https://doi.org/10.48417/technolang.2025.03.05
Research article

Scientific Restoration of Polytechnic Heritage: The Case of the Franz Reuleaux Collection

Pavel Kotelnikov[1] and Sergei Kurakov[2] (✉)
[1] State Research Institute of Restoration, st. Gastello, 44, p. 1, 107014, Moscow, Russia
[2] Bauman Moscow State Technical University, 2nd Baumanskaya st., 5, p.1, 105005, Moscow, Russia
kurakov@bmstu.ru

Abstract
The preservation of scientific and technical heritage within museum settings is inseparable from restoration technologies. The conservation of polytechnic-type exhibits is in high demand, as evidenced by recent surveys of museum professionals and administrators who identify the restoration of archival and exhibition collections as their foremost priority. This article examines case studies in reconstructing damaged kinematic models from the Franz Reuleaux collection, systematically analyzing diverse approaches to restoring such polytechnic artifacts. The authors demonstrate how emerging additive technologies significantly expand traditional conservation capabilities as well as addressing the reproduction of museum copies, replicas, and tactile models through innovative methods. The restoration of Reuleaux's museum objects necessitated intensive interdisciplinary collaboration among specialists spanning technical, humanistic, educational, and cultural domains. The project's outcomes include the reintegration of storage-bound Reuleaux collection items – deemed unfit for display due to significant losses and poor condition – into the permanent exhibition of Bauman Moscow State Technical University Museum's while providing new digital environment for promoting Reuleaux' engineering heritage among museum visitors and specialists with varying levels of expertise and professional backgrounds.

Keywords: Scientific Restoration; Franz Reuleaux; Reuleaux Collection; Polytechnic Artifact; Digital Model of Mechanism; Additive Technologies in Restoration

Acknowledgment: The authors express their sincere gratitude to Galina Alekseevna Bazanchuk, Director of the Bauman Moscow State Technical University Museum, for her many years of work on preserving and popularizing scientific and technical heritage and for her consultations in writing this article.

Citation: Kotelnikov, P., & Kurakov, S. (2025). Scientific Restoration of Polytechnic Heritage: The Case of the Franz Reuleaux Collection. *Technology and Language, 6*(3), 64-79. https://doi.org/10.48417/technolang.2025.03.05

УДК 7.025.4
https://doi.org/10.48417/technolang.2025.03.05
Научная статья

Научная реставрация политехнического наследия: Пример коллекции Франца Рёло

Павел Николаевич Котельников[1] и Сергей Витальевич Кураков[2] (✉)
[1] Государственный научно-исследовательский институт реставрации, ул. Гастелло, 44, стр. 1, Москва, 107014, Россия
[2] Московский государственный технический университет им. Н. Э. Баумана, ул. 2-я Бауманская, д. 5, стр. 1, Москва, 105005, Россия
kurakov@bmstu.ru

Аннотация
Сохранение научно-технического наследия в музейном пространстве невозможно без технологий реставрации. Тема восстановления экспонатов политехнического типа очень актуальна и остро востребована сообществом профильных музеев, где по итогам текущих опросов музейных работников и их руководителей на первом месте стоит потребность в реставрации экспозиционного и архивных фондов. В статье приводятся примеры по восстановлению утрат исторических кинематических моделей коллекции Франца Рёло, системно рассматриваются различные подходы в реставрации подобных политехнических предметов. Авторы показывают, как появление новых аддитивных технологий существенно расширяет возможности традиционной реставрации, а также рассматривают вопросы в части воспроизводства музейных копий, реплик, тактильных моделей при помощи современных инновационных технологий. Работа по восстановлению утрат музейных экспонатов Ф. Рёло потребовала высокого междисциплинарного взаимодействия между различными специалистами, как технической, так и гуманитарной сферы науки, образования и культуры. Результатом проведенной работы, с одной стороны, стало пополнение экспозиции музея МГТУ им. Баумана уникальными экспонатами из коллекции Рёло, ранее находившимися в фондохранилище по причине серьезных утрат и неудовлетворительного внешнего вида, а с другой, с применением цифровых технологий, используемых в реставрации, появилась новая возможность популяризации инженерного наследия Франца Рёло среди посетителей музея и специалистов различного уровня подготовки и профессиональных интересов.

Ключевые слова: Научная реставрация; Франц Рёло; Коллекция Ф. Рёло; Политехнический предмет; Цифровая модель механизма; Аддитивные технологии в реставрации

Благодарность: Авторы выражают искреннюю признательность Галине Алексеевне Базанчук – директору музея МГТУ им. Н. Э. Баумана за многолетнюю работу по сохранению и популяризации научно-технического наследия и консультации при написании этой статьи.

Для цитирования: Kotelnikov, P., & Kurakov, S. (2025). Scientific Restoration of Polytechnic Heritage: The Case of the Franz Reuleaux Collection // Technology and Language. 2025. № 6(3). P. 64-79. https://doi.org/10.48417/technolang.2025.03.05

INTRODUCTION

The rapid industrial growth in mid-19th century Russia revealed a critical shortage of technically trained specialists capable of designing, manufacturing, and operating complex machinery. Higher technical education programs, which provided both theoretical and applied training for engineers and technicians, universally incorporated a course on Applied Mechanics into their curricula. This discipline later bifurcated into two foundational subjects: *Theory of Machines and Mechanisms* and *Machine Design*. These became core courses at polytechnic schools and universities worldwide, though their effective instruction necessitated didactic aids—specifically, functional mechanism models (Ceccarelli & Cocconcelli, 2022). Consequently, scientific institutions began establishing dedicated machine model collections and demonstration cabinets (Fig. 1).

Figure 1. Collection of kinematic models for teaching the course Applied Mechanics at IMTS, Moscow, postcard circa early 20th century.
Source: Fund of Bauman Moscow State Technical University’ Museum

At the Technical University in Berlin Franz Reuleaux established a collection of over 800 kinematic models, which long served as a benchmark for higher technical schools in Germany and beyond (Golovin & Tarabarin, 2010; van der Wijk & Herder, 2012). Reuleaux was highly respected among applied mechanics scholars, making it no surprise that his advanced engineering and pedagogical methods gained traction in Russia. “Reuleaux’s lectures could be called brilliant in their refinement and elegance of presentation; his kinematics lectures stand out for their originality,” remarked F.E. Orlov

– professor of practical mechanics at Moscow University and the Imperial Moscow Technical School (IMTS).

Around 1870, Franz Reuleaux granted Gustav Voigt the rights to manufacture a part of the instructional models for Applied Mechanics, which Voigt then began producing on an industrial scale in Berlin. By 1907, his firm offered a catalog of 368 distinct models. Voigt's catalog was divided into two sections: the first featured Reuleaux's earlier, widely recognized models, many of which are preserved in museums across Germany, the U.S., and elsewhere.

The second section of the catalogue featured models that were produced in smaller quantities in the early 20th century, reflecting the firm's financial decline after Reuleaux's death in 1905, leading to its eventual closure. Today, roughly 20 models from this second section survive in the museum of Bauman Moscow State Technical University (BMSTU) – these are likely the last remaining Reuleaux-Voigt models in existence. A comparison of Voigt's catalog with BMSTU's collection suggests that the models acquired for the Applied Mechanics department at the Imperial Moscow Technical School (IMTS) were carefully selected. Unlike Cornell University, which owns nearly all 220 models from the first section, BMSTU's museum holds only about 50 exhibits of this type and class.

The selective acquisition was determined by several factors: the need to align with IMTS' existing teaching methodologies and curricula, the availability of similar mechanism models produced in the institute's own workshops, budgetary constraints, practical considerations, and the limited relevance of certain Reuleaux models to the school's specific focus (Tarabarin, 2019).

Today, Reuleaux's kinematic models have undergone a fundamental shift in their educational role, mirroring the transformation of traditional mechanism design courses in modern technical education. While these models have largely lost their original didactic function due to technological advancements, they remain unparalleled examples of visual teaching aids in technical disciplines. To put it plainly, they are no longer employed for demonstrating motion transformation in lectures on the Theory of Machines and Mechanisms (TMM) or for laboratory experiments. Instead, they have become objects of scholarly research - valuable artifacts representing the history of technology and engineering education (Tikhomirov et al., 2023), serving as eloquent yet silent witnesses to larger historical developments.

PROBLEM STATEMENT

Restoring polytechnic-type museum objects is a complex and multifaceted challenge that requires an interdisciplinary approach, balancing their original utilitarian function with their current museum value. Unlike cultural artifacts, these items often involve experimental alloys, plastics, and composite materials, with degradation issues like corrosion, polymer aging, and electronic component failure. The lack of standardized restoration methods necessitates adapting techniques from engineering and materials science, while the replacement of original parts versus the preservation of authenticity raises issues for the professional of ethos of restorators. Modern technologies—such as 3D scanning, non-destructive analysis, and digital twins—offer innovative solutions, but each approach sets new precedents in this evolving field.

Beyond dealing with materials that remain unstudied or poorly understood in restoration science, and besides addressing various industrial contaminants and damage from operation in harsh environments, the primary challenge in restoring polytechnical objects lies in recovering their functional purpose—not merely their form, surface finish, or visual preservation.

Despite fundamental differences between scientific/technical artifacts and works of decorative art, their restoration shares common ground in cultural heritage preservation, particularly given the extensive expertise accumulated in art conservation. As Shemakhanskaya (2015) aptly notes: “We must focus on restoration principles that preserve the artifact itself—not an idealized version of it.” This philosophy is especially relevant for polytechnical collections, which often serve as the sole material record of obsolete technologies, embodying the legacy of engineering culture.

In this context, guided by the ethos of scientific restoration of cultural heritage objects, the application of modern additive technologies in engineering allows for the functional restoration of polytechnical exhibits while ensuring complete reversibility of the restoration process. This article examines methods for restoring the operability of kinematic mechanism models using additive manufacturing technologies. Over the past decade, these processes have become widespread and remain among the most convenient and rapidly developing technologies for producing parts and components in the restoration of polytechnical objects.

RESEARCH OBJECTIVES

The collection of Franz Reuleaux's kinematic models is more than just a “time machine” that reveals how science and technology shaped and transformed our world. Its true value lies in the physical embodiment of the Great Designer's ideas – a perfect fusion of clarity and harmony, function and aesthetics. While the Bauman Moscow State Technical University Museum displays educational mechanisms from various manufacturers and numerous engineering innovators, visitors can effortlessly identify Reuleaux's models after just a brief observation. Why is this so?

All mechanisms in this collection adhere to a unified compositional, color, and architectural concept conceived by their creator. Let us outline the key distinguishing characteristics of Reuleaux's models to inform subsequent scientifically-grounded restoration methodology:

- All models in the collection feature standardized wooden bases (with rare exceptions) finished in black lacquer to simulate precious wood varieties, distinguished by their minimalist molded edge profiles and consistent dimensions across kinematic groups.

- The wooden base supports a flat 5-mm-thick cast iron pedestal plate that bears the entire mechanism model, featuring a bevelled upper edge and a planed horizontal surface machined with fine cross-feed tool marks from a planer's carriage – without subsequent grinding or polishing – all protected by a blued oxide coating that gives the cast iron components their characteristic matte black finish.
- Most Reuleaux models feature precision-cast iron brackets vertically mounted on the base plate - which Reuleaux himself classified as either “English” or “French” based on their distinct forms and proportions (Fig. 2). These flawlessly cast brackets, completely free of burrs, cavities or other defects, uniformly display the same matte black oxide coating characteristic of all iron components in the collection.

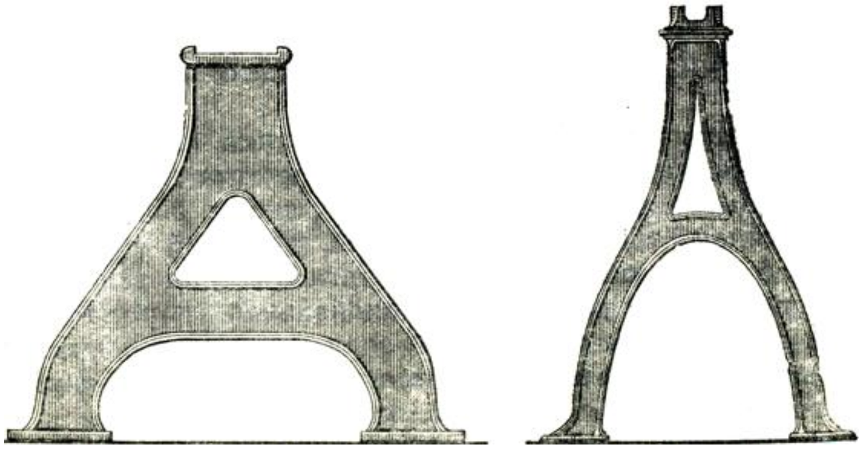
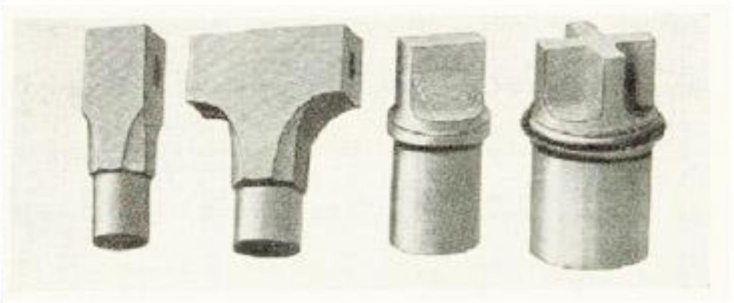


Figure 2. Examples of typical English (left) and French (right) brackets (Reuleaux, 1862).

- The moving components – kinematic links, gear wheels, and other dynamic parts – are typically crafted from brass with subsequent nickel electroplating, exhibiting a distinctive glossy “steel-like” sheen characteristic of polished metal surfaces.
- The adjustment and fastening screws in the mechanisms are made of brass and have developed a thick, dark patina over time. For ease of use, the side surfaces of their shaped heads feature knurling (Fig. 3), while the threads follow British standard inch measurements.
- Instrumental analysis of the joints and clearances in these mechanism models reveal exceptional assembly precision comparable to mathematical instrument manufacturing standards (Bazanchuk & Kurakov, 2022; Tikhomirov et al., 2024). The jewel-like fitting of components demonstrates the remarkably advanced state of German metalworking technology in the late 19th century (Fig. 3c).
- Beyond these primary materials, Reuleaux's models incorporated several other specialized components: glass panels for display stands showing mechanism trajectories, rubber-impregnated leather (red belts for pulleys), sheet metal for pointers and indicators, and similar functional elements.



a **b**

c

Figure 3. a) The arrow shows changing the shape from a cylinder to a parallelogram on the Reuleaux's kinematic model; b) Transitional forms in engineering, similar to architectural ones, according to Reuleaux (1861); c) The jewelry-like, very precise fit of the parts is clearly visible on the engagement fragment of the Shield Gearing model (Reuleaux calls the gears *Schildräder* in German). Photo by the authors.

The authenticity and historical significance of any museum object can only be fully understood by examining its material history and usage. The Reuleaux collection bears numerous traces of time that document its century-long service as educational aids – from wear patterns to repair marks, each telling a story about its pedagogical use and evolving preservation needs.

Every model in the collection features distinctive oval metal identification tags with white enamel surfaces and black lettering: A capital Latin letter and a model number identify the mechanism according to Professor Leonid Reshetov's 1950s classification system which is notably different from Franz Reuleaux's original scheme. For polytechnical objects like these, all such historical markings must be carefully preserved as they provide critical evidence for understanding the collection's educational history and technological evolution across different periods.

METHODOLOGY

Traditionally, when undertaking the restoration of lost metal elements in museum objects – for example, the metal covers or settings for painted icons or cabinet sculptures[1] – the available restoration methods are notably limited and predetermined (Ravich, 2024). Pressure-based metalworking techniques that cause deformation and alter the internal structure of artifacts are generally unsuitable or impractical. For the same reason, high-temperature and energy-intensive interventions – like direct controlled metal deposition – should be avoided. Even soldering and laser spot welding often prove inappropriate, particularly for archaeological metal objects (Treister & Ravich, 2021).

Traditional artistic restoration principles remain fully applicable to Reuleaux's technical collection, despite its purely polytechnical nature, since the conservator's objectives align with the preservation standards for decorative-applied art (DAA). They demand precision, historical authenticity, and adherence to core museum conservation principles: reversibility, fragment removal without substrate damage, and restoration marking. Crucially, conservators must avoid interventions that cause irreversible alterations to an artifact's form, appearance, or material microstructure.

The challenge of restoring functionality to damaged Reuleaux kinematic models can be addressed by drawing upon established practices from decorative-applied art conservation, where significant expertise exists in reviving historical mechanisms for museum clocks, musical devices (organs, orchestrions, pianos, music boxes), and firearm actions. Given the collection's historical significance, thorough defect analysis, available technical literature (Reuleaux, 1861, 1862, 1876), digital archives (The Kinematics Models… , 2003-2005), and equipment catalogs (Voigt, 1907), Reuleaux's models can – and should – be restored using traditional art conservation methods while strictly preserving their operational heritage and original manufacturing technology.

Recent advancements in metallurgy, additive technologies (Melnikova et al., 2023; Supchinsky et al., 2023), metal deposition, and electroplating have created new possibilities for the scientific restoration of museum-grade metal artworks. At the same time, growing global interest in mechanical collections as part of our industrial heritage has reshaped preservation approaches. Initially focused on historically significant early mechanisms as key artifacts for studying technological evolution, this movement has been amplified by digital platforms. Websites and virtual museums now enable not only lectures on mechanism theory but also courses in engineering history and technical

[1] A sculpture of chamber size or small shapes, about 60-80 cm high.

language studies, complete with analytical modeling capabilities (Bogoslovskii et al., 2024). These digital media formats offer researchers innovative perspectives on Reuleaux's engineering legacy, including novel restoration methodologies (Kotelnikov et al., 2023), merging cutting-edge materials science with expanded educational access to technical heritage.

Current analysis of additive technology applications in museum settings – including educational models, art objects, replicas, and duplicates – reveals three promising directions for the implementation of these processes in the scientific restoration of polytechnical artifacts:

• Level 1 – "Basic" Application involves the replacement of plastic parts with polymer equivalents and/or substitutions of lost metal, wooden, or other components with dimensionally identical 3D-printed replicas.

• Level 2 – The reproduction of precise or scalable replicas of historic scientific and technical artifacts (Lipson et al., 2005). This approach proves valuable when traditional restoration is impossible or requires postponement due to funding constraints. The pioneering implementation using additive technologies belongs to Cornell University Professor Francis Moon, who in the early 2000s created a digital library of over 400 kinematic models (KMODDL) and employed 3D printing to produce replicas of Reuleaux's original mechanisms (Fig. 4).

a **b**

Figure 4. A ratchet mechanism with three spring-loaded stoppers (a) Original Reuleaux model, (b) Rapid prototype model (Lipson et al., 2005).

• Level 3 – The application of additive technologies as supportive and auxiliary tools in restoration or renovation processes (reconstruction, repair, or modernization) of lost components in polytechnical objects made of metal, glass, wood, and other materials (Kotelnikov et al., 2024).

RESEARCH RESULTS

An exemplary traditional restoration of a polytechnical object involves reconstructing the motion trajectory of satellite points in Watt's planetary gear mechanism model (Fig. 5). Since the painted layer on the glass display had degraded over time, the preserved engraved grooves enabled the reversible restoration of missing elliptical motion traces.

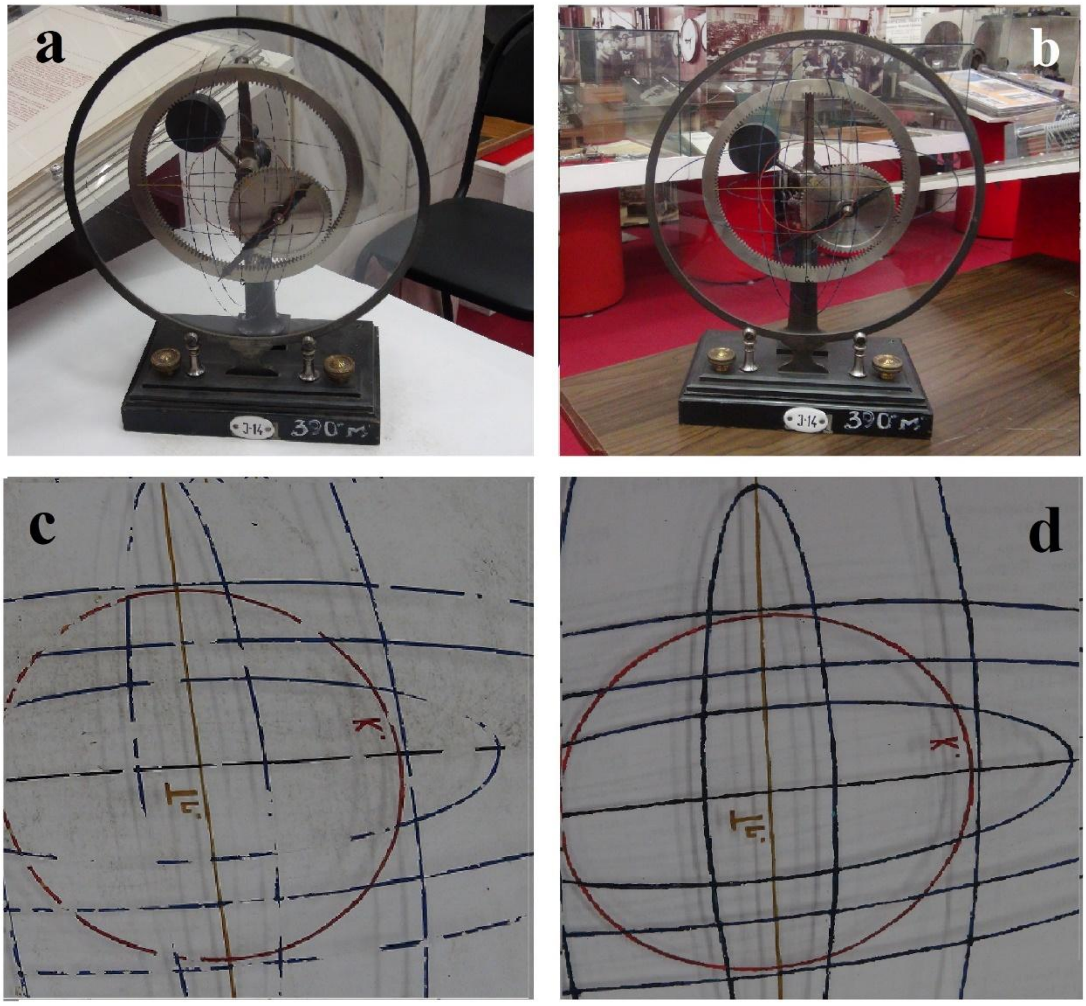


Figure 5. The planet toothing mechanism of Watt with a trajectories of satellite's points before (a) and after (b) restoration. A Fragment of the glass display before (c) and after (d) reversible restoration of the trajectory of the dots. Photos by the authors.

The Reuleaux collection at BMSTU's museum shows no significant losses and remains in good condition, as demonstrated through the functional restoration of the “Planetary Mechanism with Bevel and Spur Gears” (based on Ferdinand Redtenbacher's designs, crafted by Moscow Trade School artisans in 1862-1867, Fig. 6). Using non-contact 3D scanning, we precisely measured the gear train's geometry to reproduce a missing cogwheel through additive manufacturing. the director of the State Research Institute for Restoration (GOSNIR) Dmitry Antonov highlighted the innovative transparent replacement component (Fig. 6b). While restoring mechanical function, its visibility allows museum visitors to distinguish original from reconstructed elements, adhering to the practice of signaling reversible restoration (Kurakov et al., 2025).

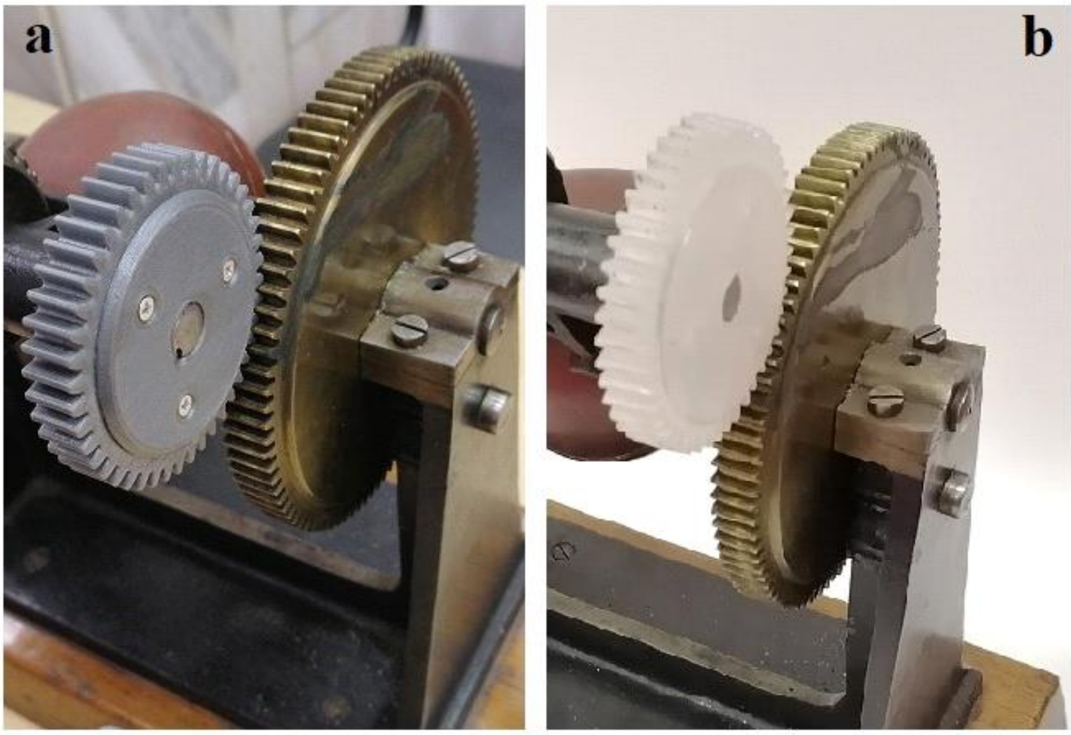


Figure 6. Fragment of the mechanism engagement restored using: a) fused deposition modeling (FDM) and b) photopolymerization with an LCD screen additive technologies. Photo by the authors.

CONCLUSIONS AND DISCUSSION

The restoration of scientific and technical artifacts must adhere to the same ethical principles and conservation standards that apply to other cultural heritage objects. This requires combining traditional art restoration methods with engineering research, enabling comprehensive interdisciplinary study by specialists from both technical and humanities fields. Such an integrated approach ensures the preservation of both physical integrity and historical significance of polytechnical exhibits. Accordingly, the kinematic models from the Franz Reuleaux collection can and should be restored using methodologies developed for decorative-applied arts.

Our research demonstrates that these approaches, when adapted for technical artifacts, successfully preserve the functional and historical value of the mechanisms while maintaining strict conservation ethics. The parallel between art restoration and engineering conservation becomes particularly evident in working with these sophisticated mechanical objects.

Modern additive manufacturing has proven exceptionally valuable for restoration in technical museum collections, meeting rigorous conservation standards in quality compliance (Sinitsa, Korzhenkov et al., 2022), dimensional precision, surface finish requirements (Pronyakin et al., 2021), process reproducibility (Sinitsa, Tumakova et al., 2022). While these techniques represent relatively new applications in heritage conservation, their effectiveness in reconstruction, renovation, and repair of polytechnical objects has been clearly established, offering new possibilities for technical museums.

We must acknowledge the financial challenges Francis Moon faced when he created his digital library of mechanical models: “Reproducing these models on the modern market would be prohibitively expensive.[2] Developing more affordable reproduction methods using thermoplastics offers an excellent alternative, though rapid prototyping technologies [i.e., additive manufacturing] inherently require compromises – we prioritized printing fully functional, pre-assembled units at the expense of dimensional authenticity” (Moon 2003). This valuable experience from our American colleagues should be adapted and advanced considering current technological progress in additive processes.

Contemporary philosopher of technology Vadim Rozin (2023) observes: “The essence of engineering methodology lies in developing technical designs that harness natural laws – through physical experiments, process calculations, and structural solutions – to activate and control phenomena for human purposes...” (p. 56). Refining additive technologies for polytechnical restoration and establishing balanced methodologies could revolutionize conservation approaches for complex cultural artifacts, particularly for what art historians term the “Russian avant-garde.” Many conservators have noted striking material, formal, and degradation parallels between abstract sculptures and technical exhibits, suggesting that engineering principles, scientific analysis, and precision measurement will become increasingly vital in art restoration practices.

[2] Cornell University's collection of approximately 250 Reuleaux models cost $8,000 in 1882 USD, equivalent to roughly $300,000 or 24 million rubles today

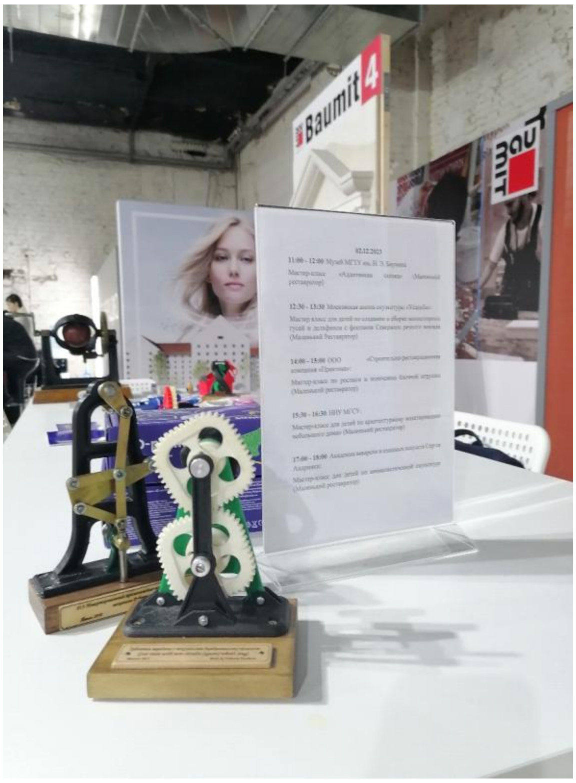


Figure 7. 3D printed replicas of Reuleaux models as props for the children's fairy tale “The Additive Kingdom.” Photo by the authors

Finally, current trends toward humanizing engineering education and practice will undoubtedly benefit from promoting Franz Reuleaux's systematic engineering legacy, as evidenced by the genuine fascination children exhibit toward replica museum mechanism models regularly displayed at our specialized “PROrestoration” exhibition (Fig. 7).

REFERENCES

Bazanchuk, G. A., & Kurakov, S. V. (2022). Ranniye matematicheskiye instrumenty v kollektsii Muzeya MGTU imeni N.E. Baumana - svyaz' yestestvoznaniya i prikladnoy nauki. [Early Mathematical Instruments in the Museum Collection of the Bauman Moscow State Technical University - The Connection of Natural Science and Applied Science]. *Life of the Earth, 44*(1), 89-98. https://doi.org/10.29003/m2625.0514-7468.2022_44_1/89-98

Bogoslovskii, S. Y., Kuznetsov, N. N., & Atangulova, A. D. (2024). The use of Fast-Flowing Chemical Processes for the Application of Metal Coatings in Artistic Creation. In *Proceedings of the 2024 6th International Youth Conference on Radio Electronics, Electrical and Power Engineering*. IEEE. https://doi.org/10.1109/REEPE60449.2024.10479681

Ceccarelli, M. & Cocconcelli, M. (2022). Italian Historical Developments of Teaching and Museum Valorization of Mechanism Models. *Machines, 10*(8), 628. https://doi.org/10.3390/machines10080628

Golovin, A. & Tarabarin, V. (2010). *Russian Models from the Mechanisms Collection of Bauman University*. Springer Dordrecht. https://doi.org/10.1007/978-1-4020-8776-9

Lipson, H., Moon, F. C., Hai, J., & Paventi, C. (2005). 3-D Printing the History of Mechanisms. *Journal of Mechanical Design*, *127*(5), 1029-1033. https://doi.org/10.1115/1.1902999

Kotelnikov, P. N., Kurakov, S. V., & Morozov, V. V. (2023). Vozmozhnosti primeneniya additivnykh tekhnologiy pri vosstanovlenii utrachennykh elementov v restavratsii predmetov iz metalla. [Possibilities of Additive Technologies in Recovering Lost Elements for Metal Objects Restoration]. *Art Heritage. Research. Storage. Conservation. 3*(7), 37-45

Kotelnikov, P. N., Kurakov, S. V., Samoilov, V. B. (2024) Sravneniye additivnykh sposobov 3D-pechati prozrachnykh polimerov v restavratsii utrat predmetov politekhnicheskogo tipa. [Comparison of Additive Methods for 3d printing transparent polymers in the restoration of polytechnic type objects]. *Art Heritage. Research. Storage. Conservation, 4*(12), 60-73.

Kurakov, S. V., Melnikova, M. A., Bogdanov, A. V., Tikhomirov, G. V., & Kotelnikov, P. V. (2025). Restoration, Current Approaches Using the Additive Technologies: Issues of Transparency. In *Proceedings of the 2025 7th International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE)* (p. 474). IEEE. https://doi.org/10.1109/REEPE63962.2025.10971027

Melnikova, M. A., Polukhin, A. D., Bogdanov, A. V. P. & Nosov, A. (2023). Modeling of Thermal Deformations of Optical Elements with Radiation of Powerful Technological Fiber Lasers. *AIP Conference Proceedings*, *2549*(1), 100001. https://doi.org/10.1063/5.0122113

Moon, F.C. (2003). Robert Willis and Franc Reuleuax: Pioneers in Theory of Machines. *Notes and Records. 57*(2), 219. https://doi.org/10.1098/rsnr.2003.0207

Pronyakin, V. I., Skrypka, V. L., & Abykanova, B. T. (2021). Surface Microgeometry Monitoring of Large-Sized Aircraft Elements. *IOP Conference Series: Materials Science and Engineering*, *1027*(1), 012024. https://doi.org/10.1088/1757-899X/1027/1/012024

Ravich, I. G. (2024). Izucheniye nekotorykh problem razrusheniya izdeliy iz latuni na sovremennom etape i perspektivnyye podkhody k ikh restavratsii. [Study of Some Problems of Destruction of Brass Products at the Present Stage and Promising Approaches to Their Restoration]. In *Current Status and Promising Approaches to Restoration, Examination and Conservation of Works of Art* (pp. 90-96). State University of Russia after A.N. Kosygin.

Reuleaux, F. (1861). *Der Constructeur* [The Constructor]. Friedrich Vieweg und Sohn.

Reuleaux, F. (1862). *Über den Maschinenbaustil* [About the Machine Building]. Vieweg. https://www.dmg-lib.org/dmglib/main/portal.jsp?mainNaviState=browsen.docum.viewer

Reuleaux, F. (1876). *The Kinematics of Machinery. Outline of a Theory of Machines*. Macmillan and Co.

Rozin, V. M. (2023). Fenomenologicheskoye osmysleniye M. Khaydeggerom tekhniki (na materiale stat'i “VOPROS o tekhnike”). [Phenomenological Understanding of Technology by M. Heidegger (on the Material of the Article “The Question Concerning Technology”)]. *Philosophy of science and technology, 28*(2), 49–62. https://doi.org/10.21146/2413-9084-2023-28-2-49-62

Shemakhanskaya, M. C. (2015). *Metally i veshchi: Istoriya. Svoystva. Razrusheniye. Restavratsiya* [Metals and Things: History. Properties. Destruction. Restoration]. Indrik.

Sinitsa, M., Korzhenkov, I., & Komshin, A. (2022). Development of a System for Controlling the Geometry of Products in Heavy and General Engineering by Non-Contact Methods. In *AIP Conference Proceedings*, 2503. https://doi.org/10.1063/5.0099471

Sinitsa, M.O., Tumakova, E.V., & Komshin, A.S. (2022). Some Features of Measurements of Dynamic Characteristics of Heavy Machinery Objects During Operation in the Far North. In A.A. Radionov, & V.R. Gasiyarov (Eds.), *Proceedings of the 7th International Conference on Industrial Engineering (ICIE 2021). Lecture Notes in Mechanical Engineering.* (p. 592-602). Springer Cham. https://doi.org/10.1007/978-3-030-85233-7_70

Supchinsky, O., Melnikova, M., Kholopov, A. Melnikov, D., & Bogdanov, A. (2023). Additive Technologies Features for Manufacturing Metal Products from Powder Materials by Direct Laser Deposition. In A. Guda, (Ed.), *Networked Control Systems for Connected and Automated Vehicles. NN 2022*. *Lecture Notes in Networks and Systems*, 510, (vol 510, pp. 393-401) Springer. https://doi.org/10.1007/978-3-031-11051-1_38

Tarabarin, V. B. (2019). *Kollektsiya modeley mekhanizmov MGTU im. N. E. Baumana. Istoricheskaya chast, 1860-1935*. [Collection of models of mechanisms of the Bauman Moscow State Technical University. Historical part, 1860-1935]. Pervyy tom.

The Kinematics Models for Design Digital Library (KMODDL) (2003-2005). https://digital.library.cornell.edu/collections/kmoddl

Tikhomirov, G. V., Egorova, O. V., Bazanchuk, G. A., & Kurakov S. V. (2023). Humanitarian Techniques in the Teaching of Technical Sciences. In V. Petuya, G. Quaglia, T. Parikyan, & G. Carbone, (Eds.), *Proceedings of I4SDG Workshop 2023. I4SDG 2023. Mechanisms and Machine Science* (vol. 134, pp. 343-349). Springer. https://doi.org/10.1007/978-3-031-32439-0_39

Tikhomirov G. V., Egorova O. V., Bazanchuk G. A., & Kurakov S. V. (2024). The Pantograph: Rare Models and Application. In M. Ceccarelli, & I. Aslan Seyhan, (Eds.), *Explorations in the History and Heritage of Machines and Mechanisms. HMM 2024. History of Mechanism and Machine Science* (vol 47., pp. 305-313). Springer. https://doi.org/10.1007/978-3-031-54876-5_22

Treister, M. & Ravich, I. (2021). Chinese Mirrors from the Burials of the Nomads of Eastern Europe of the Second Half of the 1st Millennium BC-first Centuries AD: Typology, Chronology, Distribution and Technology of Manufacture. *Advances in Archaeomaterials*, *2*(1), 24-48. https://doi.org/10.1016/j.aia.2021.07.001

van der Wijk, V., & Herder, J. L. (2012). The work of Otto Fischer and the Historical Development of his Method of Principal Vectors for Mechanism and Machine Science. In T. Koetsier, & M. Ceccarelli (Eds.), *Explorations in the History of Machines and Mechanisms. History of Mechanism and Machine Science* (vol. 15, pp 521–534). Springer. https://doi.org/10.1007/978-94-007-4132-4_36

Voigt, G. (1907). *Kinematic Models after Reuleaux*. Catalog.

СВЕДЕНИЯ ОБ АВТОРАХ / THE AUTHORS

Котельников Павел Николаевич,
113metal@gmail.com

Pavel Kotelnikov,
113metal@gmail.com

Кураков Сергей Витальевич, kurakov@bmstu.ru,
ORCID 0009-0006-9834-630X

Sergei Kurakov, kurakov@bmstu.ru,
ORCID 0009-0006-9834-630X

Статья поступила 5 июня 2025
одобрена после рецензирования 15 августа 2025
принята к публикации 16 сентября 2025

Received: 5 June 2025
Revised: 15 August 2025
Accepted: 16 September 2025