasizing on varieties Mentana and Canbera grown under Greek conditions (Papadakis, 1933b). These were followed by some unpublished works with B. Kokolios, like the ones on soil reaction and variety adaptation, as well as the reaction of wheat in adding phosphoric acid to the soil, and phenological observations on cereal plants. One should also note his work with D. Tallelis on performance of different wheat varieties in response to nitrogen fertilization (Papadakis & Talelis, 1933) . It was also during that period Papadakis published the statistical method he proposed for field experimentation with plants.

One should make a time break at this point and concentrate on Papadakis' outstanding publication on 'Agricultural Ecology' (Papadakis, 1938). This book written in French was the first of its kind to appear worldwide, and it was considered to lay the foundations of a new science. This Papadakis' piece of research constitutes a milestone in the evolution of the relevant branch of agricultural science. It was not based more on meteorological parameters as the others dealing with conventional ecology did, but relied on the effects of the environmental variables on plants' biology and therefore it lied closer to the reality. In other words, Papadakis' work did not refer to planet's flora in general but it tries to give an answer to the fundamental question: "Which species of cultivated plants suits to a specific environment?" something of great economic importance for agricultural practice globally. This book constitutes an important composition based, to a great extent, on his own experimental observations and distinguishes for its pioneering ideas, which opened up new horizons in agriculture and was the threshold of his future activities.

In Post-war period Papadakis' published work was based on his studies performed abroad, away from his mother country Greece, and constituted a different kind of research, far from the intensive field experimentation he was used to, but of a more horizontal nature, falling mainly within the subject of agricultural ecology. To start with, in 1951 he released the Atlas titled *Argentina's Ecological Map* (Papadakis, 1951) which was re-published several times since. Also, from 1963 to 1968, while working for the FAO Missions, published a series of monographs on world agricultural ecology. Among them were the ecological maps of Peru, Chile, and countries of West

Africa (Papadakis, 1966a). His book *Agricultural Geography of the World* (Papadakis, 1952) (was republished many times, and was translated into Japanese and Spanish. His book *Climatic Tables of the World* (Papadakis, 1961) has received the same attention worldwide. In fact, in a series of works, he published a system for climatic classification in the world, based on a large number of variables directly related to plant growth. The utility of Papadakis' system is significant for world agriculture, since the classification of different climatic types were not defined arbritrarily but on the basis of their suitability for the cultivation of specific plant species. And while Papadakis deals only with producing monographs, in 1963 he brakes this habit and publishes research papers in the journal "Soil Science" and "Soils and Fertilisers".

In 1964 Papadakis was invited by the authoritative journal "Field Crop Abstracts" to compose the main article, an overview, titled "Crop ecology and agricultural development" (Papadakis, 1964a). It is worth, at this point, one quoting the first part of Papadakis' Introduction to this paper, where poses the question of the ecological approach to agricultural development: "To the ecologist, the low agricultural development of a country is not a result of the unwillingness or inability of its farmers to use modern methods of production; it is due to the physical and economic conditions that have hitherto prevailed. Agricultural development is nothing but an adaptation to new conditions. As a result of the opening of new roads, new markets, technological progress, industrialization, etc., the economic conditions change; physical environment is also modified by the construction of irrigation and drainage projects, the use of fertilizers, herbicides, pesticides, fungicides and the introduction of new pests and diseases, etc. As a consequence, farmers are obliged to change their crops and their methods of growing them, to fit new conditions and to take advantage of technological advances. If this is so, the thing to do when planning the agricultural development of a country is to study the physical and economic environment and see what type of agriculture (crops, methods of growing them and cropping systems) corresponds to it; what changes in the environment are possible, or may be expected; and what changes in the type of agriculture they imply; and then to take measures to facilitate this natural evolution". And it is also worth, in relation to this article, one to study his concluding remarks on methods of action for agricultural development.

Finally, the Editorial Board of Encyclopaedia "Britannica" (1969) assigned Papadakis to write the entry "Soils" (Papadakis, 1998). This is indicative of his international recognition as an authority in this subject. It is an 11 large size, closely written pages, important piece of work. Furthermore, Papadakis published an Atlas on *Climates of the World and their Agricultural Potentialities* (Papadakis, 1966b) republished in 1975, and at the same time presented also a manual titled *Soils of the world* (Papadakis, 1964b) with a new enlarged edition in 1969. In turn, in late 1960s, Papadakis wrote two text books, one on *Fundamentals of Agronomy* (Papadakis, 1970a) and the other on *Agricultural Research* (Papadakis, 1970b) , both written in English. In those Papadakis finds the opportunity to philosophise on these particular topics of agricultural science. In the former, Papadakis comments also on his own introduction of untillage under certain conditions.

From the second half of 1960s, Ioannis Papadakis worked in parallel at another area of interest, more horizontal, namely the problems of agricultural policy and development, food provisioning for third world countries, economic issues like those of people employment, including effects of inflation on development economics. In this respect, emphasing on the need for securing world's farmers income, he seems to come full circle with young Papadakis' deep concern for the Greek wheat producers' income protection, as a prerequisite for progress, more than 40 years before. On this topic, Papadakis published *Agricultural Development* (Papadakis, 1965a), *The Food Problem of India* (Papadakis, 1967a), as well as *The World Problem of Hunger* (Papadakis, 1967b). In the meantime, Papadakis had also released an important piece of research work titled *Potential Evapotranspiration* (Papadakis, 1965b). Finally, Papadakis published in Spanish an essay titled "Errors in the science of our time" (Papadakis, 1982) which sums up his experience over a long career, an epitome of his approach to clarify the confusion in contemporary agriculture, while Papadakis the thinker emerges out of it. In fact, Papadakis refers to the decline of science, as well as the confusion of ideas in our era. He says that science of 19th to beginning of 20th century, a period he characterizes as "Golden Century of Science", was less advanced, however, it was more philosophized and satisfied man spiritually, whereas confusion of ideas prevails today, which disturbs, particularly, young people.

Ioannis Papadakis as a great thinker.

Papadakis the thinker will be the subject of this section of present article. Four are the sources where one could draw all the essential elements for this purpose, and so capture Papadakis' philosophy or the wisdom of his experience. There were actually four speeches Papadakis delivered at equal in number occasions after returning to Greece in 1983. Firstly, at the inauguration ceremony for being admitted as member of the Athens Academy. Secondly at his inauguration as Honorary Professor of the Agricultural University of Athens (Papadakis, 1994). Thirdly, at the commemorative occasion for his predecessor at Athens Academy, Nikolaos Roussopoulos, and fourthly at another commemorative occasion, that for Ioannis Karamanos, Director General of "Refugees' Settlement Commission" back in 1923.

Papadakis in his paper titled "The Greek agricultural miracle 1922–1928: Paradigm for foreigners and Greeks" gives several events to establish his view that with the rapid agricultural development of Greece in Mid-war period, a "miracle" took place. Firstly, he referred to the colossal achievement of landless peasants and refugees settlement without any bloodshed. Secondly, he explains the establishment and important role of the Central Commission of the Protection of the Income of the Wheat-producers for the rise of the wheat production in Greece. In turn, he talks about his efforts for the invention of new improved wheat varieties. Furthermore, he refers to his contribution to the generalized use of fertilizers, particularly the required nitrogenous ones. Then he underlines the significance of the above achievements and their implication of the overall economic development of the country. Finally, Papadakis believes that the country's performance in the agricultural sector during the Mid-war period could serve as an example for Greece of the '80s itself, but also for the rapid

growth of other developing countries around the world, whose economy is based on agriculture, and which face acute problems in food self-sufficiency. He concludes that solutions for such problems cannot be found in text books.

One has to define, at the outset, Papadakis' fundamental concept about science. Translating his words: "Phenomena studied by science can be classified into three categories: first physicochemical, which are simpler and it is easier to end up into conclusions; that is why sciences which study them are called positive. Second, biological, which can be considered as complex physicochemical phenomena, but science till now, has not managed to reduce them down to physicochemical. And, third, more complex phenomena, which are observed only in man, namely social, political, economic etc. Man is the only animal which has the curiosity and the ability to study and understand the phenomena observed. The outcome of this ability is science and technology. Due to the latter, life of human societies changes continuously. Whereas all other animals and plants undergo only genetic evolution owed to genes, man undergoes, in addition, a cultural evolution, due to the progress of science and technology. In agriculture we use living organisms, plants and animals, as basic "machines". The study of the latter calls for biological knowledge. The biological knowledge is physicochemical as well. In addition, soil and climate are studied, mainly, by physicochemical sciences. For these reasons, agriculture demands basic knowledge of all sciences. Therefore, agriculturists should, and in fact, understand their countries' big problems but also of humanity's in general, and their obligation to contribute to their solution is greater".

Papadakis, within the context of the agricultural practice, respected and believed firmly in the central role of peasant, the farmer. He believed that farming is not only a profession but also a way of life. He wrote: "We should not look down on peasants' wisdom. Agriculture is a tremendous experiment made by millions of farmers for millenniums and we cannot ignore this fact. Even for new techniques, experience acquired by farmers after applying them is very useful, supplementing of what we have known already. I give advice to them, in relation to the possibilities of the cultivation of a crop, its problems, the way of tackling them, etc. drawing as well from the inexhaustible mine of peasants' experience. In Argentina only, I should have interviewed peasants, extensively, more than one thousand times, the same in Bolivia, Peru, Chile, West Africa, India, Pakistan". Papadakis was devoted to primary agricultural education, that of farmers, as well as the extension service. He believed that if farmers' purchasing power for goods increases, this would have a beneficial effect on industry's development and the elevation of country's economy.

It is interesting also one to explore Papadakis' ideas for science and scientists of today. Papadakis was an adherent of moderation. He believed that: "Moderation is of great significance for science. Differences between various scientific schools of thought are frequently due to the fact that one particular school attributes extensive importance to some actors in the field, ignoring others, and the same is done by other schools but to opposite direction. If both applied moderation, then they would coincide. Speaking about moderation, one should not forget that moderation is more of less like virtue. It is easy to teach it, but difficult to abide by".

He believed that science is only one, and its splitting into separate sciences is conventional and this is done by necessity. Specialisation is essential but this should be accompanied by general education. The systems studied by agriculture are more complex than in other sciences and things do not obey to that rigid laws. That is why science did not manage to cast light on them yet. He believed also in the importance of observation, interpretation and repetition while carrying out experimentation. He quotes also that developing countries need low cost technology, adapted to their climatic and soil conditions, which differs from those of the developed ones. But little is done to work this direction. He also talked about the significance of the term "information" and "formation" for shaping a scientist's character. Finally, Papadakis was pre-eminently representing what one would call "common sense" in science. He gives several examples on this and concludes that: "What causes confusion nowadays is that sometimes "common sense", the base of humanity's all feats, particularly sciences', is missing. Perhaps, after having invented the electronic brain (computer), we consider as needless to use our own".

Another thing, and what characterizes the genuinely eminent scientists, was that Papadakis had great admiration for others in the field, who in the narrower sense, could have been regarded as rivals of him in fame. In this respect, Papadakis admired Spyridon Chasiotis, the so called, by Greek common opinion "father of Greek agriculture", the man who knew better than anybody else the problems of the Greek agriculture in his era. Furthermore, Papadakis admired Ioannis Karamanos, the young agriculturist who was appointed Director General of "Refugees' Settlement Commission" and completed successfully refugees' rural settlement. The American Henry Morgenthau, Chairman of the above Commission, appointed by the "Society of Nations" in 1922, wrote for I. Karamanos in his memoirs (Morgenthau, 1929): "a flashing figure… born leader of men". According to I. Karamanos himself: "Agricultural colonization of refugees in Macedonia, stamped with its fiery seal the fate of Greece". In addition, Papadakis admired Professor Nikolaos Roussopoulos, his predecessor at the Chair of Agricultural Sciences in Athens Academy, for his contribution to the evolution of the relevant science in Greece. N. Roussopoulos attributed much importance to the history of sciences and the philosophy of research. He was stressing that there is nothing as philosophical and didactic as the history of sciences, and the reading of the classic prototypes for shaping one's scientific spirit. He honoured the frontrunners of his science: B. Palissy, J. B. van Helmont, J. von Liebig, J. B. Boussingault and E. A. Mitscherlich, his "heroes" and the same is valid for scientific communities. But nowadays, the opposite happens. We try to stain "heroes" of science by scandal-mongering. This "desheroisation", as he called it, constitutes a threat for our society. In fact, Roussopoulos with his book on the laws governing plant yield (Roussopoulos, 1948) laid down the threshold for the positivistic model of higher agricultural education in Greece. In other words, Roussopoulos by making extensive use of mathematics, tried to quantify the biological phenomena, reducing them down to physicochemical ones (Zoiopoulos, 2011).

Finally, Papadakis admired the Nobel Prize for peace laureate (1970), eminent American agriculturist Norman Ernest Borlaugh. Borlaugh with the "dwarf" wheat

varieties, of great productivity and adaptability in a wide range of environments, he invented, he was the creator of the "Green Revolution", which aimed at eliminating famine spectre globally. Papadakis agrees with Borlaugh that the situation regarding agricultural research in the well developed countries is worrying. Companies are not interested in finding ways of application which decrease the consumption of their products, and concludes that a new start is needed. It should be mentioned, at this point, that there are some similarities in the careers of Borlaugh and Papadakis. In fact, Borlagh started as phytopathologist and emerged to be plant breeder, whereas Papadakis started as a plant breeder and ended up as top agricultural ecologist worldwide.

The return to Greece as member of the Athens Academy.

Papadakis returned to Greece following 35 years of absence, in 1982, after he was elected full Member of Athens Academy to succeed the deceased Nikolaos Roussopoulos at the Chair of Agricultural Sciences. This was preceded by his election, in 1974, with the political changeover in Greece, following seven years of dictatorship, as Corresponding Member of Athens Academy, after having been proposed by Roussopoulos. During this period Papadakis composed a dozen of papers which he published in Academy's Proceedings from 1983 up to 1994. Three of them are in English and the rest in Greek. The former consist of one paper on advances in the analysis of field experiments (Papadakis, 1984b), a second on advances in plant breeding methodology (Papadakis, 1985) and a third on increasing peasants' income (Papadakis, 1987). In his papers written in Greek, Papadakis wrote for the agricultural climate of Greece, the basic characteristics of Greek soils, the rational fertilization, the priorities for Greek agricultural research, as well as the prediction of future in science and practice by giving his experience, while at the same time drew examples from history in the cases of Laplace, Mendel and Heisenberg. Finally, Papadakis in 1989 touched upon "an important national question for Greece" as he called it, namely the rational utilization of mountainous pastures in relation to sheep and goat production development. And at the age of 92(!) Papadakis came back to give the last lecture of his life, on the management of forest pastures, so that owners care and prevent fire breakouts.

Athens Academy elected Papadakis as full Member at the age of 80, and the Agricultural University of Athens awarded him, when at the age of 90(!), the title of Honorary Professor, a unique honour, never given before to anybody else. However, Argentina, his second country, was first to honour him. That is why, when Papadakis, at the ripe age of 94, had a presentiment of the oncoming end, he went to Argentina to see his relatives for the last time, and there he died on 7 May 1997. He was buried there.

Conclusions.

Papadakis as National (Greek) agriculturist was distinguished in the area of primary agricultural education, that of the farmers. Pioneer in tackling and solving Greece's biggest agricultural problem, that of wheat self-sufficiency, he was major

national agriculturist. He was the top researcher in the area of Greek agriculture, either as plant breeder, pedologist or statistician (Zoiopoulos, 2014). On the other hand, Papadakis, as Ecumenical agriculturist, was distinguished in the field of extension service. He was teaching, but also learning a lot, from farmers' experience. He was a writer of great caliber. He was a racy thinker. Authority of an international radiance, in fact he was the founder of Agricultural Ecology, he was eminent Ecumenical agriculturist. Tireless servant of agricultural science, he dealt with a panorama of thorny questions. He sculpted the agricultural affair skillfully. He was the authoritative voice in soil and agricultural sciences in Greece (Arapostathis, 2017). He did not hesitate to expose himself at the most difficult agricultural problems all over the world. He was a bravest front-line agriculturist worldwide. He wrote his name in the "Golden Tables of History" by solving a country's problem of wheat self-sufficiency and introducing the science of Agricultural Ecology globally.

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Національна та академічна кар'єра видатного грецького агронома Іоанніса Пападакіса

Анотація. *Ця стаття грунтовно розглядає життя, діяльність та особистість видатного грецького агронома Іоанніса Пападакіса. В основному вона показує, як Пападакіс, працюючи головним чином як селекціонер рослин з 1923 року, вирішував головну проблему грецької сільськогосподарської історії – досягнення самозабезпечення Греції пшеницею, шляхом винаходу нових, високоврожайних сортів, які мають велику адаптивність до несприятливих ґрунтових і кліматичних умов країни. Вирішення цієї проблеми вважається видатним досягненням сільськогосподарських досліджень і політики в Греції. Проте сьогодні, оцінюючи з відстані часу події міжвоєнного періоду і намагаючись інтерпретувати результати цього експерименту та його наслідки для розвитку сільського господарства Греції, можна сказати, що стрімке зростання однокультурного землеробства пшениці при одночасному зменшенні площ під вирощуванням інших культур, призначених для фуражу або інших кормових ресурсів для тварин, мало негативний вплив на незбалансований розвиток різних галузей сільськогосподарського виробництва на користь пшениці. Таким чином, цей частковий підхід призвів до драматичного затримання у розвитку сектора тваринництва, що спричинило великий обмінний дефіцит при імпорті тваринних продуктів у сучасній Греції. Однак Іоанніс Пападакіс отримав доручення від Грецької держави досягти самозабезпечення країни пшеницею і в цьому відношенні працював на високому рівні. Крім того, у 1947 році, після запрошення Аргентини побудувати її екологічну карту, він переїхав на постійне проживання до цієї країни. Пападакіс опублікував (1938) першу у світі книгу "Сільське господарство і екологія" французькою мовою. Його також запросили написати статтю "Ґрунти" у Британську енциклопедію. Він працював для Організації Об'єднаних Націй з питань харчування і сільського господарства та вивчав сільськогосподарські питання в Південній Америці, Західній Африці, Південно-Східній Азії та інших регіонах. Він написав дослідження і оглядові статті на різні теми сільського господарства, включаючи польові культури, селекцію рослин, біометрію, вчення про ґрунти, сільськогосподарську екологію, а також сільськогосподарську економіку і політику. Ця стаття завершується деякими думками Пападакіса, які випливають з його власного життєвого досвіду, накопиченого за довгу службу в Греції, Аргентині та інших країнах світу.*

Ключові слова: *Греція; самозабезпечення пшеницею; Аргентина; картографування ґрунтів; світова сільськогосподарська екологія*

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Solutions for urban sanitation: A case study of Imhoff tank technology in Bandung, Dutch East Indies (1917–1938)

Abstract. *This research investigates how municipalities managed wastewater in the Dutch East Indies in the early 20th century. We focus on Bandung, one of the most important cities in the Dutch East Indies, which transformed into a modern residential area, economic center, and seat of government. This research combines primary data from written sources and field observations using historical-archaeological methods. The written sources include official reports from the Public Works Department, Civil Health Department, Bandung City Council, old maps, sewer network designs, environmental engineering journals, and newspapers published from 1909 to 1941. Using the techno-environmental approach introduced by Martin V. Melosi, this study considers urban technology as a strategic response by decision-makers to address the challenges faced by developing cities in the early 20th century. The study reveals that*

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Bandung City faced environmental problems, such as the natives' habit of defecating in rivers and open spaces, spreading diseases, and potentially polluting river water. These problems arose due to the lack of sanitation facilities and the densely populated settlements, especially in the native and Chinese residential areas. To address these challenges, policymakers, environmental engineers, and researchers initiated the design and implementation of sewers, public toilets, and wastewater treatment plants in 1917. The Municipality integrated sewers with the Imhoff Tank sewage treatment technology developed by researchers and engineers from 1932 to 1938 to introduce circular sewage treatment. Imhoff Tanks was a significant technological innovation in the Dutch East Indies. In the early 20th century, only a handful of cities in the Dutch East Indies, including Bandung, Medan, and Yogyakarta, had integrated sewer networks. Among the cities that did have sewer networks, Bandung pioneered the implementation of the Imhoff Tank. As a result, it emerged as an important laboratory and development center for Bandung and the entire Dutch East Indies. The Imhoff Tank treatment process, which produces clean water, fertilizer, and methane gas that can be used as vehicle fuel, was part of a proactive strategy pioneered by policymakers in Bandung in the early 20th century, reflecting their vision to create a healthy and sustainable city.

***Keywords**: public health; open defecation; sewage; Imhoff tank; urban technology*

Introduction.

Ensuring a healthy environment stands as an imperative for human well-being. The allure and grandeur of an urban setting hold significance only when underpinned by a healthy living environment. Studies indicate an unhealthy environment amplifies residents' mortality risk (Sun & Shang, 2015). Sanitation systems have historically been a cornerstone of healthy environments and are considered pivotal in advancing civilizations, evident in ancient societies such as the Indus River Valley, Mesopotamia, and Rome (Colman, 1995; Cosgrove, 1909). As elucidated by Melosi (2008), an optimal sanitation infrastructure comprises three key elements: a robust provision of clean water, a mechanism for the disposal of waste, refuse, excreta, and a system designed to safeguard public health. The advent of capitalism and industrialization during the 19th century in Europe exacerbated challenges related to inadequate sanitation infrastructure. The notorious episode of the Great Stink in London, England, vividly exemplifies the dire state of sanitation during that period (Halliday & Hart-Davis, 2001).

Throughout history, concerns regarding hygiene, environmental health, and the prevalence of epidemics have persisted in tropical regions like Southeast Asia. The advent of colonialism in the Dutch East Indies (Indonesia) brought challenges for the Dutch East India Company (*Vereenigde Oostindische Compagnie*) in contending with swampy environmental conditions and the looming threat of a malaria outbreak in Batavia, one of the region's major trading hubs (van den Brug, 1997). These issues

began to be addressed in the early 19th century when Governor General H. W. Daendels relocated the governmental center from Old Batavia to Weltevreden.

Until the early 20th century, public health and environmental hygiene posed significant challenges in the Dutch East Indies. The emergence of new cities in the region exacerbated urban issues like overcrowding, dense slum settlements, inadequate drainage and sewage systems, limited access to clean water, and a conducive tropical climate that facilitated the spread of diseases (Jaelani, 2018; Reerink, 2015; Tillema, 1915, 1919). Major cities like Surabaya, Semarang, and Batavia experienced cholera, malaria, typhoid, and dysentery outbreaks. Health professionals and sanitarians attributed these outbreaks to poor living conditions in the slums and the lack of hygiene practices among the native population (Gemeente Semarang, 1931; Tillema, 1919). The threat of diseases and low hygiene standards posed potential impediments to the rapid economic growth of the Dutch East Indies.

The less favorable health conditions in Batavia, compounded by its hot climate, prompted the proposition of relocating the center of the Dutch East Indies government from Batavia to Bandung. Renowned environmental health expert H. F. Tillema highlighted Bandung's potential for enhanced work productivity, cool weather, and a healthier living environment for the European population ("Gezond Bandoeng," 1922; Reitsma & Hoogland, 1927). With its advanced transportation networks, modern European districts, and commercial hubs, Bandung was conceived as an ideal settlement and administrative center for Europeans (Fakih, 2023). Simultaneously, it attracted native populations seeking employment opportunities (Himpoenan Soedara, 1936; Reerink, 2015). Governor General Paul van Limburg Stirum (1916–1921) was compelled by this vision of Bandung as an exemplary city, leading to the relocation of the central government offices to this city.

Despite its advantages, Bandung faced some challenges in terms of public health. The City Council (*Gemeente Bandoeng*) grappled with environmental issues rooted in poor sanitation practices during the colonial era. Despite ample clean water and a mild mountainous climate conducive to productivity, Bandung's native residents maintained notably low hygiene standards. Native inhabitants would defecate in the river and along major sewer lines, leading to contamination of these water sources with feces and pollutants. Moreover, these sewers were utilized for various purposes, including washing vegetables and clothes, bathing, and cleaning teeth (Tillema, 1915, 1916). In areas facing water scarcity, people resorted to using open latrines–holes dug in the ground–to meet their sanitation needs (Tillema, 1913).

In the late 19th century, the City Council and municipal government embarked on several initiatives to enhance the city. They undertook efforts to reclaim damp and swampy areas, rehabilitated villages inhabited by native populations, and initiated the paving of city streets (Kunto, 1984). The municipal administration implemented cutting-edge infrastructure and public services to address the impending challenges associated with waste management and the prevalent practice of open defecation among natives. This condition involved installing sewage pipes, establishing public

toilets, and constructing a sewage treatment plant recognized as the Imhoff Tank Technologies (P. Thijsse Jr., 1934, p. 139). These facilities were designed to segregate solid and liquid components of sewage, mitigating organic matter and pathogens within it. Notably, the gas produced from the sewage treatment plant found utility as a fuel for vehicles, a technology previously adopted in Germany and France before World War II ("Methaangas in Plaats van Benzine Voor Auto's," 1937).

Based on the historical background described above, this research aims to investigate two main issues: (1) colonial urban environmental issues in the Dutch East Indies, mainly related to public health and wastewater management in residential settlements; (2) how the city government addressed these environmental issues through the development of infrastructure, city services, and the latest technological innovations in the early 20th century. The wastewater examined in this study pertains to domestic sources, encompassing household effluents such as fecal sludge.

We chose Bandung as the subject of this research due to its distinctive spatial and social structures during the colonial era. Like other early modern cities in the Dutch East Indies, Bandung's city in the early 20th century was segregated along class and race lines (Kusno, 2014; Roosmalen, 2008; Tunas, 2007). Bandung's significance for study lies in its developmental blueprint, which was shaped by envisioning a modern European city necessitating hygiene, economic prosperity, social cohesion, and cultural viability (Fakih, 2023).

To address the problem in this study, we employ the techno-environmental approach introduced by Melosi (1990). This perspective asserts that the integration of urban technologies was not spontaneous but rather a deliberate strategy by decision-makers to tackle the challenges faced by burgeoning cities during the 19th and 20th centuries (Melosi, 1990, p. 51). This approach examines how diverse technical systems, such as urban infrastructure and services, significantly contribute to the physical expansion of cities. In this research, we analyze sewer systems' design, implementation, and upgrading to achieve a sustainable urban environment. We initially mapped population distribution and density to commence this analysis while identifying prevalent health issues within the settlement.

The techno-environmental approach to studying urban environmental history is not a recent development. It gained prominence in America during the 1990s, primarily pioneered by Joel A. Tarr et al. (1984; 1996). Tarr meticulously traced the evolution of diverse technologies and waste disposal systems in the United States, notably addressing concerns about water pollution stemming from industrialization. Donald Worster (1992) significantly expanded the purview of environmental studies by delving into water management, irrigation, and landscape alterations in the American West. Martin V. Melosi (2008) offered a comprehensive perspective, examining sanitation issues, the evolution of infrastructure, and public health concerns in America from the colonial era to contemporary times.

Historical studies of urban environments in South Asia, particularly cities under British colonialism like Bombay and New Delhi, focus on issues such as hygiene,

slums (Kidambi, 2001), water (Sharan, 2011), and sewage systems (Prashad, 2001). Within Southeast Asia, post-colonial countries' studies emphasize public health and infrastructure. The research investigates clean water supply in cities like Singapore (Otaki, Y., Otaki, M., & Sakura, 2007; Yeoh, 1993), Jakarta (Batavia) (Kooy & Bakker, 2014), Yogyakarta, Surakarta (Primaditya, 2022), and Bandung (Budiman, Ariwibowo, Saptono, Widyastuti, & Nurani, 2023). Several scholars have explored waste management historically in several cities in Indonesia: Malang (Hudiyanto, 2012), Medan (Affandi, Agustono, & Zuska, 2022), Surabaya (Husain, Indiyanto, & Sugiarti, 2023), and Cirebon (Mutawally, Zakaria, & Falah, 2024). Budiman's (2022) work touches on the history of sanitation in Bandung City but needs in-depth observations on infrastructure design patterns and sewage treatment technology. Therefore, this study addresses this gap by discussing Bandung's early 20th-century sewerage design and sewage treatment technology upgrades.

Research Methods.

This research adopts a historical archaeology method, emphasizing the complementary nature of archaeological and historical data as mutually reinforcing sources of evidence (Orser & Fagan, 1995). This approach is essential as reliance solely on archaeological data may provide an incomplete depiction of past human life (Sharer & Ashmore, 1979). Primary historical data were collected from early 20th-century publications, including official reports from the Bandung City Council (*Gemeente Bandoeng*), records from the Public Works Department (*Burgerlijke Openbare Werken*), documents from the Civil Health Department (*Dienst der Volkgezonheid*), a report from Civil Construction and Irrigation Department (*Civiele Gebouw en Waterstaat*), old maps of Bandung, engineering and scientific journals such as *De Ingenieur* and *Natuurwetenschappelijk Tijdschrift*, field notes by H. F. Tillema (*Kromoblanda, Kampongwee*), blueprints detailing Bandung's sewers and the Imhoff Tank installation, as well as publications from magazines and newspapers (*Preangerbode, Groot Bandoeng, Bataviaasch Nieuwsblad, De Locomotif*). Most primary sources we accessed were from the National Archives of the Republic of Indonesia (ANRI), The Royal Library of the Netherlands (*Koninklijke Bibliotheek*), and Leiden University Libraries Digital Collections. Supplementary to primary sources, recent research findings published in international journals serve as secondary sources to fortify the study. The archaeological data employed in this research encompasses the physical structure of the Imhoff Tank installation situated on Pelindung Hewan Street, Tegallega, Bandung City, along with the discernible remnants of the sewer infrastructure within the operations of the Tirta Wening Regional Company nowadays.

This research was carried out through a sequential approach comprising four key stages. It began by gathering historical records and on-site assessments of sewer infrastructure and the Imhoff Tank. Subsequent stages involved data categorization, verification for accuracy, and analysis using Melosi's (1990) techno-environmental

approach. This comprehensive analysis included scrutinizing historical maps, demographic distributions, sewer designs, and details of the Imhoff Tank technology. Ultimately, findings were interpreted and systematically structured into three pivotal subchapters: outlining environmental problems, environmental countermeasures, and sewage treatment technology.

Results and Discussion.

During the late colonial period, Bandung, a city in the Dutch East Indies (Indonesia), underwent a significant transformation process, evolving from a traditional town (*dayeuh*) situated in the interior of West Java to a modern urban center (Lombard, 1996; Wertheim et al., 1958). This transformation was part of the broader urbanization process that occurred in other Dutch East Indies cities like Batavia, Surabaya, Semarang, and Medan, all influenced by the agrarian capitalism policies that the Dutch East Indies government implemented under the Ethical Policy era (Naas, 2007). The Dutch East Indies government made Bandung a hub for commerce and governance, exploiting its fertile soil, abundant water sources, and temperate climate due to its mountainous terrain (Bemmelen, 1934; Coolsma, 1881). Bandung's transformation significantly impacted its society and culture, such as the emergence of new social classes, ethnic groups, and lifestyles.

Bandung's transformation into a modern city was intricately linked to its designation as a municipality (*gemeente*) in 1906. Following this status change, Bandung entered a significant 'boom town' phase, during which the Dutch East Indies government inaugurated crucial government offices in the city, such as the War Department (1917), the Communications Department (1923), and the headquarters of the train service (1923–1924). The construction of these offices was facilitated by the existing transportation infrastructure dating back to the 19th century, including the main thoroughfare known as Post Road (*De Groot Postweg*) and the western railway line (Reitsma, 1928; Roosmalen, 2008). Concurrently, the mountainous regions surrounding Bandung developed into industrial hubs for private plantations cultivating commodities such as quinine, tea, coffee, and rubber. Bandung's transformation had significant implications for the city and the region, as it increased the population, economic activity, and political influence of Bandung in the Dutch East Indies (Naas, 2012; Nurwulandari & Kurniawan, 2020)

The city's rapid urban development attracted diverse communities, such as European colonizers, Chinese merchants, Arab traders, and Sundanese peasants, who sought livelihoods in Bandung. Residents from Priangan and Java regions also migrated to Bandung, drawn by opportunities in railway work, heavy industry, trade, and plantation labor (Himpoenan Soedara, 1936; Reerink, 2015). However, this population increase also brought about urban challenges such as slums, disease outbreaks, inadequate sanitation, and high mortality rates among both native and Chinese residents (Brand, 1958), as shown in Tables 1 and 2. These elevated mortality

rates were strongly linked to socioeconomic factors such as poverty, substandard housing conditions, and poor hygiene standards (Brand, 1958; Tillema, 1915).

Table 1. Population Growth in Bandung 1906–1930 (Brand, 1958, p. 231)

Years	Population Groups				
	European	**Chinese**	**Native**	**Arabs & other**	**Total**
1906	2.199	3.704	41.393	45	47.391
1920	9.043	6.495	79.017	245	94.800
1930	19.650	16.657	130.028	480	166.815

Table 2. Mortality per Thousand (/1000) of Mid Year Population per Per Population Grup, Bandung, 1921–1926 (Brand, 1958, p. 233)

Years	Population groups		
	European	**Chinese**	**Native**
1921	12	6.5	21
1922	7	15	17.5
1923	7.5	15	16
1924	6.5	15	14.5
1925	6.5	15	15
1926	7	15.5	18

Urban Environmental problems in Bandung.

Despite the advantages of clean water sources, a cool climate, and fertile soil, Tillema, a sanitarian and urban ethnographer, noted a significant concern: the local population in Bandung still had a habit of defecating in public places. Despite being contaminated with fecal matter, they often used the Cikapundung River and the large gutters for multiple purposes, such as washing, bathing, and brushing teeth (Tillema, 1915, 1916). For those facing water scarcity, open latrines were utilized – a type of hole dug in the ground and covered with a bamboo booth for sanitation purposes (Tillema, 1913).

In rural settings, the native Sundanese community traditionally used *pacilingan*, specific areas built above fish ponds with bamboo booths and sticks as sanitation walls

(Rosidi, 2000). These simple disposal systems were located away from residences and on lower terrain to prevent the contamination of water sources and paddy fields (Prestasi & Kim, 2020; Sasmita, 2022). The *pacilingan* disposal system allows for the natural decomposition of human waste in fish ponds through anaerobic mechanisms. However, such systems were complex to adopt in urban contexts due to the higher population density, limited water availability, and the lack of fish ponds that were common in rural areas. As a result, *'poep maar-raak*' or open defecation became widespread in urban areas.

The poor hygiene practices of the native population were associated with the outbreaks of cholera, typhoid, and dysentery by Dutch doctors and sanitarians (Tillema, 1919; Tuyter, 1930). The bacterial contamination of food and drinking water caused these diseases. The sources of bacterial transmission included insufficient handwashing, ingestion of contaminated food and beverages, and dirty feet from contact with soils (Longhem, 1920; Tuyter, 1930). Moreover, the situation was aggravated by poorly lit and overcrowded houses and inadequate drainage and sewage systems (Bandoeng, 1929; Tillema, 1919). The housing conditions of the native population differed markedly from those of the Dutch and European residents, who lived in houses with solid walls, sufficient lighting, ventilation, and toilets that met the health standards suitable for the tropical climate (Bergmans, 1909; Taylor, 2013).

These issues were prevalent in the natives's settlements, known as *kampung*, and the Chinese settlements, referred to as *Chineesche Kamp*, were acknowledged by the Bandung municipality (Bandoeng, 1929; Kunto, 1986; Wertheim et al., 1958). The government considered both these settlements insufficient public health and hygiene standards and characterized them as primitive areas (Wertheim et al., 1958). These *kampungs* and *Chineesche Kamp* were mainly situated in the western and southern parts of Bandung City, adjacent to markets and rice fields (Roosmalen, 2008).

The western area of Bandung was a vibrant center of commerce and social interaction for the native and Chinese populations due to its high concentration of shops and markets (Heetjans, 1925; Kunto, 1986). It was also close to the train station, which connected Bandung with other regions and attracted many passengers (Tunas 2007). Some of the districts in this area, such as Suniaraja, Pasar Baru, Citepus, Cibadak, and Kaum, were densely populated with *kampung* and *Chineesche Kamp* settlements (see Figure 1). The Bandung Municipality reported that the average population density in these districts was 250–350 people per hectare in 1925 (Heetjans, 1925). Population in the district Suniaraja, Pasar Baru, Citepus, Cibadak, and Kaum contrasted with the lower population density in the northern area of Bandung, which ranged from 25–75 people per hectare (Heetjans, 1925).

Figure 1. Native and Chinese settlements densely populate the western part of Bandung (Heetjans, 1925; Topographisch Bureau, 1905).

Environmental challenges, such as inadequate drainage systems and a lack of waste disposal facilities, plague the congested Suniaraja, Pasar Baru, and Citepus districts. The poor sewage infrastructure in these districts increased the risk of gastroenteritis-related diseases, such as cholera, typhoid, and dysentery. News articles from 1909 to 1914 reported sporadic cholera cases in districts like Citepus, Cibadak, and Tegallega ("Cholera," 1914; "Cholera Te Bandoeng," 1913; "De Cholera Te Bandoeng," 1910). These outbreaks were linked to the local population's lack of proper sanitation facilities. According to a report by *Gemeente Bandung* (Heetjans, 1925), septic tank systems were impractical in densely populated areas like Suniaraja, Pasar Baru, and Citepus due to the proximity of houses. Moreover, septic tanks could contaminate groundwater sources in these areas (Heetjans, 1925).

Bandung City lacked a comprehensive sewage system until 1916. The existing sewers were poorly constructed and planned, and they mainly discharged sewage into nearby rivers (Gemeente Bandoeng, 1919). This substandard sewage and drainage infrastructure caused frequent flooding during the rainy season (Gemeente Bandoeng, 1919). These problems affected the native or Chinese neighborhoods and the northern area where the European population lived. However, the north area had better health protection as the European population used septic tanks.

In response to these challenges, the Bandung Gemeente Public Works Office recognized the need for an integrated drainage and sewage system. Therefore, in 1917, the Public Works Department, led by Heetjans, began planning to construct integrated drainage and sewage channels (Gemeente Bandoeng, 1919). The western region was prioritized, especially the densely populated Pasar Baru, Suniaradja, and Citepus, as it urgently needed a sewer network. The Municipal Public Works Department also designed toilets, clean hydrants, and public washing facilities for Bandung's villages (Bandoeng, 1929; "Kampong Toestanden," 1925).

Environmental Countermeasures: Sewerages (*rioleering*) and Public Toilets.

The Bandung City Government acknowledged the need for a systematic approach to address the sewerage problems that exceeded the individual residents' capacity. Therefore, the city engaged engineers and health experts to develop a comprehensive sewage management system. This initiative, which commenced in 1917, involved key figures such as Heetjans, the Director of Public Works; J. J. van Lonkhuijzen, the Inspector of the Civil Health Service of West Java; and C.A.E. Van Leeuwen, the Engineer of the Public Works Repair Bureau. The design of the sewer and drainage system, which cost 1,000,000 guilders, received a 50% subsidy from the central government (Rioleering van Bandoeng, 1926a). The plan, submitted by *Gemeente Bandung*, obtained the approval of the central government, with the endorsement of Perelaer, the Head of the Public Works Department, and De Vogel, the Head of the Civil Medical Service.

The Bandung City Works Department developed a 15-year plan for constructing the sewers (Rioleering van Bandoeng, 1926b). The sewer construction commenced in 1919 and underwent refinement in 1925, eventually completing the entire sewer network by 1938. During this period, the city also implemented various improvements in the *kampung* (*kampong verbetering*) alongside the extensive drainage and sewerage network construction. These improvements comprised road repairs, stormwater drainage system installations, house-to-house clean water supply pipe installations, the closure of old wells, and even the provision of electricity (Bandoeng, 1929; P. Thijsse Jr., 1934).

According to the reports compiled by *Gemeente Bandung* in 1919 and 1925, Bandung had two types of sewers. The first type of sewer was designed to collect rainwater, feces, urine, and kitchen waste. These were open concrete channels measuring 3 meters in width initially implemented in East Bandung, especially around the War Department and government offices (Bandoeng, 1929; Heetjans, 1925). However, these combined sewerages posed health concerns due to their open structure, which could facilitate bacterial transmission. Moreover, residents often used these open channels to dispose of garbage and even for defecation (Bandoeng, 1929; P. Thijsse Jr., 1934). The technical condition of the combined sewerages increased the risk of disease transmission and escalated maintenance costs.

The second type consisted of sewers (*riol*) intended to collect feces, urine, and kitchen waste, deemed safer from a health perspective by experts such as J. J. Van Lonkhuijzen and C.A.E. Van Leeuwen. These sewers were constructed below ground level, made of concrete, and measured 90 cm in diameter (see Figure 2) (*De Koerir* 9 Maret 1938; KITLV, 1930). The price per meter of concrete sewers for this size was 21 guilders (Gemeente Bandoeng, 1919, p. 52). The sewer system, mainly established in West Bandung and covering about 135 hectares, including densely populated villages, was initiated in 1925 (Dienst der Volksgezondheid, 1936; P. Thijsse Jr., 1934, p. 139). The sewer network, comprising four main channels, followed specific routes: three ran from west to east, and one from north to South,

namely: (1) Dunguslaja-Kebonjukut, (2) Sukahaji-Ciateul Kulon, (3) Ciparay-Sindangpalay, and (4) Kebonjukut-Tegallega, aligning with the course of the Cikapundung River (see Figure 3) (Heetjans, 1925).

Figure 2. The installation of sewer pipes and the construction of concrete joints for sewerage in Bandung took place between 1929 and 1930 (KITLV 157009, KITLV 157013).

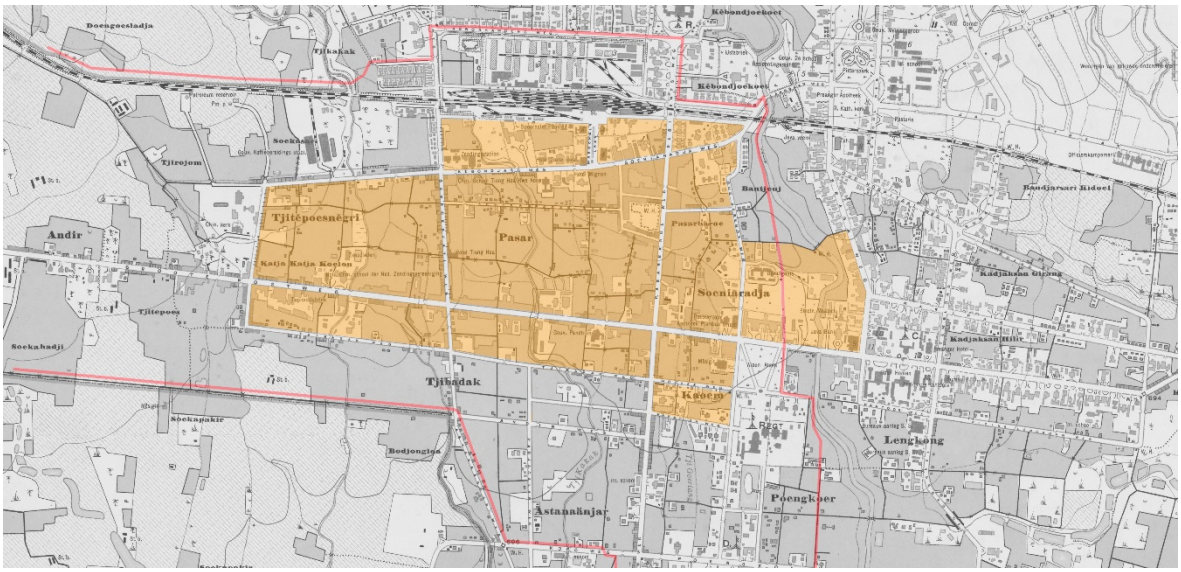

Figure 3. The reconstruction of the sewer network in western Bandung in 1925 was based on the report Sewerage and Drainage Plan 1925 of Bandung and the Bandung Guide Map 1946. (Red lines indicate the sewer network; orange shading indicates dense residential areas) (Heetjans, 1925, pp. 45–47; AFNEI Headquarters Survey Department, 1946).

The *kampungs* in Bandung were equipped with a main sewer network that efficiently collected and distributed sewage and waste through pipes that connected houses, toilets, and public washing stations (Bandoeng, 1929; P. Thijsse Jr., 1934). This sewer system was supplemented by 70 public toilets, 70 public bathrooms, and 70 public washing stations distributed across the *kampungs* by the 1930s (Gemeente Bandoeng, 1924; Thijsse, 1935). Some of the *kampungs* that benefited from the improved public toilet facilities were Babatan, Cipurut, Gempol, Astana Anyar, Ciateul, and Rasamala (see Figure 4) ("Kampong Toestanden," 1925; Reerink, 2015). According to the Bataviaasch Niuewsblad newspaper ("Kampong Toestanden," 1925), the villagers had adopted these public toilet facilities and appreciated their convenience and hygiene.

Figure 4. Public toilet and washing facilities built in the *kampungs* (KITLV 157053).

This sewerage network has its final discharge point in the Tegallega area of South Bandung, where the last effluent undergoes treatment using the activated sludge method (Gemeente Bandoeng, 1919). After treatment, the processed sewage is discharged into the Citepus Hilir River. This closed sewer system relies on the *spoilwater* (rinse water) from the Cikapayang and Leuwilimus Rivers, which have a flow rate of 818 liters per second (Gemeente Bandoeng, 1919; Heetjans, 1925). The success of Bandung's sewer system can be attributed to the city's sloping landscape in the South, which facilitates the gravitational flow of sewage and wastewater toward the city's southern region. This area, which consists mainly of rice fields with few residential zones, reduces the risk of pollution and bacterial transmission, enabling optimal sewage management (Heetjans, 1925).

Heetjans, the City Public Works Department head, devised the sewer design with foresight, considering Bandung's expected population growth and expansion. Heetjans

planned an additional network that would span from Cibuntu in the west to Binong in the east, envisaged for the future when Bandung's population was projected to reach 378,000 by 1965. The elaborate design included the locations of sewage collection and treatment plants (Heetjans, 1925). Researchers continually pursued advancements in the final treatment station to secure a fitting, cost-effective treatment method.

The Bandung Municipality initiated the construction of a modern wastewater treatment plant using Imhoff or Emscher tank technology in 1932. The Municipality appointed Ir. L. W. Hofland led this plant's research and implementation. The primary goal of establishing the Imhoff Tank was not solely to prevent environmental pollution but also to harness the methane gas generated from the septage. According to the calculations by the Public Health Department, the Imhoff Tank in Bandung had the potential to produce 320 m^3 of methane gas, envisaged for use as motor vehicle fuel (Dienst der Volksgezondheid, 1936). This project's approach to utilizing methane gas drew inspiration from successful implementations in Germany and France before World War II ("Methaangas in Plaats van Benzine Voor Auto's," 1937). To ensure the project's success, the Bandung City Government engaged engineers from *Technische Hoogeschool* Bandoeng, including Professor C. P. Mom and Ir. Baumgarten ("Methaangas Voor Auto's Belangwekkende Demonstratie Door Gemeentedienst Te Bandoeng," 1937; Mom, 1941).

Imhoff Tank and Methane gas utilization.

The Imhoff Tank, also known as the Emscher Tank, is a sludge treatment technique initially developed by Karl Imhoff in the Essen District of North Germany in 1907 (Kinnicutt, Winslow, & Winthrop Pratt, 1919). Functioning on a principle akin to a septic tank, the Imhoff Tank is a primary treatment facility to separate solids and water in wastewater and treat settling solids (sludge). Notably, Imhoff Tanks can precisely capture the gas produced by fecal sludge for use as fuel, a feature not present in conventional septic tanks. Initially employed in Germany, England, and America, this technology can reduce suspended sludge solids by 50–70% and lower chemical oxygen demand by 25–50% (Hoffman, Platzer, Winker, & von Muench, 2011; Mom, 1941).

In the context of initiatives to enhance urban environmental conditions and public health, adopting Imhoff Tanks represented a crucial technological innovation in the Dutch East Indies. During the early 20th century, only a handful of cities in the Dutch East Indies, including Bandung, Medan, and Yogyakarta, boasted integrated sewer networks (Dienst der Volksgezondheid, 1936). Surabaya and Batavia, the most densely populated centers, could not complete integrated sewer networks due to the economic crisis that struck the Dutch East Indies. Among the cities with sewer networks, Bandung pioneered the implementation of Imhoff Tanks. Consequently, the application of Imhoff Tanks in the Tegallega area of Bandung emerged as a crucial laboratory and development center, not only for Bandung itself but for the entire Dutch East Indies. The system's development involved consultations with the water

purification laboratory in Manggarai, and the trials received full support from the Dutch East Indies Association for the Promotion of Hygiene (*Nederlandsch-Indische Vereeniging ter bevordering der Hygiëne*) (P. Thijsse Jr., 1934, p. 139). The government, particularly the Public Health Service, strategically planned the success of the Imhoff Tank project as a pilot system that could be replicated in other cities across the Dutch East Indies in the future (see Figure 5).

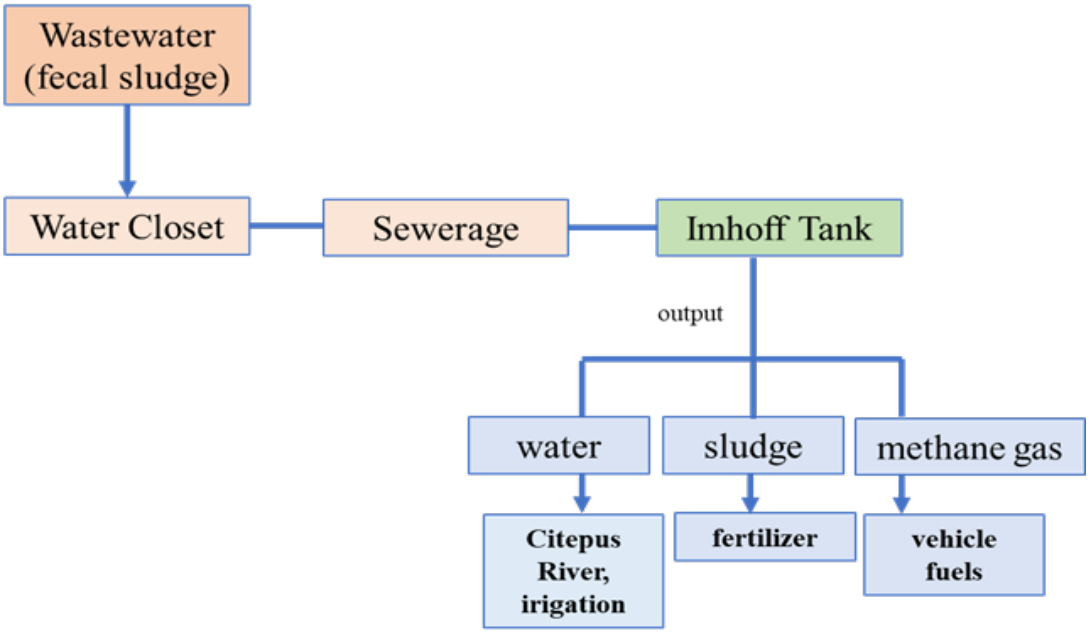

Figure 5. Wastewater management scheme in Bandung in the early 20th century.

With a development and research duration of approximately seven years, by 1938, the Imhoff Tank sewage treatment plant could effectively manage wastewater from 160 hectares of sewers in Bandung City (*Het nieuws van den dag voor Nederlandsch-Indië* 9 Maret 1938). According to a report by Ir. L. W. Hofland, this sewer network was projected to gradually expand to cover 598 hectares, encompassing the built-up area of Bandung City (Hofland, 1936). The Imhoff Tank Installation played a crucial role in collecting and treating wastewater primarily originating from the western and southern areas of Bandung, including densely populated districts like Suniaraja, Banceui, Landraad, and Alun-alun ("Bandoeng's Rioleering," 1938). The wastewater conveyed through the sewer network underwent treatment at the Imhoff Tank installation in the southern part of the city, near the Citepus River. The treated water from the Imhoff Tank, exhibiting significantly improved cleanliness, was discharged into the Citepus River. Subsequently, the water from the Citepus River served to irrigate the rice fields of residents scattered in the southern part of the city. Simultaneously, the sludge separated from the Imhoff Tank was found to be applicable as fertilizer for plantations.

The Imhoff Tank design comprises two vertically arranged compartments: the upper compartment for solid particle separation and the lower compartment for the

anaerobic digestion of settled sludge. The Imhoff Tank, owned by the Bandung City government, was constructed below ground level, featuring a compartment structure depth of 11.15 meters and a compartment surface width of 13.7 meters (Figure 6). With these dimensions, the Bandung municipality established a pair of Imhoff Tank installations: the upper compartment's width was 5.7 meters, the lower compartment's width was 3.95 meters, and four gas storage tubes with a diameter of 4 meters (Hofland, 1936; Mom, 1941). The Imhoff Tank installation (see Figure 7) was additionally equipped with a pumping machine for sludge removal and a laboratory room (Mom, 1941; Nauta, 1937). To actualize the Imhoff Tank installation, the Public Health Service Departement and the Bandung City Government allocated a budget of 82.360.58 guilders, covering the expenses for constructing the Imhoff Tank, pump house, pump and mixing installation, and other supporting costs (Dienst der Volksgezondheid, 1936).

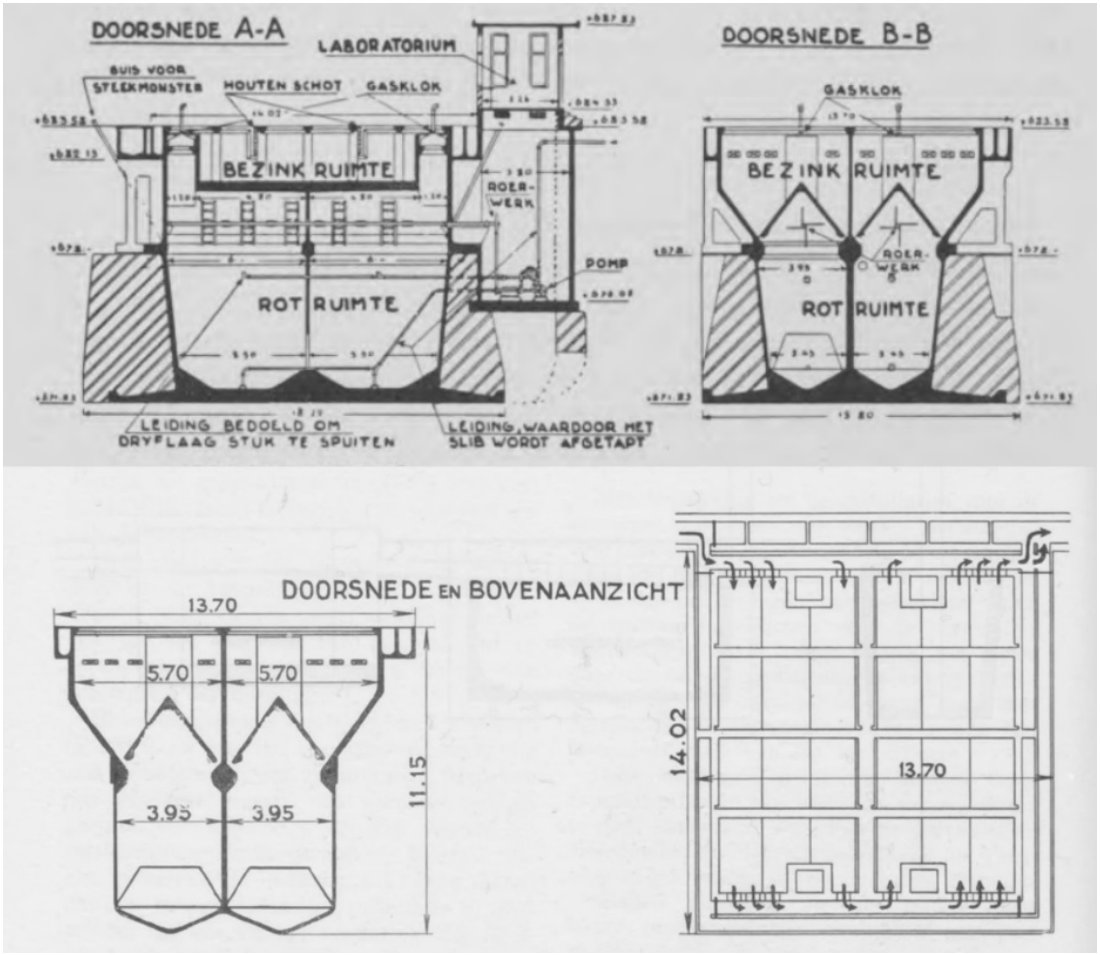

Figure 6. Imhoff Tank installation design (Nauta, 1937; Mom, 1941).

Figure 7. The sewage treatment plant, Imhoff Tank, in Tegallega, Bandung. Number 1 shows the laboratory room, and number 2 shows the methane gas collection tube (Mom, 1941, p. 163; personal documentation, 2023).

The wastewater treatment mechanism of the Imhoff Tank involves seven stages. Initially, wastewater or septage enters the upper compartment, which is larger and open, facilitating the easy inflow of raw wastewater. The wastewater is retained in this compartment for a specific period, allowing solid particles to settle and descend to the lower compartment. Subsequently, heavier solids like sludge and other particles settle in the lower compartment, marking the second stage, primary sedimentation. The third stage involves liquid and solid phase separation, employing a pyramid or inverted pyramid-shaped sludge hopper between the upper and lower compartments to let the clean liquid flow out while retaining sludge or other solids in the lower compartment. The fourth stage entails anaerobic digestion of sludge in the lower compartment. During this stage, anaerobic bacteria decompose the organic matter of the sludge, reducing its volume, stabilizing the organic content, and generating biogas, including methane (CH_4) and carbon dioxide (CO_2). In the fifth stage, the gas produced from sludge digestion accumulates in the upper compartment and can be discharged or collected through a gas pipe into a unique tube. The sixth stage involves the dehydration and volume reduction of the settled sludge in the lower compartment. Finally, in the seventh stage, the remaining sludge in the lower compartment is discharged through a pipe.

In the context of the Imhoff Tank application in Bandung, the methane gas produced underwent testing for powering the city's cleaning service trucks (“Methaangas in Plaats van Benzine Voor Auto’s,” 1937). Ir. Baumgarten, alongside Dr. C. O. Schaeffer, conducted mechanical developments to purify the carbon dioxide (CO_2) content to harness the methane gas from the Imhoff Tank treatment.

Additionally, they worked on the advancement of gas carburetors for vehicles, enabling the conversion of energy from methane (CH_4) into a usable fuel source (Figure 8) (Mom, 1941).

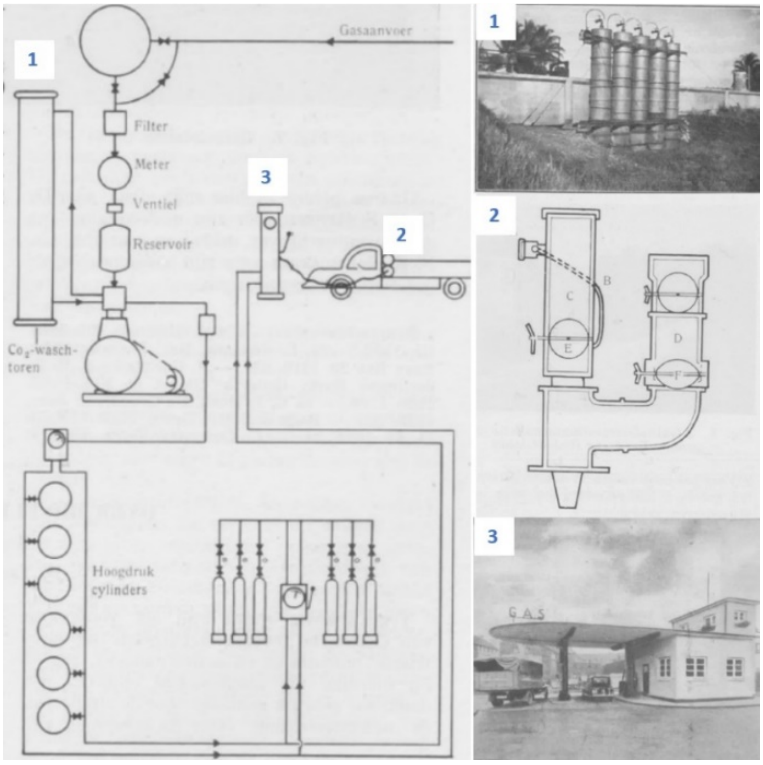

Figure 8. Flow of methane gas utilization for vehicle fuel. Number 1 indicates methane gas collection toren; number 2 indicates a combination of gas carburetor and gasoline carburetor; and number 3 indicates a gas filling station (Mom, 1941, p. 163).

Based on a report by Ir. L. W. Hofland, overseeing the development and research of the Imhoff Tank, the sludge decomposition process in tropical areas with a temperature of 26 °C, such as Bandung, occurs more rapidly than in subtropical regions like Europe (Hofland, 1936). These conditions create a more favorable environment for generating methane gas abundantly and quickly from sludge decomposition. The gas composition from the Imhoff Tank includes methane (CH_4) at 71.4%, hydrogen (H_2) at 3.5%, carbon dioxide (CO_2) at 21.3%, Nitrogen (N_2) at 2.5%, and oxygen (O_2) at 1.3%. The average calorie production from the gas composition is 6,500 Calories/m^3, and the daily gas supply reaches 320 m^3. They calculate the daily calories, which results in 320 m^3 × 6,500 Cal = 2,000,000 calories. Using 1 HP/hour = 630 calories, so 2,000,000 calories can be translated to 3,300 HP/hour, equivalent to 3,346.8 HP/hour (Hofland, 1936).

With such energy potential, a research and development team composed of Ir. L. W. Hofland, Professor C. P. Mom, and Ir. Baumgarten explored various options for methane gas utilization, including applications in industries and commercial enterprises such as welding, water refinement, processing of mining products, coal

companies, and gas companies (Hofland, 1936). However, commercial enterprises tended to find methane gas less economical and efficient among the considered options. One contributing factor was the perceived distance of the methane gas plant (Imhoff Tank) from the city center, coupled with the availability of cheaper alternatives like cokes (Hofland, 1936). In light of this assessment, Ir. L. W. Hofland proposed that the methane gas produced from the Imhoff Tank could be more effectively employed for internal purposes within the Bandung Municipality. Internal purposes included providing energy for the Imhoff plant itself and fueling the garbage trucks of the Municipal Cleaning Service Department. The research team ultimately opted for the second alternative, utilizing methane gas as fuel for waste collection vehicles. The effectiveness of methane gas utilization was tested publicly by Professor C. P. Mom, A. W. Allirol, and Ir. Baumgarten on October 12, 1939 ("Lezing Di Gemeente," 1939). The trial received a positive response from city officials and journalists at the demonstration. Unfortunately, the onset of World War II, which also impacted the Dutch East Indies, likely impeded further development and utilization of this technology. Post-World War II, following the end of Dutch colonial rule in Indonesia, the Imhoff Tank installation in Bandung has yet to be fully utilized and today stands as an abandoned colonial heritage urban technology.

Conclusions.

This study reveals that the emerging modern cities in the early 20th century in the Dutch East Indies (Indonesia) encountered analogous environmental challenges: densely populated slums, inadequate sewerage systems, restricted access to clean water, and the looming threat of diseases (cholera, malaria, typhoid, dysentery) due to poor hygiene practices among the population. These issues significantly escalated the risk of population mortality. Bandung City, envisioned by the Dutch East Indies government as a modern city suitable for European habitation, grappled with environmental problems that demanded urgent attention. These challenges included the practice of native populations defecating in rivers and open areas, spreading diseases, and potentially polluting river water. Such conditions persisted due to insufficient sanitation facilities, particularly in native (*kampung*) and Chinese (*Chineesche Kamp*) residential areas such as Suniaraja, Pasar Baru, Citepus, and Cibadak districts.

To address the environmental challenges in Bandung, the municipality government, in collaboration with the Public Works Department, engineers, and environmental engineering researchers, initiated the construction of urban infrastructure, facilities, and technology in 1917. Prioritizing public toilets, sewer networks, and sewage treatment plants, the city government adopted a sustainable approach in designing the sewer network, planning its extension until 1965, aligning with the city's developmental potential and anticipated population growth. Environmental engineers and researchers introduced cutting-edge technology known as the Imhoff Tank between 1932 and 1938 to mitigate wastewater pollution proactively. This technology facilitates circular wastewater treatment, separating solid

and liquid waste while capturing methane gas. The treated water from the Imhoff Tank is discharged into the river, serving residents in rice fields for irrigation. Simultaneously, the sludge output serves as fertilizer, and the collected methane gas is utilized to fuel vehicles of the Municipal Cleaning Service Department. The implementation of the sewer network and the Imhoff Tank by the Bandung City Government during the early 20th century exemplified their commitment to realizing a vision of a healthy and sustainable city.

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Conflicts of interest.

The authors declare no conflict of interest.

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Рішення для міської санітації: Кейс технології Імхоффа в місті Бандунг, Нідерландської Ост-Індії (1917–1938)

Анотація. *Це дослідження вивчає, як муніципалітети управляли стічними водами в Нідерландській Ост-Індії на початку 20-го століття. Ми зосереджуємося на Бандунгу, одному з найважливіших міст Нідерландської Ост-Індії, яке перетворилося на сучасний житловий район, економічний центр і місце уряду. Це дослідження поєднує первинні дані з письмових джерел і польові спостереження за допомогою історико-археологічних методів. Письмові джерела включають офіційні звіти від Департаменту з будівництва, Департаменту цивільного здоров'я, Міської ради Бандунгу, старих карт, проекти каналізаційної мережі, журнали з екоінжинірінгу та газети, опубліковані з 1909 по 1941 рік. Використовуючи техно-екологічний підхід, запропонований Мартіном В. Мелосі, це дослідження розглядає міську технологію як стратегічну відповідь приймачів рішень на виклики, що стоять перед розвиваючимися містами на початку 20-го століття. Дослідження показує, що Бандунг мав проблеми з навколишнім середовищем, такі як звички місцевих мешканців залишати екскременти у річках та на відкритих територіях, що призводило до поширення хвороб і потенційного забруднення води в річках. Ці проблеми виникли через відсутність санітарних умов та щільне заселення, особливо в місцевих та китайських житлових районах: Кампунг і Китайський Табір. Для вирішення цих викликів політики, екологічні інженери та дослідники ініціювали проектування та впровадження каналізацій, громадських туалетів та очисних споруд для стічних вод у 1917 році. Муніципалітет*

інтегрував каналізаційні системи з технологією очищення стічних вод за допомогою баків Імхоффа, розроблених дослідниками та інженерами з 1932 по 1938 рік, щоб впровадити циклічну очистку стічних вод. Баки Імхоффа стали значущим технологічним вдосконаленням в Нідерландській Ост-Індії. На початку 20-го століття лише декілька міст у Нідерландській Ост-Індії, включаючи Бандунг, Медан та Джок'якарту, мали інтегровані каналізаційні мережі. Серед міст, які мали каналізаційні системи, Бандунг першим застосував впровадження баків Імхоффа. В результаті він виріс у важливий лабораторний і розвитковий центр для Бандунгу і всієї Нідерландської Ост-Індії. Процес очищення за допомогою баків Імхоффа, який виробляє чисту воду, добриво та метановий газ, який може бути використаний як паливо для транспортних засобів, був частиною активної стратегії, впровадженої політиками в Бандунгу на початку 20-го століття, що відображає їхню візію створення здорового та сталого міста.

Ключові слова: *громадське здоров'я; відкрита дефекація; каналізація; бак Імхоффа; міська технологія*

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The history of the development of 3D printing technologies and their use in world artistic ceramics

Abstract. *The article is devoted to the study of the history of the emergence and development of additive technologies in world artistic ceramics. The article analyzes information on the history of the emergence of additive technologies. The principle of operation of 3D printing equipment, features of its use, the most common areas of use and materials used in 3D printing have been considered. An analysis of the specifics of the technical characteristics of 3D printers and technologies for 3D printing with ceramic masses has been shown that the use of ceramic materials as raw materials for 3D printing is a progressive trend due to the emergence of the possibility of forming ceramic objects and products that are practically indestructible reproduction and replication using traditional methods. In this article, the authors have been analyzed the advantages and disadvantages of manufacturing ceramic products by 3D printing. It has been established that the main difference between the production of three-dimensional plastic or metal elements and ceramic elements is the main feature of the ceramic manufacturing technology, namely that the printout is not a ceramic product before firing in the oven, that is, without firing, it is simply an element printed from*

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clay materials (that is, such a printout before firing is called the "green part" – an unprocessed element). Currently, there are no 3D printers that can immediately produce ready-made ceramic products, all elements printed from ceramic materials require drying and firing. But, despite this nuance, printers that print with clay materials are called ceramic 3D printers. As 3D printing can accurately realize the creative thinking of artists and designers, 3D printing technology is increasingly used in the creation of ceramic products and contemporary ceramic works. The authors of the article emphasize that three-dimensional printing with clay provides ceramists with completely new opportunities for creating ceramic products with a complex configuration, texture, etc. Ceramic artists from all over the world are already actively using this technology in their work. Therefore, part of the study is devoted to examples of the use of 3D printing technology in world artistic ceramics, as well as to the description and analysis of the most interesting achievements in this direction of creativity, according to the authors.

***Keywords**: 3D printing; additive manufacturing; clay; decorative and applied art; technology and equipment for 3D printing; artistic ceramics*

Introduction.

The development of modern technologies makes it possible to involve new technical and production possibilities in artistic practice, in particular computer technologies, which gives artists the opportunity to expand the arsenal of their creative pursuits. All over the world, in recent years, one can trace the growing interest in the production of ceramic products using additive technologies, i.e. 3D printing of products with ceramic materials (Baltazar, Dias-de-Oliveira, Pinho-da-Cruz, Gouveia, & Olhero, 2021; de Abreu et al., 2023; Pires, Luís, Fernandes, & Oliveira, 2023). Research laboratories, institutes, firms and individual artists have appeared, developing new methods of making ceramic products and equipment for this process.

It is well known (Valera-Jiménez, Marín-Rueda, Pérez-Flores, Castro-García, & Canales-Vázquez, 2021; Hu, X., Lai, Hu, Y., Li, Zhao, & Tong, 2022; Lamnini et al., 2022) that 3D printing ceramic materials presents significant challenges due to several unresolved issues, including excessive surface roughness, suboptimal mechanical properties, high porosity, and low precision of parts. Additionally, adapting ceramic 3D printing technology to different materials is challenging, often necessitating the development of specific 3D printing techniques for particular properties, which increases costs. However, with ongoing advancements in technology and theory, ceramic 3D printing has made substantial progress and remains a major research focus. While traditional ceramics benefit from high-temperature sintering, which is difficult to replicate in ceramic 3D printing, the latter can produce complex 3D structures that are impossible to achieve with traditional ceramic processes.

The aim of the article is to research the history of the development of 3D printing technologies and their use in world artistic ceramics.

Research Methods.

This study is devoted to the study of the history of the emergence and development of additive technologies. Information on the history of the emergence of additive technologies was analyzed, namely, the principle of operation of 3D printing equipment, features of its use, and materials used in 3D printing were considered.

Three-dimensional printing with clay provides ceramists with completely new ways of creating ceramic products of complex configuration, texture, etc. Ceramic artists from all over the world are already actively using this technology in their work. Therefore, part of the study was devoted to examples of the use of 3D printing technology in world artistic ceramics, as well as to the description and analysis of the most interesting achievements in this direction of creativity, according to the authors.

Results and Discussion.

Review of the history of the emergence of additive technologies.

The earliest technologies of modern 3D printing first began to appear in the late 1980s, at that time they were called rapid prototyping technologies – RapydPrototype (RP). This is because the processes were originally conceived as a quick and cost-effective way to create prototypes for industrial product development.

The emergence of the first devices, which can be attributed to the predecessors of 3D printers, dates back to the early 1980s, when Dr. Hideo Kodama developed the first rapid prototyping system using photopolymers. The operation principle of this device consisted in the layer-by-layer reproduction of objects according to the given model. Actually, most modern 3D printers work according to this principle.

The next stage in the field of 3D printing was the invention of stereolithography (SLA) by the American Charles Hull in 1984, a patent for this technology was issued in 1986. Thanks to this technology, it became possible to produce on 3D printers objects that were modeled on a computer by the method of 3D modeling, that is, according to computer digital models. A liquid substance based on acrylic – a photopolymer that solidified under the action of an ultraviolet laser, turning into a plastic product – also served as a material for printing.

In the early 1990s, Charles Hull's company 3D Systems Corporation (which is still one of the leaders in the industry) established the production of printers based on the technology of laser stereolithography from photopolymers (SLA). 3D Systems built its first commercial rapid prototyping system, the SLA-1, in 1987 and after extensive testing sold it in 1988. However, even though SLA technology may claim the top spot in the history of 3D printing, it was not the only rapid prototyping technology at this time.

In 1987, Carl Deckard, who worked at the University of Texas, applied for a patent in the US for selective laser sintering (SLS-Selective Laser Sintering). This patent was issued in 1989, and SLS was later licensed to DTM Inc. and later acquired by 3D Systems.

Also, in 1989, Scott Crump, co-founder of Stratasys Inc. applied for a patent for FDM-Fused Deposition Modeling (FDM) technology, which the company still owns, the technology used today by many entry-level, open-source RepRap (Replicating Rapid Prototyper) printers. The FDM patent was issued to Stratasys in 1992 in Europe.

In 1989, Hans Langer founded EOS GmbH in Germany. After playing around with SL technology, EOS shifted its focus to SLS technology. Today, EOS is recognized worldwide for the quality of its products for industrial prototyping. In 1990, EOS sold its first Direct Metal Laser Sintering (DMLS) stereo system in collaboration with the Electrolux division in Finland, which was later acquired by EOS.

Other 3D printing technologies emerging in these years include the production of ballistic particles (BPM - Ballistic Particle Manufacturing), originally patented by William Masters, the production of objects by the method of lamination (LOM – Laminated Object Manufacturing), patented by Mykhailo Feigin, mask stereolithography (SGC – Solid Ground Curing), patented by Yitzhak Pomerantz and three-dimensional printing (3DP), patented by Emmanuel Sachs. Thus, in the early nineties, there was an increase in the number of competing companies in the rapid prototyping market, but only three of them have survived to this day – 3D Systems, EOS and Stratasys.

It should be noted that the term "3D printing" was first used only in 1995 at the Massachusetts Institute of Technology, and the term "3D printer" was officially used only in 1996, when the Actua 2100 device from 3D Systems was created. The first 3D printers were low-power, worked slowly, and when trying to speed up the production process, products came out with large errors. Only since 2005 have 3D printers appeared with high print quality.

Until 2008, 3D printers could only work with one type of material – ABC plastic. Later, with the development of the 3D printing industry, the number of materials with which printers can work gradually increased. At the moment, there are more than a hundred of these materials. Among them: acrylic, concrete, hydrogel, paper, gypsum, wood fiber, ice, metal powder, nylon, polycaprolactone (PCL), polylactide (PLA), polypropylene (PP), low-pressure polyethylene (HDPE), clay, chocolate, and even human cells.

Fields of Application, Principles of Operation of 3D Printers and Features of 3D Printing Technologies.

The main feature of modern 3D printers is that all models are printed layer by layer, layer by layer. Almost any thing can be created on a 3D printer – from children's toys, souvenirs, dishes, fabrics for sewing clothes, to implants for use in medicine, as well as things with a large number of details – cars, planes, and even houses.

Industries where 3D printing can be used:

- Construction. There is an assumption that in the future the process of constructing buildings will be much faster thanks to 3D printing.

- Medicine. Thanks to 3D printing, doctors have been able to create copies of the human skeleton, blood vessels, etc. 3D printers are widely used in dental prosthetics.

- Architecture and design. Creation of mock-ups of interior elements, buildings and areas allows to evaluate the ergonomics, functionality and appearance of the prototype.

- Education. 3D models are excellent visual materials for learning at all levels of education.

- Automotive industry. Such a method as 3D modeling allows to test the car at the development stage.

- Modeling. Production of packaging materials, toys and souvenir products.

- Light industry. Production of various elements of consumer goods. Manufacturing of clothes and shoes. Currently, similar clothes and shoes are used only at shows. The material here is polyurethane, rubber and plastic.

- Jewelry business. 3D modeling technologies allow to create full-fledged products from metal powder.

- History and anthropology. Models are created on the basis of archaeological finds and allow to assess the reliability of the scientists' assumptions.

- In all other areas not mentioned above, 3D modeling is gradually finding its application.

Thanks to the advent of 3D printing technologies, it has become possible to mechanize and, to some extent, simplify many complex technological processes (Shelyagin, et al., 2005; Strelko et al., 2019). Currently, 3D printing technologies are actively developing and improving all over the world. Each company that develops and manufactures 3D printers seeks to cover as many areas of application of 3D technologies and 3D printing as possible. The variety of 3D printers and consumables for 3D printing is increasing every day.

The principle of forming products by three-dimensional printing is called additive (from the word Add (English). The work of all 3D printers is related to computer design. First, it is necessary to create a computer model of the future object. This can be done with the help of a three-dimensional graphic editor of the CAD system (3D StudioMax, SolidWorks, AutoCAD), or by previously scanning the ready-made object in 3D. Then, with the help of a special software product, the designed or scanned object is divided into layers and a set of commands is generated, which determines the sequence of applying layers of material during printing. Information about any material object to be printed is loaded into the memory of the 3D printer. Similar to a regular paper printer, it creates, that is, reproduces, exclusively on the basis of downloaded data, a material object. The only difference from 2D printers is that objects are reproduced in three-dimensional space. Next, the 3D printer forms the object layer by layer, gradually applying portions of the material (Figure 1).

Placing the print head in the system of two coordinates X and Y, the printer applies the material layer by layer according to the modeled (given) electronic circuit. When

moving the platform one step along the Z axis, the construction (drawing) of a new level of the object begins.

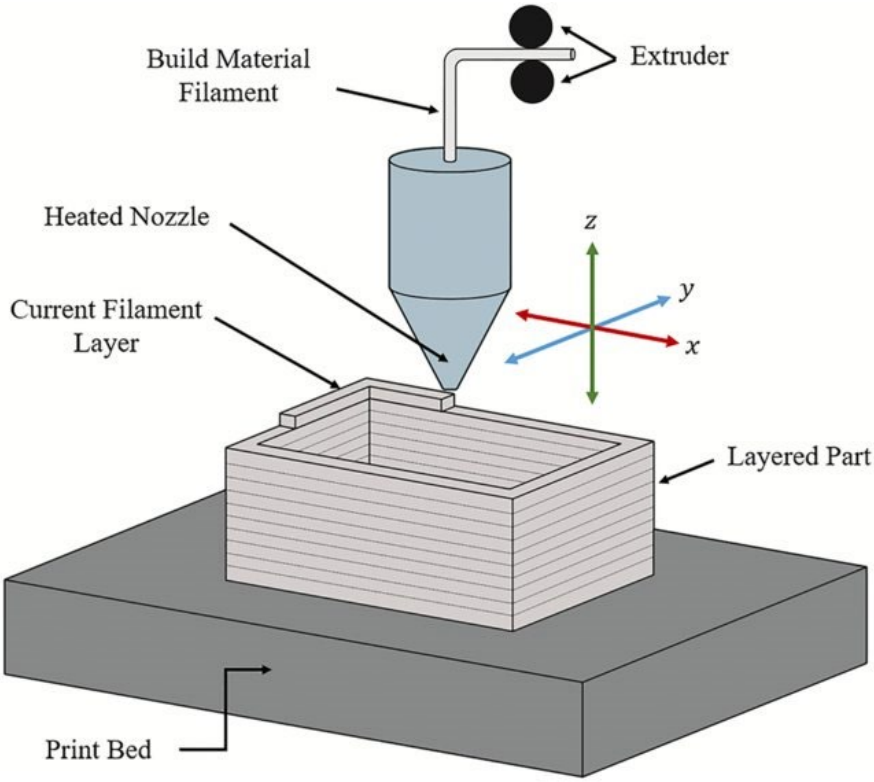

Figure 1. Basic working principle of material extrusion printing (Shah et al., 2019).

Professional 3D printers use different properties of the materials from which they print. As mentioned above, many materials can be used for printing in additive manufacturing (plastic, metal, glass, ceramic, wood, sand, and even human tissue). Some types of printers are able to simultaneously work with different materials, both in terms of properties and color.

Printing on 3D printers can be done in different ways, depending on the material used. There are quite a lot of three-dimensional printing technologies (Bernatskyi & Khaskin, 2021; Strelko, Pylypchuk, & Berdnychenko, 2019). They differ in the principle of formation of layers and their connection. The main technologies are SLA, SLS, DLP, EBM, HPM, FDM.

SLA (**Stereolithography**) technology: (laser) stereolithography (Sokolovskyi & Bernatskyi, 2023). Thanks to this technology, it is possible to build printed objects the fastest. The technology uses a photopolymer on which a laser beam is directed, thanks to which the material hardens. After hardening, the product can be easily processed (glued, painted, etc.).

SLS (**Selective laser sintering**) technology: selective laser sintering is the sintering of powder reagents under the influence of a laser beam (Berdnikova et al., 2021). This is one of the technologies that allows the production of molds for metal and plastic casting.

DLP technology (**Digital light processing**): digital light processing. This is a relatively new technology, for the implementation of which stereolithographic printing devices are used. Printers of this type use digital light processing. This technology uses photopolymer resins and a DLP projector to create three-dimensional figures.

EBM (**Electron Beam Melting**) technology: electron beam melting. This technology uses electron beam melting to create three-dimensional objects. A special material – metal clay – was developed for layer-by-layer surfacing of high-precision parts. This material is made from a mixture of organic glue, metal shavings and water.

HPM, FDM (**Fused Deposition Modeling**) technology: modeling by the method of thread deposition. The object is formed by layer-by-layer application of threads of molten thermoplastic. The material solidifies immediately after exiting the nozzle, which moves in three planes. In some models of 3D printers, a second thread from a different, soluble material is used to build support structures. This technology makes it possible to obtain final models from structural and high-performance thermoplastics. This is currently the only technology that provides mechanical, thermal and chemical strength of parts. An interesting device has appeared these days that is used for manual printing on the basis of FDM technology – pens for drawing 3D objects. Pens are made according to the same scheme as printers. The plastic thread is fed into the handle, where it melts to the desired temperature and is squeezed out through a small nozzle. The last device is especially interesting for use by artists. It allows to create three-dimensional objects actually using lines.

Features of Printers and Technologies for 3D Printing with Ceramic Masses.

Currently, it is obvious that with the development of new technologies, the question arises as to where exactly it is appropriate to use them, because along with a large number of really useful products, 3D printers create a lot of unnecessary things. Special concerns arise regarding ecology and the environment, because currently most products are printed from plastic or other material that is not disposed of. A great alternative was the use of clay as a printing material. Nowadays, certain products are printed from ceramics for medicine, aerospace, design, etc. The use of ceramic materials as raw materials for 3D printing is a progressive trend due to the emergence of the possibility of forming ceramic objects and products that are practically impossible to reproduce and replicate using traditional methods.

Over the past few years, interest in the production of ceramic products with the help of 3D printing has significantly increased throughout the world. It should be noted that the first prototypes of printers that used ceramic powder masses for printing were developed in the 1990s by Emmanuel Sachs and his colleagues from MIT (Massachusetts Institute of Technology). At that time, the first Binder Jetting printers were developed and successfully used to print raw ceramic elements.

The Binder Jetting method (technology of inkjet printing with the help of applying powder and gluing it with a binder) is still used by many manufacturers of 3D printers. In general, Binder Jetting can be used to 3D print ceramic materials such as ExOne or

Voxeljet. Voxeljet devices are used by the British chemical concern Johnson Matthey, whose special research and development department developed in 2017 a pilot unit for printing large elements (on the scale of hundreds of kilograms) and is looking for new applications for printed ceramics (for example, as a substrate for catalysts for the chemical industry).

One of the first 3D printers that prints directly with clay (clay mass) was produced in 2013 by students of the University of Bristol (England) under the leadership of Stephen Hoskins (Hoskins & Huson, 2014; Huson & Hoskins, 2014). This 3D printer created a complete ceramic product, fully ready for heat treatment.

Actually, it should be noted that all currently known 3D printers that print using clay raw materials create only "semi-finished products", i.e. "raw" products, which can be called ceramic only after drying and full firing at a temperature suitable for the clay used. In the terminology of 3D printing, such unfinished products are called "green object", apparently by analogy with fruits or fruits.

In the same year, 2013, the Israeli research and design studio Studio Under announced the development of a 3D printer, which claimed the title of the largest device for printing ceramics in the world at that time. Studio Under, founded in 2012 by designers Eran Gal-Or and Omer Merzel, designs and prints ceramic products, which it distributes worldwide. In 2013, the studio presented the technology of color 3D printing from ceramic materials, which allows the production of colored products. Studio Under developed a fast 3D printer that could print products from ceramic materials (as well as from almost all types of paste-like materials - metal paste, plastic resins, concrete, etc.) in large sizes. The printing area of the printer was 800×800×850 mm, and its speed was equal to 450 mm/h. The device had a special extruder, as well as a cartridge with a capacity of 20 liters, which allowed printing large-sized products. Studio Under used Autodesk Shapeshifter software for work.

Information about similar developments in the following years came from several more countries, in particular from the Netherlands, the United States of America, etc.

At the beginning of 2018, the Ukrainian-American startup Kwambio presented the first industrial printer designed for precise ceramic printing using Binder Jetting technology (Pei, Kabir, & Leutenecker-Twelsiek, 2023; Tabard et al., 2021; Zgalat-Lozynskyy et al., 2021).

In turn, JetX® has proposed Nano Particle Jetting printers, which are equipped with a head that injects resin droplets containing an appropriate amount of ceramic or metal powder particles (Lyu, Yang, Li, Tan, & Liu, 2023; Oh et al., 2019; Zhong et al., 2022).

Another technology widely used for the production of ceramic components is robocasting (Peng, Zhang, & Ding, 2018; Zhang et al., 2020; de Abreu et al., 2023). Extruding ceramic paste from an extruder may seem primitive compared to other methods, but it is much cheaper and works great for printing large parts. Researchers liked the technique, resulting in a large number of amateur designs for printing ceramic materials using the DIW technique. Some of them have spawned companies that sell

all-ceramic printers and/or offer custom printing services. One of them is Vorm Vrij, which offers Lutum printers for printing clay as well as other thick paste materials (Lamnini, et al., 2022; Pei, Kabir, Leutenecker-Twelsiek, 2023).

Manufacturers of ceramic printers often emphasize that their products do not harm the ecological balance of the planet. For example, the Vorm Vrij company emphasizes that clay is a more environmentally friendly material, especially compared to plastic. The Italian company WASP very clearly emphasizes its "sustainability" (its full name is "Complex Peacekeeping Project"). This company makes ceramic printers that work in the delta system, and has also become famous in recent years for the development of a large-sized printing device that can print houses. Other DIY ceramics printers include the Potter Bot (cartesian head movement). The GAIA Multitool (delta system) series of Polish universal printers is also known.

The next significant technologies in ceramic 3D printing are SLA and DLP. The use of stereolithography in 3D printing with ceramic materials, as mentioned above, has been known since the 90s of the last century, in particular at the University of Michigan (USA). The company that commercialized the technology was Austrian Lithoz, founded in 2011 as a branch of the Technical University of Vienna. Lithoz now sells advanced LCM (lithography ceramic manufacturing) or DLP printing systems with ceramic particles dissolved in resin. The company also offers some ceramic materials for its printers: aluminum and zirconium oxides, SiAlON, a calcium phosphate-based material (derived from calcium phosphate certified for use in implants), and other custom-made compositions as well.

Printers for printing with ceramic materials based on SLA technology are offered by the French company 3DCeram (Charbonnier, Laurent, Blanc, Valfort, & Marchat, 2016; Nakai et al., 2021; Fournier et al., 2023). In addition to printers, the manufacturer sells ceramic pastes (their range is very similar to Lithoz's offer), as well as additional devices for cleaning prints of raw pastes and kilns for firing ceramics.

Of course, there are still many companies on the market that offer printers and printing materials for ceramics based on photopolymerization. Ceramic printers working on DLP technology are sold by the Dutch company Admatec, the company Formlabs recently introduced its own ceramic resins (they belong to the Form X platform, that is, a number of experimental products). Ceramic resins for SLA / DLP printers, as well as ceramic powders for Binder Jetting printing are also available from the American company Tethon 3D.

Italian 3D printer manufacturer WASP has developed LDM (Liquid Deposition Modeling) technology. Printing with clay on a 3D printer with its help is very simple. The method of liquid application of clay solves many technical problems associated with printing from clay materials. However, some difficulties have yet to be overcome. The firm has high hopes for a collaboration with artist and ceramic 3D printing teacher Francesco Pacelli, through which they plan to find out why some of the finished models are subject to damage or deformation and how this can be prevented. For some time, it has been testing the capabilities of the WASP Delta Style 3D printer equipped with

their LDM extruder and demonstrating some of the ceramic designs he modeled. According to Pacelli, it is the clay substance and the way it is processed and mixed that is the key to developing the right printing technology using such materials. 3D printing with clay using LDM technology allows to tightly control the flow of clay material fed to the extruder. The process is strictly synchronized with a stepper motor, which guarantees a consistent supply of material. This prevents the formation of air bubbles, deformations and other defects that can ultimately cause the destruction of ceramic products. Of course, not every material is suitable for such a case. 3D printing with clay is an unusual business. Accordingly, clay for a 3D printer should be unusual. The artist is exploring different types of ceramics to expand the amount of raw clay available for 3D printing. He also experimented with different blends, textures and printing parameters for LDM technology and found some successful solutions to many of the most common problems. Among other things, he found that covering freshly printed objects with plastic bags will help maintain the correct humidity level necessary to prevent drying and cracking during preparation for firing. The collaboration between Pacelli and WASP is an ongoing project that will continue to develop new materials for 3D printing and determine the optimal printing parameters for different types of ceramics.

The technology of 3D printing with ceramic materials is now actively interested all over the world. It is good that Ukraine is not an exception. So, the Odesa startup Kwambio, which was founded back in 2015 by Volodymyr Usov, developed its version of a 3D printer with ceramic materials, which was named "Ceramo One". In addition, the people of Odessa also opened the first factory for 3D printing of ceramic products in Ukraine and Europe. According to the developers, the main difference between the Ukrainian Kwambio printer and its analogues in the world is high speed (160 mm/s) and printing accuracy (20 μm), as well as a wide selection of materials of its own development, which allows printing both design objects and industrial samples. The maximum size of the product that "Ceramo One" can print at one time is 35×35×38 cm. Larger products can be printed in parts. The new printer prints using special clay-based powders, which were also developed at the factory. Thanks to its own production, Kwambio has expanded the range of color solutions: now there are about 100 colors of ceramic powders in the assortment.

In a fairly short period of development of 3D printing technologies with ceramic materials, companies have appeared in the world that have established the production of industrial samples of 3D printers and offer to purchase them. Let's try to make an overview of the main proposals in this field (Table 1).

Table 1 provides an overview of the ceramic 3D printer market. 3D printers are listed in alphabetical order. If necessary, such printers can be purchased on the manufacturer's websites. Let’s note that most of the prices in the table are price ranges, that is, indicative.

Table 1.

List of 3D printers that print with ceramic materials as of 2024.

No.	Printer	Technology	Print volume, mm	Country	Estimated cost, $
1	3d-figo — FFD 150H	FFF/FDM	150×150×120	Germany	50000–100000
2	3DCeram Ceramaker	resin	300×300×110	France	250000
3	3D Systems ProX DMP 200 Dental	powder	140×140×100	USA	250000
4	Admatec ADMAFLEX 130	resin	96×54×120	Netherlands	€125000
5	AIM3D ExAM **255**	FFF/FDM	255×255×255	Germany	50000–100000
6	DDM Systems LAMP	resin	no data available	USA	250000
7	ExOne Innovent	Jetting	160×65×65	Germany	100000–250000
8	HP Jet Fusion 3D 4210	Jetting	406×305×406	USA	100000–250000
9	Kwambio Ceramo One	Jetting	350×350×380	Ukraine/USA	25000
10	Lithoz CeraFab 7500	resin	76×43×150	Austria	250000
11	nScrypt 3Dn 450HP	FFF/FDM	no data available	USA	250000
12	Prodways ProMaker V6000	resin	120×500×150	France	250000
13	Voxeljet VX4000	Jetting	4000×2000×1000	Germany	250000
14	XJet Carmel 1400	Jetting	500×280×200	Israel	250000

Analysis of the advantages and disadvantages of manufacturing ceramic products by 3D printing.

The main difference between the production of three-dimensional plastic or metal elements and ceramic elements is the main feature of the ceramic manufacturing technology: the printout is not a ceramic product before firing in the oven, that is, without firing, it is simply an element printed from clay materials (as previously noted, such a printout before firing is called the green part - an unprocessed element). Currently, there are no 3D printers that can immediately produce ready-made ceramic products, all elements printed from ceramic materials require drying and firing. But, despite this nuance, printers that print with clay materials are called ceramic 3D printers.

In general, ceramic materials provide a number of properties: high strength and dimensional stability; low density; chemical stability; high electrical insulation capacity; high resistance to abrasion and corrosion. Thanks to these properties, 3D printing with ceramic materials is suitable for an extremely diverse range of applications.

Since the authors were interested in the use of 3D printing in artistic practice, the biggest advantage of this technology for use in the production of works of art is the possibility of multiplying (replicating) the same elements, which is a rather monotonous job and, of course, a machine can handle it better. The next advantage is

the possibility of manufacturing extremely complex products in terms of design and configuration. The variety of possibilities and the large space for experiments will also, probably, allow the wider use of 3D printers as another tool in the arsenal of the modern ceramic artist.

But, unfortunately, 3D printing with clay is not yet a perfect process. It presents some of the risks, problems and limitations that can be encountered in the most used manufacturing technologies. The reason for this is the peculiar characteristics of the clay material, such as excessive softness and the amount of time required for drying. Many objects are at risk of shrinkage or cracking before they can be fired. Also, 3D printing with clay involves significant limitations in geometry. The reason is the use of auxiliary materials unsuitable for clay raw materials. And this can cause the destruction of printed objects.

One of the main problems that can be encountered in the process of 3D printing is the coefficient of reduction (shrinkage) of clay. Depending on the process used for printing, drying, firing or hot pressing a ceramic object can cause shrinkage of up to 20 percent. Such shrinkage can be a significant problem if the nature of the ceramic product requires precise dimensional control.

Various researchers have found that some components that are successfully used in 3D printing technologies with other components are practically not acceptable at all, or create certain problems when printing with clay materials. Thus, organic ingredients such as cellulose in the ceramic powder used as a binder cause an increase in clay shrinkage. In addition, due to the combustible nature of these organic binders, the products received a too porous structure, which sometimes caused their destruction or significant deformations under the influence of high temperatures during the firing process.

Quite often there are problems with the composition of the mass required for printing for powder printing methods. Preferably, the powder together with the clay materials should additionally contain at least one silicate, usually sodium silicate. Also, the powder should have the plasticity that clay gives, which will ensure the preservation of the shape of the product and the possibility of its preservation during the firing process. It is important that the materials used for 3D printing are adapted to receive and hold the glaze. The best powder formula for printing ceramics:

(a) about 50% to about 80% clay;
(b) from about 5% to about 20% feldspar;
(c) from about 2% to about 10% refractory cement;
(d) from about 2% to about 10% frit;
(e) from about 0.5% to about 4% sodium silicate.

It should be noted that among all 3D printing technologies, only two can print ceramic products from clay materials. Both technologies were discussed in more detail in the previous paragraph, so let’s only note that this is the "Binder Jetting" technology (Baltazar, Dias-de-Oliveira, Pinho-da-Cruz, Gouveia, & Olhero, 2021; Marques, Miranda, Silva, Pinto, & Carvalho, 2021; Valera-Jiménez, Marín-Rueda, Pérez-

Flores, Castro-García, & Canales- Vázquez, 2021) working with powder masses and the technology of "direct ink writing" or "robocasting" – extrusion of ceramic paste from an extruder , that is, a technology that works with pasty (plastic) ceramic masses (Malik, Selvakannan, Mazur, Li, & Bhargava, 2022; Monfared et al., 2022; Pires, Luís, Fernandes, & Oliveira, 2023).

Examples of the use of 3D printing technology in world artistic ceramics.

During the last century, the definitions and boundaries of art have changed radically, as have the technologies and methods of artistic practices. One of the most noticeable trends is that the latest techniques and technologies are more often penetrating the field of art. Artists are increasingly actively using new materials and technologies that facilitate certain processes or realize complex creative ideas.

Thanks to the development of computer technologies, it is now possible to free artists from tedious mechanical work, to speed up the manufacturing of certain elements or the execution of certain processes, and in some cases to improve their quality. If a few years ago 3D printing with ceramic materials was of interest mainly to 3D printer developers, programmers and people connected with new technologies, now more and more artists are becoming interested in this technology to create their own creative works. Often, artists begin to create their own 3D printer samples adapted to their needs.

An integral part of the creative process is computer 3D modeling and visualization, which is an integral part of product development and is used for several purposes: to create product prototypes; for preparation for direct production using a 3D printer; for a preliminary assessment of the physical and technical characteristics of the designed objects. To reproduce a three-dimensional object in reality, of course, it is necessary to design a 3D model in digital format. Such a model is created using graphic 3D programs.

One of the artists who uses modern technologies in his work is Anton Alverez's, a Swedish artist of Chilean origin who graduated from the Royal College of Art (London, Great Britain) in 2012. In his creative pursuits, he tries to combine technological innovations with traditional craftsmanship (Figure 2, Figure 3). His practice is focused on designing systems and creating tools and processes for the production of sculptural objects and architecture. The technological equipment developed by the artist to assist in the creation of works is an integral part of the artist's creativity and even himself (Figure 4). With his creativity, he demonstrates that an artist can become both a craftsman and an engineer, and there is no boundary between these roles. Alvarez continues, as if playing, to expand the boundaries of art, creating works that are rich in tradition and at the same time extremely unconventional squeeze plastic clay mass of various configurations.

Figure 2. The Project of Anton Alverez's "Alphabet Aerobics". National Centre for Craft and Design Sleaford, UK (2016). (Thisner, 2016).

Figure 3. The Project of Anton Alverez's "Alphabet Aerobics". National Centre for Craft and Design Sleaford, UK (2016). (Thisner & Bodiam, 2016).

Figure 4. The Extruder of Anton Alverez's. Project “Alphabet Aerobics”. National Centre for Craft and Design Sleaford, UK (2016). (Thisner, 2016).

Alvarez usually works with quite large volumes. The artist is not limited to simply squeezing the clay through the extruder, he controls the process, cooperates with the machine, allowing the clay to sag under its own weight, or to bend in the direction he needs. Such technological development allows the artist to create complex plastic and geometric forms.

The creative possibilities of 3D printing technology are explored by the Emerging Objects studio from the United States of America in its project "GCODE. Clay" presented at the creative studio "Space 2214" in Berkeley as part of the open exhibition "Pattern, Predictability and Repetition" in 2016. The design studio Emerging Objects was founded by Ronald Rael, a professor of architecture at the University of California, Berkeley, and Virginia San Fratello, an associate professor at California State University, San Jose. Rael's work is aimed at researching actionism through art and architecture, through the land art of the 1960s. San Fratello is interested in finding digital, ecological and building design elements in architecture. Given the similarity of their interests, it is only natural that they turned to 3D printing technology in their creative pursuits. As part of the project, a series of objects from various clay materials,

including porcelain, potter's clay and fireclay, were printed. Authors of "GCODE. Clay" aimed not only to explore the potential of digital control of the creative process, but also to explore the plasticity of various ceramic materials, the limitations caused by gravity and the behavior of hardware. Describing their project, the artists noted that they forced the 3D printer to go beyond its usual limits and create a series of controlled errors. As a result of the experiment, various 3D-printed vases, bottles, pots and other objects were obtained (Figure 5).

Figure 5. The project "GCODE. Clay" of design studio Emerging Objects (Rael, San Fratello, Wilson, & Schofield, 2016).

The smallest details are made extremely carefully and form various textures imitating knots and weaving (Figure 6).

Figure 6. The project "GCODE. Clay" of design studio Emerging Objects (Rael, San Fratello, Wilson, & Schofield, 2016).

In 2016, the German designer Steffen Hartwig, as part of his master's thesis, produced a series of 3D-printed ceramic products using a 3D printer of his own development (Figure 7).

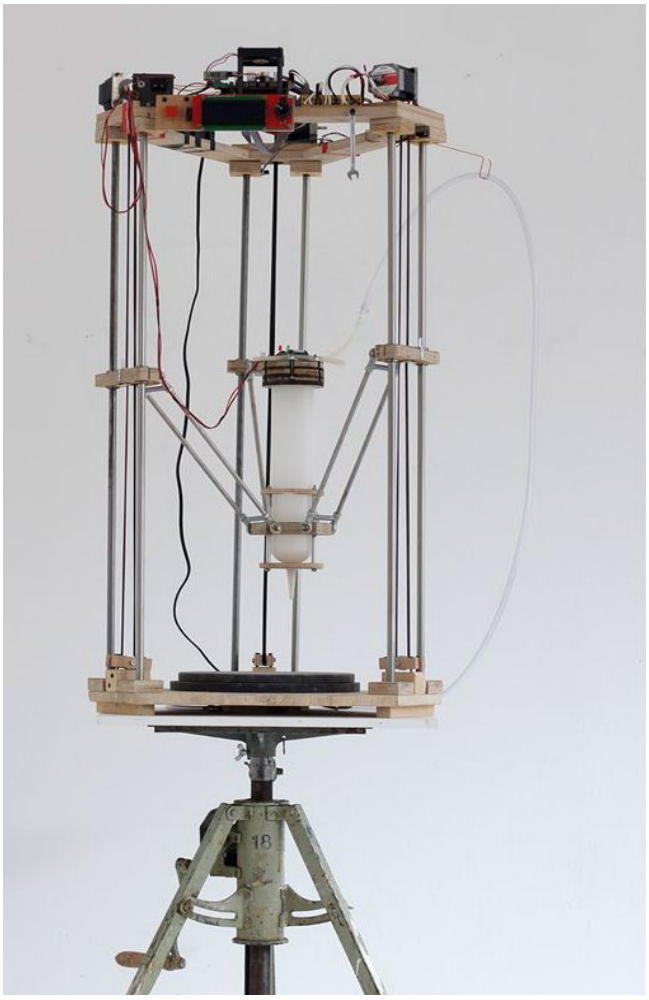

Figure 7. 3D printer of his own development of German designer Steffen Hartwig (Fioretti, 2016).

The artist is extremely interested in ceramics and pottery, as one of the oldest types of human creativity. He is passionate about this topic and collects original pottery items, so he had the idea of merging innovative techniques and traditional types of creativity. The young designer began to explore the boundaries between man and machine, trying to find a way to express traditional craftsmanship through digital technology. Obviously, because of this, his collection is dominated by, at first glance, very simple objects, practically standard ceramic products such as vases and bowls, but in many works, there are some imperfections that the author created on purpose. Such bright, unusual, but programmed details add originality and a certain "handicraft" to his machine-printed products. (Figure 8).

Figure 8. The experimental 3D printing of stoneware clay by of German designer Steffen Hartwig. “Early vase with big loops” (a) and “Breakfast arrangement” (Hartwig, n. d.).

Olivier van Herpt has been dealing with the problems of 3D printing from ceramic materials since 2014, starting with the period of study at the Eindhoven Design Academy. For him, 3D printing of ceramic products is a paradox: on the one hand, it allows a person to create incredibly complex shapes, on the other hand, it completely excludes a person from the process. Olivier built a machine with a piston extruder, which is capable of building clay products up to 90 cm high and 60 cm in diameter, using plastic clay (rather than a slime-like mass, like most machines) (Figure 9).

Figure 9. 3D Printed Ceramics of Olivier van Herpt (van Herpt, 2014).

By changing the settings on the 3D printer, the artist can experiment and give the works different shapes and looks. Van Herpt actively exhibits his works in the most prestigious galleries and museums in the world: the Stedelijk Museum in Amsterdam, the Cooper Hewitt in New York, the London Design Museum, and the Pompidou Center in Paris. In his work, the artist refers to the traditions of ceramic production. In the "Adaptive Manufacturing" series of works, he designs vase-like objects with a variety of interlaced patterns (Figure 10), reminiscent, according to the artist, of artisans' products, when each object was made by hand, so they were individual and unique. But now there is a machine that makes a product from start to finish. Each unique vase from this collection demonstrates the potential of cutting-edge technology while harkening back to a bygone era (Figure 10).

Figure 10. The "Adaptive Manufacturing" series of works of Olivier van Herpt (Smits, 2014).

In 2017, Olivier was offered to make a modern porcelain product (Figure 11) for the art museum Den Haag (Kunstmuseum Den Haag). For this project, the artist developed the first large-scale porcelain 3D printing equipment. The project is called "Arcanum" and consists of fourteen porcelain pieces standing on top of each other and based on an original 17th-century Delft faience pyramid base. Just as Delft faience once arose from the attempts of Dutch artisans to unlock the secret and reproduce Chinese porcelain, Olivier also had to overcome certain difficulties and unravel the secrets. He had to come up with a printing technology with two-color porcelain that would imitate ancient products. The artist managed to develop porcelain 3D printing with cobalt oxide pigment. The idea of supplementing the ancient flower pyramid with individual cup-shaped elements – modern and quietly beautiful – turned out to be successful. Taking the old and creating the new with respect for it is truly a challenge.

Figure 11. The project “Arcanum”. Porcelain flower pyramid (Schreurs, 2017).

During 2014–2023, Olivier van Herpt also created many impressive unique interior items in the form of floor-standing vases of asymmetrical shape, complemented by a play of fastidious textures. These objects open a new world of digital technologies. The small stripes remind that the object was 3D printed, but only when viewed from a close distance. Among van Herpt's recent projects is "Blue and White" (2018) – thin-walled vases, the color of which is reminiscent of Delft faience. Each object is one meter high.

The Dutch company "VormVrij 3D" deals with 3D printing technologies, manufacture and sale of equipment for printing with clay materials. The company was founded by designers Marlike Venacker and Jao van den Herik, graduates of the Design Academy in Eindhoven. The founders of the company have diverse interests in the fields of design, art, culture, and are also activists in organizations that help women and children in West Africa and in environmental organizations. The special attention

of artists to 3D printing with clay materials is dictated, in fact, by the struggle to reduce the use of plastic and return to environmentally friendly materials, one of which is clay.

Figure 12. The project “Blue and White”. Porcelain (van Herpt, 2018).

The VormVrij 3D team hopes that combining materials from the past with modern technologies will change the perception of household ceramics. The 3D printer of the "LUTUM 4" company is able to print products of quite significant sizes: up to 85 cm in height and with a base area of up to 58×79 cm. The base of the printer is heavier, adapted to work with clay, which is much heavier than other materials used for 3D printing. The base withstands the weight of the clay when making large products and prevents their possible deformation. The printer is built on the Arduino platform with Ramps 1.4 shill (add-on board), three 2A type stepper motors and "air" print heads. 3D printing of products takes from fifteen minutes, which significantly exceeds the speed of most existing 3D printers. Of course, the exact printing time depends on the size of the product and the humidity of the clay used. The company not only manufactures equipment and printers for 3D printing, but also prints ceramic products itself, cooperating with various artists and designers, conducts master classes, actively popularizes 3D printing methods, etc. Quite often, "VormVrij 3D" ceramic products are traditional basic ceramics, jugs, vases, baskets (Figure 13). More modern models are also presented, such as complex-shaped vases (Figure 14), as well as sculptural compositions depicting various anthropomorphic elements (Figure 15).

Figure 13. Products of VormVrij 3D (n .d.).

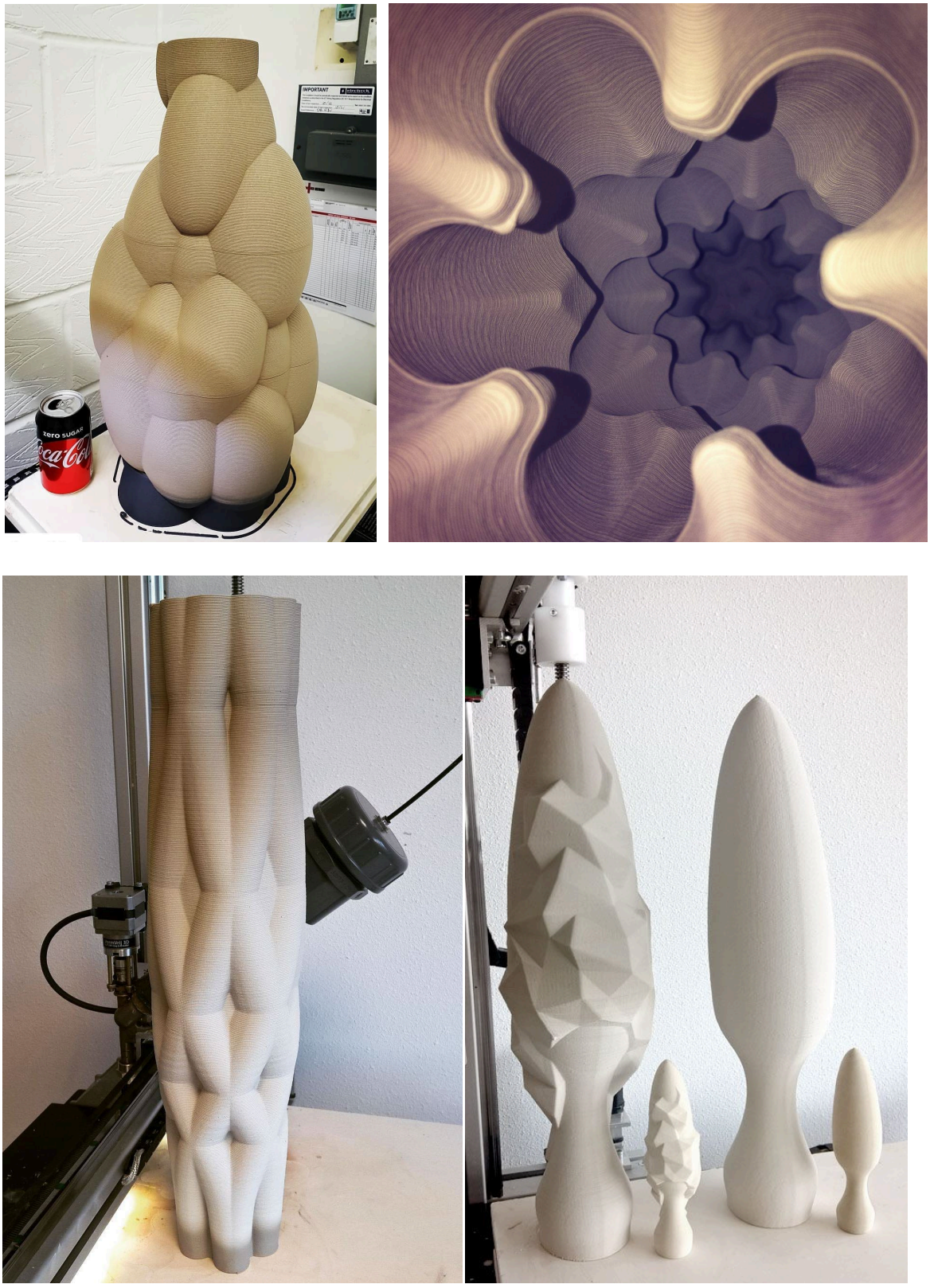

Figure 14. Products of complex configuration VormVrij 3D (n .d.).

Figure 15. Products of sculptural compositions depicting various anthropomorphic elements of VormVrij 3D (n .d.).

Noticeable improvement in print quality and significant increase in product size of VormVrij 3D (Figure 16).

Figure 16. "VormVrij 3D. Printing with clay materials (n .d.).

Turkish ceramist Fatih Aslan, who works at the Department of Ceramics and Glass at Dokuz Eylul University in Izmir, Turkey, is engaged in research in the field of industrial design, 3D printing with clay materials. The artist designs porcelain lamps of quite large sizes and complex shapes (Figure 17), and prints sculptural ceramic objects in the form of female portraits (Figure 18).

Figure 17. Fatih Aslan. Lamps, porcelain. 3D printing (Aslan, n .d.).

Figure 18. Fatih Aslan. Sculptural portraits. 3D printing (Aslan, n .d.).

As 3D printing can accurately realize the creative thinking of artists and designers, 3D printing technology is increasingly used in the creation of ceramic products and contemporary ceramic works (Hu, X., Lai, Hu, Y., Li, Zhao, & Tong, 2022).

Handcrafting ceramic pottery in the traditional method or virtual reality (VR) with intricate surface details is still challenging for the ceramic and graphic artist (Dashti, Prakash, Navarro-Newball, Hussain, & Carroll, 2022). Free-form pottery modeling can be efficiently geometrically modeled with the right tools with detailed 3D print outputs, yet challenging to be manufactured using traditional art. The new advanced pottery VR simulation is a promising method to recreate the traditional pottery simulation for a better experience with some barriers. The challenges that arise from surface detail in pottery are a tedious task accomplished by mesh blending and retopology.

Conclusions.

The article examines the history of the development of 3D printing technologies and their use in world artistic ceramics.

An analysis of the specifics of the technical characteristics of 3D printers and technologies for 3D printing with ceramic masses has been shown that the use of ceramic materials as raw materials for 3D printing is a progressive trend due to the

emergence of the possibility of forming ceramic objects and products that are practically indestructible reproduction and replication using traditional methods.

It has been established that the main difference between the production of three-dimensional plastic or metal elements and ceramic elements is the main feature of the ceramic manufacturing technology, namely that the printout is not a ceramic product before firing in the oven, that is, without firing, it is simply an element printed from clay materials (that is, such a printout before firing is called the "green part" – an unprocessed element). An analysis of various technologies for 3D printing of ceramic products in art has been shown that currently there are no 3D printers that can immediately produce ready-made ceramic products, all elements printed from ceramic materials require drying and firing. But, despite this nuance, printers that print with clay materials are called ceramic 3D printers.

At the same time, three-dimensional printing with clay already today provides ceramic artists with completely new opportunities for creating ceramic products of complex configuration, texture, etc.

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Історія розвитку технологій 3D друку та їх використання у світовій художній кераміці

Анотація. *Стаття присвячена вивченню історії виникнення та розвитку адитивних технологій, що застосовуються у світовій художній кераміці. Авторами проведено аналіз інформації стосовно способів отримання виробів шляхом пошарового нарощування матеріалу, розглянуто принцип дії обладнання для 3D-друку, визначено особливості його використання, перераховано найпоширеніші галузі, в яких застосовуються ці технології та матеріали. Здійснений аналіз технічних характеристик 3D-принтерів та технологій друку керамічними масами, показав, що використання цих матеріалів в якості сировини для 3D-друку є прогресивною тенденцією, яка надає можливість формувати керамічні об'єкти та вироби, які практично не піддаються відтворенню та тиражуванню за допомогою традиційних методів. У дослідженні зосереджено увагу на перевагах та недоліках виготовлення керамічних виробів способом 3D-друку, а також встановлено факт відмінності між виробництвом тривимірних пластикових або металевих елементів і керамічних об'єктів. Ця відмінність зумовлена особливістю технології виготовлення кераміки, оскільки роздрукований предмет не є керамічним продуктом до випалу в печі, тобто без випалу – це просто елемент, надрукований із глиняних матеріалів (така роздруківка до випалу називається «зеленою частиною» – необробленим елементом). Наразі не існує 3D-принтерів, які могли б одразу продукувати готові керамічні вироби – всі елементи, надруковані з керамічних матеріалів, потребують сушіння та випалу, не зважаючи на це, принтери, які друкують глиняними матеріалами називають керамічними 3D-принтерами. Оскільки 3D-друк може точно реалізувати творчий задум художників і дизайнерів, технологія такого друку все частіше використовується у створенні керамічних виробів і сучасних керамічних арт-об'єктів. Автори статті наголошують на тому, що тривимірний друк глиною надає художникам-керамістам абсолютно нові необмежені можливості створення керамічних виробів складної конфігурації, з різноманітною фактурою*

та тональними розтяжками, тож наразі керамісти усього світу почали активно застосовувати цю технологію у своїх творчих практиках. Значну частину дослідження присвячено прикладам використання технології 3D-друку провідними фахівцями світової художньої кераміки, а також фіксації та аналізу найбільш цікавих, на думку авторів, здобутків цього сучасного та інноваційного творчого напрямку.

Ключові слова: *3D-друк; адитивне виробництво; глина; декоративне та прикладне мистецтво; технологія та обладнання для 3D-друку; художня кераміка*

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Carved support beams of the Hetmanate

Abstract. *The article examines the carved support beams from the apartments of representatives of the families of the Cossack elders and the Orthodox clergy of the Hetmanate from the last quarter of the 17th till the end of 18th centuries. The creation of multi-ornamented support beams was a kind of confirmation of the social status of the owners of the houses and their artistic preferences, and an expression of the skill level of the master carvers of that time. The aim of the study is to analyze all the support beams of representatives of the Cossack elders and clergy of the 17th and 18th centuries known today and to achieve general undertanding regarding the specifics of these monuments of the material culture of the Hetmanate. For the first time in historiography, on the basis of information about the support beams preserved in museum collections and highlighted in scientific publications, a comprehensive general analysis of these monuments as a phenomenon of material culture was carried out. As a result of the analysis of information about 22 carved support beams of the 17th-18th centuries from the territory of the Hetmanate, it was concluded that the common features of these monuments are the presence (with some exceptions) of straight Orthodox crosses and inscriptions in the Church Slavonic language in the centers of the artefacts. In the ornamentation of the support beams, features characteristic of the late baroque and classicism can be traced. At the same time, both simpler and more richly decorated artefacts exist. The second group includes support beams from the houses of individual representatives of the Cossack elders. Each support beam was a visual manifestation of the owner's wealth and social status, and of their artistic preferences against the background of generally accepted cultural canons. At the same time, carved support beams are examples of the skill of Ukrainian*

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master carvers of the early modern era, which need to be preserved for future generations. In general, the images on these products are permeated with Christian symbolism, although they also contain some symbols that occur in pagan sign systems.

Keywords: *support beam; museum collection; Hetmanate; Cossack elder; clergy*

Introduction.

Carved support beams are one of the most attractive monuments of material culture of the early modern era in the history of Ukraine. According to the well-argued opinion of P. Yurchenko, a well-known researcher of contemporary architecture, "the artistic decoration of the support beams belongs to the best examples of Ukrainian architectural carvings of the 18th century."[1]

The Hetmanate is a unique cultural and historical region of Europe in the second half of the 17th and 18th centuries, located on the cultural and ethnic borderlands. During the early modern period, the culture of its inhabitants, developing in general along the lines of trends characteristic of a large area of Eastern Europe, acquired specific expressive features. One of their material carriers are carved support beams. Similar support beams were also used in other regions of our country – Podillya, Halychyna and Pokuttia, on the lands of the Zaporozhian Host the Lower. But it was on the territory of the Ukrainian Cossack State that the support beams turned into unique works of art. Accordingly, every support beam preserved to this day is a masterpiece, often underestimated, of museum collections. Considering the time intervals that separate the 21st century, from the 17th–18th centuries, there are only a few pieces of wooden carved support beams left. Quite a few of them have not been entered into scientific records and are hence unknown to the general public of researchers and experts. Due to the physical presence of more than 20 such products in the museum collections of Ukraine and more than 10 references to other products in scientific publications and archival sources, there are grounds for a thorough comparative analysis of their characteristics. The relevance of this article is also strengthened by the lack of a complex scientific study, which would have comprehensively characterized the carved support beams as the monuments of the material culture of the early modern era, their structure, epigraphy, and stylistics.

The purpose of this scientific investigation is to present a general description of the carved support beams of the early modern era of the Hetmanate, on the basis of the analysis of museum objects and other diverse sources, a comparison of their forms, decor and inscriptions.

Literature Review.

The first mention of a carved support beam of the early modern era from the territory of the Hetmanate was published during the era of romanticism – a time of renewed interest in Cossack culture. The article published in 1855 provides the

[1] Yurchenko, P. H. (1968). Wooden architecture. History of Ukrainian art In history of Ukrainian art. Vol. 3, p. 68.

decipherment of the inscription on the beam from the house of Natalka Rozumovska. Attention is drawn to the fact that the data about the owner is written in a different handwriting than the other text.[2] The next published information about the support beams is connected to the time when the first support beams entered museum collections at the beginning of the 20th century. In particular, in 1911, G. Pavlutskyi presented to the general public the data of the oldest of the Hetmanate's support beams known to this day (1688, with the name of Archimandrite Theodosius Uglytskyi),which was used in a house on the territory of the Yeletsky Monastery in Chernihiv. The researcher has published the first and the only photograph to date with the image of the support beam of the Hetmanate of the early modern era in-situ.[3] Before that, M. Biliashivskyi acquired, for the collection of the Kyiv City Museum, a support beam dated 1758 from the priest's house in the village of Dashiv (Lytyn district, Podilsk province), and published an article about it.[4] A support beam from Pidpilnenska Sich[5] has entered got into the museum funds of the Katerynoslav museum named after O. Pol.

In 1913–1914, three support beams from the territory of the Hetmanate entered the museum collections. The first one, from the house of the Kyshen centurion Hryhoriy Pototskyi, was found by employees of the Zaporizhzhia department of the Katerynoslav Museum named after O. Pol in 1913 in the Ozerky village of Kobeliaky District and brief information about this fact was published (now kept in the Nikopol Museum of Local History).[6] Information about the other two support beams, which were found in 1914 by K. Moshchenko during expeditions to collect antiquities for the Natural History Museum of the Poltava Provincial Zemstvo,[7] has not yet been published.

Over the next several decades, no early modern carved support beams have entered Ukrainian museum collections. The next period of scientific study of carved support beams is during 1960s–1980s. This is connected with the revitalization of museum construction and monument preservation activities in Ukraine and, accordingly, active work on preserving the monuments of the past. In particular, P. Yurchenko published thorough summaries of several products available to him for study in the context of the history of wooden architecture. He highly appreciated the artistic value of these artifacts, provided art history descriptions of the main elements and motifs.[8] At the same time, several support beams entered the museum funds as a

[2] The old house of Razumovskikh in Lemeshki (1855, March). Moskvitianin. Issue 6, Part 2. C. 187-188.
[3] Pavlutsky, G. (1911). Civil architecture in Ukraine. Grabar I. History of Russian art in Pre-Petrine era. (Moscow and Ukraine), Volume 2. Architecture (pp. 414-415).
[4] N. B. (1904). An old support beam. Archaeological chronicle of Southern Russia, (3), 95-96.
[5] Catalog of the Ekaterinoslav Regional Museum named after O. M. Pol (1910). Archeology and ethnography. P. 142.Ekaterinoslav: Printing house of the Provincial Board.
[6] Katerynoslav Museum named after A. N. Pol (1914). Ukraine. Book 1. P. 151.
[7] Catalog of the historical-ethnographic department of the natural-historical museum of the Poltava provincial zemstvo. Part 2. No. 5197-9060. S. 312.
[8] Yurchenko, P. H. (1968). Wooden architecture. History of Ukrainian art In history of Ukrainian art. Vol. 3, p. 67-69.

result of expedition work to collect exhibits for the newly opened museums of folk architecture and life in Pereyaslav[9] and Kyiv. One support beam entered the National Museum of Folk Architecture and Life of Ukraine in 1971, thanks to the efforts of scientists from the "Polissia" department. In 1982, during an expedition to collect items for a new exhibition, in an abandoned house in the Klymkivka village, Nadezhda village council, Dykanka district, employees of the Dykanka historical and local history museum found and transported to their institution a 1741 support beam. The most recent example of adding a carved support beam to a museum collection is the transfer to the Horishni Plavni Museum of Local History by a local resident, S. A. Temchenko, of a wooden artifact dated 1780 from the Grygoro-Brygadyrivka village of the Eastern Starostat of the Horishni Plavni urban community of the Kremenchuk district.

However, the study of most of the support beams found in the second half of the 20th century began only at the beginning of the 21st century, when information about items from the museum collections of Pereyaslav[10] and Dykanka[11] was introduced into scientific circulation. Here, among other things, questions were raised regarding the identity of the owners of the houses for whom these support beams were made, and the semantics of the images on them. Despite the existence of several specific studies, a general scientific coverage of the research results of carved support beams of the early modern era as a historical and cultural phenomenon and movable monuments-documents of the specified period has not yet been published.

Discussion.

Information about the Ukrainian carved support beams of the early modern era is currently contained in more than ten scientific publications. Usually, data on certain products (or complexes of products from individual museums), the semantics of images, interpretations of elements and motifs are provided, and conclusions are drawn about the presence of pagan meanings in them. At the same time, no comprehensive study of these products as a cultural phenomenon of the Hetmanate with an analysis of all components of morphology and decor has yet been published, without which no conclusions about the semantics of the images are convincing. The authors of this

[9] Zham, O., &Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, 25-35. ; Shkira, M., Shkira,, N., &Shkira L. (2018). Support beams in the context of the study of traditional folk dwellings of the end of the 19th - beginning of the 20th century of the Museum of Folk Architecture and Life of the Central Dnipro region of the National Historical and Ethnographic Reserve "Pereyaslav". Eminak: Scientific Quarterly Journal, 3(1(21), p. 122.

[10]. Shkira, M., Shkira, N., & Shkira, L. (2018). Support beams in the context of the study of traditional folk dwellings of the end of the 19th - beginning of the 20th century of the Museum of Folk Architecture and Life of the Central Dnipro region of the National Historical and Ethnographic Reserve "Pereyaslav". Eminak: Scientific Quarterly Journal, 3(1(21), 113-122; Zham, O., Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, 25-35.

[11] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), 1386-1396.

scientific work processed data on 22 support beams from the last quarter of the 17th till the end of 18th century, obtained as a result of direct research of products in museum collections, and the analysis of information from publications and archival sources. The products come from the settlements of the former Hetmanate, which now belong to the Poltava, Sumy, Kyiv, and Chernihiv regions (Table 1). That is, they cover the left bank part of the studied region and the city of Kyiv.

Table 1.
Data about the support beam of the Hetmanate

Number	Name of the institution where it is stored/recorded	Quantity	Year of installation, place of residence / finds, decipherment of the inscription	Note
Support beams preserved in museum collections				
1	House of Theodosius of Chernihiv. Yelets monastery. Chernihiv	1	1688, Chernihiv, "ПРИ ФЕWДО: УГЛИЦ: АХІ: РО АХНИ» (DURING THEODOSIUS UGLYTSKYI ARCHIMANDRITE OF 1688)	Based on the publications[12]
2	Oster Museum of Local Lore	1	1704, Oster, «ОСНОВАНІЄ СЄГО ЗДЄ ЗДАНОГО ДОМУ ГОСПОДЬ ЗИЖДУЩІЙ ЄГО СПОВІЄТ КО БЛАГОМУ УТВЕРДИТЬ КЛАДИ СИ ДА НЕ ПОДВИЖИТСЯ О ІИСУСЄ ХРИСТѢ БОЗѢ ПАЧЕ УКРЕПИТСЯ ЩЫТОМ БОГОРОДИЦИ ПРЕСВЯТЫЄ ДѢВЫ НЕБЕСНА ВОЕВОДЫ МИХАИЛА ДАБЫ : ЖИВУЩІИ В НЕМУ ТУ ВСЕГДА СОХРАНЕНІИ ОТ ВСЄХ ПРОТИВНЫХ ВѢТРОВЪ ЦѢЛЫ НЄВРЕЖДЄННЫ ГОСПОДЬ ДА СОХРАНИТЪ ИХЪ ВОЛОДѢНИЕ В РОДЫ В ЩАСЛИВОСТИ С БОГОМ ВО ВѢЧНИЕ РОДЫ : МИРЪ ТИШИНУ ЗДРАВІЄ ДА БУДУТ ИМѢТИ : ПАНЪ МИХАИЛЪ ХЄНЦИНСКІЙ З ПАНЕЮ І ДѢТИ : ИХ ЖЕ КОШТОМ ВСЕЦѢЛЫМ СЕЙ ДОМ ЗАЛОЖИСЯ : В ОСТРѢ ГРАДѢ ВО ВРЄМЯ БЛАГО СОВЄРШИСЯ ПИСАНО В РОКУ АѰД МІСЯЦЯ АВГУСТА КЗ ДНЯ» (“THE	Based on materials provided by the Oster Museum of Local Lore.

[12] Pavlutsky, G. (1911). Civil architecture in Ukraine. Grabar I. History of Russian art in Pre-Petrine era. (Moscow and Ukraine), Volume 2. Architecture (pp. 414-415); Adruh, A. (2020). Wood carvings and iconostases of Chernihiv of the second half of the 17th and early 18th centuries. Severyan Severyan chronicle, 2, p. 43.

			FOUNDATIONS OF THIS HERE BUILT HOUSE THE LORD WHO IS CREATING IT SHALL SHROUD AND FIX FOR BENEVOLENCE, THE GROUNDS OF THIS HOUSE SHALL NOT BE SHAKEN THANKS TO JESUS CHRIST GOD, THEY SHALL ONLY BE STRENGTHENED BY THE SHIELD OF THE HOLY MOTHER OF GOD THE VIRGIN WITH THE HEAVENLY GENERAL MICHAEL SO THAT: THOSE LIVING IN IT SHALL ALWAYS BE PROTECTED FROM ALL OPPOSING WINDS SAFE AND SOUND THE LORD SHALL PRESERVE THEIR BELONGINGS THROUGH GENERATIONS IN HAPPINESS WITH GOD FOR EVERLASTING YEARS: PEACE, TRANQUILITY, HEALTH THEY SHALL HAVE: MISTER MICHAIL KHENTSINSKY WITH MADAM AND THE CHILDREN: AT THEIR COST THIS WHOLE HOUSE WAS ESTABLISHED: IN THE OSTER CITY AT THE BENEVOLENT TIME IN THE YEAR OF AOD THE MONTH OF AUGUST KZ DAY").	
3	Estate of I. P. Kotliarevskyi in Poltava	1	1705, Poltava, «СОЗДАСѦ ДОМЪ СЕЙ ВОИМѦ ѺЦА И СNА И СТАГО ДХА АМИНЬ : РОКУ АѰЄ МЦѦ АВ : А» ("THIS HOUSE WAS CREATED IN THE NAME OF THE FATHER AND THE SON AND THE HOLY SPIRIT. AMEN. AUGUST 1, 1705").	Based on the museum exposition
4–12	National historical and ethnographic reserve "Pereyaslav"	9	1. 1702 (?), Kyiv, «БЛАГОДЕНСТВУЮЩОГО ВОТРОИЦИ : ЄДИНАГО БГА А ТЩЕНІЄМ ПНА ΣОЗОНТА ГРАБѺВСКАГО ПИΣАРА ПОЛЪКУ КІЄВСКОГО КОТОРОМУ МИРОТВОРНОЙ ПРЕЧИСТОЙ БЖІЄЙ МАТЕРІ БЛАГОСЛОВЕНИЕМ І БЛАГОСЛОВЛЕНІЕМ АРХІЄРЕЄМ І ЗА ВИΣОКОРОДНАГО	Based on the publications[13] and the exposition

[13] Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, 25-35; Shkira, M., Shkira, N., & Shkira, L. (2018). Support beams in the context of the study of traditional folk dwellings of the end of the 19th - beginning of the 20th century of the Museum of Folk Architecture and Life of the Central Dnipro region of the National Historical and Ethnographic Reserve "Pereyaslav". Eminak: Scientific Quarterly Journal, 3(1(21), 113-122.

			ѦСНЕВЕЛМОЖНАГО ЄГО МЛОТИІ ПНА ІѠАННА МАЗЄПЫ ГЕТЪМАНА ВОЙСКЪ ЕГО ЦАРСКАГО ПРЕСВЕТЛАГО ВЕЛИЧЕСТВА ЗАПОРОЖСКОГО ТОМУ ЖЪ ВОЗВЫШЬРЄЧЄНОМУ ПНУ ГРАБОВСКОМУ І ЖОНЕ ЕВО АННЕ СОЛОМОНОВНЕ В ПРЕМІРНОЕ І БГУ УГОДНОЕ СОЖИТЕЛЬСТВО» ("THE BENEFICIENT IN THE TRINITY: THE ONE GOD BY THE EFFORTS OF MR. SOZONT HRABOVSKYI, THE SCRIBE OF THE KYIV REGIMENT, TO WHOM THE BLESSING OF THE PEACE-GIVING IMMACULATE MOTHER OF GOD AND THE BLESSING OF THE BISHOP AND THE GRACE OD THE HIGHLY-BORN AND ARCHNOBLE MR. IOANN MAZEPA, THE HETMAN OF ARMY OF HIS ROYAL HOLY MAJESTY OF ZAPORIZHZHIA TO THE SAME EXALTED MR. HRABOVSKYI AND HIS WIFE ANNA SOLOMONIVNA FOR A PERRFECTLY PEACEFUL AND GOD-PLEASING COHABITATION"). 2. 1704, Pereyaslav, «ПОСПѢШЄНІЄМЪ БГА СNА БЛГОСЛОВИМАГО СОВЄРШЄНІЄМЪ ДХА СВ ПОКЛАНЯЄМАГО В РОК АѰД СОZДАНЪ ДОМЪ СЄЙ РАБОМЪ БЖІИМЪ ЛЄОNТІЄМЪ ПАНКЄВѢЧЄМЪ ПОЛКУ ПЄРЄѦСЛА… СО…» ("WITH THE ASSISTANCE OF GOD THE SON BLESSED BY THE FULFILLMENT OF THE VENERATED HOLY SPIRIT IN THE YEAR 1704 THIS HOUSE WAS CREATED BY THE SERVANT OF GOD LEONTIY PANKEVICH THE SO… OF THE PEREYASLAV REGIMENT"). 3. The date and location are unknown, «… РАБ БОЖИЙ ИННИКЕНТИЙ ИРКЛИЕВ…» ("... THE SERVANT OF GOD INNYKENTII IRKLIYEV...".) 4. 1743, city of Kyiv (?),«ЊѦСНЕ В БГУ ВИСОКОПРЄПОДОБНѢЙШАГО ГДИНА ГДИНА ПЕЧЕРСКІѦ ЛАVРИ АРХИМАНДРИТА ТИМОѲЄѦ ЩЄРБАЦКОГО СОѠРУЖИСА	

			ДОМЪ СЕИ РОКУ АѰМГ МАѦ ПОСЛѢДНѢ» ("THE HIGH IN GOD AND THE MOST REVEREND LORD OF THE HOLY KYIV-PECHERSK LAVRA, ARCHIMANDRITE TIMOFII SHCHERBATSKYI BUILT THIS HOUSE IN THE YEAR АѰМГ LAST DAY OF THE MONTH OF MAY"). 5. Unknown year, Kyiv (?), «ИСУСА ИЗБАВЛЕНИЕ СИЮ БОЖЬЕМУ ИНОКА ИЕРОМОНАХА ПРИНАДЛЕЖАЩЕГО ТРОИЦИ СОЗДАСЯ ДОМЪ СЕЙ РАБОМ БЖЅИМ АНДРЄЄМ ГРАБОВСКИМ : » ("THE DELIVERANCE OF JESUS TO THIS GOD'S HIEROMONK BELONGING TO THE TRINITY, THE HOUSE WAS CREATED BY THE SERVANT OF GOD ANDRII HRABOVSKY"). 6. 1755, Kyiv (?), «ВСЄДѢИСТВУЮЩIИ ВО ТРОЙЦЫ СЛАВИМЫЙ БГЪ ПРИЗРЪ С ВИСОТЫ СВОЄѦ И УСТРОИ ДОМЪ СЄЙ ТЩАНІЄМЪ И ИЖДИВЄНІЄМЪ КІЄВСКОГО МѢЩАНИНА IѠАННА ГРИГОРОВИЧА ЛѢТА ГОСПОДНѦ 1755 В МѢСѦЦѢ СЄНТѦБРѢ» ("ALLPERVADING IN THE TRINITY GLORIFIED GOD WATCHED FROM HIS HEIGHT AND BUILT THIS HOUSE WITH THE EFFORT AND SUSTENANCE OF THE KIEV BURGHER IOANN GRIGOROVYCH IN THE YEAR OF THE LORD 1755 IN THE MONTH OF SEPTEMBER"). 7. 174?, location are unknown, «… ПАВЛОМ ѲЕДОРОВИЧЕМ И ЖЕНОЮ ЄГО АГАФИЄЮ АФАНАСИЄВNОЮ РОКУ 174…» ("...BY PAVL FEDOROVICH AND HIS WIFE AGAFIA AFANASIEVNA IN THE YEAR 174...".) 8. 1752, location are unknown, «СІНЕМЪ БЖIИМ ПОΣПѢШЕСТВОМЪ ПРЄЧИСТИѦ БГОМАТЄРЄ : СОЗДАНЪ ДОМЪ СЕЙ Р : Б : ИОАННОМЪ АНДРѢЄВСКИМЪ 1752 ИЮНѦ 29 ДНѦ» ("BY THE SON OF GOD WITH THE ASSISTANCE OF THE IMMACULATE MOTHER OF GOD: THIS HOUSE WAS CREATED BY	

			THE SERVANT OF GOD IOANN ANDREEVSKY JUNE 29, 1752"). 9. 1761, location are unknown, «ЗА БЛАГОСЛОВЄНІЄМ БГА ѠТЦА : ПОСПѢШЄНІЄМ СНА СОВЄРШЕНІЄМ СТАГО ДХА : СОЗДАНЬ ДОМЪ СЄЙ РАБОМ БЖІИМ ФЄОДОРОМЪ АНДРЄЄВИЧЄМЪ ТАРАПОНОМЪ : 1761 ГОД МЦѦ ФЄВРАЛѦ 1 ДНѦ» ("WITH THE BLESSING OF GOD THE FATHER: THE ASSISTANCE OF THE SON AND THE FULFILLMENT OF THE HOLY SPIRIT: THIS HOUSE WAS CREATED BY THE SERVANT OF GOD FEODOR ANDREVICH TARAPON: FEBRUARY 1, 1761").	
13	Nikopol Museum of Local History	1	1733, Ozerky village, Kobeliaky district, Poltava province, «… ОТЦА И ПОСПЕШЕНІЕМЪ СЫНА И СОВЕРШАНІЕМЪ СВЯТОГО ДУХА СОWРУЖИСЯ ДОМЪ СЕЙ СТАРАНІЕМЪ И КОШТОМЪ РАБОМ БОЖІИМЪ ГРИГОРІЄ ПОТОЦКІМЪ ЕГО МИЛОСТІЮ ПАНОМЪ СОТНИКОМЪ КИШЕНСКИМЪ РОКУ 1733 МЦ …» ("... OF THE FATHER AND THE ASSISTANCE OF THE SON AND THE FULFILLMENT OF THE HOLY SPIRIT, THIS HOUSE WAS CONSTRUCTED WITH THE EFFORT AND EXPENSE OF THE SERVANT OF GOD, GRYGORII POTOTSKYI, HIS GRACE, THE LORD OF THE CENTURION OF KYSHENKA, YEAR 1733 THE MONTH...").	Based on the publication[14] and resources of the Facebook network
14–15	Poltava Museum of Local History named after Vasyl Krychevsky	2	1. 1741, Zhovnyn, Poltava province, «ГОΣПОДИ БЛАГОСЛОВИ ДОМЪ СЄЙ И ЖИВУЩИХЪ В НЄМЪ БЛАГОСЛОВЄНИЕ СВЯТЫЯ ТРОИЦЫ СОЗДАСЯ ДОМЪ ПНОМ ДИМЯНОМ БУЛИПОШЕМ РОКУ 1741. ІЮНЬ», "GOD BLESS THIS HOUSE AND THOSE WHO LIVE IN IT WITH THE BLESSING OF THE HOLY TRINITY THE HOUSE WAS CREATED BY MR. DYMYAN BULYHOSH IN JUNE, 1741." 2. Without inscriptions, the place of discovery is unknown	Based on the museum funds

[14] Katerynoslav Museum named after A. N. Pol (1914). Ukraine. Book 1. P. 151.

16	Dykan Museum of Local History named after D. M. Harmash	1	1741, p. Klimkivka, Dykanka territorial community. The front side: «ΣЕЙ ДОМЇ GѺТЕЦЪ СОЗДА, СЕЙ ДОМ ΣЫНЪ УТВЕРДИ, СЕЙ ДОМЪ ДХЪ СТЫЙ ΩБНОВЫ : К [КОПЬЕ] Т[ТРОСТЬ] СОЗДАНЪ ДОМЪ СЕЙ КОШТОМЪ БЛАГОРОДНОГО ЄГО МИЛОСТІ ПНА ФЕОДОРА ѦКОВЕНКА СОТНИ[КА]». ("THE FATHER CREATED THIS HOUSE, THE SON ESTABLISHED THIS HOUSE, THE HOLY SPIRIT RENEWED THIS HOUSE K/T THIS HOUSE WAS CREATED AT THE COST OF THE NOBLE GRACE MR. FEODOR YAKOVENKO CENTURION".) The bottom line is «РОКУ ОТ РОЖДЄСТВА ХРСТВА АѰМА ГО МЦѦ [МІСЯЦЯ] ІЮНЯ А-ГО ЧИСЛА» ("ON THE 1ST DAY OF JUNE 1741 IN THE YEAR FROM CHRIST'S BIRTH."). Reversal: «… ДОМУ БЛАГОЧЕСТНО ЖИТЫ ТЕБЕ БГА ВЪ [ТР]ОИЦЫ NАВЕКИ ХВАЛИТЫ» ("THIS HOUSE SHALL LIVE PIOUSLY AND SHALL PRAISE THEE GOD IN THE [TRINITY] FOREVER").	Based on the museum funds
17	National Museum of Folk Architecture and Life of Ukraine	1	1753, city of Oster, Chernihiv region, «БЛАГОВОЛЄНІЄМ ОТЦА : ИЗВОЛЕНІЄМ СНА : СОДЕЙСТВОМЪ СВЯТАГО ДУХА СОЗДАСЯ ДОМ СЕЙ СТАРАНІЄМ І КОШТОМ РАБА БОЖІЯ ЯКИМА КІВУЛІ : И ЖЕНЫ ЄГО КСЕНІИ ПО ПОЖАРЕ 1753 ГОДА ИЮНЯ 22 ДНЯ» ("BY THE GOOD WILL OF THE FATHER: THE ALLOWANCE OF SON: THE HELP OF THE HOLY SPIRIT, THIS HOUSE WAS CREATED BY THE EFFORTS AND EXPENSE OF THE SERVANT OF GOD YAKYM KIVULIA: AND HIS WIFE KSENIA AFTER THE FIRE ON JUNE 22, 1753")	Based on the photos and descriptions provided by the museum
18	Konotop city local history museum named after O. M. Lazarevskyi	1	1763, the house of the retired Cossack Petro Pankevych from the Altynivka village, Krolevets district, «ОТЕЦ ДЕЙСТВУЄТ СЫН ДУХ СВЯТЫЙ ОСВЯЩАЕТ: ТРОЙЧЕСКАЯ БЛАГОДАТЬ: ДОМ СЕЙ ПРОСВЕЩАЕТ: СОЗДАН СЕЙ ДОМ ПЕТРОМ ПАНКЕВИЧЕМ АБШИТОВЫМ…ОСТАВШЕЕСЯ ВСЕ НАСЛЕДИЕ ЕГО ВНУКУ	Based on the the photo and description provided by the museum

			АНДРЕЮ ФЕДОРОВИЧУ ПАНКЕВИЧУ» ("THE FATHER ACTS, THE SON, THE HOLY SPIRIT SANCTIFIES: THE TRIUNE GRACE: THIS HOUSE ENLIGHTENS: THIS HOUSE WAS CREATED BY PETRO PANKEVYCH ABSHYTOV... ALL THAT REMAINS WILL BE THE INHERITANCE OF HIS GRANDSON ANDRII FEDOROVYCH PANKEVYCH").	
19	Museum of local history of the city of Horishni Plavni	1	1780, the town of Keleberda, Poltava province, «БЛАГОСЛОВЕНІЕМЪ ОТЦА, ПОТЕШЕНІЕМЪ СЫНА И ДЕИСТВИЕМЪ СВЯТАГО ДУХА СОЗДАСЯ ДОМЪ СЕЙ ФЕДОРОМЪ БАБЦЕМЪ 1780 ГОДА ИЮНЯ 18 ДНЯ» ("BY THE BLESSING OF THE FATHER, THE CONSOLATION OF THE SON, AND THE ACTION OF THE HOLY SPIRIT, THIS HOUSE WAS CREATED BY FEDOR BABETS ON JUNE 18, 1780")	Based on the photos and descriptions provided by the museum
Support beams, about which there is information in publications and archival sources				
20	Natalia Razumovska's house	1	1711, p. The village Lemeshi of Kozeletsky district, «БЛАГОСЛОВЕНІЕМЪ БОГА ОТЦА, ПОСПЕШЕНИЕМ СЫНА СОДЕЙСТВИЕМЪ СВЯТАГО ДУХА. СОЗДАСЯ ДОМ СЕЙ РАБОЮ БОЖЬЕЙ НАТАЛІИ РОЗУМИХИ, 5 МАЯ 1711 ГОДА» ("WITH THE BLESSING OF GOD THE FATHER, THE ASSISTANCE OF THE SON, THE COOPERATION OF THE HOLY SPIRIT. THE HOUSE WAS CREATED BY THE SERVANT OF GOD NATALIA ROZUMIKHA, MAY 5, 1711").	Based on the publication[15]
21–22	Poltava Museum of Local History named after Vasyl Krychevsky	2	1. May 1726, p. Lebekhivka, Poltava province, inscription indecipherable. 2. The place of discovery and the content of the inscription are unknown.	Based on the archival documents

[15] The old house of Razumovskikh in Lemeshki (1855, March). Moskvitianin. Issue 6, Part 2. C. 187-188.

As far as we can understand today, the carved support beams were mostly made of pine wood both in the territory of the Hetmanate and in the Sich lands. This light and strong tree is widespread in Ukrainian lands, cheap and durable. But it is not very convenient for decorating by carving. That is why the masters of the Hetmanate used other types of wood as well. For example, the most decorated support beams are carved from linden[16] and oak[17]. The use of the latter is also associated with longevity and prestige.

The length of the completely preserved products is from 355 cm (a support beam without inscriptions, which is exhibited in the Poltava Museum of Local History named after Vasyl Krychevskyi) to 615 cm (a support beam from 1753 from the city of Oster). But in most preserved support beams, it is about 4 m. The height is from 22.5 to 36 cm.

Support beams were made from a straight trunk of the appropriate length and thickness. The workpiece was trimmed in the form of a rectangle so that the core was approximately in the center and the young layers of the wood were removed. The top surface was made flat and even or slightly rounded. The sides and bottom were usually profiled (except for the product, which is kept in the Local History Museum of the city of Horishni Plavni (Table 1: 19)).

All processed support beams contain a complex of relief and counter-relief images carved with the help of various tools (Fig. 1–3). Of course, in the early modern period, support beams without carvings were also used on the territory of the Hetmanate, but they did not attract the attention of researchers, museum workers and collectors. Accordingly, information about them has not been preserved and it is impossible to study them.

A rectangular band was usually left in the upper parts of the side surfaces, on which an inscription was applied or, in one case (a product stored in the Poltava Museum of Local History named after Vasyl Krychevskyi (Table. 1: 15)), a strip of ovals demarcated by elements in the form of oblique crosses. A similar strip is found under the upper profile belt on one of the most richly decorated support beams of the Hetmanate.[18] Only sometimes (for example, a product exhibited in the Museum of folk decorative and applied art of Kyiv region in Pereyaslav[19]), the text was contained under the belt. It is important to emphasize that the carvers tried to apply the image symmetrically. Symmetry performed an organizing function in the composition, but as

[16] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), 1390.

[17] Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, p. 32.

[18] Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, 32-33.

[19] Shkira, M., Shkira, N., & Shkira, L. (2018). Support beams in the context of the study of traditional folk dwellings of the end of the 19th - beginning of the 20th century of the Museum of Folk Architecture and Life of the Central Dnipro region of the National Historical and Ethnographic Reserve "Pereyaslav". Eminak: Scientific Quarterly Journal, 3(1(21), p. 121. Photo.

in general in folk art, the masters did not make perfectly symmetrical structures. Undoubtedly, the surface was previously marked. The individual skills of the carver, his desire for perfection and integrity of the work were also of great importance. It is known that symmetry is associated with the static and, accordingly, peace and balance. As a result of taking into account the laws of symmetry by carvers, the support beam gave the impression of hidden greatness and immovability.

The inscriptions on the support beams contain variously worded blessings, the names of the owners, the dates of installation (written in letters under the titles or Arabic numerals) (Table 1). They were made in Cyrillic, the Church Slavonic language of the time, with addition of some letters of the Greek and Latin alphabets (Fig. 1). In particular, the letters Σ, W, V, Z, N. In many cases, the letters are carved and combined into words so artistically that the inscriptions are perceived as an intricate ornament. Abbreviations characteristic of the spelling of the Hetmanate are quite often used, consisting of parts of frequently used words or phrases. Titles could be placed above such constructions. In the transcripts of the inscriptions presented in Table 1, the authors of the article revealed the abbreviations, since in Cossack times they were also revealed during reading. Of the divine characters, "Father, Son and Holy Spirit", "God", "Trinity", "Jesus", "Mother of God", "Michael" are mentioned (Table 1). By the way, a blessing similar to the one applied to some of the support beams was also used on the lute of 1773 from the Zaporizhzhia church of the Baibakivka village of Novomoskovsk district (currently Tsarychanka district of the Dnipropetrovsk region): "By the blessing of the Father and the command of the Son and the assistance of the Holy Spirit ... this temple was created ..."[20].

Sometimes the inscriptions recorded data about the social status of the owners, mostly men. But three products (Table 1: 4, 17, 20) also contain the names of women. On several support beams, the inscriptions contain original wording and information (Table 1: 2, 4, 16–18).

In addition to the inscriptions, some of the products contain only crosses on the front sides. Sometimes rosettes or coats-of-arms were added to these basic images (support beams from Zhovnyn (Table 1: 14, Fig. 2:5) and Oster (Table 1: 17, Fig. 3:5)) on the lower planes. On some of the support beams, carving covered the entire visible surface (for example[21]), or the front (more intricate) and reverse (simpler).

[20] Cossack antiquities in the collection of the Dnipropetrovsk National Historical Museum named after D. I. Yavornytskyi: [Catalogue]. Dnipro, Art-Pres, 2016. P. 132.

[21] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), p. 1389, fig.2.

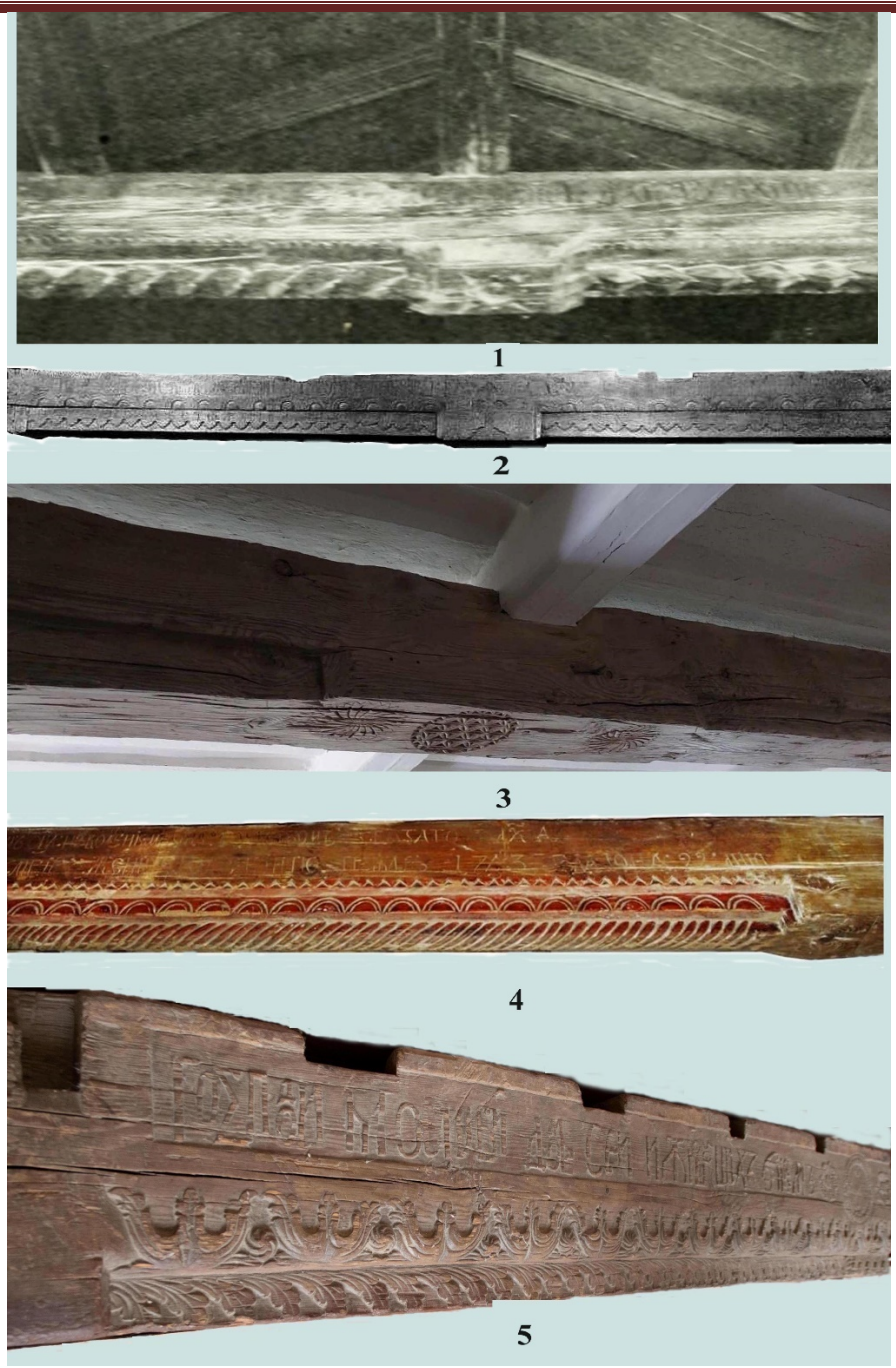

Figure 1. The support beams of the Hetmanate: 1. From the house of the archimandrite of the Yelets monastery, Theodosius Uglytskyi. M. Chernihiv, 1688. Photo of 1908. According to H. Pavlutskyi. 2. From the house of the Shyshaky centurion Fedor Yakovenko, Klymkivka, 1741. Photo by A. Shcherban. 3. From the house of archimandrite of the Holy Kyiv-Pechersk Lavra, Timofii Shcherbatskyi. M. Kyiv, 1743. Photo by T. Radionenko. 4. From the book of Yakym Kivulia. Oster, 1753. Photo courtesy of the National Museum of Folk Architecture and Life of Ukraine. 5. From the house of icon comrade Demyan Buliubash. Zhovnyn, 1741. Funds of the Poltava Museum of Local History named after Vasyl Krychevskyi. Wood, carving, end of the 17th–18th century.

Figure 2. Crosses in the centers of the front surfaces of the support beams of the Hetmanate. 1. From the house that belonged to the family of Ivan Kotliarevsky after 1751. M. Poltava, 1705. Photo by A. Shcherban. 2. From the house of the Kyiv scribe Sozont Hrabovskyi. M. Kyiv, 1702 (?). According to the publication of O. Zham and T. Grudevych. 3. From the house of Kyshen centurion Hryhoriy Pototskyi. Ozerky, 1733. Funds of the Nikopol Museum of Local History. 4. From the house of icon comrade Demyan Buliubash. Zhovnyn, 1741. Funds of the Poltava Museum of Local History named after Vasyl Krychevskyi. 5. From Yakim Kivulia's house. Oster, 1753. Photo courtesy of the National Museum of Folk Architecture and Life of Ukraine. Wood, carving, 18th century.

Figure 3. Additional decorative elements on the support beams of the Dnipro region. 1–2. From the house of icon comrade Demyan Buliubash. Zhovnyn, 1741. Funds of the Poltava Museum of Local History named after Vasyl Krychevskyi. 3, 4, 7. From the house of the Kyiv scribe Sozont Hrabovskyi. Kyiv, 1702 (?). According to the publication of O. Zham and T. Grudevych. 5. From the house of icon comrade Demyan Buliubash. Zhovnyn, 1741. Funds of the Poltava Museum of Local History named after Vasyl Krychevskyi. 6. From the house of Kyshen centurion Hryhoriy Pototskyi. Ozerky, 1733. Funds of the Nikopol Museum of Local History. Wood, carving, 18th century.

Among the latter is the support beam from the house of representatives of the Orthodox clergy, which since 1751 belonged to the grandfather of the outstanding Ukrainian writer I. P. Kotliarevskyi, deacon of the Assumption Cathedral in Poltava[22] (Table 1: 2). The analysis of the available museum exhibits made it possible to conclude that other support beams carved for the houses of clergy usually had a simple decoration; as well as products from the lands of the Zaporizhzhia Nyzova Army. The most intricately decorated are the support beams from the houses of individual representatives of the Cossack nobility[23].

The central elements of the images on the front sides of the support beams (with the exception of a few artifacts, in particular, 1755, which is now kept in the Museum of Folk Decorative and Applied Art of the Kyiv region in Pereyaslav, belonged to a Kyiv burgher) were crosses. Different in shape (Fig. 2), they contained additional elements: instruments of torture of Jesus Christ (spear and cane), Adam's head and bones, letters and abbreviated words ("INCI" – Jesus the Nazarene King of Judea, "Jesus Christ" – Jesus Christ, "NIKA" – (from the Greek – victory), "CGLM" – Cross of God Lobne Mistse, "RB" – "Rai Byst"[24]).

Among the widespread elements of ornaments on the support beams are friezes of semi-oves (Fig. 1: 2, 4), usually located in the lower part of the "belt". By the way, friezes from semi-oves were also carved on the door of a church from the Kyiv region in 1706[25]. They were also used to decorate the interiors of the Church of the Savior in Poltava, built in the same year. Such elements were used en masse for ornamentation of clay bowls and plates.

On the support beam from the city of Zhovnyn (plate 1: 14), a strip of floral ornament is carved from the leaves of the "king of baroque ornamentation" – acanthus, from the bottom of the band, and the central medallions are framed by wreaths of laurel leaves (a symbol of glory) (Fig. 1: 5, 3 : 1). The use of "round and semi-round leaves" in this part of the beam is mentioned in the description of the support beam from the Poltava Museum of Local History named after V. G. Krychevskyi[26], which could not be physically found.

In the lower part of the relief band of the lateral part of the support beams, as well as underneath it, sometimes there are images of broken wavy lines which can be

[22] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), p. 1391, fig.3: 1-3.

[23] Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, 25-35; Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), 1386-1396.

[24] Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, p. 34.

[25] Yurchenko, P. H. (1968). Wooden architecture. History of Ukrainian art In history of Ukrainian art. Vol. 3, p. 67, fig. 45.

[26] Inventory book of the Poltava State Museum. No. 30 (started in 1939). Page 461.

interpreted as strips of upside-down triangles (for example, Fig. 1: 2[27]), or "teeth" (Fig. 1: 4)[28] – classic triangles (Table 1: 17). Similar stripes were also used to frame individual elements of ornaments (for example, the central rosette on the lower platform of the support beam of Shisha centurion Fyodor Yakovenko) or their compositions. Such elements, in particular, are present on Sozont Hrabovskyi's support beam and are repeated several times on the artifact from I. Kotliarevskyi's house (Fig. 3: 2, 3), where it is, in fact, the only ornament[29]. Bands of small elements are also sometimes found under the upper profile belt.

Below the belt or on the edges, a profile was quite often carved in the form of a part of a shaft with an oblique notch, which was perceived as a "twisted", or less often – a braided rope (Fig. 1: 1–4). The half-shaft is sometimes located in the center of the lower surfaces of the support beams with the most complex profile.

In the case when the support beam was given complex profiling, the central part usually remained unprofiled, having the appearance of a rectangular flat plane (Fig. 1: 1–3). This feature is determined technologically (so as not to weaken the most stressed part of the support beam), symbolically and aesthetically. After all, it contains the most semantically saturated images. This plane in many support beams (in particular, 1688) is framed with convex images of "twisted" ropes. If the bottom of the central part of the support beam is not highlighted, imitation ropes stretch through the entire artifact. It is worth noting that the image of the twisted "rope" is also on the church door, which is kept in the Dnipropetrovsk National Museum named after D. I. Yavornytskyi[30].

Rosettes are among the common elements of images on support beams. According to formal features, five of their varieties are distinguished. The first, the most common (the authors recorded eight cases), was located in the center of the support beam in the lower part. These are geometrized six-petal rosettes in circles and their complicated variants and combinations[31] (Fig. 3: 3). Such signs are one of the oldest and most common elements of images on Slavic carved support beams. In particular, they are found on a product of 1669 from Lviv[32]. In scientific publications, during the analysis

[27] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), p. 1391, fig. 2: 1l,3l,3n, fig. 3: 2-3; Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, p. 32.

[28] Yurchenko, P. H. (1968). Wooden architecture. History of Ukrainian art In history of Ukrainian art. Vol. 3, p. 69, fig. 47.

[29] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), p. 1391, fig. 3: 2-3.

[30] Cossack antiquities in the collection of the Dnipropetrovsk National Historical Museum named after D. I. Yavornytskyi: [Catalogue]. Dnipro, Art-Pres, 2016. P. 132.

[31] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), p. 1391, fig. 2: 2n; Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, p. 26; Yurchenko, P. H. (1968). Wooden architecture. History of Ukrainian art In history of Ukrainian art. Vol. 3, p. 69, fig. 47.

[32] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), fig. 4: 1.

of the semantics of rosettes on the support beams of the early modern era, the interpretation of the presence of pre-Christian meanings in them is quite common. But if such a content could have existed in earlier years, it was certainly not interpreted as such by the owners of the houses during the last quarter of the 17th and 18th centuries. Otherwise, they would not be placed in the homes of representatives of the Orthodox clergy. But such signs were on most of the investigated support beams from their houses. A possible version of the interpretation of similar rosettes on baroque cannons was expressed by O. Malchenko. He drew attention to the fact of their use in wooden churches and believed that on cannons they can be read as "a place where light is born"[33].

The second type of rosettes, which were used on the support beams of the Hetmanate, were vortex ones. They are inscribed in a frieze of a classical floral ornament composed of acanthus leaves on a support beam from Zhovnyn (Fig. 3: 1). On Sozont Hrabovskyi's support beam, such images are located on both sides of a composition of six-petalled rosettes in the center of the lower surface (Fig. 3: 3)[34].

The third type, rare, is known only on a product from Oster (Table 1:18, Fig. 2: 5). These rosettes have the form of a straight equilateral cross inscribed in a circle, the ends of which are connected by arches. Four such signs are located in the corners of the central plane of the front part of the support beam, on both sides of the main cross. By the way, the names of the evangelists are inscribed on the support beam from the house of Sozont Hrabovsky in these places, in circles with "flower petals" around the perimeter, which with some stretch can be attributed to the rosettes of the next type (Fig. 3: 7)[35].

The fourth type is "flower" rosettes. On the support beam from Zhovnyn (Fig. 3: 2), they separate the central medallion with a cross from the inscription. There is a similar rosette in the same place on Ivan Rabits' support beam from Zaporizhzhia[36]. Rosettes – "roses" in Baroque art (in particular, the ornamental design of engravings) symbolize "beauty", "holiness", "prayer". They are connected with the rosary, that is, a rosary of prayers addressed to the Virgin Mary[37].

The fifth type is a "sun-shaped" rosette with sharp rays. Such a symbol is carved in the center of the lower part of the support beam from the house of the archimandrite of the Yelets monastery, Theodosius Uglytskyi (Fig. 1: 1). One of the rosettes made by

[33] Malchenko, O. (2007). Artistic casting of cannons in the Hetman region during the reign of Ivan Mazepa, p. 95.

[34] Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, p. 33, photo 6.

[35] Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, p. 34; Shkira, M., Shkira, N., & Shkira, L. (2018). Support beams in the context of the study of traditional folk dwellings of the end of the 19th - beginning of the 20th century of the Museum of Folk Architecture and Life of the Central Dnipro region of the National Historical and Ethnographic Reserve "Pereyaslav". Eminak: Scientific Quarterly Journal, 3(1(21), p. 122. Photo.

[36] Yurchenko, P. H. (1962). Ukrainian folk art. Carving and artistic metal arranged, p. 48, fig. 9.

[37] Malchenko, O. (2007). Artistic casting of cannons in the Hetman region during the reign of Ivan Mazepa, p. 95.

Ivan Rabits has similar features. The solar circle with rays is also found (it surrounds the cross on the reverse side) on the 1741 support beam of Shyshaky Cossack centurion Fedor Yakovenko[38].

On both sides of the central face medallion with a cross on a support beam of 1733 from the house of the Kyshenka centurion Hryhoriy Pototskyi (Nikopol Local History Museum), four elongated triangles are carved from indentations (horizontally located) (Fig. 3: 6). In this way, they could depict bunches of grapes. There is a more realistic bunch of grapes on the support beam from Zhovnyn, but it is placed vertically (Fig. 3: 1). By the way, "grapes" are also carved on the product from Zaporizhzhia – on the edges of the front and back sides and in the center on the lower part of Ivan Rabits' support beam

Three support beams in the centers contain coats of arms. The Kyshenka centurion support beam on the back has a medallion with the coat of arms of the Russian Empire – a double-headed eagle with crowns on the heads, a scepter and the state in its paws. A similar coat of arms, but at the bottom, is found on the support beams of a resident of Oster (National Museum of Folk Architecture and Life of Ukraine). The coat of arms of the owner is carved from below on the support beam from Zhovnyn (Fig. 3: 5).

A few support beams have plant images in the decor, scattered across the field without forming stripes. In this respect, the support beams of Sozont Hrabovskyi and Fedir Yakovenko stand out the most. In the first, plant elements (stems with flowers) are located in the center on the front and lower planes, on both sides of the main images. It is on the support beam of Sozont Hrabovsky that the earliest known images of ornamental elements were recorded, which became "signature" for the work of first Vasyl Krychevskyi, and then – Heorhiy Narbut, and through them – the art of Ukrainian modernism and avant-garde. These are counter-relief triangles, which consist of smaller triangles placed in a "checkerboard" order (Fig. 3: 7). True, Vasyl Krychevskyi interpreted them as bunches of grapes, and on Hrabovskyi's support beam they are presented as elements of flowers placed on thin stems that grow from the space between the leaves and petals. On Fedir Yakovenko's support beam, individual plants (in particular, tulip-like ones) are located on both sides of the central cross on the front and back sides[39].

Unique for Ukrainian carved support beams is the image of the head of a predatory animal with an open mouth and a protruding tongue, which is found on the support beam of Sozont Hrabovsky above the central cross in front of the word "Glory" (Fig. 3: 4). Researchers O. Zham and T. Gruzdevych believe that this is an image of a

[38] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), p. 1389, fig. 2: 2z.
[39] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), p. 1389, fig. 1: 2l, 2z, 1z, 3z.

"snake"[40]. But if to take into account that sharp ears are carved on the head, then such a statement can be considered false. Unfortunately, the absence of a body does not allow to specify who it is. After all, in a similar way, the heads of a "dragon", "wolf" or "lion" could be depicted in the decoration of cannons and tiles of the Baroque era. Undoubtedly, when choosing this symbol for the support beam, as well as the officer's cannon, it was not the bloodthirstiness of such an animal that was taken into account, but its glory, strength and courage[41]. It is interesting that this image is asymmetrical. Agreeing with the opinion of O. Malchenko regarding the decoration of the cannons[42], it is possible to conclude that it gave the place where it was located an emphasized internal dynamics.

P. Yurchenko concluded that "the simplicity of execution, ease and free placement of the compositions give reasons to believe that the architectural carvings on doors, support beams, cornices and brackets were performed, as a rule, by carpenters-builders themselves, and not by master carvers. This can be ascertained by comparing the carvings on the door frames, support beams and staples with the carvings on the iconostases"[43]. We can only partially agree with this statement. After all, the work of the author of the carving on support beam from Zhovnyn, who mostly used the elements of ornaments characteristic of "classical" and "high" art, stands out. Highly skilled carvers applied images on the support beams from the houses of Sozont Hrabovskyi and Fedir Yakovenko and several other artifacts. Literacy and high artistry, the use of specific abbreviations indicate that the sketches of most inscriptions were made by educated people familiar with artistic calligraphy. These inscriptions were undoubtedly carved by them themselves or under their control.

Various types of ornamental elements and motifs are found in the ornamentation of artistic support beams. Although there are certain commonalities in their combination, there are always exceptions to the rules. So, it is possible to conclude that their decoration falls under the category of traditional folk art with the "bricolage" of thinking inherent in the creators. It is manifested in the use of a certain set of decor elements and inscriptions, which were situationally combined into unique compositions. From various sources (for example, older examples of church and civil architecture, printed products), the carvers borrowed the most essential elements in each specific case, subordinated their own vision to the requirements of the customer, and put them into the structure of a kind of apotropaic center of the manor and a panegyric to the owner. The combination of "inscription-ornament-symbols" gave the group of highly artistic support beams a strong artistic effect, which is a manifestation of the "Mazepa Baroque" and its remnant.

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[40] Zham, O., & Hrudevych, T. (2021). Support beam in the house of the tanning master of the Museum of Folk Architecture and Life of the Central Dnipro region: a historical, art-critic, historiographic review. Severyan annals, 6, p. 34.

[41] Malchenko, O. (2007). Artistic casting of cannons in the Hetman region during the reign of Ivan Mazepa, p. 87.

[42] Malchenko, O. (2007). Artistic casting of cannons in the Hetman region during the reign of Ivan Mazepa, p. 84.

[43] Yurchenko, P. H. (1968). Wooden architecture. History of Ukrainian art In history of Ukrainian art. Vol. 3, p. 69.

The rooms, for which the Hetmanate's carved support beams were made, had a width of about 3 to almost 6 m, and the interior appearance of the ceiling in them differed due to different ways of attaching the crossbars to these beams. Some of the support beams have a flat top surface without grooves. In this case, the ceiling structure is not reconstructed. But several products contain grooves at the top for laying "support beams". Some of them were planned from the very beginning. Others were cut out after decorating the support beam, damaging the inscriptions. The dimensions of the cutouts, which were used to lay the ceiling elements perpendicular to this support beam, attract attention.

Grooves preserved in the upper part and near the ends of the Zhovnin support beam (Fig. 1:5) allow to reconstruct the original method of fixing it in the walls and building the base for the ceiling. In particular, it is noticeable that the crossbars were fixed with a dovetail fastener. That is, their ends had the shape of a triangle, which was inserted into the groove of the corresponding shape of the support beam with the wider part towards the inside. This guaranteed the impossibility of falling out of the groove. On the frontal side of the rooms, the crossbars were located less often (about 30–40 cm apart). Two of them, which were located near the outer wall of the room, were almost twice as wide as the next ones (13.5 and 11.5 cm at the exit from the support beam instead of 6.5–6 cm). On the reverse side of the support beam, the crossbars were placed more densely, narrower ones were located between the wider ones. In this way, a peculiar rhythmicity of the visual appearance of the ceiling was created. In the upper bars of the room walls, the ends of the support beam were fixed with the help of complex locks. At the same time, it is sometimes noticeable that the plates of the walls ("spear") were also located above the support beam, providing it with an ideal fixation. Accordingly, the support beam tightly pulled the top of the log cabin.

Captured in a photo taken for a report by F. Hornostaev, a member of the Imperial Moscow Archaeological Society, at the XIV Archaeological Congress in Chernihiv in 1908, the support beam illustrates the fact that carved beams were also used for the construction of ceilings of an archaic (so-called "humped") appearance. The building, located in the garden of the Yelets monastery in Chernihiv, was made of wood on a stone foundation. Inside were five cell-like rooms, the largest of which contained a carved support beam. Church tradition testified that the house was created at the personal request and order of the monastery's archimandrite Theodosius Uglytskyi, Dmytro Rostovsky also lived there[44]. By the way, Taras Shevchenko depicted the "humped" ceiling with support beams in two drawings and corresponding etchings ("Starosty" and "Gifts in Chyhyryn 1649"), in his album "Painting Ukraine" in 1844[45]. The analyzed photo emphasizes the fact that the "support beams" here were quite wide, located in shallow grooves at a distance of about 1 m from each other. The lower edges

[44] Pavlutsky, G. (1911). Civil architecture in Ukraine. Grabar I. History of Russian art in Pre-Petrine era. (Moscow and Ukraine), Volume 2. Architecture (pp. 414-415).

[45] Adruh, A. (2020). Wood carvings and iconostases of Chernihiv of the second half of the 17th and early 18th centuries. Severyan chronicle, (2), p. 43.

of the rafters rested on each of the support beams. Similar grooves are seen on several support beams from museum collections. Accordingly, the ceilings in the rooms with such support beams could also be "humped".

The inside of the rooms was obviously "washed". That is, the wood was not plastered or whitewashed. At least on the support beams examined by the authors, there are no traces of the use of whitewash, and the details of the images on many products (especially the centers of the front parts) have been smoothed out due to repeated washing. The data show that the support beams of 18 century in Hetmanate were established from mid-spring (April 25) to late summer (August 1). This is the optimal period of the year for building houses, when it is more or less dry outside and it is comfortable to work.

Support beams occupied one of the central places in the Ukrainian bright rooms. Together with the penance, the oven, and the plate shelf, they performed the function of important elements of the interior, the sacred centers of the dwelling. Therefore, it is not surprising that the wealthy strata of the population tried to decorate them a lot, apply religious symbols and texts that were supposed to bless the house and its inhabitants, bring happiness, peace and well-being to it, and protect it from troubles. In addition, these exquisite architectural details recorded the time of construction of the house and the name of the founder, and glorified it. Since the images were intended to be perceived from afar, the elements of decor and inscriptions were large, usually massive, drawn with thick, rough lines. But some products (for example[46]) had delicate sketches.

Obviously, various signs were applied to the ceiling beams in Ukrainian houses since ancient times. As for the Hetmanate (Fig. 1: 1), as mentioned above, the oldest of such products known today, dated 1688, already contained information about the founder, the rosette and the "rope", and had complex profiling. That is, in the last quarter of the 17th century, a set of signs was fully formed, which carvers usually used until the end of the Cossack period. Taking into account this fact and the presence of older carved support beams with some similar elements of decor and inscriptions in Lviv, the authors support P. Yurchenko's opinion that elements of classical ornaments (in particular, Ionic) entered the wooden architecture of the Dnipro region "probably from the beginning of the XVII century ... Along with the motifs of classical ornament, Ukrainian craftsmen simultaneously perceived the shapes of profiles on which these ornaments were reproduced. This is how the profiling of wooden architectural details – doors, cornices, support beams, etc., appeared, which is one of the main features of wooden architecture of the 18th century on the Dnipro River and the Left Bank[47]. Such details, obviously, at first (until the time of the Liberation War of the Ukrainian people led by Bohdan Khmelnytskyi) were owned by the estates of Polish-Ukrainian magnates

[46] Shcherban, A., & Babkova, N. (2023). Support beam of 1741 from the funds of the Dykanka Historical and Local History Museum. The Ethnology Notebooks, 6(174), p. 1389, fig. 2.
[47] Yurchenko, P. H. (1968). Wooden architecture. History of Ukrainian art In history of Ukrainian art. Vol. 3, p. 67.

and nobles, houses of wealthy Jews in the territory of the Middle Dnipro region. Although, none of them have survived till our time, this is evidenced by references in the diary of Pavlo Aleppskii in 1654.

For example, when describing the buildings of the town of Pryluky (Hetmanate region), the unfinished palace of Yarema Vyshnevetskyi "made of huge logs and polished boards inside and out" is mentioned. At the top of its humped roof was the date "written in Greek" – 1647. Palace of M. Kalynovskyi in the Mankivka village (Eastern Podillia) was also wooden, smoothly planed on all four sides and polished, decorated with carvings[48]. The body of Cossack elders, which was formed during the middle of the 17th century (among which there were also people from the Polish nobility) continued to use some elements of the building culture of its predecessors. Folk craftsmen gradually transformed ancient traditions of carving, adapting to the needs of customers.

The times of "Mazepa Baroque" brought rich decoration to architecture in general. Its influences were also reflected on the support beams, created for individual houses of the Cossack chieftainship. The fact is that the craftspeople life of that time, as Cornelius Gurlitt noticed, was marked by the stamp of a passionate desire to surpass the rival, to create an unparalleled thing. "Pride" contrasted with Christian humility, the desire to be visible and beyond comparison, the desire for "satisfaction"[49] obviously drove the desire of the craftsmen who decorated the support beams, to decorate them with exquisite images and to remake the old ones. Although, in the houses of other social strata of the Hetmanate, in particular, the Orthodox clergy and lowly people of the 18th century, the installation of more modestly decorated support beams continued.

In addition to the support beams, the living rooms of the houses of wealthy Ukrainians began to be decorated during the Baroque era, for example, with richly ornamented ceramics. The aspiration and realization of the opportunities of the broad strata of the population of the Hetmanate region to decorate housing and everyday life took place during the heyday of national and cultural life in the studied territory, as a result of which a peculiar type of housing and its interior conditions were described in detail by ethnographers of the 19th century[50]. One of the earliest such descriptions for the Hetmanate territory was made by Pavlo Aleppskii in 1654. Describing the cells of the Kyiv Pechersk Monastery of the Assumption of the Virgin Mary, he claimed that there were "all kinds of paintings and beautiful images", furnaces with "beautifully painted tiles". "Each cell is decorated with all kinds of decorations, beautiful, tidy, so

[48] Aleppskii, P. (1897). The journey of the Antioch Patriarch Macarius to Russia in the middle of the 17th century, described by his son, Archdeacon Pavlo Aleppskii (based on the manuscript of the Moscow Main Archive of the Moscow Ministry of Foreign Affairs). Issue 2. (From the Dnipro to Moscow), pp. 26-27, 83.
[49] Chechot, I. (1982). Baroque as a cultural concept. Research experience of K. Gurlitt. Baroque in Slavic cultures, p. 346.
[50] Sherotskij, K. (1914). Essays on the history of decorative art of Ukraine (p. 1; pp. 12-17). Kyiv.

that it cheers the souls of those who enter it and adds life to its residents."[51] The elements of tile ornamentation are similar to those fixed on the support beams.

It is generally known that the Baroque period was generally marked by the growth of the role of "beauty" in the daily life of wide sections of the population of Europe. For example, the concept of beauty in architecture at that time was described by G. Velfin (translated by Anatolii Makarov): "The pictorial style (in architecture) reaches its highest tension in interior spaces. Here are the most favorable opportunities for combining tactility with the charm of what is not felt by touch. Here, for the first time, the motifs of the limitless and the invisible properly appear".[52] All this can be said about the baroque Ukrainian house with its decorated tiled stoves and support beams. The tendency to adornment is also visible in other branches of the folk artistic culture of the time. In particular, in fine arts, textile production, manufacture of products and bone, decoration of church metal products and books, iconostases.[53]

In addition to the aesthetic function, the baroque images on the support beams were supposed to carry a symbolic load. This is evidenced by the fact of choosing a limited number of ornamental elements and motifs among the variety of existing ones. But the interpretation of their semantics is the subject of a special study. In short, during the period under study, it had a status (marked the owner's belonging to a certain social stratum), metaphorical and talismanic-magical character (it was supposed to protect the lord and the household from "evil" forces and promote their well-being). The mass use of amulet images in the Baroque period can be explained by the appearance a new tragically tainted worldview in the 17th century. Baroque man was endowed with a special sense of metaphysical anxiety for himself, the world, nature, past and future, God, the human race[54]. For this purpose, people turned to God and saints. By the way, Ukrainians were very religious. In particular, Pavlo Aleppskii in 1654 did not spare them praise in this regard: "we saw extraordinary piety, God-fearing and humility"; "what a blessed country! Its great merit is that there is absolutely no one in it who is a stranger from another faith, but only pure Orthodox, faithful and pious. What zeal, characteristic of a holy soul and pure faith, truly Orthodox!"[55].

The analysis of available sources indicates that the rich baroque decoration of the support beams of the region during the second half of the 18th century gave way to the brevity of inscriptions and symbols characteristic of the era of classicism. The confirmation of this is the support beam design, which is kept in the museum of Horishni Plavni.

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[51] Aleppskii, P. (1897). The journey of the Antioch Patriarch Macarius to Russia in the middle of the 17th century, described by his son, Archdeacon Pavlo Aleppskii (based on the manuscript of the Moscow Main Archive of the Moscow Ministry of Foreign Affairs). Issue 2. (From the Dnipro to Moscow), p. 47.

[52] Makarov, A. (1994). The light of the Ukrainian Baroque. P. 85.

[53] Ukraine is a Cossack state. 2004. P. 91, 241, 242, 874-876.

[54] Makarov, A. (1994). The light of the Ukrainian Baroque. P. 42, 62.

[55] Aleppskii, P. (1897). The journey of the Antioch Patriarch Macarius to Russia in the middle of the 17th century, described by his son, Archdeacon Pavlo Aleppskii (based on the manuscript of the Moscow Main Archive of the Moscow Ministry of Foreign Affairs). Issue 2. (From the Dnipro to Moscow), p. 23, 27.

Conclusions.

As a result of the analysis of information about 22 carved support beams of the 17th–18th centuries from the territory of the Hetmanate region, it has been found that the common features of these monuments are the presence (with some exceptions) in the centers of products of straight Orthodox crosses, inscriptions in the Church Slavonic language. In the ornamentation of the support beams, features characteristic of the late baroque and classicism can be traced. At the same time, both simpler and more richly decorated products are encountered. The second group includes support beams from the houses of individual representatives of the Cossack elders. Each support beam was a visual manifestation of the owner's wealth and social status, their artistic preferences against the background of generally accepted cultural canons. At the same time, carved support beams are examples of the skill of Ukrainian master carvers of the early modern era, which need to be preserved for future generations. In general, the images on these products are permeated with Christian symbolism, although they contain individual symbols that were found in pagan sign systems.

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Анотація. *У статті досліджено різьблені сволоки з помешкань представників родин козацької старшини та православного духовенства Гетьманщини останньої чверті 17–18 ст. Створення багатоорнаментованих сволоків було своєрідним підтвердженням соціального статусу власників будинків, їх мистецьких уподобань та вираженням рівня майстерності тогочасних майстрів-різьбярів. Метою дослідження є аналіз усіх відомих на сьогодні сволоків представників козацької старшини та духовенства 17–18 ст. та створення узагальнюючої картини щодо специфіки цих пам'яток матеріальної культури Гетьманщини. Вперше в історіографії на основі відомостей про збережені нині в музейних фондах та висвітлені в наукових публікаціях сволоки здійснено комплексний узагальнюючий аналіз цих пам'яток як явища матеріальної культури. В результаті аналізу інформації про 22 різьблений сволок 17–18 ст. з території Гетьманщини зроблено висновок про те, що спільними рисами цих пам'яток є наявність (за окремими винятками) по центрах виробів прямих православних хрестів, написів церковно-слов'янською мовою. В орнаментації сволоків прослідковуються риси, характерні для доби пізнього бароко та класицизму. Притому виокремлюються простіше і багатше декоровані вироби. До другої групи відносяться сволоки з хат окремих представників козацької старшини. Кожен сволок являвся візуальним проявом заможності та соціального статусу господаря, його мистецьких уподобань на фоні загальноприйнятих культурних канонів. Паралельно, різьблені сволоки – приклади майстерності українських майстрів-різьбярів ранньомодерної доби які потребують збереження для наступних поколінь. Загалом зображення на цих*

виробах пронизані християнською символікою, хоча й містять окремі символи, що зустрічалися в язичницьких знакових системах.

***Ключові слова**: сволок; музейна колекція; Гетьманщина; козацька старшина; духовенство*

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Prussian blue pigment: Bridging the historical palette to modern innovations

Abstract. *This comprehensive review explores the multifaceted realm of Prussian Blue, a pigment with a rich history and varied applications tracing its origins, artistic applications, and chemical properties. Beginning with its origins as a laboratory creation, the paper traces its evolution into a revered pigment in the artistic world. The review explores the electronic transitions responsible for Prussian Blue's deep blue hue, shedding light on the intricate chemistry behind its vivid coloration. Additionally, the pivotal role of iron ions in determining the pigment's properties is examined in detail, highlighting the importance of precise composition in achieving desired color characteristics. Challenges in the reintegration of Prussian Blue into conservation and restoration projects are also explored, emphasizing the importance of careful preservation techniques to maintain the pigment's integrity and vibrancy. The review discusses the pigment's lightfastness and stability, addressing common issues such as fading and discoloration over time. A notable phenomenon of bronzing particularly associated with Chinese Blue has been characterized by the appearance of yellow or brown hues on the surface of the pigment, that has puzzled artists and conservators for centuries. The review delves into the underlying causes of bronzing, examining factors such as environmental conditions, pigment composition, and application techniques. The review explores the pigment's interactions with other blues and whites, offering insights into the spectrum of shades achievable through careful color mixing and layering techniques. The paper revisits the perennial debate surrounding the permanence of Prussian Blue. While some argue for its enduring stability and*

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longevity, others point to instances of fading and discoloration observed in historical artworks. The manuscript navigates these conflicting perspectives, providing an understanding of Prussian Blue's permanence in different contexts. Prussian Blue stands as a testament to the symbiotic relationship between science and art, where its molecular structure and vibrant shades continue to inspire both chemists in laboratories and artists in studios. The Prussian Blue emerges as a captivating convergence of art and chemistry that has left an indelible mark on laboratory benches and artists' canvases. The unique interplay of ferric and ferrous ions, not only renders a deep blue color but also makes it sensitive to the variation of its environment. The interplay of its refractive index, bronzing tendencies, and tinting strength shapes its artistic applications, influencing the vibrant hues it contributes to diverse palettes. The permanence paradox surrounding Prussian Blue underscores the importance of precision in its preparation. As artists mix and blend, the pigment unveils its versatility, playing a pivotal role in color harmonies and shade variations. Beyond its role in art, Prussian Blue finds diverse applications in medicinal and industrial contexts. From its use as an antidote for heavy metal poisoning to its incorporation into high-performance materials such as batteries and sensors, Prussian Blue continues to demonstrate its versatility and utility in modern society. The review highlights these varied applications, showcasing Prussian Blue's enduring relevance and evolution beyond its historical roots.

Keywords: *Prussian blue synthesis; historical formulation; pigment stability; artistic application; impurities and additives; particle size and morphology*

Introduction.

Prussian blue, Fe $[Fe^{3+}Fe^{2+}(CN)_6]_3$, Iron (III)-hexacyanoferrate (II), has been heralded as an inaugural modern pigment since its inception in the early 1700s. The Prussian blue is a subject of both admiration and caution for colourists, as encapsulated by Linton in 1852: "a rich and fascinating pigment to the colourist, but not to be depended upon; and yet difficult to avoid" (Linton, 1852). Its historical significance is marked by various duplication such as potash or non-bronze blues, bronze blues (integral in printing inks), and dispersible blues, with its widespread production commencing around 1730. The incorporation of extenders like barium sulphate ($BaSO_4$) or calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$) has given rise to a spectrum of pigments, occasionally referred to as Brunswick blues (Hasluck, 1916). Prussian blue's prevalence endured until approximately 1970 when it began yielding ground as an artist's pigment to phthalocyanine blue. This evolution, captured by the transition from Prussian blue to phthalocyanine blue, represents a pivotal shift in artistic pigments over time (Hasluck, 1916; Linton, 1852). In India, many historical works of arts from Himalayan regions to south west India including Rajasthan and Goa have been decorated using Prussian blue as artist palette that need proper conservation.

The inception of modern color can be traced back to the accidental discovery of Prussian blue in 1704 by the Berlin-based colour maker Diesbach. The pigment,

resulting from Diesbach's experimentation with the oxidation of iron, marked a pivotal moment in the world of pigments. By 1724, Woodward documented the preparation of Prussian blue in England, solidifying its presence on the artistic palette (Woodward, 1724). The manufacturing process involved heating equal parts of saltpeter (KNO_3) and potassium tartrate in a red-hot crucible, followed by the addition of dry, powdered cattle blood. Incandescence ensued, and the resultant mass was washed with water. The wash water underwent treatment with a solution of alum ($K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$) and ferrous sulphate. The introduction of hydrochloric acid to the greenish precipitate yielded the distinctive Prussian blue color. Despite its high tinting strength, Prussian blue exhibits only moderate permanence to light and air. This iron-hexacyanoferrate pigment has remained a mainstay in the artistic realm since its availability to artists in 1724 (Kraft, 2009).

Prussian blue, discovered in 1704, has exhibited remarkable versatility in artistic applications. Its amalgamation with various pigments has yielded a spectrum of color and shades. Noteworthy mixtures include combinations with Naples yellow, yellow ochre, chrome yellow, and cadmium yellow, resulting in vibrant green paints. Additionally, the fusion of Prussian blue with bone black has been instrumental in achieving intensely deep black shades (Rogge & Bomford, 2022). Widely distributed since the early 1700s, Prussian blue held its status as one of the most commonly used blue pigments until approximately 1970. Phthalocyanine blue has since emerged as a prominent substitute in contemporary artistic endeavours, marking a shift in pigment preferences (Rogge & Bomford, 2022).

The use of Prussian Blue in Indian artworks is often associated with the British colonial period. During the British rule in India, which started in the late 18th century and continued for almost two centuries, there was an exchange of artistic techniques and materials between the East and West. Prussian Blue found its way into Indian art through this cultural interchange. The pigment's rich blue color and chemical stability made it appealing to artists working in various mediums. Indian artists started incorporating Prussian Blue into traditional paintings, miniatures, and other forms of art. It added a vibrant and lasting blue hue to their creations. The adoption of Prussian Blue also coincided with the decline of traditional Indian pigments like indigo, which was used for centuries. The new pigment became part of the evolving palette of Indian artists, contributing to the diversity of color in Indian artworks during this period. The use of Prussian Blue continued into the post-colonial era and the modern period. Today, it remains a significant part of the artist's palette in India, reflecting the continued fusion of traditional and modern elements in Indian arts. Fig. 1 shows use of Prussian blue in the mural art of 16^{th} to 17^{th} century Goa churches.

The aim of this comprehensive review is to explore the multifaceted state of Prussian Blue, tracing its origins, artistic applications, and chemical properties. By investing into its rich history and varied applications, the study seeks to shed light on the intricate chemistry behind its vivid coloration and the pivotal role of iron ions in determining its properties. Additionally, it aims to address challenges in conservation

and restoration projects, while also examining the pigment's interactions with other colors and its diverse applications beyond the realm of art. Ultimately, the study aims to provide a holistic understanding of Prussian Blue's enduring relevance and evolution in both artistic and modern contexts.

Figure 1. Prussian blue used in the art works of Goa churches (Author's Figure).

The aim of this comprehensive review is to explore the multifaceted state of Prussian Blue, tracing its origins, artistic applications, and chemical properties. By investing into its rich history and varied applications, the study seeks to shed light on the intricate chemistry behind its vivid coloration and the pivotal role of iron ions in determining its properties. Additionally, it aims to address challenges in conservation and restoration projects, while also examining the pigment's interactions with other colors and its diverse applications beyond the realm of art. Ultimately, the study aims to provide a holistic understanding of Prussian Blue's enduring relevance and evolution in both artistic and modern contexts.

Color and Spectral Reflectance.

The distinctive color of Prussian Blue originates from an electronic transition, specifically from a low-spin Fe^{2}+ ion in a carbon-coordination centre to a high-spin Fe^{3}+ ion in a nitrogen-coordination centre. This transition occurs upon the absorption of visible light at 680 nm, generating an intense coloration with an extinction coefficient (ε) of 9800 $mol^{-1}cm^{-1}$ (Goldanskii, 1967). This absorption phenomenon, known as the intervalence transfer band, is responsible for the striking coloration exhibited by Prussian blue. Despite its predominantly deep blue appearance, Prussian Blue can exhibit variations in undertones, leaning towards reddish or green hues. These variations are contingent on the preparation conditions, encompassing factors such as the oxidizing agent employed, reactant concentrations, pH levels, temperature, and batch size.

Iron blues, such as Prussian Blue, are susceptible to bronzing, a phenomenon where the color of the pigment appears to change or take on a bronze-like hue when exposed to certain environmental conditions, such as light, humidity, or pollution. This

alteration can affect the appearance and stability of artworks or objects containing Prussian Blue pigment. This effect is attributed to the rapid rise in the refractive index of the blue pigment at the red end of the spectrum, becoming most apparent when observed at near-glancing angles (Creagh, Lee, Otieno-Alego, & Kubik, 2009). Bronzing is particularly noticeable in the pure pigment and is more pronounced in Chinese blues (Legnetti, 1984). This bronzed tone is valued in certain applications, such as in printers' ink. In a recent study, Haskovic & Ibragic, (2022) proposed Prussian blue as a pigment for retouching due to its ability to replace more fugitive pigments like indigo and, to some extent, blue copper pigments such as azurite. This recommendation is grounded in the pigment's stability and suitability for retouching applications.

Tinting strength and Infrared Absorbance.

The tinting strength of Prussian blue is notably high, particularly when compared to other pigments with low refractive indices (Briggs, 1918), mostly due to its superfine structure. According to Hurst (1902), a small amount, such as one-half ounce (42.5 gm), can perceptibly tint a substantial quantity of lead white, indicating its potent colouring ability. The refractive index of Prussian blue is reported to be 1.56 in blue light (McCrone, 1988; Taft, Mayer, & Kuniholm, 2000), and it possesses a cubic crystal structure. This relatively low refractive index makes it a transparent pigment suitable for glazing techniques in painting. Prussian blue exhibits extremely high absorbance in the photographic infrared region, ranging from 700 to 900 nm. The addition of less than 1% Prussian blue to a highly reflective white surface can reduce its reflectance by 50% (Scholz, Schröder, Gulaboski, & Doménech-Carbó, 2005). While generally lightfast, prolonged exposure to light can induce color changes in Prussian blue (Gettens & Stout, 1966). However, due to its intense color, Prussian blue can be challenging for reintegration, often requiring dilution or layering. The pigment's strong absorption of infrared radiation results in a dark appearance in infrared photographs. Fig. 2 shows the colour and structure of Prussian blue.

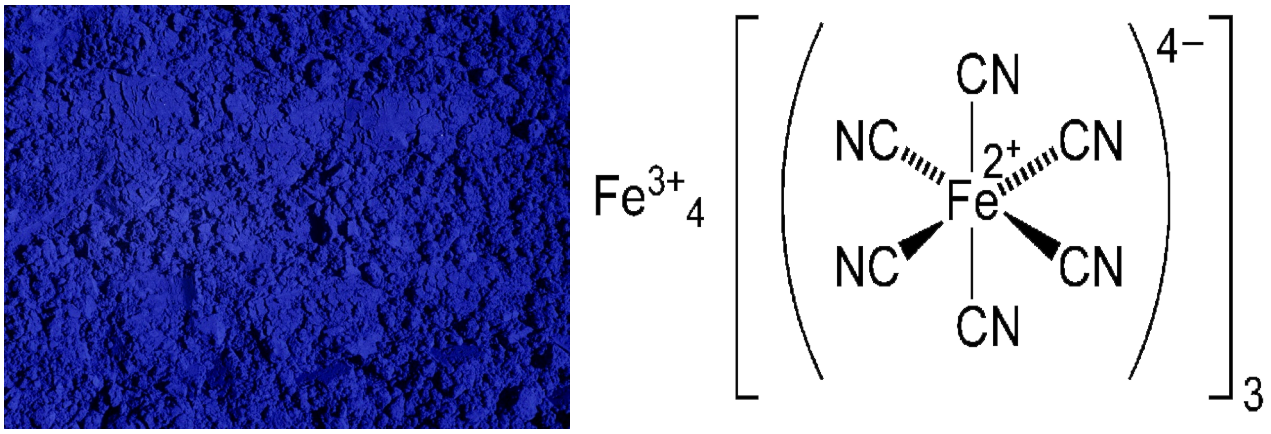

Figure 2. The Prussian blue colour and its atomic structure (Author’s Figure).

Ultramarine Blue, derived from lapis lazuli, has a deep blue color, high tinting strength, and good lightfastness with complex crystal structure (Roy, 2007). Cerulean Blue, known for its lighter and greenish shade has a lower tinting strength compared to Prussian blue. Cobalt Blue offers a bright, pure blue with moderate tinting strength. Ultramarine and Cobalt blues are known for their excellent lightfastness. Cerulean and Cobalt blues might be more forgiving in terms of reintegration due to their lighter tones. Indigo was historically significant in India as blue colorant and was used extensively for textiles (Fitzhugh & Winter, 1985). Lapis Lazuli was used for centuries, especially in Indian miniature and wall paintings.

The amalgamation of blue pigments with other blues or white is a prevalent artistic practice, yielding various shades and tones. The selection of pigments and their ratios significantly influences the resulting color. Ultramarine blue, renowned for its profound color, can, when mixed with titanium white, generate a spectrum of lighter blues, dependent on the proportion (Doerner, 1984). Titanium white has also been the base colour for Prussian blue. Cerulean blue, a lighter variant, combines with cobalt blue to produce diverse intermediate shades, embodying a balance of both pigments' properties (Gettens & Stout, 1966; Gottsegen, 2006). Cobalt blue, boasting a bright and pure tone, blends seamlessly with zinc white to create a softer effect, often employed for crafting pastel shades (Mayer, 1991).

The research and development of blue pigments by European countries have historically influenced various regions, including India. The European exploration and trade routes introduced pigments like Prussian blue and synthetic ultramarine to India. These pigments became part of the vibrant Indian art scene, influencing traditional artistic practices. The availability of new blue pigments expanded the color palette for Indian artists. Artists could experiment with a wider range of blues, contributing to the diversity and richness of Indian art. The introduction of synthetic pigments involved advanced chemical processes. Indian artists and craftsmen might have learned and adapted these techniques, contributing to the technological exchange. Understanding the properties and behaviours of new pigments also influenced art conservation practices in India. The adoption of European blue pigments might have influenced the visual language of Indian art and contributed to the synthesis of traditional Indian artistic elements with Western influences. The trade of pigments facilitated cultural exchange, contributing to a more interconnected global artistic community. Knowledge gained from European research on pigments, their stability, and degradation could have influenced conservation practices in India. Fig. 3 shows the Prussian blue modern application in India.

Permanence.

The assessment of Prussian blue's permanence has yielded conflicting perspectives. Kirby and Saunders (2004) and Heaton (1932) indicated a lack of permanence, advising caution, especially in mixtures. Prussian blue is not considered part of the permanent palette and is generally recommended to be avoided, particularly

in mixed applications. Additionally, mixing Prussian blue with lead white may lead to discoloration and a greenish tone, although this might be a consequence of the medium yellowing rather than the pigment itself.

Figure 3. Prussian blue modern application in India (Author's Figure).

Iron blues, particularly Prussian blue, are susceptible to chemical reduction in the presence of reducing media. Reduction occurs when the pigment loses electrons, resulting in color loss. This decolourization can be corrected by exposing the paint to air, facilitating the re-oxidation of Prussian blue. The phenomenon of Prussian blue losing color upon exposure to light and regaining its blue hue when stored in the dark was first observed by Franz Fernback in 1834 and later by Field in 1845 (Kirby, 1993; Samain et al., 2011). Kirby's (1993) investigation into the fading and color changes of early Prussian blue provided valuable insights. However, caution was raised by Levison (1976), emphasizing that while Prussian blue is permanent in its pure form, it tends to lose permanence when mixed with white pigments. The permanence rating drops significantly when Prussian blue is mixed with titanium white, highlighting a potential vulnerability in certain compositions. The permanence rating drops from eight (permanent) when pure, to only four when mixed with 1:10 titanium white (Kemp Maer Jr., Beasley, Collins, & Milligan, 1968). However, the titanium white has also been the base colour for Prussian blue.

The permanence of Prussian blue has been influenced by variations in its preparation and the care taken by different manufacturers. Harley (1982) referenced an observation of yellow appearing when water was applied to Prussian blue watercolour cakes. This yellow color might have resulted from a water-soluble impurity, potentially yellow prussiate of potash, which is potassium Ferro cyanide. The function of Prussian blue as an anticaking agent could be attributed to its ability to absorb moisture from the environment. While it's true that Prussian blue can exhibit a yellowish hue when water is applied due to impurities like potassium ferrocyanide, this doesn't negate its moisture-absorbing properties. In fact, this absorption of moisture could help prevent clumping by keeping the surrounding environment dry. Earlier formulations of Prussian blue that have exhibited lower permanence compared to modern preparations

due to a higher proportion of adsorbed impurities, possibly stemming from less efficient washing of the final product or the use of less pure starting materials. Even the modern preparation has the similar problems due to the colloidal nature of Prussian blue and its extremely fine particle size. Prussian blue can undergo oxidation to produce a dark brown ferric complex, Fe Fe $(CN)_6$, which is prone to auto-reduction. The formula Fe Fe $(CN)_6$ has also been associated with a compound known as Everitt's green. Chadwick and Sharpe (1966) proposed that Everitt's green, also known as Berlin green, is likely a result of the partial reduction of the fully oxidized brown material. The green color intensity implies the presence of at least low concentrations of Fe (II).

Chemical properties.

Since its invention, Prussian blue has been a subject of extensive study by chemists. Early work on its chemistry was summarized by Coleby (1939). Prussian blue can exist in two forms: as an insoluble polymeric ferric ferrocyanide or as an alkali ferric ferrocyanide. It is a stable and inert transition metal complex, belonging to the class termed type II mixed valence, and possesses semiconductor properties. The room temperature resistivity of Prussian blue is reported to be 10^7ohm cm (Robin, 1962). Additionally, the compound displays ferromagnetic behaviour at extremely low temperatures, below -267°C.

Prussian blue exhibits specific chemical properties. It dissolves in concentrated mineral acids, 10% oxalic acid, and decomposes in dilute alkali. The pigment is resistant to dilute (10%) mineral acids, polar and nonpolar solvents, fatty acids, drying oils, and plasticizers, demonstrating excellent bleed resistance. Prussian blue remains stable up to at least 140°C and may ignite at higher temperatures. According to the ASTM D93-52 (1990a) standard, the flash point of Prussian blue is reported to be in the range of 600°C to 615°C. Notably, the addition of hot sulphuric acid to Prussian blue results in the evolution of hydrogen cyanide. Prussian blue also exhibits zeolitic properties, acting as an ion-exchange resin that readily exchanges group I cations such as lithium, sodium, potassium, rubidium, and cesium (Estelrich-& Busquets, 2021).

Mossbauer spectroscopy (Fluck, Kerler, & Neuwirth, 1963) and photoelectron spectroscopy (Wertheim & Rosencwaig, 1971) provide insights into the coordination of low-spin iron(II) to six carbon atoms and high-spin iron(III) to the six nitrogen atoms of cyano groups in Prussian blue. The electrochemistry of Prussian blue has been comprehensively reviewed by Itaya, Uchida & Neff (1986) and additional information on the compound's chemistry can be found in the research work of Duncan & Wigley (1963).

Compatibility.

Prussian blue is very sensitive to alkali and cannot be used in fresco or alkaline media such as lime paints, sodium or potassium silicates, alkaline polymer emulsions, or casein paints. The use of any alkaline material such as a soap or ammonia in cleaning areas that were painted with Prussian blue is likely to be detrimental. When applied to

Prussian blue, these alkaline surfactants can lead to chemical reactions that alter the pigment's molecular structure. Specifically, the alkaline environment can induce hydrolysis of Prussian blue, breaking down its chemical bonds and resulting in color changes or degradation. Additionally, alkaline conditions can promote the leaching of metal ions from the pigment, further compromising its integrity.

Hasluck (1916) cautioned against using Prussian blue in distemper for the walls of new buildings containing lime or whiting, as the alkali could cause the blue to turn into a "dirty-brown colour" (Gervais et al., 2013). Studies on the effect of paper de-acidification on the color of Prussian blue have been conducted. Since Prussian blue was used to tone paper, testing should be done before using alkaline materials in treating blue paper or watercolours. The literature often mentions that Prussian blue can be mixed with all pigments except those that are alkaline, specifically calcium carbonate and lead white, although there is little evidence of any detrimental interaction in modern formulations. Kühn (1986) described the decolourization of Prussian blue in a mixture with zinc white. Prussian blue mixed with zinc yellow to give "zinc green" is converted to zinc ferrocyanide, destroying the paint's color (Samain et al., 2011). Parnell (1846) described Prussian blue's use as a dye for calico and indicated that Prussian blue lacked the essential fast dye requirement of "resisting the action of alkalis and soaps." The sensitivity of Prussian blue to alkali is exploited for micro chemical testing to identify the pigment. In modern formulations of Prussian blue, the addition of nickel improves its resistance to alkali (Hughes & Rowe, 1983).

Oil absorption and grinding properties.

The oil absorption of Prussian blue during grinding varies depending on the quality and type of Prussian blue used. Treatment with surfactants can cause drastic changes in the physical properties of Prussian blue, including oil absorption. Technical data supplied by Degussa (1974) showed a variation in oil absorption depending on the type of Prussian blue used, with a range of oil absorption for each formulation (Abel, 1999). The total variation for oil absorption of all types of Prussian blue was from 40 to 72 ml of oil per 100 g Prussian blue. The Kirk-Othmer Encyclopedia (Eckroth, Grayson, Kirk, & Othmer, 1978) listed 35 to 56 g oil absorbed per 100 g of Prussian blue. The National Institute for Standards and Technology (formerly the National Bureau of Standards) requirement for Prussian blue is a minimum of 48% by weight of Prussian blue in linseed oil. A large proportion of poppy seed oil, 65% to 110% (that is, 65 to 110 lbs. per 100 lbs. Prussian blue), is required (Schilling, 2005). The high proportion of oil required to produce a workable paint, combined with the low refractive index of Prussian blue, means that visible changes in the color of the medium are easily perceived, and changes in the color of the paint are often due to changes in the medium and not the pigment itself. These changes perceived in the colour of the paint is due to the increase in the refractive index which shifts the transparency / opacity of the medium.

It is challenging to mix Prussian blue in water-based paints, and artists often add alcohol to help form a good paint. Without alcohol, the particles of Prussian blue tend to "float" on the surface. Manufacturers use poly alcohols and surfactants to produce workable paints.

Prussian blue is a hard material and challenging to grind. During grinding, care must be taken to avoid overheating as it may possibly ignite. The formulation produced by the A. Milori Company, Paris, was the first to provide easily worked material. The differences in working properties and texture of different preparations usually depend on the handling of the immediately precipitated material since it tends to agglomerate rapidly. High moisture content makes it easier to produce smaller aggregates of the pigment. Some of the problems in grinding are thought to result from unremoved impurities that include excess starting material. Treatment with surfactants helps to remove impurities but markedly affects the physical properties of the pigment. Adding aluminium stearate to Prussian blue oil paint provides a smooth and workable texture (Eckroth, Grayson, Kirk, & Othmer, 1978).

Toxicity.

In 1710, Prussian blue was considered non-poisonous as it contained no arsenic, making it recommended not only for painting but also as a medicine (Estelrich & Busquets, 2021). Prussian blue is employed as a medicinal antidote to radioisotope and heavy-metal poisoning (Šimonović, Kargačin, & Kostial, 1986). Prussian blue is not listed in the 1982 Registry of Toxic Effects of Chemical Substances; no acute toxicity data exist. The pigment is listed in the GRAS File, the U.S. Food and Drug Administration's list of chemicals generally believed to be safe, CFR, 1991 (De Rovira Sr., 2017). Prussian blue is non-mutagenic in the Ames Salmonella test (Mortelmans & Zeiger, 2000). Due to its low toxicity, it is used in cosmetics. While Prussian blue does contain cyanide groups, its insolubility, tight binding of cyanide group with iron, stability, limited bioavailability, and low toxicity make it nontoxic in practical applications. However, it's essential to note that the dry pigment, being a colloidal powder, can be irritating to the lungs when inhaled, and caution should be exercised. Prussian blue burns and evolves cyanogen, which is highly toxic.

Composition.

Two formulas for Prussian blue are commonly given: K $Fe[Fe(CN)_6]$ and $Fe_4[Fe(CN)_6]_3$• Modern formulations of Prussian blue are M' Fe_m $Fe_n(CN)_6$ • nH_20, where M' is a potassium (K^+), ammonium (NH^{4+}), or sodium (Na^+), and n = 14–16. Currently, the use of both sodium and ammonium ions predominates. The use of ammonium ions in the formulation was first introduced in the United States following World War I, when potassium was an expensive commodity (Sistino, 1973).

Due to the colloidal nature of Prussian blue, various surface-adsorbed ions are present, which can complicate analytical results. The correct formulation has been determined using x-ray diffraction methods (Buser, Schwarzenbach, Petter, & Ludi,

1977) and neutron scattering (Herren, Fischer, Ludi, & Hälg, 1980). These sources revealed the presence of interstitial water, water of crystallization, and adsorbed water molecules. Additionally, Wilde, Ghosh, & Marshall (1970) demonstrated that different preparations of Prussian blue contained impurities in the form of 5% to 15% Fe_2O_3.

The formulation of Prussian blue, where M1 is a potassium ion, has been referred to as soluble Prussian blue or soluble Turnbull's blue. Despite being described as soluble, this complex is insoluble; however, it is easily peptized, meaning it disperses readily in aqueous solutions. There was once a belief that using ferrous salts and potassium ferricyanide in manufacturing resulted in Turnbull's blue, while using ferric salts and potassium ferrocyanide produced Prussian blue. It is now understood that both methods yield the same compound identified as $Fe_4III[FeII(CN)6]_3 \cdot xH_2O$ (Chadwick & Sharpe, 1966). Adjusting the molar ratio of reactants to 1:1 yields $KFe[Fe(CN)_6]$. The ASTM (1990c) standard for the dry pigment, D261-25, reapproved 1987, allows for no extenders, organic color, or lakes. The maximum moisture content is 8%, and up to 5% of other materials may be added to improve the handling characteristics of the pigment.

Adulteration and Sophistication.

Prussian blue is available both as a pure pigment and in mixtures with extenders and bulking agents. The addition of extenders often results in the pigment being sold under a different name. These extenders include alum, iron oxide, calcium carbonate, calcium sulphate (gypsum), barium sulphate (also known as "heavy spar"), starch, alumina, magnesia (Riffault, 2023), and clay or pipe clay. Commercial mixtures of Prussian blue with zinc white were also sold, typically not under the name Prussian blue. Antwerp blue, as described by Riffault and colleagues, is a mixture of variable proportions of Prussian blue, alumina, magnesia, and zinc oxide. The earliest date of commercial mixtures with zinc oxide is unknown, but Feeser et al. (2012) mentioned the use of zinc white mixed with Prussian blue. Stillman (1905) provided a recipe for Prussian blue paint containing "1 qtr Prussian blue, 14 lbs terra alba or barytes to 1/2 gallon of refined linseed oil, or alternatively 1 cw Prussian blue, 1 qtr barytes, and 1 qtr whiting in linseed oil to consistency."

The addition of nickel or cobalt in formulations has been shown to reduce the sensitivity of Prussian blue to alkali (Holtzman, 1945), but the exact mechanism behind this phenomenon is not fully understood. However, one proposed explanation is that nickel ions may interact with the cyanide groups present in Prussian blue, forming stable complexes that are less susceptible to alkali-induced degradation.

Bersch (1901) previously defined Antwerp blue as a pigment prepared by precipitating "a solution of two parts of zinc sulphate and one to two parts of green vitriol (according to whether a pale or deep blue is desired) by a dilute solution of yellow prussiate." This was described as a mixture of Prussian blue with zinc cyanogen compounds (Zhang, Chen, Fu, Yan, Tao, & Yang, 2022). Similarly, Hurst (1892) provided a similar recipe for Antwerp blue and suggested that Brunswick blues

(Prussian blue mixed with barium sulphate) had largely replaced Antwerp blue (Friend, 1910).

Nickel-containing preparations have been used in architectural applications since about 1938 (Brown, 1968). These preparations have the formula $Ni_2Fe_2[Fe(CN)_6]$ h. A modification that substitutes zinc for nickel has also found minor use in architectural applications. Prussian blue has historically been utilized in mixtures with yellow pigments to produce green hues. One such commercial mixture is chrome green (or cinnabar green), which combines Prussian blue with chrome yellow ($PbCrO_4$) along with varying amounts of white pigments or extenders. Small rods or spheres (1-2 μm) of chrome yellow are coated with Prussian blue to give a green color. Chrome yellow, commercially available in the early 1800s, was often mixed with Prussian blue shortly thereafter (Kühn & Curran, 1986). The term Brunswick green, initially associated with copper compounds, was later applied to a mixture of chrome yellow and Prussian blue. Additionally, Prussian blue has been employed in the creation of zinc green pigments. The term Victoria green was used for a combination of zinc yellow and Prussian blue (Brown, 1968), although it was also applied to a mixture of zinc chrome green and hydrated chrome oxide (Kühn & Curran, 1986). Prussian blue has also been combined with organic yellows, white pigments, and extenders. For instance, a mixture of Prussian blue and gamboge has been referred to as Prussian green, malachite green (Gleason & Walker, 1969), or Hooker's green, finding use in both oil and watercolour painting. However, these pigments are now being replaced by more stable mixtures. Olive lake, a blend of a yellow lake and Prussian blue, was documented as well (Brown, 1968).

Monthiers blue, named after its discoverer (Monthiers, 1846), is a modified form of the formula resulting from the reaction of ordinary Prussian blue with ammonia (Eastaugh, Walsh, Chaplin, & Siddall, 2008). It has been described as having a finer color and increased durability. Monthiers blue is obtained from the oxidation of the precipitate formed by the action of ammoniac ferrous chloride upon potassium ferrocyanide, with a chemical formula of $(Fe_2)2Fe(CN)_6\ 6NH_3 9H_2O$. Additionally, Prussian blue has been prepared on substrates like mica to create pearlescent greenish pigments (Armanini & Johnson, 1977; Pfaff, 2008).

Modifications of Prussian blue to produce brown compounds have been described. Linton (1852) outlined one such modification to produce a pigment called Prussian brown. This process involved adding yellow prussiate of potash ($K_4[Fe(CN)_6]$) to a solution of copper sulphate, resulting in a rich chocolate-brown pigment. However, this pigment had the disadvantage of being "totally destroyed by alkaline solutions, which are frequently used as abstergents in picture-cleaning." Another method to obtain Prussian brown involves calcining (heating) iron blue, and the discovery of this method has been credited to Mr. Telfer (Wilkins, 1998). Calcining to produce a black pigment was described by J. F. L. Mérimée (Taylor, 1957).

Identification and characterization.

Optical Microscopy observation.

Prussian blue, regardless of its formulation, is characterized by an extremely fine particle size, typically ranging from approximately 0.01 to 0.2 μm in diameter (Keggin & Miles, 1936). The shape and size of Prussian blue aggregates depend on the manufacturing process and can vary considerably. It's important to note that these aggregates consist of submicron particles, which smear or clump when dry, resembling indigo in appearance (Wild, 1929; Stewart-Remington & Francis, 1954).

Dispersed Prussian blue appears transparent and may resemble a blue streak or flat flakes in transmitted light; in reflected light, it appears blue (Ašpergěr, 1952). Clumps or aggregates of particles are opaque. Prussian blue shares this property with indigo and phthalocyanine blue. Due to its cubic crystallographic system, the particles are isotropic and completely extinguished between crossed polarizers (Coccato, Moens, & Vandenabeele, 2017). When pure pigments are examined at 100 to l,000 X magnification, this property distinguishes Prussian blue from indigo and phthalocyanine blue, which both have low birefringence. In practice, the individual particles are too small to resolve and the admixture of other pigments, which are often birefringent, make it extremely difficult to use isotropic behaviour to characterize Prussian blue. While this property can distinguish Prussian blue from indigo and phthalocyanine blue at high magnification, the small size of individual particles and the presence of other pigments complicate its characterization using isotropic behaviour. Fig. 4a illustrates the appearance of blue paint under an optical microscope, showing very few blue flakes among lead white particles. Welsh (1988) noted differences in the agglomerate shape of Prussian blue prepared using original recipes (with cattle blood) and more recent recipes.

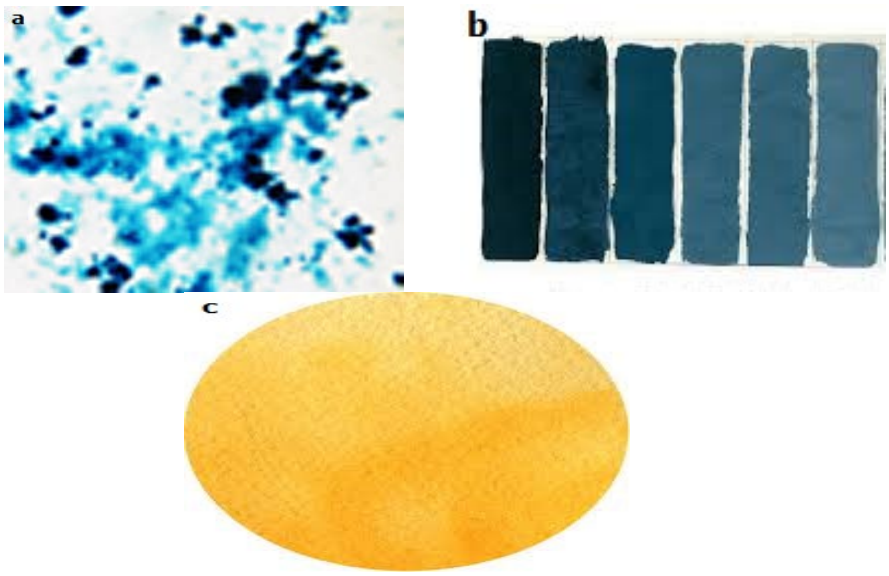

Figure 4. Optical image of Prussian blue *(a)*; Prussian blue colour on mixing different concentration of lead white *(b)*; Chrome green on mixing chrome yellow in Prussian blue *(c)* (Author's Figure).

The former consists of angular fragments of varying size, which could be mistaken for natural ultramarine. This highlights the challenge of identifying Prussian blue using optical microscopy. Large plate-like fragments of Prussian blue were found in many paintings by J. M. W. Turner (1775-1851) (Townsend, 1993). Schilling and Scott (1989) described the use of a Chelsea filter as an aid in distinguishing between ultramarine and Prussian blue, as reported by Mactaggart P. & Mactaggart A. (1998). A recent instrumental method to distinguish these pigments has been detailed by Gajić-Kvaščev et al. (2023). Fig. 4(a-c) shows the optical image of Prussian blue and colour of Prussian blue mixed with different concentration of lead white and chrome green colour on mixing chrome yellow in Prussian blue.

In the identification of Prussian blue, particularly within pigment mixtures, challenges arise due to its well-dispersed nature. For instance, a 5% by volume mixture of Prussian blue well dispersed in lead white, yielding a sky-blue tint when combined with linseed oil, may not be readily observable at normal magnifications using transmitted light microscopy (Peric, 2008). The presence of impurities, bulking agents, and extenders can contribute to birefringence, complicating the identification process.

Chemical identification.

Prussian blue can be effectively distinguished from other blue pigments through specific chemical tests. One distinctive characteristic is its sensitivity to alkali and its inertness to acids (Kraft, 2021). Upon the addition of 4M NaOH to Prussian blue, a rapid conversion to a brown compound occurs. In favourable instances, the blue color can be restored by introducing acid to the test mixture (Plesters, 1956). The presence of iron (III) in the alkaline solution can be confirmed by the formation of a red color upon the addition of ammonium thiocyanate. These tests enable the differentiation of Prussian blue from other blue pigments like ultramarine (both artificial and synthetic), phthalocyanine blue, and indigo. Notably, indigo is affected by dilute alkali only after prolonged heating or exposure, while the other mentioned pigments remain unaffected (Day, Herren, Ludi, Güdel, Hulliger, & Givord, 1980). Prussian blue can be distinguished from indigo and phthalocyanine blue through various tests. One common method is the Prussian blue test, where a sample is treated with hydrochloric acid, resulting in the formation of ferric chloride and a white precipitate. Another method involves the addition of potassium ferricyanide, which produces a characteristic deep blue color in the presence of Prussian blue. Additionally, spectroscopic techniques like X-ray diffraction can be used to identify the crystalline structure unique to Prussian blue. Upon ignition, it decomposes rapidly, leaving a residue of ferric oxide. Prussian blue demonstrates very good lightfastness. It is considered non-toxic. The pigment exhibits fair permanence in both light and air.

Crystal structure.

Prussian blue exhibits cubic crystal structure with isotropic refractive index. Under Optical Microscopy (OM) Prussian blue exhibits small particles with a

discernible greenish hue. These particles tend to clump together, forming amorphous aggregates. From a technical standpoint, the pigment is a finely divided ferric ferrocyanide, resembling a dye in its microstructure. The particles are characterized as soft, with an average size of approximately 0.5 μm. Notably, Prussian blue is soluble in 10% oxalic acid.

Prussian Blue Synthesis Methods: A Comparative Overview.

Artificial Precipitation Method.

The artificial variety of Prussian blue is synthesized by precipitating a solution of potassium ferrocyanide with a more saturated solution of iron(III)-chloride. The crucial factor is the combination of ferric ions (from the chloride) with ferrocyanide, resulting in the formation of the pigment. Williamson (1845) emphasized the necessity of having the two irons in different oxidation states (ferric vs ferrous) for the successful synthesis. Ludi (1981) contributed to the understanding of the underlying chemical processes in this precipitation method.

19th Century Method.

Copperas (hydrated sulphate of iron) is dissolved in water and boiled. Nitric acid is added until red fumes cease, and sufficient sulphuric acid is introduced to clarify the solution. This results in the formation of per sulphate of iron. A solution of ferrocyanide of potassium is then added until precipitation occurs. The precipitate is washed with acidulated water and dried. García-Jareño et al. (1988) documented this 19th-century recipe.

Laboratory Synthesis (Fisher Scientific).

Fisher Scientific is a contemporary source for laboratory-grade Prussian blue. A solution containing 2g $FeCl_3$ in 100 ml deionized water is gradually introduced into a stirred solution of 1g $K_4[Fe(CN)_6]$ in 200 ml deionized water. The resulting blue precipitate is filtered and subsequently dried at an elevated temperature, approximately 100°C.

While both methods ultimately result in the formation of Prussian blue through precipitation, laboratory synthesis allows for greater control over the reaction conditions and the properties of the resulting pigment.

Conclusions.

In conclusion, this comprehensive review offers a holistic exploration of Prussian Blue, spanning its origins, chemical properties, artistic applications, and contemporary relevance. From its serendipitous discovery to its diverse applications in art, science, and industry, Prussian Blue continues to captivate and inspire. As we continue to uncover new facets of this enigmatic pigment, its legacy as a symbol of creativity, innovation, and discovery remains as vibrant as ever. Beyond artistic allure, Prussian Blue's ventures into medicinal antidotes and industrial applications. The paper

illuminates the chemical intricacies and also the perceptible changes in color, the challenges of reintegration, and the dynamic interplay with other pigments. The knowledge gained can be scientifically applied in field conservation of artworks in the light of sensitivity of the pigments to certain chemicals.

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Прусський синій пігмент: Поєднання історичної палітри із сучасними інноваціями

Анотація. *Цей комплексний огляд досліджує багатогранний світ прусського синього, пігменту з багатою історією та різноманітними застосуваннями, простежуючи його походження, художнє використання та хімічні властивості. Починаючи з його походження як лабораторного винаходу, стаття відслідковує його еволюцію до пігменту, шанованого у світі мистецтва. Огляд досліджує електронні переходи, відповідальні за глибокий синій колір прусського синього, проливаючи світло на складну хімію його яскравого забарвлення. Крім того, детально розглядається важлива роль іонів заліза у визначенні властивостей пігменту, підкреслюючи важливість точної композиції для досягнення бажаних колірних характеристик. Також досліджуються проблеми повторного використання прусського синього у консерваційних і реставраційних проектах, наголошуючи на важливості ретельних методів збереження для підтримки цілісності та яскравості пігменту. У статті розглядається світлостійкість і стабільність пігменту, вирішуючи загальні проблеми, такі як вицвітання та зміна кольору з часом. Характеризується явище бронзування, особливо пов'язане з китайським синім, що проявляється у вигляді жовтих або коричневих відтінків на поверхні пігменту, яке здавна спантеличувало художників і реставраторів. Огляд занурюється у підстави бронзування, вивчаючи такі фактори, як умови навколишнього середовища, склад пігменту та техніки нанесення. Стаття досліджує взаємодію пігменту з іншими відтінками синього та білого, пропонуючи уявлення про спектр відтінків, досяжних завдяки ретельному змішуванню та технікам нашарування кольору. Робота знову піднімає давню дискусію щодо довговічності прусського синього. Хоча деякі дослідники стверджують про його стійкість і тривалість, інші вказують на випадки вицвітання та зміни кольору, які спостерігаються в історичних творах мистецтва. Рукопис розглядає ці суперечливі погляди, даючи розуміння сталості прусського синього у різних контекстах. Прусський синій стоїть як свідчення симбіотичних відносин між наукою і мистецтвом, де його молекулярна структура та яскраві відтінки продовжують надихати як хіміків у лабораторіях, так і художників у студіях. Прусський синій виникає як захоплюючий перетин мистецтва і хімії, залишаючи незабутній слід як в лабораторних дослідженнях, так і на художніх полотнах. Унікальна взаємодія іонів заліза не тільки надає глибокий синій колір, але й робить його чутливим до зміни навколишнього середовища. Взаємодія показника його заломлення, тенденцій до бронзування і фарбувальної здатності, формує його художні застосування, впливаючи на яскраві відтінки, які він додає до різних палітр. Парадокс довговічності прусського синього підкреслює важливість точності в*

його підготовці. Коли художники його змішують, пігмент виявляє свою універсальність, відіграючи ключову роль у колірній гармонії та варіаціях відтінків. Крім своєї ролі у мистецтві, прусський синій знаходить різноманітне застосування у медичних та промислових контекстах. Від його використання як антидоту для отруєння важкими металами до включення у високоефективні матеріали, такі як батареї та сенсори, прусський синій продовжує демонструвати свою універсальність та корисність у сучасному суспільстві. Огляд висвітлює ці різноманітні застосування, демонструючи тривалу актуальність і еволюцію прусського синього поза його історичним корінням.

Ключові слова: *синтез прусського синього; історичне формулювання; стабільність пігменту; художнє застосування; домішки та добавки; розмір часток і морфологія*

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Bukovyna as part of the Austro-Hungarian Empire and its socio-economic development on the eve of rail way construction

Abstract. *This article examines how the socio-economic conditions in Bukovyna influenced the formation and development of the railway network in the region. It explores whether these processes aligned with the global trends of the time. Based on the analysis of scientific literature, memoirs, and archival materials, it was found that the topic of the formation and functioning of the railway network in Bukovyna had not been systematically studied. It was revealed that the Austrian authorities, by turning Bukovyna into an internal colony of the Habsburg Empire, kept the region in the position of a raw material appendage and a market for the industry of the empire's central provinces. The tariff, customs, credit, and tax systems introduced by the imperial government supported this process, acting in the interests of Austro-Hungarian capital. The development of the railway network was aimed at ensuring the economic interests of the empire, which affected the socio-economic development of Bukovyna. In particular, the construction of railways improved the transport infrastructure, leading to increased trade and higher volumes of raw material and goods transportation. However, this development had a dual nature. On one hand, it promoted economic growth and modernization of the region, but on the other hand, it intensified Bukovyna's dependence on the central provinces of the empire, limiting its economic autonomy and the development of local industry. The article also analyzes the impact of railway construction on the social aspects of life in Bukovyna. The railway became an important factor in migration, contributing to urbanization and the growth of the working class. However, at the same time, social tensions increased due to the unequal distribution of economic benefits and the intensification of local population exploitation. The conclusions of the article emphasize the need for further*

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research to fully understand the impact of railway development on Bukovyna in the context of the Austro-Hungarian Empire and to compare these processes with similar developments in other parts of the world.

***Keywords**: railways of Bukovina; Austro-Hungarian Empire; transport network; Habsburg dominion; Chernivtsi*

Introduction.

More than 140 years of peace established since 1848 contributed to the rapid growth in the population of Bukovyna. Representatives of different nationalities started to come from other Austrian provinces and neighboring countries and, as a result, Bukovyna became a polyethnic province consisting of 9 nations. Ukrainians and Moldovans, and then Romanians in the middle of the 19th century were the largest ethnic groups. Under the rule of Austria, which was more developed than Turkey, Bukovyna managed to create more favorable conditions for the development of agriculture, handicrafts, trade and towns. The national economy and culture developed more intensively after 1848, when the attributes of the outdated feudal era were abolished, promoting the emergence of new industries. Railways helped to connect the region with other provinces and states, domestic and foreign trade became large-scale, and so Chernivtsi and other towns were developing fast. They started to build an educational system, make changes in the social sphere and promote national cultures, contributing to the Ukrainian and Romanian national revival.

The period of Habsburg dominion (1774–1918) is a remarkable period in the history of railway construction in Bukovyna. As a separate unit of the empire, it ceased to exist with the collapse of Austria-Hungary. At different times, these 144 years were evaluated differently, from admiration and praises to the Austrian "humanitarian mission" to the general accusation of its cruel (overt or disguised) oppression. Nevertheless, it concerned not only Bukovyna, but other provinces as well. Only time can show the weighted and realistic estimates. T. M. Islamov notes: "Indeed, there was oppression. But Austria-Hungary has never been accused of mass deportations, ethnic genocide, or ethnic "cleansing"… None of the states that inherited all or part of its territory has provided national minorities with the freedom of development enjoyed by oppressed peoples" (Islamov, 1995, p. 67).

Among the complex problems of the historical past of Austro-Hungarian Empire, the matter of development and function of its railroad system is of great interest to historians. And it is not an odd thing, as the thorough study of the work of railway transport allows us to identify the fundamental laws of internal development processes of any country, to comprehensively characterize its socio-economic, military, and, in many ways, political state, etc (Agora, 2022; Gabdulina, Turkhanova, Kurmanbayeva & Abisheva, 2022, p. 843; Pylypchuk & Strelko, 2019, p. 20; Strelko & Pylypchuk, 2021, p. 261; Sinha, 2021, p. 169; Domonkos, & Schlett, 2021; Strelko & Pylypchuk, 2021, p. 23; Pylypchuk & Strelko, 2020, p. 20). The same can be said about the history

of railway transport in the vast expanses of Austro-Hungarian Empire as a whole and its separate regions, Bukovyna, for example.

Results and Discussion.

During that period, Bukovyna has undergone various changes in the state system: the Bukovyna region was governed by a military administration, there was a district administration within Galicia and a regional administration of the Duchy of Bukovyna. In general, modern European forms of administrative management, local self-government and legal procedures were gradually developing in this region, together with land and water transport.

More than 150 years have passed since the first railway lines appeared in Bukovyna. The appearance of the first lines was preceded by long negotiations on the construction of tracks, railways and railway stations (Strelko & Pylypchuk, 2021, p. 452). Local and foreign entrepreneurs were interested in improving Bukovyna's transport links, seeking to facilitate the use of raw materials from this rich region and the import of industrial goods from Austria and other European countries. It is clear that transport construction in Bukovyna accelerated the development of capitalist relations in the region's economy and at the same time became the basis for increasing colonial and imperialist oppression and looting of the population living on Bukovyna land.

In turn, the emergence of railway transport in Bukovyna in the late 19th century contributed to the rapid growth of manufacturing and agriculture, the growth of town and their populations, as well as to the involvement of new areas of the region. Of course, all this necessitated the prompt movement of people and goods: raw materials had to be transported to manufacture centers, while finished products had to be delivered to consumers. Old traditional communications and vehicles could not meet this need. I. V. Zhaloba, Chernivtsi historian, noted: “That is why the growing pace of capitalism rose the question of creating a fundamentally new mode of transport, that is, railways, these peculiar results of the most important branches of the capitalist, coal and iron industry” (Zhaloba, 1990, p. 51).

Railway construction in Bukovyna was managed by the Austrian government, primarily in order to unite the economically and politically disparate parts of the empire. At the same time, it helped to secure the interests of the Austrian bourgeoisie: the railways provided a more reliable connection between Austrian enterprises, the Bukovinian market and the sources of raw materials. The railways also best corresponded to Austria's expansionist intentions in South-Eastern Europe.

The purpose of this article is to investigate the socio-economic conditions for the formation and development of railway network in Bukovyna, and define whether this process fit into the world context.

The history of Bukovyna as part of the Austrian Empire begins with the manuscript named “The Description of Bukovyna” by Gabriel Anton von Splény von Miháldy, the first military administrator of Bukovyna (Polek, 1893, p. 23). This

manuscript is valuable not only because it provides some historical context, but also because it provides a plan for administrative and legal reforms in the region, as well as a plan for the construction of communication routes. Surprisingly, no significant work on Bukovyna to properly analyze these issues has been published in 100 years since then. The only exception is the publication of Joseph Maximilian Ritter von Winiwarter, who considered certain aspects of the legal status of Bukovyna as part of Austria-Hungary and highlighted some problems of road construction (Ritter von Winiwarter, 1826, p. 18).

In the late 18th – early 19th century there have been significant changes in the historical destiny of Bukovinian lands conquered by Turkey as part of the Moldavian principality in 1514 (Rakovskyi, 1932, p. 1). On the one hand, Bukovyna ended up with more than 250 years of Turkish rule with its Asian barbarism, despotism and dirt. On the other hand, its territorial unity was broken, and it became part of different states(Bukovyna, 1998, p. 416).

Taking advantage of the weakening of Turkey during the Russo-Turkish War between 1768–1774 and trying to create complications for Russia, the Austrian government succeeded in signing an Austro-Hungarian Convention on July 6, 1771 through Johann Amadeus Franz de Paula Freiherr von Thugut, its envoy in Constantinople. According to this Convention, Austria undertook to achieve favorable conditions for Turkey in its peace with Russia and acquired Little Wallachia. However, after the first partition of Poland, when Eastern Galicia was ceded to Austria, Austria demanded Bukovyna from the Turks instead of Little Wallachia, stating that the upper reaches of the Prut gravitated to Galicia and these lands were formerly part of the Galician principality, and one Hungarian king was titled the "King of Galicia and Lodomeria". In fact, the increased interest of the Habsburgs in Bukovyna was due to its favorable strategic location, since after the first partition of Poland Bukovyna formed a wedge between occupied Galicia and Transylvania (a historical region which was part of Hungary until 1918, and later belonged to southwestern Romania) (Kaindl, 1894, p. 25). In order to study the territory of Bukovyna, then occupied by the Russians, military topographic expeditions were created. At the same time, Joseph II ordered to study the history of Bukovyna, and the official Austrian historian F. Hormeier prepared a fake historical reference which substantiated the "right" of Austria to occupy this territory.

The Austrian government decided to occupy Bukovyna before the complete evacuation of Russian troops (Kaindl, 1894, p. 10). With the consent of the Russian commanders, on August 8, 1774, Joseph II ordered to occupy Bukovyna and Khotyn. Between September and October, the entire territory of Bukovyna was occupied (Baier, 1900, p. 22). On May 7, 1775, the Austro-Turkish Convention on the eternal assignment of the Port of Bukovyna (except for the Khotyn Raion) to Austria was signed. On May 12, 1779, a similar convention was signed on the demarcation of the north-eastern borders between Chernivtsi Tsinut and Khotyn Raion(Polek, 1904, p. 48). The annexed territory kept the name "Bukovyna". In fact, its occupation ended

the Austrian seizure of western Ukraine. Most of the feudal lords, as demanded by the Austrian government, swore allegiance to the Habsburgs on October 12, 1777. Taking care of their own privileges, seeking to be equated with the Austrian and Galician nobles, the feudal elite helped the invaders to keep the population of Bukovyna in subjection.

From the first days of the Austrian occupation, Bukovyna was subordinated to the Court Military Council and the General Military Command of Galicia and Lodomeria in Lviv (Kaindl, 1908, p. 224). At that time, Bukovyna was called "Bukovyna district", "Czernowitz Generalat", or "Galician Border Generalat". Since 1779, Chernivtsi has been the administrative center of Bukovyna. According to a patent dated June 18, 1786, Bukovyna was the 19th district of Eastern Galicia (in fact, Bukovyna became part of the Galician province as a political and administrative district on February 1, 1878) (Polek, 1900, p. 68). This decision was confirmed by the imperial patent dated September 29, 1790, and lasted until April 4, 1849.

Bukovyna (Chernivtsi) district was divided into four smaller districts, renamed into counties starting from September 1, 1794: Chernivtsi, Vyzhnytsia, Seretsk, Suceava and a separate Russ-Campulung (Dolhopole) county. A county consisted of 12 localities with 10 communities each. The Bukovyna district was headed by a starosta (headman) and few deputy commissioners. Between 1817 and 1848 the region was completely subordinated to the Galician province (Die Österreichsh-ungarische Monarchie 1899, p. 532). In 1832, a magistrate was established in Chernivtsi, headed by the Burgomaster(Kaindl, 1908, p. 224).

This is how Bukovyna became a new part of the Austro-Hungarian monarchy during the formation and flourishing of Austrian absolutism and, interestingly, the beginning of its decadence, which was accompanied by attempts to preserve the feudal order. This was expressed in the support of aristocratic land tenure, the preservation of the remnants of guild restrictions, state regulations, and so on. In terms of foreign policy, Austria at that time stood on the extreme right flank of the counter-revolutionary, feudal-absolutist camp.

Assessing the life of Bukovyna after its incorporation into Austria, one cannot disregard the fact that the Habsburg Empire had a higher level of socio-economic development than the Ottoman Empire. The possibility of comprehensive communication with Eastern Galicia and other Slavic peoples was also important for the Ukrainian population of Bukovyna. This circumstance played a significant role in the fight against Germanization. At the same time, we should keep in mind that Bukovyna played the role of a raw-material appendage, a "continental colony" of Austria, which had a pronounced effect on the region's economy.

The newly annexed region of Bukovyna had a territory of 10,441 square kilometers, and its population was distributed unevenly. The population density was higher between the Dniester and the Prut, and lower between the Prut and the Seret, and along the Cheremosh up to Vyzhnytsia. The population of the region numbered

75,000 people in 1775, and grew to 450,000 by the middle of the 19th century (Fischer & Zurkowski, 1899, p. 121, 194).

By the time Bukovyna annexed to Austria, the majority of the population consisted of Ukrainians, followed by Moldovans, Romanians, and others. Austrian officer Budinsky, who was sent by Emperor Joseph II to study the region and its population, noted: "Because most locals are Rusnaks, they mostly speak the Rusnak language. Only a quarter of them speaks Moldavian". Because the Bukovinian lands had been part of Moldavia for several centuries, the vast majority of the population belonged to the Orthodox (or "Wallachian") faith. Moreover, the local feudal lords were dominated by Moldavians, and Moldavian had been the official language, so the officials of the Military Administration of Bukovyna considered the indigenous population of the region to be "Wallachians".

An increase in population occurred both due to natural increase and due to migration from neighboring lands (Eastern Galicia, Transylvania, Germany, refugees from Russia, etc.). At the end of the 18th century, German economic colonization of Bukovyna began. In the middle of the 19th century there were 19 German colonies (including Chernivtsi, Sadagora, Kaliczanka, etc.). The vast majority of the population lived in villages. There were very few towns with a small number of inhabitants. For example, in 1774 Chernivtsi still retained the features of the village, both in its population and its appearance. According to the census of 1776 there were 2,000 people (Kaindl, 1894, p. 10), and this amount grew up to 18,000 people by the middle of the 19th century. In the late 19th century there were two towns in the north of Bukovyna in addition to Chernivtsi: Sadagora (2,871 inhabitants) and Vyzhnytsia (4,447 inhabitants) (Derzhavnyi arkhiv Chernivetskoi oblasti, fond 3, opys 1, nr. 5392, ark. 1–2). Chernivtsi was the center of tradesmen, craftsmen and industrial workers, as well as a small number of intellectuals. The population of Chernivtsi suburbs: Klokuchka, Kalichanka and others, was engaged in agriculture. In general, the population of the region mostly consisted of agricultural workers. The main part of agricultural land was concentrated in the Prut-Dniester interfluve. In this area, more than 78% of the land was arable, while in the Prut-Siret interfluve it was about 50%. The rest of the territory was occupied by forests.

In the period considered in this article, timber and other cargoes were mostly transported by water means and conventional carts. However, everyone understood the importance of land communications. New communication routes were as important for the life of the population as food.

The revolution in the Austrian Empire between 1848 and 1849 ended in defeat. Yet some of its achievements, namely, the abolition of serfdom, cancelled restrictions on the development of handicrafts, permission to buy and sell land, etc. created the conditions for the rapid development of capitalism. However, this process was uneven in different regions of the Austrian Monarchy (renamed to Austro-Hungarian Monarchy since 1867). As a rule, industries in Upper and Lower Austria developed

better. The economically backward regions became inland colonies, a kind of appendage for the developed provinces.

Northern Bukovyna was one of the most backward lands in the Austro-Hungarian Empire, and its economy in the mid-19th century was in a state of deep decline. The features of capitalism were very weak, and manifested themselves mainly in the sphere of money circulation. Suffice it to say that in 1880, for example, agriculture employed 75% of the population of the Norther Bukovyna, industry employed 11.1%, while trade and transport employed only 7.6%. In fact, the economy of Bukovyna developed under the conditions of its colonial position as part of the Habsburg Monarchy. In March 1901, the newspaper "Bukovyna" (Chernivtsi) noted that "these lands used to be and are now considered a Viennese colony" (Bukovy`na, 1901, p. 2). In addition, the Austrian capitalists sought to compensate for the absence of external colonies by increasing the exploitation of the occupied lands. For this purpose, Austrian leaders developed a system of measures for the colonial enslavement of Bukovyna land. One of them was customs legislation aimed at protecting the manufacture in the western provinces of Austria. From then on, manufacturers had the most favorable conditions for the production of goods in the backward regions of the Austrian Empire (Galicia, Bukovyna, Transcarpathia), and could sell them at exorbitant prices. In addition, the industry of Bukovyna was not competitive and could not resist the industry of the western regions of Austria. The lands of Bukovyna were artificially divided into separate administrative districts without taking into account economic and living conditions and the ethnic composition of the population. For instance, Eastern Galicia was united with Polish lands west of the San river to create the so-called "Crown Land", or the "Kingdom of Galicia and Lodomeria". From 1786 to 1854 it included Bukovyna. By 1854 Bukovyna, inhabited mainly by Ukrainians and by Romanians in the south, was separated and became a province (or the Duchy). In turn, the Duchy of Bukovyna was divided into counties. The vast majority of the Bukovinian population (up to 70% in 1910) were agricultural workers, and the number of industrial workers (11.1%) even decreased. At the same time, the trade and bureaucratic apparatus grew rapidly (Mitteilungen des statistischen, 1908, p. 49). The bureaucratic and police caste became an obedient and powerful instrument of the government in the hands of the Habsburgs.

The main part of the Bukovinian economy in this period was agriculture. Due to insufficient equipment, agriculture has changed little since the Middle Ages. In 1853, Franz von Schmik, the regional president, noted: "Ordinary peasants do not own a single piece of iron on their plows, harrows and carts" (Derzhavnyi arkhiv Chernivetskoi oblasti, fond 3, opys 1, nr. 68, ark. 32). Similarly, we should also note the low technical level of agriculture in the region. Thus, the Commission of the Regional Sejm noted that there was "no community in Bukovyna where proper crop rotation was introduced, as the fields were fertilized every 15 years" (Derzhavnyi arkhiv Chernivetskoi oblasti, fond 3, opys 1, nr. 68, ark. 83). Livestock was in an

abandoned state, while vegetable growing, horticulture, silkworm breeding and beekeeping did not develop at all.

Things were even worse with the tax policy. At the very beginning of the land cadastre in the late 19th century, the profitability of Bukovinian lands was significantly overestimated and the land tax increased by 54%. For comparison, note that it increased by 15% in Upper Austria, by 11% in Styria, and only by 4.5% in Lower Austria. That is why the agriculture of Bukovyna was in the worst position in comparison with other lands of the Austro-Hungarian Empire.

Without any doubt, the tax policy of the Austro-Hungarian Empire was aimed primarily at keeping Bukovyna in the position of an agrarian region. Due to this, the tax burden was constantly growing. The newspaper called "Halychanyn" noted: "The financial conditions in our region are much stricter than in other provinces of the monarchy" (Derzhavnyi arkhiv Chernivetskoi oblasti, fond 3, opys 1, nr. 5392, ark. 1-2). This even caused an interesting paradox: small local businesses in Bukovyna and Galicia paid higher taxes than large West Austrian ones. Thus, in 1893, the Czech Savings Bank in Prague paid 6% of income tax, while the Galician Savings Bank in Lviv paid 51% (Kravets, 1998, p. 19).

The industrial tax in Bukovyna was one of the major ones. Thus, from 1891 to 1896, it increased from 101,716 to 118,437 guilders, respectively (Avstro-Vengrija, 1899, p. 269). At the brickyard in Chernivtsi, this tax increased from 142.27 krones to 209.0 krones within a year (from 1906 to 1907).

The productivity of the Bukovyna region was artificially inflated, especially when compiling cadastres. This caused the tax in Bukovyna to be overstated several times more than in other provinces of the empire. The court tax was also discriminatory. While Bukovyna paid 188,000 in Roman gold, Lower Austria, for example, paid 423,700, although its economy was much more developed. According to official data, from 1870 to 1896, for example, the sum of all taxes per capita in Bukovyna increased from 4 to 7–8 guilders. This tax policy undoubtedly led to the ruin of a large number of enterprises, especially small ones. This was confirmed by the newspaper "Bukovynskie Vedomosti": "We could avoid that danger… if the purest colonial policy had not been introduced in the field of financial management" (Bukovinskie vedomosti, 1895, p. 3).

Government subsidies for the development of agriculture in Bukovyna were insignificant. Thus, in a lean year (1898) the economy of Bukovyna was to receive 500,000 gold coins, but in fact received only 50,000. For comparison, for Salzburg (Austria), which was in a much better economic position and where the damage was estimated at 411,980 zlotys, the allocated aid amounted to 150,000 zlotys. This fact speaks for itself.

Also, the economic development of Bukovyna was suppressed by customs legislation. It protected, first of all, the industry in the central provinces of Austria-Hungary. Thus, in March 1903 the newspaper "Bukovyna" pointed out that "industrial taxes are a heavy burden for us" (Bukovyna, 1905, p. 2).

At the same time, Austria-Hungary created favorable conditions for the sell of goods manufactured in the western provinces, selling them in Bukovyna at a much higher price. This was one of the peculiar methods of economic plunder of Bukovyna. Here is what the newspaper "Dilo" wrote about this in 1880: "What is the outcome? First they pay us for our raw materials, process them in their homeland and then send them back in a modified form, so that we return not only what they paid us, but also the cost of their work together will the commercial and industrial earnings ... Thus, they develop productively at our expense and exploit our region to our own detriment and to their benefit" (Dilo, 1880, p. 4). In 1896, the newspaper "Bukovyna" wrote: "Our land is rich in everything we need. But what difference does it make if, extracting raw fruits from the ground, we have to sell them cheaply, and buy expensive products from foreign factories. Strangers use us for their benefit, reducing us to poverty" (Bukovyna, 1896, p. 5).

Among the measures of colonial oppression in Bukovyna, we can distinguish the tariff policy. Its aim was to prevent the development of diversified industry and to keep Bukovyna in the position of a raw material appendage and a market for the western provinces. M. Vasylko, Deputy of the Regional Sejm, stated: "railway tariffs not only hinder the development of this industry in our region, but can even terminate its existence" (Wasilko, 1901, p. 275).

The Council of State Railways in Vienna held in the autumn of 1890 also stated that the existing tariff policy put Western Ukrainian enterprises in an unequal position in comparison with the enterprises of the central regions (Derzhavnyi arkhiv Chernivetskoi oblasti, fond 3, opys 1, nr. 68, ark. 13–16). M.G. Kukurudziak explains: "The essence of the government's policy was to reduce tariffs for transportation of industrial goods from the western provinces to Eastern Galicia, Northern Bukovyna and Transcarpathia, and increase rail transportation from western Ukraine to the centers of the empire. Import tariffs were also higher for machinery, equipment, etc., than for enterprises in the central provinces. For example, the tariff for the transportation of a ton of coal from Duxer (now Duchtsov, Czech Republic) to Vienna (600 km) was 687 kreutzers, and 1,067 kreutzers from Jaworzno (now Jaworzna, Poland) to Chernivtsi (663 km) (Kukurudziak, 1998).

At the same time, the export of raw materials (such as commercial wood) from Bukovyna to the central regions of Austria was 25% cheaper than the export of finished wood products. The Galician newspaper "Dilo" wrote: "Bread from our fields, oxen from our farms, skins of our horses, calves and sheep, rags from our regional household, pigs, salt from Wieliczka, oil from Boryslav mines – all this and many more materials are sent to the West by railways" (Dilo, 1880, p. 3).

In general, the Austro-Hungarian Empire developed just like any other European state. For example, in 1812 there were more than 200 cartels in Austria alone (excluding Hungary) (Prister, 1952, p. 448). Among them were oil cartel, machine-building, cement, sugar cartels and many others. In fact, monopolistic syndicates have taken a dominant position in the country's industry. Here is what the Chernivtsi

newspaper “Gazeta Polska” wrote about cartels in its article called “Austrian Cartels”: “The most important industries are included into cartels. Iron, steel, wool, cotton, linen, cloth, glass, paper, porcelain, enamelware, sugar, oil, cement, glue, soda, zinc, leather, wire, nails, tin, mineral fertilizers and other common goods are now in the hands of Austrian cartels” (Gazetta polska, 1901, p. 7). As a rule, cartels artificially increased prices by 20–30%. In Bukovyna, Austrian cartels impeded local industry from development. For instance, the cartels stubbornly resisted the construction of a sugar factory in the village of Zhuchka, Chernivtsi district. The only reason for the competition between the cartel and the sugar factory was profit. Constantly raising sugar prices in the middle of the country, the cartel sold it abroad for nothing.

In the early 20th century the importance of bank capital has increased in Bukovyna. Previously, banks were engaged only in granting loans and mediation in money circulation, but from then on, they began to invest their money in production (Strelko & Pylypchuk, 2021, p. 45). Austro-Hungarian, Anglo-Austrian and Viennese associations and Czech banks started to operate in Northern Bukovyna. One of the largest offices belonged to the Austro-Hungarian Bank, and amounted to 63.7 million krones since 1907. Overall, between 1911 and 1912 there were 23 banks in Chernivtsi, including several savings banks.

In the early 20th century banks started to involve in industry. They funded industrial development, participated in the creation of industrial enterprises and actually managed them. In fact, banks subjugated the entire economy of Northern Bukovyna. As a rule, the bank capital was not of local origin, but originated from Austria, England, Germany, Hungary or Czech Republic. At the same time, Austrian capital held the first positions. M. M. Kravets notes: “This was natural. Austrian businessmen were very interested in possessing colonies. They tried to compensate for the absence of external colonies at the expense of annexed lands. Keeping Northern Bukovyna and other western Ukrainian lands in the position of backward agricultural areas to ensure the sale of goods from the western provinces and meet their needs for cheap agricultural products was the real motive of Austria and its financial circles. The Austrian government acted in favor of entrepreneurs of the ruling nation, developing a system of colonial oppression” (Kul'chickij, 1963, p. 24).

The penetration of foreign capital into Northern Bukovyna was conditioned not only by the backward position of the western Ukrainian lands, but also of the whole Austria-Hungary, which was financially dependent on foreign capital. It is known that in the early 20th century foreign investments in the Austrian economy reached 9.8 million krones, including 4.653 million from Germany and 3.270 million from France (Oppengejm, 1920, p. 30). By 1900, the total amount of foreign capital in all sectors of the economy of Bukovyna was 41.4 million krones, including more than 23.5 million from the Austro-Hungarian Empire (Lytvynov, 1957, p. 85). According to J. S. Hoenigsman, in 1912 the total Austro-Hungarian and foreign capital in the industry of Galicia amounted to 596.7 million krones, or 73% of the total amount of operating capital (Khonihsman, 1971, p. 125).

M. G. Kukurudziak made the following comment on the penetration of foreign capital into Bukovyna: "Predatory use of natural resources and ruthless exploitation of workers in the region brought significant profits to Austrian and foreign capitalists. For instance, in 30 years (from 1858 to 1888) Austrian and foreign bankers financing railway construction in Galicia and Bukovyna received 54,115 thousand Roman gold of net income in the form of interest on capital and dividends. In 1897 alone, more than 56 million guilders were transferred from Bukovyna to bankers in the central provinces of the monarchy. These profits could be used to develop the production capacity in the region. The dominance of Austro-Hungarian and foreign capital played a negative role in the development of Western lands, because this development was determined not by regional needs and interests of the local population, nor even the available natural resources, but only by the interests of foreign capital (Kukurudziak, 1998, p. 39).

As we can see from the above, the industry of Bukovyna was underdeveloped in the period under study. It demonstrated the distinctive characteristics of colonial and semi-colonial countries: unilateralism, absence of heavy industry, small number of factories, primitive technologies. According to official data, in 1890 the total energy supply of industrial enterprises in Austria was 479,523 horsepower (hp), with only 1,925 hp or 0.4% in Bukovyna. Without any doubt, the backward position of the Bukovyna industry and the slow development of manufacture slowed down the process of transforming agriculture on a capitalist basis. A significant obstacle to the development of capitalism in the region was a number of feudal remnants, which, according to the local press, permeated "almost all of our cultural, economic and political life". Landlords were one of them. In the late 19th – early 20th century, 43.5% of land in Northern Bukovyna belonged to landlords (for comparison, it was 42.1% in Galicia and 30.0% in Transcarpathia).

The development of capitalism in Northern Bukovyna was hindered by other medieval remnants like propination, the "exclusive right" of landlords to mills, and the "exclusive use of the driving force of water" within all landlord's ownership" (Derzhavnyi arkhiv Chernivetskoi oblasti, fond 3, opys 2, nr. 2980, ark. 5). The latter "law" forbade the construction of sawmills, mills and other water-powered enterprises without the landowner's consent. Although the "rights" of landlords to mills and water were abolished in 1863, in fact, they existed for a long time (Derzhavnyi arkhiv Chernivetskoi oblasti, fond 3, opys 2, nr. 194, 198).

The government policy of the Austro-Hungarian Empire aimed at inhibiting the development of Northern Bukovyna found support among local (Bukovinian) landlords. Guided by selfish class interests, the landlords did not want peasants to move to industrial work, as this could lead to a rise in wages of agricultural workers. That is why expenditures on the industry in the regional (Bukovyna) budget occupied a secondary place, and a significant part of the budget, as well as government subventions, was aimed at supporting the landlord economy. In short, the landlords were interested in maintaining existing relations and limiting the industrial development of the region.

And yet, with the development of capitalism, Bukovyna was drawn into the system of the general Austrian market. Railway construction, which was carried out for 2 main reasons, that is, strategic reason and the export of raw materials from Bukovyna, immediately connected the Bukovyna region with the northern and western provinces of Austria-Hungary, Russia, Dnieper Ukraine and Romania. In particular, the railway between Lviv and Chernivtsi was built in 1869, and then extended to the Romanian border (up to Iasi) (Strelko, Pylypchuk & Berdnychenko, 2021, p. 47). The Chernivtsi-Novoselytsia railway, built in 1884, helped to strengthen economic ties with the Russian Empire.

A network of regional (local) railways in Bukovyna began to appear in 1880–1890s (Strelko, Pylypchuk & Pylypchuk, 2022, p. 149). During that period the following local railways were built: Hlyboka-Berehomet with Karapchiv-Chudei branch (now the village of Mezhyrichchya, Storozhynets district), Berehomet-Mezhybrody (Southern Bukovyna), Nepolokivtsi-Vyzhnytsia, Luzhany-Zalishchyky, and others. The length of the railways was constantly increasing from 117 km in 1881 to 592 km in 1913.

And yet the length of the railway lines in Bukovyna was 2–3 times less than in the central regions of Austria. Only the government's desire to detain the economic development of Northern Bukovyna can explain the slow construction of railways. Besides, the initiated railway construction was carried out solely for strategic reasons or in order to make better use of the region as a supplier of cheap raw materials and a market for the highly developed western provinces. As for the interests of the region itself, it was mostly driven by the desire of the landowners of Northern Bukovyna for enrichment. The interests of the local population were not taken into account. Here is what the Chernivtsi newspaper “Ruska Rada” wrote: “Think of who could take advantage of the railways, if not the landlords, who could take wood and crops and sell it at a large cost? Where these railways were built, if not at the landlord’s property, making the landlords collect innumerable sums? And at whose expense were those railways built, if not peasant ones, because the region gave us three million krones in taxes, of which more than half were made by peasant sweat blood” (Ruska rada, 1904, p. 4).

It is clear that the interests of entrepreneurs were intertwined with the interests of state authorities. For example, the government had its own shares in the joint-stock company of 2 new local railways (Luzhany-Zalishchyky and Nepolokivtsi-Vyzhnytsia), and its representative was one of the large Bukovinian landlords (Polek, 1908, p. 76). In 1904, the income of this company amounted to 1,434,950 krones. By 1900, the length of railways in Bukovyna was only 486.2 km. In 1910, it reached 594 km, which was only 2.5% of the total Austrian network. There were 4.5 km of railways per 100 km of land in Galicia, 4.6 in Bukovyna, less than 3.0 in Transcarpathia, while it reached 9.8 in Lower Austria, 7.4 in Upper Austria, 9.8 in Moravia and 11.4 in Bohemia.

"The delay of railway construction in Northern Bukovyna had a double impact on the local industry, which, on the one hand, suffered from the lack of railroads, and on the other hand, weakened the competitive ability to inherit them due to its backward position. Small-scale handicraft production turned out to be in a difficult situation," noted M. M. Kravets (Kravets, 1998, p. 19). There is another opinion about the construction of railways in Bukovyna: "The export of manufactured goods from the central Austrian provinces, enforced by the emergence of railways, significantly undermined local industry and handicrafts" (Shevchenko, 1980, p. 339). The number of artisans decreased, for example, from 5,646 in 1864 to 3,330 in 1880 (Volkspress, 1910, p. 1). Unable to withstand competition, more than 20 local businesses closed in the late 19th – early 20th century (Mitteilungen des statistischen, 1896, p. 5; Mitteilungen des statistischen, 1908, p. 5, 11, 57, 71).

In the development of capitalist industry, the main place was occupied by industries whose purpose was to develop rich raw material resources with a tendency to process them in the western provinces of Austria-Hungary and abroad. At that period, the manufacture of sawn timber was the leading branch of the Bukovinian industry. For instance, in 1902 there were 117 operating sawmills in Bukovyna, which employed 2,678 people (including 2,345 workers). The development of sawn timber manufacturing in Bukovyna was conditioned by the presence of large forests. However, high transportation costs had a very negative impact on the development of industry in Northern Bukovyna. For example, transporting timber from Bukovyna to Germany by rail was more expensive than transporting roundabout – through Galati, Odesa, the Black Sea, the Dardanelles, the Mediterranean Sea, the Atlantic Ocean or Belgium. What an absurd, but this is what Austrian government did. It was only after many petitions and complaints that the government was forced to make some concessions, and the transportation of timber from Northern Bukovyna to Germany became possible by rail (Gazeta polska, 1900, p. 2). For example, transporting one car of timber from Hungary to Vienna cost 52–140 krones cheaper than from Bukovyna.

Conclusions.

By transforming Bukovyna into an internal colony of the Habsburg Empire, the Austrian authorities kept it in the position of a raw material appendage and a market for the industry of its central provinces. The tariff, customs, credit and tax systems introduced by the imperial government supported this process, acting in the interests of Austro-Hungarian capital.

Today it is well known that, although much has been done, much more could have been done for industrial development and for solving the peasant issue (the predominance of landless peasants was absolute, causing mass emigration), as well as for raising the secondary (and, consequently, higher) education for the natives of Bukovyna if the Austrian (and local) authorities had not indulged the selfish aspirations of the ruling elite (primarily German) and local land magnates. Fearing competition and striving to have cheap labor at hand, local landlords did not meet the vital needs of

the local population and industrialists or delayed the resolution of pressing issues for years and decades. In fact, this was common for other provinces and gave rise to centrifugal forces, which, in the end, were one of the reasons for the collapse of the Austro-Hungarian Empire.

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Буковина як частина Австро-Угорської імперії та її соціально-економічний розвиток напередодні будівництва залізниці

Анотація. *Дана стаття досліджує, як соціально-економічні умови в Буковині вплинули на формування та розвиток залізничної мережі в Австро-Угорській імперії. Авторами статті досліджено, чи відповідали ці процеси світовим тенденціям того часу. На основі аналізу наукової літератури, мемуарів та архівних матеріалів виявлено, що тема формування та функціонування залізничної мережі на Буковині не була систематично досліджена. З'ясовано, що австрійська влада, перетворивши Буковину на внутрішню колонію Габсбурзької імперії, утримувала регіон в положенні сировинного додатку та ринку збуту для промисловості центральних провінцій імперії. Впроваджені урядом Габсбурзької імперії тарифні, митні, кредитні та податкові системи підтримували цей процес, діючи в інтересах Австро-Угорського капіталу. Розбудова залізничної мережі була спрямована на забезпечення економічних інтересів імперії, що вплинуло на соціально-економічний розвиток Буковини. Зокрема, будівництво залізниць сприяло поліпшенню транспортної інфраструктури, що призвело до активізації торгівлі та збільшення обсягів перевезень сировини та товарів. Однак цей розвиток мав двосторонній характер. З одного боку, він сприяв економічному зростанню та модернізації регіону, але з іншого – посилював залежність Буковини від центральних провінцій Австро-Угорської імперії, обмежуючи її економічну самостійність та розвиток місцевої промисловості. Авторами статті також проаналізовано вплив залізничного будівництва на соціальні аспекти життя населення Буковини. Встановлено, що залізниця стала важливим чинником міграції, сприяла урбанізації та зростанню чисельності робітничого класу. Однак водночас зростала соціальна напруга, пов'язана з нерівномірним розподілом економічних благ та посиленням експлуатації місцевого населення Буковини. Висновки статті підкреслюють необхідність подальших досліджень для повного розуміння впливу залізничного розвитку на Буковину в контексті Австро-Угорської імперії та порівняння з аналогічними процесами в інших частинах світу.*

Ключові слова: *залізниці Буковини; Австро-Угорська імперія; транспортна мережа; панування Габсбургів; Чернівці*

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History of the development of theater architecture: (5th century BC – beginning of the 20th century)

Abstract. *The article analyzes the stages of formation and development of theater architecture (from antiquity to 1900) in accordance with the evolution of culture,*

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historical, social and economic development of human society. A description of the technologies of the theater building of different eras, its design and construction norms are presented. The authors made an attempt to explain the evolution of architectural styles of theater buildings from ancient times to modern times. It helps to understand the influence of cultural, technological and social factors on architectural decisions. The impact of the development of architectural styles in the construction of theaters of different eras on cultural heritage is also considered. The authors emphasize the need for a comprehensive coverage of the importance of considering the architectural features of theater buildings as part of the cultural heritage of various peoples and eras. For this purpose, the authors reviewed architectural masterpieces that have become symbols of their cities or countries. The authors separately considered the issue of technical progress in the construction of theaters at different times. This part of the article is devoted to explaining the technological innovations that influenced theater architecture, such as improved acoustics, lighting, and construction methods. Also, the authors of the article reviewed modern trends in the use of materials and energy-efficient solutions. The article analyzes the relationship between the development of theater architecture and social aspects, such as changes in audience tastes, the role of theater in society, and the reflection of political and cultural trends in buildings. The authors of the article attempted to determine the influence of theater architecture on modern architecture and society. In particular, an overview of the influence of the heritage of outstanding architects of theater buildings and their contribution to the development of architecture in general is made. The article shows that the expansion of the typological structure of the architecture of various theaters created the prerequisites for a variety of compositional schemes and a fundamentally different presentation of architectural tasks. Different city-building conditions, typological foundations and individual characteristics of the theater led to the appearance of new buildings that contrast in their structure, style and means of artistic expression. Historical experience shows that theater architecture is as inexhaustible as theater art, as inexhaustible and complex multi-meaning concept of theater.

Keywords: *theater architecture; art; scene; the art of architecture; culture*

Introduction.

Theater, like other forms of art, reflects its time, human environment, social structure and needs of society (Pylypchuk, O. Ya., Strelko, & Pylypchuk, O. O., 2021; Pylypchuk, O. Ya., Strelko, Korobchenko, & Pylypchuk, O. O., 2022). After all, theatrical art has found its supporters since ancient times (Amoruso, 2023; Tsagareli, 2022; Mastrothanasis & Grammatas, 2022). Over the centuries, new genres and new roles of actors appeared, the fashion for performances changed, but at all times the theater remained one of the most fascinating spectacles. Therefore, the performance with the participation of talented performers became a real event.

Throughout the history of the stage, artists, directors and architects sought to create new forms of theatrical space. At each stage of historical development, new

proposals were developed, which often rejected established traditions, expressed a principled view of the architecture of the stage and hall, and formed a new theater architecture (Proskuryakov, Bohdanova, Kopylyak, Proskuriakov, & Klymko, 2022; Gray, 2022; Paine, 2023).

In general, the development of theater architecture represents an amazingly rich picture. Different artistic styles and systems, methods of decorative design, typological organization of space are beautifully intertwined, erasing chronological boundaries. Progressive currents overcome the resistance of traditions. The complex and contradictory evolution of theater architecture is closely connected not only with technical progress, but also with general trends in the development of theatrical art (Proskuryakov, Ivanov-Kostetskyi, Bohdanova, Kopylyak, & Gumennyk, 2020; Sandu et al., 2021; Haberlandová & Krišteková, 2023).

The architecture of the modern theater is the result of a long and complex path of theater development throughout its history. Its character and variety have always been determined by the artistic tasks that the theater set before itself. All this can be traced to the basic stages of the development of the theater stage.

Today, the individuality of new theater buildings is formed not only by the means of architectural composition, but also by penetrating the nature of theatrical art, which gives rise to new options for the structure of the building, the composition of its premises, the contents of the halls, and the construction of the theater space. Today, thanks to the systematic sequence of work in the field of scenography and theater architecture, it was possible to overcome a number of stereotypes and dogmas that determined the uniformity of the theater hall, the construction of the stage, the auditorium, the composition and composition of the main premises. Alternatives have disappeared: a theater of mass action or a chamber theater, a tiered hall or a single amphitheater, one hall or several.

The expansion of the typological structure of theater architecture created the prerequisites for a variety of compositional schemes and a fundamentally different presentation of architectural tasks. Different construction conditions, typological foundations and individual characteristics of the theater led to the appearance of new buildings contrasting in their structure, style and means of artistic influence.

History shows that theater architecture is as inexhaustible as theater art, as is the theater's inexhaustible complex significance.

Many scientists and architects from different countries and eras were engaged in researching the history of theater architecture (Como, Smeragliuolo Perrotta, Talenti, & Teodosio, 2018; Muecke, 2023; Alvarez-Morales et al., 2023).

One of the first prominent researchers who made a significant contribution to this field should be mentioned Vitruvius (Marcus Vitruvius Pollio) – an ancient Roman architect and engineer, the author of the treatise "De architectura" (On architecture), in which he described the principles of building theaters and other public building (Bianco, 2023; Anderson, 2023; Cigola & Fang, 2016).

The works of Vitruvius, in particular his treatise "De Architectura" (On Architecture), are of great importance for understanding the history of theater architecture for several reasons. "De Architectura" is one of the few surviving written sources that describes in detail the architectural principles and practices of antiquity. Vitruvius provides valuable information about the design, construction techniques, and materials used in Roman theaters (Figure 1).

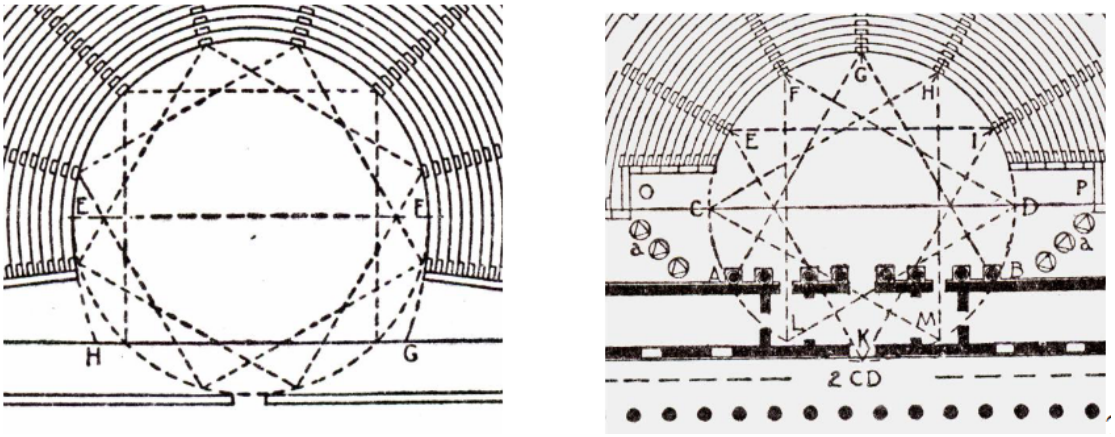

Figure 1. 1- Vitruvius geometrical lay out of the Greek theatre 2- Vitruvius geometrical lay out of the Roman theatre (Haddad & Akasheh, 2006, p. 4).

Vitruvius developed and described the standards and principles that apply to the construction of theaters, such as proportions, acoustics, layout, and decor. These principles became the basis for architectural theory for many centuries to come. In his work, Vitruvius pays particular attention to the importance of acoustics in theaters (Figure 2).

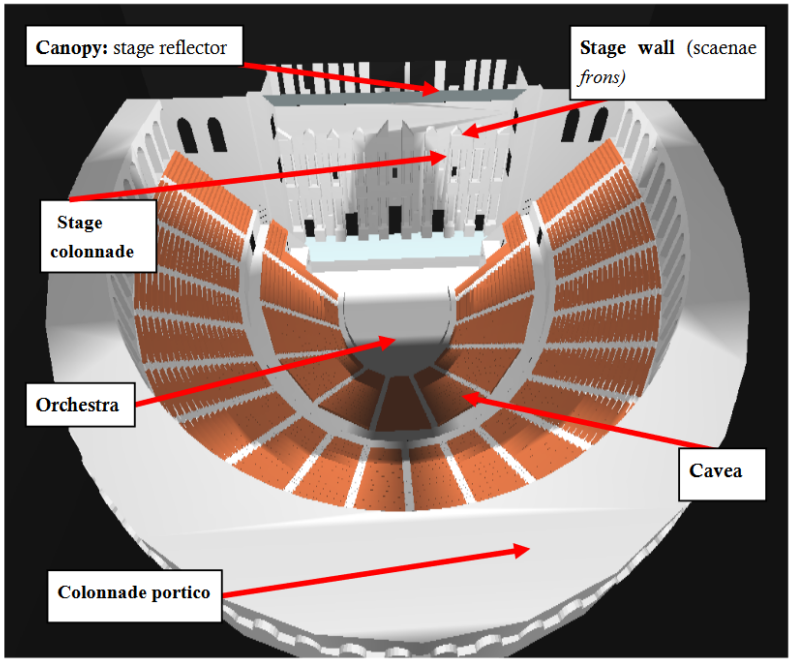

Figure 2. The main architectural and acoustical elements of a typical open-air Roman theatre according to Vitruvius and acoustic simulation (Haddad, 2008).

It describes how theater spaces should be designed to ensure optimal sound distribution. This includes recommendations for the shape of the hall, the use of certain materials and the placement of seats for the audience. Vitruvius emphasizes that theater architecture should be not only aesthetically attractive, but also functional. His recommendations concern the organization of the space, convenience for the audience and actors, as well as security.

Vitruvius' work was revived and studied during the Renaissance, greatly influencing architects of the time such as Leon Battista Alberti (Carnevali, 2022; Muecke, 2023; Di Stefano, 2021) and Andrea Palladio (Solís Rebolledo & Cueto Ruiz-Funes, 2020; Loi, 2022; Murphy et al., 2021). Their works and theater buildings reflect Vitruvian principles (Figure 3).

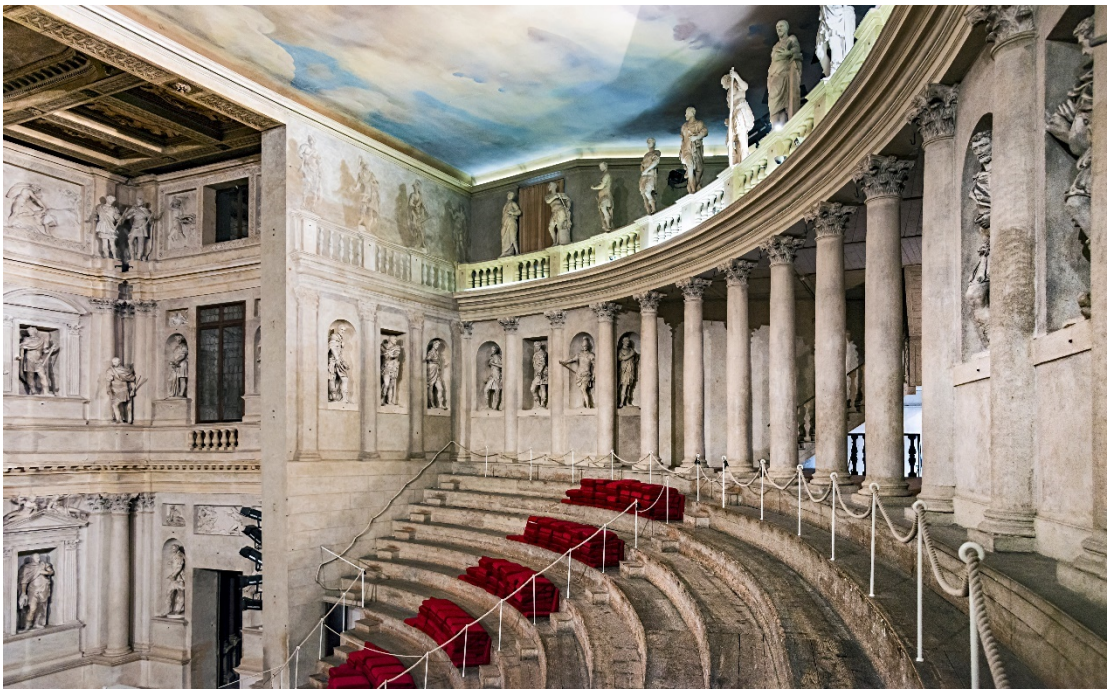

Figure 3. Interior of Teatro Olimpico (Vicenza) – Gradinata (Descouens, 2016).

Vitruvius provides a context for understanding the development of Roman architecture and urban infrastructure. His descriptions include not only technical details, but also cultural, social and political aspects, making his works a valuable historical source. "De Architectura" was often used as a textbook on architecture in medieval and Renaissance academies. Vitruvius systematized the knowledge of his era and passed it on to subsequent generations of architects and builders. Due to these aspects, the works of Vitruvius are fundamental for understanding not only the architecture of theaters, but also the development of architecture as a whole. His treatise "De Architectura" remains an important source of knowledge for modern researchers and practitioners in the field of architecture.

The work "European literature and the Latin Middle Ages" by Ernst Robert Curtius (Ernst Robert Curtius) is a broad and detailed study of the literary and cultural

traditions of medieval Europe. Curtius analyzes the development of Latin literature and its influence on European culture, covering the period from the fall of the Roman Empire to the beginning of the Renaissance. Although the main focus of Curtius in this work is on literature and culture, his work is also of some importance for understanding the development of theater buildings in the Middle Ages (Rotger, 2023; Huber-Rebenich, 2022; Grabócz, 2022). Curtius provides the broad cultural context in which medieval literature developed, including theatrical performances. His analysis helps to understand how literary and theatrical traditions influenced the architecture of theater buildings. It examines the intertextual connections between different literary works and their stage productions, which can provide information about the spatial organization of medieval theater buildings. Curtius analyzes the symbolism and rituals that were important in medieval culture. This can shed light on how theater spaces were used for ritual and symbolic purposes, which influenced their architectural design. In his work, Curtius explores the aesthetic principles that governed medieval culture. This includes an analysis of how theatrical performances influenced the architecture and design of stage spaces. Curtius' work "European Literature and the Latin Middle Ages" became the foundation for many researchers who study medieval culture, literature and architecture. It provided a deep understanding of cultural processes and traditions that influenced the development of theater buildings. Although Curtius did not focus exclusively on theater architecture, his work provided an important context and conceptual framework for understanding the cultural and literary factors that shaped medieval theater architecture.

Among the following researchers, whose works made a significant contribution to the study of the history of theater architecture, Nikolaus Pevsner should be mentioned, who made a significant contribution to the study of the architecture of Great Britain. Pevsner is known for his multi-volume work "The Buildings of England", which became fundamental for the study of the architectural heritage of England (Hultzsch, 2014; Engel, 2015). "The Buildings of England" is a series of books consisting of more than 40 volumes and covering detailed descriptions of architectural structures in each English county. This work was published from 1951 to 1974 and is still an important source of information for architectural historians, restorers and architects. Although "The Buildings of England" covers a wide range of architectural structures, including churches, castles, houses and public buildings, it also contains information on theatres. Pevsner thoroughly documented and classified theater buildings in each county, providing information on their architectural styles, construction history, and design features. This includes a description of the exterior, interior layout and decor elements. Pevsner provides a historical context for each building, including the theatres, allowing a better understanding of how these structures fit into the overall development of architecture and urban infrastructure in England. In his work, Pevzner explores the evolution of architectural styles, including those used in theater buildings. It helps to understand how tastes and technology have changed over the centuries and how this has been reflected in the design of theatres. The

information collected by Pevzner is extremely valuable for the preservation and restoration of historical theaters. His detailed descriptions and analysis help restorers to restore these buildings while respecting their original architecture and historical significance. Pevsner's work "The Buildings of England" can be considered an encyclopedic resource that significantly influenced further research on architecture in Great Britain. His methodological approach to documenting and analyzing architectural structures has become a model for many researchers. Regarding the history of theater architecture, Pevzner provided important data and context that help to understand the development of this architectural form in different historical periods.

Sir John Summerson was one of the most influential British architectural historians of the 20th century. His works cover various aspects of British architecture, from classicism to modernism (Summerson, 1957; 1986; 2003a; 2003b; Summerson & Powers, 2023). Summerson was also a curator at the National Gallery in London and had a significant influence on the study of Britain's architectural heritage. Although known for his extensive research on British architecture, Summerson also made a significant contribution to the understanding of the architectural history of theatres. His work in this field includes several important aspects. Summerson explored the various architectural styles that influenced the design of theaters in Great Britain. He detailed how classical, gothic and baroque elements were adapted for theater buildings. He analyzed how social and cultural changes influenced the development of theater architecture. In particular, he investigated how the growth of the urban population and the development of cultural institutions influenced the construction of new theaters and the modernization of existing ones. Summerson has written about several notable theaters, analyzing their architectural features, construction history, and influence on the further development of theater architecture. His works include analyzes of such famous theaters as the Royal Opera House in Covent Garden and Drury Lane. He explored the contribution of individual architects to the development of theater architecture, particularly such figures as John Vanbrugh and Robert Adam. Summerson analyzed their projects and their influence on the evolution of theater space. Summerson studied how theaters are integrated into urban infrastructure, how they influence urban planning and neighborhood development. He saw theaters as important cultural and social centers shaping the surrounding urban environment.

Among the many works of John Summerson, several are of special importance for understanding the architecture of theaters. The book "Georgian London" examines the development of London during the Georgian era, including the architecture of the theaters of the time (Summerson, 2003b). Summerson analyzes how Georgian architecture influenced the design of theater buildings. "Architecture in Britain, 1530–1830" takes a detailed look at British architecture over three centuries, including the development of theatres (Summerson, 2003a). In "The Architecture of the Eighteenth Century", Summerson examines the architectural achievements of the eighteenth century, including theater buildings and their place in the cultural life of the time (Summerson, 1986).

Sir John Summerson made a significant contribution to understanding the development of theater architecture through his detailed research and analytical approach. His works have become important sources for further researchers and architects studying the history and development of theater buildings in Great Britain. His ability to integrate architectural analysis with cultural and social context has made his works indispensable for understanding not only the architecture of theaters, but also the wider architectural heritage.

The listed researchers, like many others, made a great contribution to the understanding and preservation of the historical heritage of theater architecture, offering a multifaceted view of the evolution of theaters over the centuries.

The purpose of this article, devoted to the history of the development of theater architecture, is multifaceted. Here are some tasks that must be solved to achieve this goal:

1. Coverage: Explanation of the evolution of architectural styles of theater buildings throughout history, from ancient times to modern times. It helps to understand the influence of cultural, technological and social factors on architectural decisions.

2. Cultural heritage: highlighting the importance of theater buildings as part of the cultural heritage of different peoples and eras. An overview of architectural masterpieces that have become symbols of their cities or countries.

3. Technological progress: Explaining the technological innovations that influenced theater architecture, such as improvements in acoustics, lighting, and construction methods. Overview of modern trends in the use of materials and energy-efficient solutions.

4. Social context: Analysis of the relationship between the development of theater architecture and social aspects, such as changes in audience tastes, the role of theater in society, and the reflection of political and cultural trends in buildings.

5. Impact: Determining the impact of theater architecture on modern architecture and society. An overview of the influence of the legacies of prominent architects of theater buildings and their contribution to the development of architecture in general.

Therefore, the purpose of the article is aimed at revealing the history and significance of the development of theater architecture as part of the world's cultural and scientific heritage.

Research Methods.

The study of the history of the architecture of theater buildings required the use of a complex approach when choosing methods, covering various aspects, from the study of architectural styles and construction technologies to the analysis of the socio-cultural context and functional features of theaters. The authors used the historical method, in particular, a chronological analysis was made when studying the development of theater architecture in different historical periods. With the help of stylistic analysis, the identification of architectural styles characteristic of different eras

and their influence on the design of theaters was carried out. Comparative analysis was used to compare different theater buildings to identify common features and unique features. With the help of sociocultural analysis, the role of theaters in society is investigated. In particular, the impact of cultural events and trends on the development of theater architecture was investigated.

The study of the history of the architecture of theater buildings is a multifaceted field that requires the integration of various methods and approaches. The use of historical, architectural, sociocultural, and interdisciplinary approaches allowed the authors to get a certain idea about the development, functioning, and influence of theater buildings in different historical periods.

The Main Stages of the Development of Theater Architecture.

Ancient Greece Theater.

Theater construction at that time was carried out on a large scale (Figure 4). Today, it is possible to find more or less preserved ruins of theaters in Athens, Oronos, Argos and a number of smaller cities in Greece. In general, theaters in Ephesus, Aspendos, Priene, etc. have also been preserved in Asia Minor. Today, there are more than 55 ancient theater buildings in Greece. The analysis of their constructions shows that the Greeks borrowed the experience of theater construction from other nations and therefore it is believed that they laid the fundamental foundations of theater architecture for many centuries to come (Nastou & Zerefos, 2023; Amadasi, Bevilacqua, Iannace, & Trematerra, 2023; Balaskas, 2021).

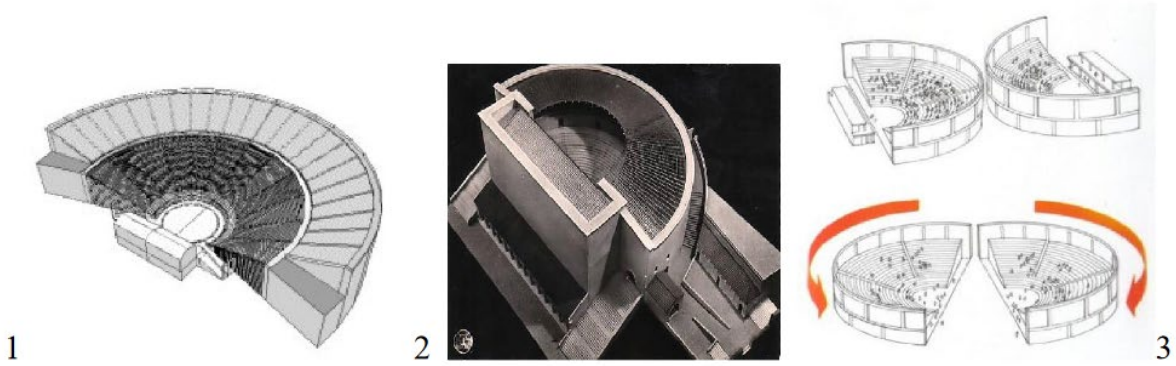

Figure 4. 1- Open air Greek theatre 2- Roman Odeon (roofed theatre) 3- Roman amphitheatre (Haddad & Akasheh, 2006, p. 2).

One of the first theater buildings built in Ancient Greece was the Theater of Dionysus (Figure 5) in Athens (5th century BC) (Sturgeon, 1977). It was named after the temple located opposite. Subsequently, the theater was rebuilt several times - the design of the amphitheater, the dimensions and the location of the stage were changed. In fact, the theater of Dionysus is considered the most typical of Ancient Greece (Poehlmann, 2015). Its architecture is sufficiently fully described in books on the history of the theater.

Figure 5. The Theatre of Dionysus Eleuthereus in Athens (Hartmann, 2017).

The form of the stage dictated its conditions for the composition of the play. At the early stage of theater development, the orchestra was the only playground for both the actor and the chorus. In the Greek theater, when the playwright himself was the only actor performing his play, the flat plane of the orchestra fully satisfied the conditions of the play. The chorus was usually placed around the entire perimeter of the orchestra of the quadrangle, and the actor acted in the middle of the platform. However, later, when Aeschylus introduced a second actor, and then increased them to three and even four, one orchestra was not enough (Sweeney, 2021).

The performance gave complete freedom to the playwrights in choosing the place of action, without oppressing their creativity with the narrow possibilities of the stage, so they easily transferred their characters to various situations that were necessary for expressing the general idea of the performance.

The work of the great dramatists Aeschylus, Sophocles, Euripides, and Aristophanes reflected the most important aspects of the social, political, and spiritual life of the ancient Greeks and created a theater of perfect artistic form. The universal nature of the ancient Greek theater determined the peculiarities of the organization of theatrical performances and the arrangement of buildings.

The decoration of the antique spectacle consisted of flat painted shields. Such aspects of design are considered purely functional – they marked a rather conventional place of action. Various adjustment mechanisms for the movement of actors in the play were of great importance in the production of the play.

Roman Theater.

Of course, the Roman theater, having adopted the traditions and skill of the Greeks, made its own changes in the construction of the theater stage. These changes reflect the new conditions of existence of the theater and the new nature of drama. The disappearance of the choir had a great impact on the shape of the stage. The orchestra began to lose its original meaning already in the 5th century. B.C. in Greece, when more and more acting actors began to appear in the plays, replacing the chorus of the ancient tragedy. That is why in the Roman theater, where the chorus is completely absent, we still find something similar to the Greek orchestra, but it is no longer a playground, but a free area where the audience could be located. The action is completely transferred to the paraskenia – a wide and low rectangular site (Beacham, 1979), surrounded on three sides by capital walls, which were called skena. The shape and frontal placement of the proscenium in relation to the audience made it possible to build mise-en-scenes along the entire front of the playground, developing them also in the depth of the stage.

By the middle of the 1st century BC, and even much later, Roman theaters were temporary wooden structures built for public celebrations and various celebrations. The first monumental constructions made of stone date back to 13 BC, when the famous Theater of Marcellus and Theater of Pompey (see Figure 6) were built in Rome (Packer, Burge, & Gagliardo, 2007).

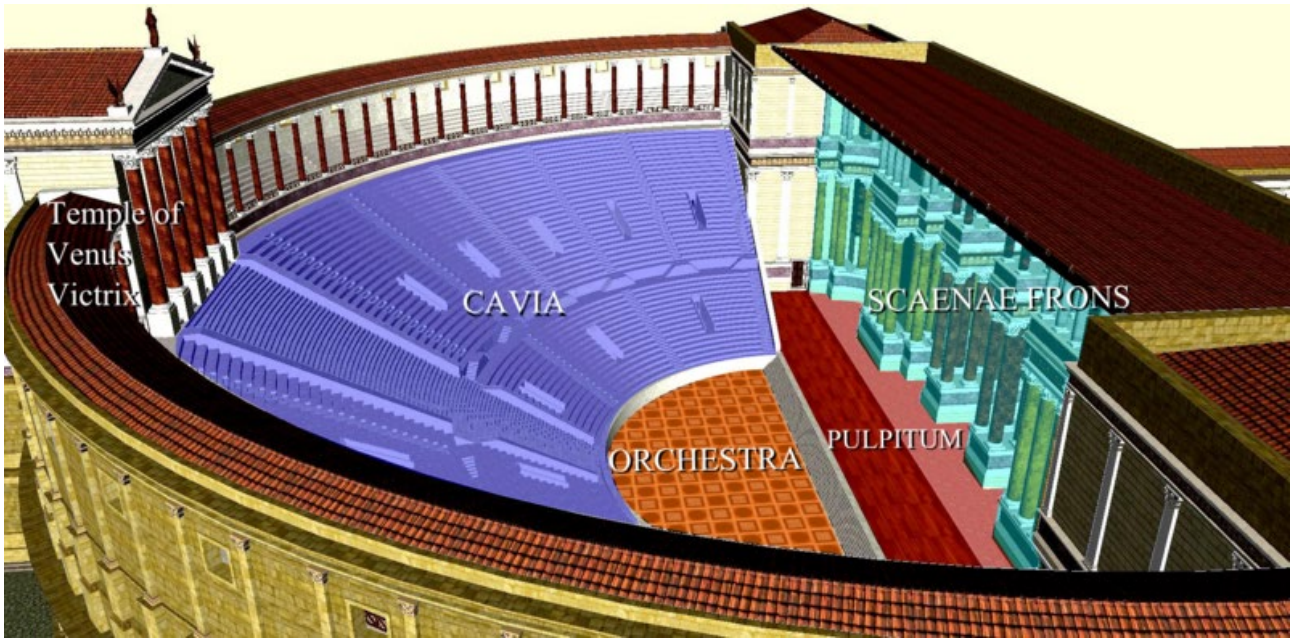

Figure 6. Theatre of Pompey highlighted diagram (Tskhondia, 2012).

The Theater of Marcellus on the banks of the Tiber River in Rome, the construction of which was conceived by Julius Caesar and completed by Octavian Augustus in 12 BC. The theater was 111 meters long and could accommodate 11,000 spectators (Sultanova, 2023). In the Middle Ages, the building was rebuilt into a fortress, over which the palace of the noble Orsini family was built. Unlike Greek theaters, Roman theaters were built on a level site (Picozzi, 2020). The amphitheater was built on stone structures, and the proskenii and skene were monumental multi-story buildings with magnificent architectural framing.

After the completion of the construction of the Theater of Marcellus and the Theater of Pompey in Rome, theater construction became widespread. At this time, a number of Roman theaters of the imperial era could be found in Greece, Spain, Africa and the Middle East. As an example, the most well-preserved ancient Roman theater in Orange (France).

The date of its construction is attributed to the period of the rule of the Roman emperor Octavian Augustus (27 BC – 14 AD). In its form, all the main elements of the ancient Roman theater were embodied: fireplace benches placed in a semicircle for spectators - an amphitheater; a semicircular platform, which used to be used for performances by actors, a choir and musicians – an orchestra; behind it rises a rectangular screen (today's scene); finally, the space of the stage is covered by a stone wall – proskenii –the height of which was 37 meters, and the length – 103 meters (Ros, 1996). Compared to Greek theaters, the architecture of this wall is much richer. The side and central walls were covered with three tiers of Corinthian columns, between which there were statues in niches. The playground was raised above the level of the orchestra by 1.65 m. Sandwiched between the side walls of the skene and covered by a decorative ceiling, it had quite impressive dimensions – 61.12×9.30 m. The overlapping of the skene by the ceiling is evidenced by the grooves made in the upper part of the wall. They served as supports for the cantilever beams that supported the hard and soft ceiling.

Indoor theaters also existed in Greece – they were called odeons (Ciaburro, Iannace, Lombardi, & Trematerra, 2020). However, they were not intended for showing performances to the general public, but for rehearsals and training. The overlap of the stage is attributed to the theater of Ancient Rome. Many sources testify to the overlapping of not only the stage part of the theater, but also the entire amphitheater. Awnings in theaters served for the convenience of the audience, protected them from direct sunlight, wind and rain. The arrangement of the porticos also had a military purpose – firewood was stored here, which was necessary during the siege of the city by the enemy.

The curtain first appeared in the Roman theater. It rose from under the stage, for which a special slot was arranged in its front part. The presence of the curtain indicates that the nature of the drama required such decorative items that could not be quickly and imperceptibly replaced during the performance. Behind the curtain, the periacts returned – triangular prisms that carried three different decorations on their faces, the

objects of props were changed, platforms were extended or rolled away, etc. Performing all these operations in front of an audience of thousands did not allow the aesthetics of the theatrical performance, which was changing.

Thus, it is possible to see that the influence of the ancient theater on the entire subsequent history of European theatrical culture is enormous. Many directors, artists and architects of different countries have repeatedly turned to that improved architectural form, which was created by the Greeks and improved over the course of a whole millennium. Functionality, harmonious perfection and high artistic taste were manifested in the simple and ordinary form of the amphitheater and the open stage. There is no doubt that for a long time the theater will turn to the experience of ancient architects.

Middle Ages Theater.

The riches of the ancient world were not immediately revealed to the people of the Middle Ages: theatrical art was so forgotten that it left behind such vague ideas that, for example, poems with a good beginning and a bad end were called tragedy, and comedy – with a sad beginning and a good end. Initially, in the Middle Ages, it was believed that the ancient plays they found were performed by one person.

Of course, the heritage of ancient culture has been partially preserved. However, the language of educated people – Latin – was not understandable to the barbarian conquerors. The culture of Europe was now increasingly influenced by the Christian religion, which gradually took over people's feelings.

After the fall of the Roman Empire, the revival of the theater began in the 9th century, when the prevailing Christianity introduced theatrical performances in church ceremonies. Staging of Gospel episodes led to the emergence of a special theatrical genre – liturgical drama. For the first time in history, theatrical performances began to take place in a closed room – in a church.

Church Theater Technique. The architectural features of the church determined the forms of the stage space (Girón, Álvarez-Corbacho, & Zamarreño, 2020). At first, the action of the drama developed on a limited platform – near *the altar*. Therefore*, the central nave* of the building, *the chancel*, *the narthex*, and *the preacher's pulpit* began to be used. The most important moments of the drama were played out in the middle of the building.

In the 12th century the so-called simultaneous design principle begins to take shape. Simultaneous decorations are stationary decorations installed in advance on the playground in a certain sequence. The performer's transition from one scenery to another meant a change of place of action. By this time, the action of the drama was already played out on the entire site of the church, for which other rooms were also used. In each of them there were decorations of individual episodes, which were hidden by curtains. At the right moment, these curtains were opened, revealing this or that place of action.

The arrangement of performances required a lot of attention to the artistic side of the performance. Objects of the church ritual began to be replaced by special props. The campaigning and propagandistic character of the church ritual demanded an increase in spectacle. Therefore, a special place in the performance is occupied by various effects. Mechanical beasts and mythical monsters are depicted, the technique of flying over the stage and effective lighting were actively developed.

The crypt, which was located under the church, was used for the effect of the appearance of characters from the ground, and also meant the entrance to "hell". The dome, which was located in the center of the building, served to raise and lower decorative devices along with the role of Christ and angels. Thus, the lower stage (the crypt), the actual stage (the floor level of the church, or a special platform) and the upper stage (the dome) were used in the church theater.

An important role was given to lighting effects. Hundreds of candles and lamps illuminated the scenery and the performers, and they were witnessed simultaneously with the help of a kind of Bickford cord. Of course, at that time all lighting effects were made with the help of ordinary fire.

The church theater existed for several centuries. But along with performances in the church premises, new types and genres of theater were developed. Already at the beginning of the 12th century the theater first appears on the streets and squares of cities. At that time, a new type of theater was born – street theater (Wang, 2020).

Street Theater. The exit of the theater from the closed space of the church determined not only other conditions for staging the performance, but also new genres. The most popular was the mystery – a multi-day presentation on biblical topics. The founder of this genre can be considered the "Gonfalone" society, which appeared in Rome in 1265. And in 1402, another society "Brotherhood of the Lord's Passion" was founded in Paris for this purpose (Greer, 2000). This defined the three-story structure of the stage. "Hell" was located on the first floor of the stage, unseen by the audience, on the second – the main place of action of the performance, and on some elevation "heaven" was depicted. Thus, only the two upper stages were open to the audience, and the lower one, like a "hold" in a modern theater, served for technical purposes. The presence of this kind of hold made it possible to equip the main stage with trapdoors, etc. The most common technique was the principle of placing separate fragments that marked this or that place of action. So, a gilded chair meant a palace, a part of a stone wall with barred windows – a prison, a cross – Calvary, the place of Christ's crucifixion, etc.

In the era of the Middle Ages and the Early Renaissance, stage platforms and places for the audience were built specifically and did not have a uniform form. During the 14th and 16th centuries, small amphitheaters were built in France and England and some other European countries. In some cases, arenas of Roman circuses were used. The so-called *pageants* became the most popular in England. These are peculiar pods that had a two-tier structure: the upper one was a stage, and the lower one served as a place for actors to change clothes.

In general, the medieval mystery was played out on three types of platforms: circular, frontal (conversational) and mobile. The ring version consisted of a high ring-shaped platform, where the action took place on two levels – on the platform and the area of land that was inside it. The front version consisted of a rectangular platform – decorations of the platform with gazebos - decorations of the palace, paradise, purgatory, etc. Mobile – underwater, on which the scenery of one of the episodes of the mystery was set: folk farces were performed on small platforms that rose to the height of human height.

In the middle of the 16th century the church and royal authorities finally banned the performance of the mystery, as the comedic and critical elements of the performance began to supplant the religious direction of the performance. Mystery as a genre of theatrical art was dying, yielding to a new theater – Renaissance drama. In general, the church and secular theater of the Middle Ages did not leave many monuments of theater architecture and various iconographic material. And yet their experience did not disappear without a trace. He nourished not only the Renaissance theater, but also had a significant impact on the development of the theatrical art of later times.

The birth of the "box scene". Information about the arrangement of the Renaissance theater and the early Baroque theater is extremely inaccurate, few and sometimes contradictory. The theater buildings were not preserved either, as they were wooden structures that quickly collapsed or burned during a fire. The first known mention of the construction of the theater dates back to the end of the 15th century. Theatrical performances of the end of the 15th and the first half of the 16th centuries did not have a systematic character. They were given mainly on the occasion of some court holiday. Stage platforms and places for spectators were formed either in one of the halls of the ducal castle, or in the courtyard of a luxurious palace. Theatrical architecture of that time was formed under the powerful influence of the ancient theater, on the one hand, and the practice of staging mystery performances, on the other.

Ancient traditions were most vividly manifested in the composition of spectator cities – in the form of a semicircular amphitheater. The amphitheater form made it possible to solve the problem most advantageously – the supremacy of the location of princely seats. As in the ancient theater, princely seats were installed on the orchestra in the center of the hall, on some elevation. The steps of the amphitheater, on which the courtiers and guests were accommodated, surrounded the princely seats with a steep bend. The architect and artist Sebastiano Serlio (1457–1552) gave the most complete description of the scene of the Italian theater, its lighting and the principles of theatrical perspective in his work "*Regole generali di architettura*" (1545) (Mohler, 2021). In his book, Serlio summarized the experience accumulated by practitioners of the Renaissance theater, defined the basic rules for building a stage and creating the external form of a performance. According to the drawing and description of Serlio amphitheater had 14 steps of the same width and the last 15th – much larger. The

semicircular amphitheater covered the orchestra, which repeated the shape of the orchestra of the Roman theater. The first row of seats, which is located at the level of the orchestra, consisted of seats for the highest nobility, higher – on the steps of the amphitheater – there were seats for noble ladies and gentlemen. The uppermost and widest step was intended for the courtiers. Thus, the rank principle of distribution of audience seats was already manifested here. The semicircular orchestra platform is not only a tribute to ancient traditions, but also an attempt to separate the stage from the auditorium in order to create a great artistic effect.

S. Serlio indicates the scenes and scenery of three types of tragic, comic and satire. Thus, the decorative design of the Renaissance theater was based on the principle of the immutability of the scenery, which was determined by the genre of the performance. A special place in the history of the theater of the Italian Renaissance is occupied by the Teatro Olimpico in Vicenza (Italy), a typical academic theater that recreates a model of Roman theater architecture in a closed room (Menta, 2023). The first theater building, built of stone and preserved to this day, is an excellent example of theater architecture, which is organically combined in one space of the auditorium and the stage.

The amphitheater, elliptical in plan, closely adjoined the portal wall of the stage, covering a small platform – the orchestra – in the middle part of the hall. The scene was an open square of rectangular shape, bounded on three sides by decorative palace-type walls. Three arches are cut into the central wall, behind which is placed an inclined part of the stage with decorations installed on it. The side walls have low openings that connect the open stage with the backstage areas. In general, the composition of the Roman theater is preserved here with three classical exits in the center and two side exits, which replace Greek travesties. This theater completes the history of the Renaissance stage, which at the end of the 16th century. underwent significant changes under the influence of the rapidly developing Baroque theater.

The emergence of a theater with changing scenery. The new requirements for setting up the stage and the principles of creating the external form of the performance were prepared by extensive experience in staging interludes and with the development of opera and ballet. The new genre demanded an enchanting show, saturated with various stage effects, numerous changes of scenery. And for this, completely new stage conditions, different techniques and new means of creating the external form of the performance are needed. The transition of the theater to a closed room, equipped with a stationary stage, on which all the necessary devices and mechanisms for the movement of the scenery and the implementation of effects could be installed, was also of great importance for the further development of the stage and decorative art.

The production of interludes, and even more so opera performances, required a much larger stage space. The top of the stage received a significant development. The scenic "sky" was not depicted as an ordinary vault, but consisted of several rows of hard surfaces that had a concave profile. Behind them were placed lamps that illuminated the surfaces of individual parts of the "sky", as well as clouds cut out of

plywood that could move along a cable stretched across the stage. This method of masking the top of the stage is encountered for the first time and is actually considered the progenitor of theater pods, just as upper lights are the first soffit. The use of parapets and continuous clouds indicate a new step in the technological development of the overstage space.

The search for means of changing the scenery in the performance led to the abandonment of the relief perspective and its replacement with a pictorial one. The first examples of changing the scenery identified three main ways of changing the scenery design: masking the building scenery with scenic backdrops; retractable hard decorations; changing scenery with the help of a thelars. Thelars, or from the Greek, periacts – three-sided prisms covered with a painted canvas and placed according to the plans of the scene.

The Italian scene at the end of the first quarter of the 17th century. takes on the real features of the classical stage – the box, which dominated for several centuries and today is the most common form of the stage. The portal arch sharply demarcates the space of the stage and the space of the auditorium. A drop curtain was placed behind it, which appeared before the audience only at the beginning and at the end of the performance. In front of the stage in the plane of the portal, there was the so-called front moat – a prototype of the orchestra pit, separated from the auditorium by a deaf barrier. The front moat contributed to the enhancement of the stage illusion, distancing the audience from the stage, there were places where the falling curtain could fall.

Lamps were attached to the inner wall of the barrier, which served as a modern ramp. The stage ended with a rear ditch, a long hatch for effects and masking the lines of contact of the rear with the stage. Retractable scenery walls, thelars could not fully meet the growing needs of an opera performance, as they had limited possibilities in the number of scenery changes. The theater aspired to such a system that would allow for sudden changes of a larger number of paintings using beautiful scenic scenery that created a high degree of illusion. In the twenties of the 17th century. such was the backstage technique. This scene combined a new system of performance design and new, specially designed stage equipment.

The name of the inventor of the swing system has not yet been established, but there is every reason to believe that one of the authors of the new technique was the architect Giovanni Battista Aleotti (1545–1630), the builder of the Duke Farnese Theater in Parma (Clemente, 2022a). The Farnese Theater went down in history as the first theater equipped with stationary stage machines. The architecture of this building is extremely controversial. On the one hand, there is a wonderful stage with large reserve platforms on the sides, a wide barrier and the latest stage equipment. On the other hand, there is an auditorium that repeated ancient traditions with very unfavorable ancient data.

Moving the scenery across the entire width of the stage is necessary for a number of stage effects, and mainly for changing scenic background. Theater scene of the 17th century had not yet acquired grate arrangements, a system of decorative trays, did not

have sufficient height for this reserve, therefore, when completing the composition, the backstage backs could be changed only with the help of rocking machines, which were rolled to the sides or, in some cases, wound on wooden scales fixed in vertical part of the stage box.

The stage-box, stage machines, flat scenic scenery, which illusorily conveyed the volume and space, are becoming widespread in European countries at this time. The further development of the stage and its techniques took place together with the development of the opera genre, and took place under the sign of the expansion of editing possibilities, increasing the variety and complexity of effects. At this time, artistic techniques were developed, with the use of theatrical painting, special machines, preserving the principle of illusion. Theatrical effects acquired a new quality - artistic expressiveness and stylistic unity with the rest of the performance components.

Starting from the middle of the 17th century, strict rules of the unity of the place are reflected in theatrical and decorative art. On the stage of the drama theater, the principle of stationary scenery is once again confirmed. The design of the performance is deprived of the signs of the era, the exact place of action. Pompous palace halls created by the hands of painters fill the European scene and dominate there for almost a century and a half.

Tier Theater. 17th century in the history of the theater is characterized not only by fundamental transformations in the field of modern technology, but also by the achievements of theater architecture. The formation of public theaters led to new requirements for accommodating the audience and for reforming the theater space. The first public theaters began to appear in the last quarter of the 16th century. In 1576, the "Theatre" building was built in London (Fleay, 1882). After this theater, a number of other buildings were built on the bank of the Thames, including the famous "Swan" and "Globe".

The famous London Globe theater, which was a typical English theater of the beginning of the 17th century, had the shape of a Roman amphitheater without a roof. Founded in 1599, this theater is famous for the fact that one of its co-owners was Shakespeare, most of the dramatist's plays premiered on the Globe stage. The theater stage adjoined the rear part of the building, and a stage platform ("gallery") rose above its deep part. A "house" was located even higher – a building with one or two windows. There were no decorations here, instead, special signs were placed that indicated the time and place of this scene. The auditorium accommodated from 1,200 to 3,000 spectators. At the same time, there were no seats for ordinary people: they were crowded in the parterre, standing on the dirt floor. On the inner side of the wall, there were boxes for the aristocracy, and above them was a gallery for wealthy burghers. The richest and noblest spectators sat on the sides of the stage, on portable three-legged stools. Only the foundation remained from the first historic building, which is now preserved. The modern building of the theater is an exact reconstruction of the structure

at a distance of 200 m from the previous place. The building has a round shape, built of old oak, and the roof is covered with straw (see Figure 7).

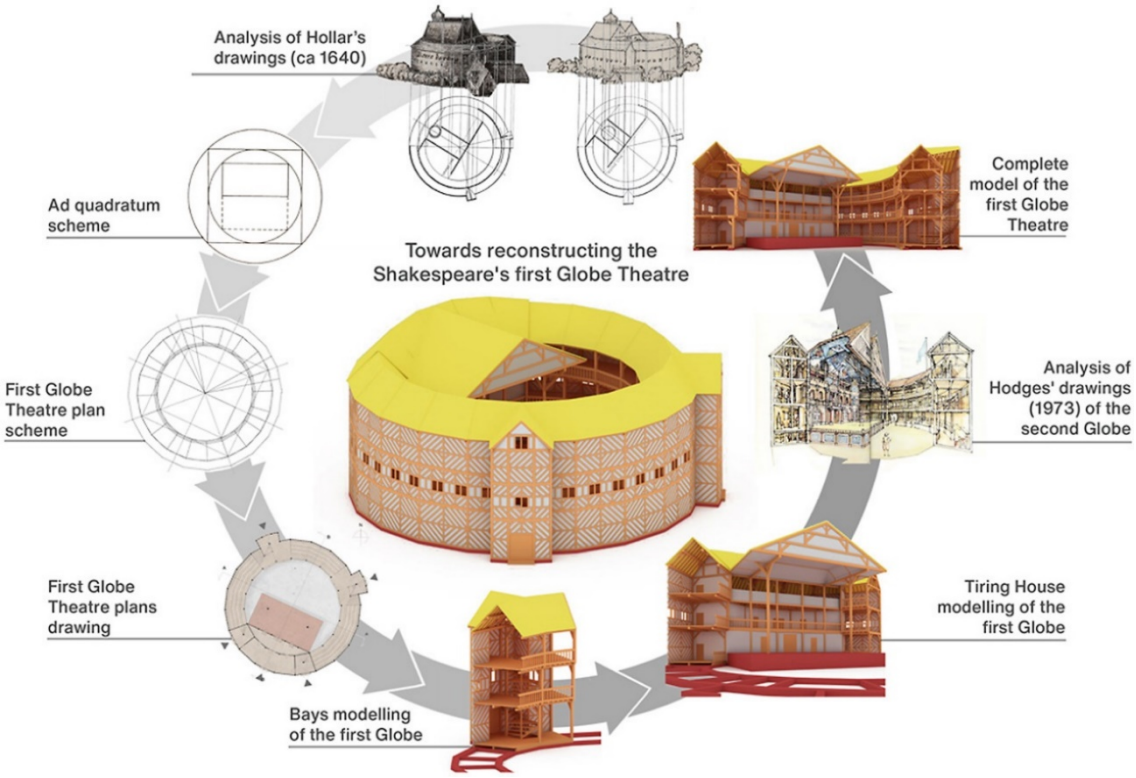

Figure 7. Towards reconstructing the Shakespeare's first Globe Theatre: A virtual model for research and development (Croce, Leccese, Mordagà, & Salvadori, 2022).

English theaters are the prototype of tiered or rank theater. The small amphitheatres of the court theaters could not satisfy the interest in theatrical art among the bourgeois-democratic layers of the population. The task was to develop new principles of layout of the auditorium, which provided, on the one hand, for a clear division of the audience according to social characteristics, and on the other hand, for the placement of the maximum number of seats in the minimum space. The tiers acquired their final appearance in the theater "San Cassiano", built in Venice in 1637 (Colvin, 2004). It was the first theater that was open to the general public. At the end of the 17th century Venice became the opera capital of the world. The theater "San Cassiano" gave performances until 1807, when it burned to the ground.

Initially, tiered theaters were open balconies placed one above the other in three floors. In subsequent buildings, the differentiation of the public not only by social status, but also by family name led to the division of balconies into separate, isolated boxes. A so-called avanloge was added to each box – a small salon located on the other side of the corridor that covered the audience hall. Later, in some theaters, both rooms were closely adjacent to each other. The division of audience seats into separate, independent cells freed the theater from the need to build larger foyers and aisles. Since the boxes were reserved by families, the life of the audience during the performance

took place in these closed rooms. There they met acquaintances and exchanged impressions. The tiered system sharply differentiated the quality of individual seats in terms of stage visibility. So, for example, the maximum viewing angle in the Vienna Court Theater along the middle axis was equal to 31 degrees, and along the axis of visibility from the upper box, which was adjacent to the portal of the stage, it increased to 44 degrees. Thus, the audience sitting in the upper side boxes could see only the first plan of the stage, and even then, in a strong distortion. As for the decorations, their prospective construction was calculated from the central point of the auditorium.

The first tiered theaters were intended for opera. The main concern of the architect was not the visibility of the stage, but the acoustics. The acoustic data of the theater largely depends on the shape of the auditorium. After numerous searches, theoretical calculations and practical tests, a type of construction in the form of a truncated ellipse or horseshoe was developed, which was called "Italian curve". The most advanced manifestation of the "Italian curve" was in the auditorium of the Milan theater "La Scala", built by G. Piermarini in 1776 (Clemente, 2022b).

By the number of seats, it was the largest theater in Europe. The ground floor and 6 rows, divided into 200 boxes, could accommodate 3,000 spectators. Despite the huge size of the hall, its acoustics were unmatched. The wide opening of the portal, the side parts of which merged with the barriers of the boxes, also contributed to the creation of the best acoustics. And this theater could not overcome the contradictions that are present in the combination of a deep box with a vertical stage of seating. Good visibility of the stage was ensured only from the central part of the hall. Paying the main attention to acoustics, planning decisions of the stage, Italian architects sparingly and inexpressively developed the internal architecture of buildings. In contrast to the Italians, the French architects strove for an unusual appearance and richness of architectural decor, for the maximum increase of ceremonial spaces for the public.

The origins of the French tiered theater can be found in the first theater building built in Paris: the rectangular hall of the "Hôtel de Bourgogne" was surrounded by a tier of boxes. In the second half of the 18th century the rectangular shape of the auditorium, characteristic of France, is replaced by an elliptical one. The first builder of this type was the architect Jacques-Germain Soufflot, who in 1756 initiated a new stage in the development of French theater architecture with a theater in Lyon (Delledonne, 2022). The theater in Lyon was the first theater built as a separate building, open from all sides. The wide opening of the portal, the shortened auditorium, which approached the circle, and the special pattern of the portal area are characteristic of the French theater.

By the beginning of the next century, the spectrum turned out to be very small and in 1826 it was demolished, and a new Lyon Opera was built in its place. In 1885, the city decided to rebuild the opera house on the same site and a competition was announced. According to the results of the competition, the construction of the theater was entrusted to the outstanding French architect Jean Nouvel (see Figure 8).

Figure 8. L'Opéra National de Lyon (Lyon Opera, n. d.)

The construction was completed in 1903 (Pasler, 2020). The shell of the existing building of 1831 was left - walls, facade and foyer. The total height of the building with 5 underground floors, a depth of 20 meters and a 6-story dome was 62 m, the volume is about 80,000 square meters. m. The auditorium is built in the traditional Italian style, horseshoe-shaped and has 6 tiers of balconies. The capacity of the hall reached 1100 seats.

The development of the classical stage of the French theater is completed by the Grand Opera in Paris, built by Charles Garnier in 1875 (Sealy, 2021). The auditorium with 5 tiers and boxes accommodated 2150 seats. At that time, the stage of the Paris Grand Opera took first place not only in terms of its dimensions, but also in terms of the level of mechanical equipment (see Figure 9). The dimensions of the stage, the classical technique brought to perfection, impressed contemporaries with the wealth of editing possibilities.

Wheeled machines, lifting-convex platforms, extendable beams for lifting scenery from the hold presented wide opportunities for changing scenery and various effects. And today this theater, designed as a monument to the majesty of France, is an impressive sight. French theater has had a strong influence on theater construction in many countries.

In conclusion, it is worth noting that the study of the history of theater architecture is of considerable importance to modern science for several key reasons. The architecture of theaters reflects the cultural, social and political characteristics of the era in which they were built. By studying these structures, we can better understand how aesthetic tastes, technological possibilities, and social structures of society changed. Theaters were often the place of introduction of new architectural and technical solutions.

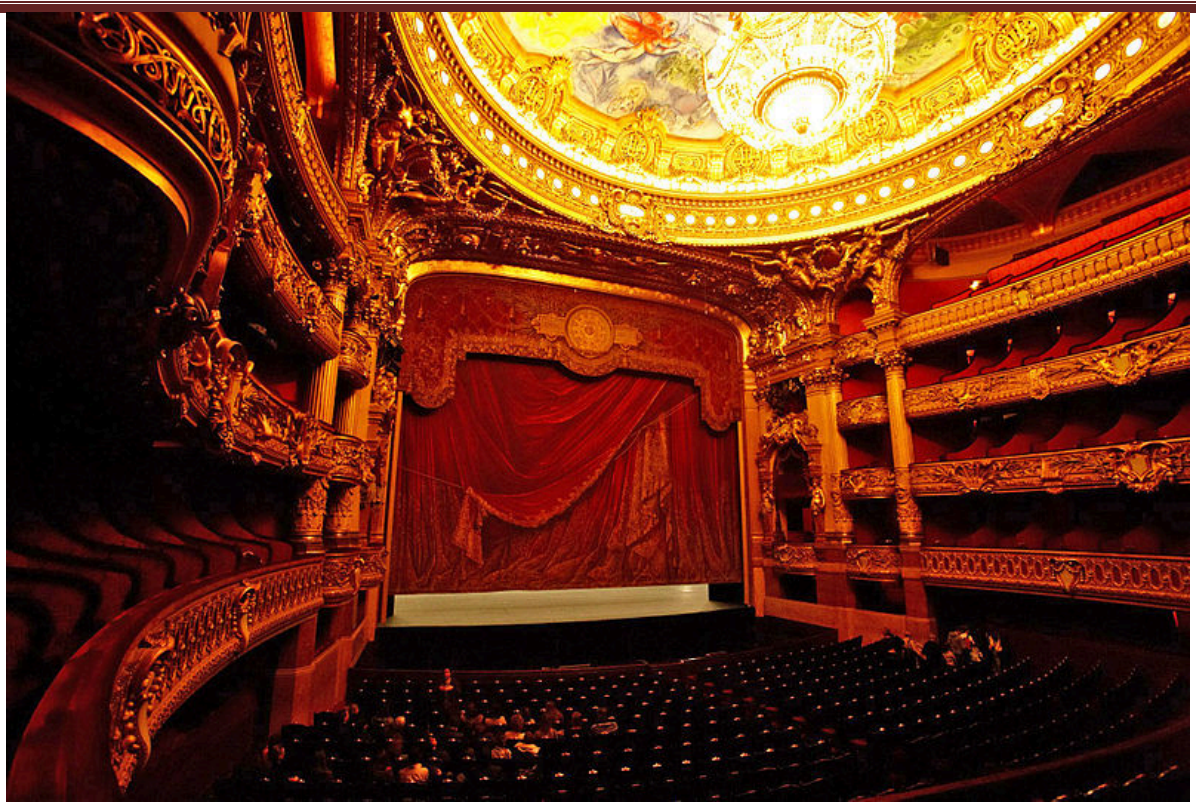

Figure 9. Auditorium and stage of the Palais Garnier (Ikeda, 2012).

By studying them, one can trace the development of building materials and techniques, as well as innovations such as the acoustic properties of halls and stages (Sukaj et al., 2021; Sanvito, 2021; Till, 2019). Understanding the history of theaters is important for the preservation and restoration of these architectural monuments. This allows to restore their authentic appearance and functions, preserving the historical and cultural heritage for future generations. Theaters often served as centers of public life and had a great influence on the development of cities and society. Studying their architecture helps to understand how they influenced urban planning, public space and social dynamics. The history of theater architecture combines knowledge from various disciplines, such as history, art history, archaeology, cultural studies and even engineering. This creates opportunities for interdisciplinary research and new discoveries at the intersection of different fields of knowledge.

Thus, the study of the history of theater architecture not only helps to better understand the past, but also contributes to the development of modern science, culture and society.

Conclusions.

The article analyzes the stages of formation and development of theater architecture (from antiquity to 1900) in accordance with the evolution of culture, historical, social and economic development of human society.

A description of the technologies of the theater building of different eras, its design and construction norms are presented. The authors made an attempt to explain

the evolution of architectural styles of theater buildings from ancient times to modern times.

It is shown that the expansion of the typological structure of the architecture of various theaters created the prerequisites for a variety of compositional schemes and a fundamentally different setting of architectural tasks. Different town-building conditions, typological foundations and individual characteristics of theaters led to the appearance of new buildings that contrast in their structure, style and means of artistic expression.

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Історія розвитку архітектури театру: (V ст. до н.е. – початок XX ст.)

Анотація. *У статті здійснено аналіз етапів становлення та розвитку архітектури театру (від давнини до 1900 року) у відповідності з еволюцією культури, історичним, соціальним і економічним розвитком людського суспільства. Представлено опис технологій театральної будівлі різних епох, її норм проектування і будівництва. Авторами виконана спроба пояснення еволюції архітектурних стилів театральних будівель від давніх часів до сучасності. Це допомагає розуміти вплив культурних, технологічних та соціальних чинників на архітектурні рішення. Розглянуто також вплив розвитку особливостей архітектурних стилів у будівництві театрів різних епох на культурну спадщину. Авторами наголошується про необхідність всебічного висвітлення важливості розгляду архітектурних особливостей театральних будівель, як частини культурної спадщини різних народів та епох. З цією метою авторами здійснено огляд архітектурних шедеврів, які стали символами своїх міст або країн. Окремо авторами розглянуто питання технічного прогресу при будівництві театрів у різні часи. Ця частина статті присвячена поясненню технологічних інновацій, які вплинули на архітектуру театру, такі як покращення акустики, освітлення та конструкційні методи. Також авторами статті виконано огляд сучасних тенденцій у використанні матеріалів та енергоефективних рішень. У статті виконано аналіз зв'язку між розвитком архітектури театру та соціальними аспектами, такими як зміни у смаках глядачів, роль театру у суспільстві, та відображення політичних та культурних тенденцій у будівлях. Авторами статті виконана спроба визначення впливу архітектури театру на сучасну архітектуру та суспільство. Зокрема, зроблено огляд впливу спадщини видатних архітекторів театральних будівель та їхній внесок у розвиток архітектури загалом. У статті показано, що розширення типологічної структури архітектури різних театрів створило передумови для розмаїття композиційних схем і принципово відмінної постановки архітектурних завдань. Різні градобудівельні умови, типологічні*

основи і індивідуальні особливості театру призвели до появи нових споруд, які контрастні за своєю структурою, стилістикою і засобами художнього вислову. Історичний досвід свідчить про те, що театральна архітектура така ж невичерпна, як і театральне мистецтво, як невичерпне і складне багатозначуще поняття театру.

Ключові слова: *театральна архітектура; мистецтво; сцена; мистецтво архітектури; культура*

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BOOK REVIEWS

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Whether the biosphere will turn into the noosphere? Review of the monograph: L. A. Griffen. The last stage of the biosphere evolution: monograph. Kyiv: Talkom, 2024. 200 p. ISBN 978-617-8352-32-5

The biosphere is usually thought of as the shell of our planet, formed by *living* matter, *literally* as a certain "sphere of life." However, for V. I. Vernadsky, who developed the doctrine of the biosphere, it was a *geological* phenomenon, the part of the earth's crust, that was *suitable* for the existence of life. He was talking about a certain structure originally formed not by living but by *inert* matter. Life appeared millions of years later, also thanks to the biosphere. The biosphere not only created the conditions for the existence of life, it *gave rise* to life itself. The latter arose due to the interaction of planetary and cosmic factors, in particular, the *inert matter* of the earth's crust and solar *energy*. And then life in the biosphere developed owing to all the same factors – the *material* of the inert matter of the biosphere and the *energy* of the sun's ray, also causing the evolution of the biosphere itself.

Living organisms function as active agents that cause and determine the direction of the biosphere evolution. Using its inert matter for their *own construction*, they thereby change the character of the biosphere. The biomass of living organisms gradually increased due to the transition of atoms of inert matter into living matter. But the life of every living organism is limited in time, and after its end, the substance that made it up *completely turned back into* the biosphere for further use. This, in Vernadsky's words, "current of atoms" between living and inert matter under the influence of solar energy was the main reason for the evolution of the biosphere. But as a conclusion of his doctrine of the biosphere, Vernadsky suggested that with the appearance of mankind on the planet, a new factor in the evolution of the biosphere arises – mind ("scientific thought"), which accelerates and qualitatively changes the evolutionary processes in the biosphere, gradually turning it into the "sphere of mind" – the *noosphere*.

This assumption of the scientist caused a significant resonance in the scientific and semi-scientific community. Especially recently, there have been a lot of materials

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devoted to this issue and at the same time to another such "sphere" – the technosphere. But despite the abundance of relevant publications, there are still no *defined ideas* about these phenomena. Different opinions are expressed, but attempts to generalize and analyze them with consideration of the issue on solid scientific grounds, are hardly ever made. One of such attempts is the peer-reviewed monograph in which the author sought to consider this issue in connection with the peculiarities of society as a kind of biological superorganism on the basis of its scientific and technological progress, which largely determines the interaction of living and inert matter in the biosphere today.

Having considered the main provisions of V. I. Vernadsky's concept, as well as a number of current publications on the noosphere and technosphere, the author comes to the conclusion that many of those who seem to consider themselves followers of Vernadsky, *have actually departed far* from his views. The main content of publications about *the noosphere* is actually reduced to considering it not as a material phenomenon, but as a kind of "emanation of the mind" that creates this very noosphere. This causes a certain euphoria in these authors in anticipation of the beneficial moral and ethical consequences of its functioning. As for the *technosphere*, even its composition is not really defined, but despite the recognition of its usefulness, many of the publications are downright imbued with technophobia.

As a result, the author considered it necessary to study the current evolution of the biosphere on the basis of its history and to see how society as an active biological organism differs from the previous ones, and what impact these differences have on modern processes in the biosphere. In this regard, he consistently considers the emergence and development of living organisms in the biosphere, their evolution, as a result of which the processes of interaction between living and inert matter change. With the enormous variety of their forms arising as a result of the development of living matter, the main direction of evolution associated with the *complication of the structures* of living organisms can be clearly traced in this development. From the very beginning, they were *separate* autotrophic and heterotrophic types of *cells*. Their interaction with each other led to the formation of colonies of such cells, and then to the formation of an integral *multicellular organism* with the division of functions first between its constituent cells, and then between the organs.

This division was caused by the need to improve the adaptation of a living organism to the *environment* in which it exists. Its main task is to resist *entropy* more and more successfully, as all material objects – with the destruction of their structures and the degradation of energy – are susceptible to the growth of entropy in our world. The development of living organisms, on the contrary, presupposes a *decrease* in their entropy, which can be achieved only by removing its material carrier into the environment and consuming objects with *negative* entropy from it. According to E. Schrödinger, a living organism remains alive only as long as it receives negative entropy from the environment. And this means the need for a constant *material exchange* of a living organism with the environment.

The very need determines the main direction of the evolution of living organisms. For this purpose, they become more *complex*, including the formation of their *own* specialized *subsystems* designed for the more and more successful implementation of this function. And this presupposes the development of a living organism's ability to successfully perform the necessary actions, on the one hand, and to determine the nature of these actions depending on specific conditions, on the other. In other words, the formation and development of two functional subsystems of the body, one of which is intended for *material* (material and energy), and the second – for *informational* interaction with the environment. In a single-celled organism these systems are only outlined in the form of its internal structural components. And in a multicellular organism they already represent groups of specialized cells and then *special organs*. In fact, for the sake of their development and improvement, the evolution of living organisms takes place.

The author of the monograph examines in detail the nature of the ongoing evolutionary changes from this point of view. And first of all, he emphasizes the above-mentioned "general line" on the *complication* of the structure of organisms. In this direction, after multicellular organisms consisting of an organic group of various cells, the next stage in the evolutionary development of living things was the appearance of a kind of "collective" organism consisting of previously independent separate individuals – *a superorganism*. Now the idea of "collective" associations of eusocial insects as unified, *integral* organisms is almost universally accepted. Their appearance basically was revolutionary in nature – precisely as the next stage in the development of living organisms. The division of functions was realized *on the level of separate individuals*. However, these organisms were not able to change their relationship with the biosphere in the same revolutionary way, particularly because of their size that did not contribute to the development of a powerful informational system.

This happened much later on another evolutionary branch, in which the size of multicellular organisms provided the possibility of their development due to the growth of the *brain size*, which not only ensured the enlargement of hereditary programs of behavior, but also their formation in ontogenesis on the basis of experience. So, the *relationship* between living organisms and the inert matter of the biosphere has also changed. Many species of animals in interaction with inert matter not only introduced it into their composition as usual (some – autotrophs – directly, others – heterotrophs – indirectly) but also used *external* material objects (objects of "pre-technology" – from a spider web to a beaver dam) in interaction with the environment. This is potentially a very significant point, although it did not play a particularly important role until the appearance of a new kind of superorganism - human *society*.

Society, like any other biological organism, also forms two functional subsystems – one for *informational* and the other for *material* interaction with the environment. But, unlike the superorganisms of eusocial insects (ants, bees, termites, etc.), these are *systems*, not just *an external association* of their constituent functioning individuals. First of all, this concerns the information subsystem which, in addition to providing

appropriate connections with the environment, also plays the role of a protective, and most importantly, *unifying shell* for the entire superorganism which is formed and functions due to the interaction of the cerebral structures of the individuals that make up the social organism.

In the opinion of the author, the role of connecting elements between informational processes in the brain of each member of society is performed by special *material* formations – *signs,* that form *sign systems*. They provide the *transcoding* of individual information which is processed by the brain of each individual in internal *natural individual* codes by means of "external" *common* codes jointly *formed* in each individual by *society* as a whole. The result of the *social* functioning of such an information system, which significantly exceeds the information of each individual brain in its power, is the appearance of a completely new phenomenon – *social consciousness*. Exactly this makes society an *integral* biological organism in which the individual consciousness of each member is a *reflection* of the social consciousness.

Thanks to social consciousness, the nature of the interaction of the entire social organism also changes with its environment. Regarding the reduction of entropy, this interaction is carried out in the form of a special process – *the production process*. This process begins with social consciousness which forms tasks for individuals on this interaction. It includes the analysis of the environment, the needs of individuals and society as a whole, the possibilities and means for obtaining *consumer goods,* necessary for the satisfaction of individuals from the environment through their labor, the choice of the object of labor as well as the imperative impulse for individuals to participate in the labor process.

This process, just like the formation of social consciousness, is embodied by the same individuals, but in a different capacity. Under the influence of *individual consciousness*, which has accepted the attitude of social consciousness, individuals perform actions aimed at its realization, that is, the *transformation* of an *object of labor* taken from nature into an *object of consumption* necessary for society with the help of means of production. The latter, being a carrier of negative entropy, enters society to reduce its entropy. As a result, the entropy of society decreases, and the entropy of the consumer increases. Therefore, at a certain point, it ceases to perform its function, and it is removed back into the environment as the *waste*, increasing meanwhile its entropy.

Any other organism carries out a fundamentally similar process. But in relation to society, the author pays special attention to the fact that, in contrast to the metabolism of multicellular animals, *additional* material objects obtained through the transformation of environmental objects also take part in social "metabolism" – tools of labor and consumer goods (technical devices). Entropy is transferred from the social organism as a whole into the environment by their means. For this purpose, they are functionally and physically included in the composition of the social organism. Namely they, together with individuals in their "creative" function, form the second functional subsystem of society (its "*technosphere*").

This moment – the introduction of environmental objects into the composition of a biological organism – is of fundamental importance. Prior to this, in order to provide its existence in interaction with the environment, a living organism could use only the possibilities directly *inherent in its constituent organic matter*. The appearance in its composition of transformed objects of nature, first of all its inert matter, creates conditions for the use of the forces of nature itself that are also "external" to its living matter, opening up new, extremely wide opportunities for the biological organism. These possibilities are now limited only by the resources of *nature itself*, which fundamentally changes the nature of its interaction with it. The latter circumstance also turned out to be very significant, but its effect became known much later.

Accordingly, the first informational subsystem of society, based on social consciousness, is a certain "sphere of mind" of the social organism, i.e. its "*noosphere*". It includes all the same individuals, but in their intellectual function. Specifically, its material structure consists of the *cerebral* structures of individuals, which are *active* agents of the noosphere, since those processes that are commonly called *ideal* are carried out exactly in them; material *sign systems* that provide the transcoding of information from the individual into the social (and vice versa), and consequently, the interconnection between the cerebral structures of individuals through their sense organs and effectors, thus creating the integrity and unity of the entire *given information system*; specialized *technical devices* contributing to the receiving, processing, keeping and transmission of information; and in a certain sense, all the objects of *material culture* created by society *without exception* are in their *aspect* that represents the objectified in them information, distributed by the cerebral structures of individuals as required.

The author draws special attention to the fact that in this case, in addition to their biological elements, *environmental objects* are also organically introduced into the composition of the organism, *removed from the environment* and turned into elements of the organism itself. After returning to an environment with increased entropy, they appear to be with high energy expenditures and do not completely respond to regeneration, which leads to a steady reduction in the resources of nature, and consequently in the environment of society existence as a biological organism. At the first stages of the development of society, these losses in the environment were not particularly noticeable, although even then the economic activity of society caused significant damage to the environment. But with its development, losses increased quite rapidly, especially with the evolutionary development of the social organism.

Biological evolution did not stop with its emergence. But its object now became not a single multicellular individual, but the entire social organism that took evolutionary changes upon itself. Initially it existed in the form of a primitive tribe with a common noosphere and technosphere, the structure of which was mentioned above. We will only add that the very nature of the interaction of society with the environment as a whole required the appropriate structuring of the noosphere and technosphere so that they would provide the integral nature of society. Therefore, the task of its

functional subsystems included two points: providing direct interaction with the environment and ensuring the integrity of society. Accordingly, both the noosphere and the technosphere were structurally and functionally divided into *extroverted* and *introverted* components.

And as a result of their development (thanks to scientific and technological progress), the growth and division of a primitive tribe are starting, followed by interaction between newly formed social organisms with the formation of new associations, just as before the division with the subsequent unification of unicellular organisms led to the emergence of multicellular organisms. We will not dwell on this here, although the author examines this process and its mechanisms in sufficient detail, showing how the structure and functions of operating subsystems developed in this process. We will only note that as a result of these interconnections, the original integrity of social organisms is lost, they turn into some only partially independent quasi-organisms (such as a state or civilization) with interacting and counteracting *private* noospheres and technospheres. And this, with regard to the additional expenditure, caused the increasing of environmental resources use, *reducing itself* due to the withdrawal of resources in order to include them in this aggregate "social organism" (with subsequent transformation into waste).

But simultaneously with the disjunctive processes, there are also unifying processes. Despite the significant differences in the noospheres of different social formations, the processes of borrowing and unification are taking place between them. Moreover, there has been for four centuries in the world *a forced globalization* of one of the civilizations – the western one, which imposes its noosphere on all mankind as the dominant one. However, now social processes in the world are proceeding in such a way that the possibilities of this are gradually decreasing, but there is a possibility of *voluntary* joint formation of a common noosphere – the "*sphere of mind*" not of planet Earth, but of *united humanity*. And consequently, the formation of an integral, but now *single social organism* again over time. And this gives hope for future changes in the state of the biosphere, which today is very alarming and continues to deteriorate.

The depletion of our planet's resources is a growing public concern. There are more and more ideas aimed at possible changes in the situation. Existing ideas include proposals for the organization of sustainable development, limiting consumption, humanization of thinking with increased ethical aspects, the joint "co-evolution" of society and nature, and many others. The author of the monograph considers the proposed solutions to be purely palliative. They may be useful, but they can only postpone the danger, not eliminate it. After all, they can neither stop the scientific and technological progress of mankind, which is directly related to the expansion of consumption of Earth's biosphere the resources, nor increase their quantity.

The only effective solution is *movement into space* with its *unlimited* resources. Despite all the seeming fantastic nature of such a decision, humanity is quite capable of it. The first step in space exploration has already been taken, although it is still immeasurably far from a real exit even to near space with the transfer to it of the

productive activities of mankind with its ever-expanding consumption of resources and the removal of waste. Technically, this can be done on the basis of further scientific and technological progress.

But from the societal point of view, only *united humanity* can solve such a problem. For these reasons, V. I. Vernadsky, touching upon this issue, asserted that "the creation of the noosphere from the biosphere" "requires the manifestation of mankind as a single whole. This is its inevitable prerequisite". The solution of this grandiose task presupposes that the entire human civilization will turn within the boundaries of the Earth into *a truly integral* social superorganism, which alone can be able to accomplish such a gigantic achievement. The author of the monograph believes that today's social processes in the world lead in this direction and analyzes them in great detail. However, we will not stop to discuss these matters further here, since they would require a very extensive exposition.

By the time when a real prospect of going into space is achieved, as a result of scientific and technological progress, and in particular the development of artificial intelligence, all production functions *will be transferred* to the corresponding technical systems, *completely excluding* direct human intervention in them, leaving him only the processes that can never and under no circumstances be transferred to technical devices (as "inanimate" ones that do not have their own *will to life*) – *goal-setting* and *innovation*. Now it is difficult to predict with sufficient certainty what the productive labor of a person will look like exactly. The author believes that people's lives will be based on *scientific* and *creative* activities *as their natural forms*. In itself, this activity will become not so much productive labor as *a way of life*, the main way of satisfying *social needs*.

Thanks to the universal informational interconnections, which, together with people and their individual consciousnesses and the universal technical systems of storage and processing of information, will make up the noosphere of society, in which every person will be able *to receive* any desired information from it and *contribute* the information developed by him into the general system, preserving personal authorship. And, as a result of the constant processing of *all* the information received both from individuals and from outside by the public consciousness, a "public production order" will be formed for production *from the noosphere*. Bypassing the human, it will *directly* reach *the technosphere* as a *universal system of interconnected local self-governing technocenoses* that produce both consumer goods as well as the means of production.

As far as exodus into space is concerned, today we cannot imagine what decisions our distant descendants will make, but in the foreseeable future humanity is unlikely to be in need of populating space on a permanent basis. The *extroverted* parts of the functional subsystems of the universal social organism will be oriented there for the organization of automated unmanned production. Meanwhile, the natural and artificial objects that fill the earth biosphere will actually enter the *introverted* parts of these subsystems. The Earth's biosphere *will not transform* into the noosphere, it will simply *coincide* with the introverted parts of both the noosphere and the technosphere of

society, *completely turning* from the *environment* of the existence of the social organism into *a cozy common home of all humanity*. This will be *the last stage of the biosphere evolution*.

In relation to the limited volume of the review, we have not fully considered the content of the monograph here, including the author's rather detailed argument of his point of view on quite important aspects of the problem. For the same reason, many specific issues related to this topic (for example, regarding the development of artificial intelligence) are omitted. Therefore, we invite those who are interested in the considered above problems to directly find the monograph itself, which is available on the Internet, in particular, on the website of the author *lagrif.org*.

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