Original Scientific Paper https://doi.org/10.24867/GRID-2026-p44

Artistic and Material Analysis of Dinar, Tolar and Euro

ABSTRACT

Printed money in Slovenia represents an important part of the country's graphic, artistic, and technological heritage, as thirteen different currencies and means of payment have circulated within Slovenian territory since 1820. This paper examines the relationship between the visual design of banknotes and their material and structural properties. The aim of the study was to determine how age, wear, and developments in graphic production technologies affect the quality of the paper substrate and its physical characteristics. Three banknote samples were included in the study: a Yugoslav 100-dinar banknote (V1), a Slovenian 10-tolar banknote (V2), and a 5-euro banknote (V3). In addition to a visual and formal analysis, we examined the basic, surface, structural, and optical properties of the paper, as well as its microscopic characteristics using optical microscopy. Although all analysed samples were manufactured from cotton fibres, they were produced under different historical, economic, and technological conditions. The results indicate that the contemporary euro banknote exhibits the highest degree of material homogeneity, density, and structural compactness, reflecting advances in manufacturing processes and quality control. The older samples, particularly the Slovenian tolar, showed more pronounced signs of mechanical wear, fibre deformation, and changes in surface structure. The findings confirm that prolonged circulation and use significantly contribute to the degradation of banknote paper. At the same time, the study demonstrates that modern banknote production technologies provide a more effective balance between durability, security, and resistance to wear.

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KEY WORDS
Banknotes, paper, graphic design, paper properties, microscopic analysis

1. Introduction

Printed money represents an important segment of cultural, design, and technological heritage, as it reflects the political, economic, and social transformations of a particular period. Since the beginning of the nineteenth century, several different currencies have circulated within Slovenian territory, and their banknotes bear witness not only to monetary history but also to the development of graphic art, printing technologies, and security systems. Although banknotes are increasingly being replaced by bank cards and digital payment methods in contemporary society, they remain an important carrier of national identity, visual communication, and technological innovation. Due to their everyday use, banknotes are continuously exposed to mechanical stresses such as folding, abrasion, compression, and machine counting, all of which affect their material and structural properties. Their durability is therefore directly related to the selection of raw materials, the development of manufacturing processes, and the introduction of new security and graphic technologies. At the same time, the visual design of banknotes combines aesthetic, functional, and security requirements, making them an important subject of research at the intersection of graphic technology, materials science, and design.

This paper examines the relationship between the visual design of banknotes and their material properties through a comparative analysis of three historically distinct means of payment: a Yugoslav 100-dinar banknote, a Slovenian 10-tolar banknote, and a 5-euro banknote.

The aim of the study is to determine how the development of graphic technologies, different production conditions, and prolonged circulation influence the physical, structural, and optical properties of the paper substrate. By comparing banknotes produced in different economic and technological environments, the research contributes to a better understanding of the impact of technological progress on the durability, quality, and resistance of modern security printing products.

1.1. Samples

This study investigates the properties of banknote paper materials, which, due to their specific nature and everyday use, are continuously exposed to mechanical stresses such as folding, rubbing, and machine counting.

The aim of the research was to compare the properties of banknotes from different historical periods and produced using different graphic production technologies.

Three samples were selected for analysis: Sample 1 (V1), a Yugoslav 100-dinar banknote, Sample 2 (V2), a Slovenian 10-tolar banknote and Sample 3 (V3), a 5-euro banknote. Although all three samples were based on cotton fibres, they were produced under different economic conditions.

The measurements were performed on circulated banknotes. During sample selection, special attention was paid to choosing banknotes that exhibited a comparable degree of material wear in order to ensure the validity of the comparative analysis. Yugoslav dinars and Slovenian tolars were printed in large quantities and under considerable time pressure during periods of high inflation, raising concerns about their long-term quality and durability when compared with the modern, strictly controlled production of euro banknotes.

1.1.1. Dinar (1945-1991)

Following the end of the Second World War, the monetary system was centralized under the National Bank of Yugoslavia, which operated through republican branches, including the National Bank of Slovenia. During the 1950s, banking activities recovered, although frequent monetary instability often increased the importance of foreign convertible currencies in everyday life.

Throughout its existence, the Yugoslav dinar underwent several design changes that reflected the political and ideological identity of socialist Yugoslavia (Figure 1). Banknotes commonly featured partisans, workers, farmers, fishermen, and female figures, while the reverse sides often depicted cities, landscapes, or national landmarks. Portraits of prominent Yugoslav figures, ornamental elements, and revolutionary monuments were also frequently included.



» **Figure 1:** *Sample 1 (V1), the Yugoslav 100-dinar banknote, which was in circulation between 1945 and 1991*

The visual language of the dinar emphasized the working individual in factories and rural environments, highlighting the connection between industrial development and agricultural prosperity. Artistic and cultural heritage also appeared on banknotes, including representations of monumental sculptures such as the memorial by Miodrag Živković in the Sutjeska National Park, one of the most recognizable memorials of the Yugoslav period.

1.1.2. Tolar (1991-2007)

Following Slovenia's declaration of independence in 1991, preparations began for the introduction of a new national currency. After a design competition organized by the Bank of Slovenia, the first regular issue of the Slovenian tolar entered circulation on 30 September 1992. The banknotes were designed by Miljenko Licul, Zvone Kosovelj, Rudolf Španzel, and Janez Boljka (Čelik, 2011).

The visual composition of the tolar was divided vertically. The obverse featured a portrait of a prominent Slovenian figure alongside the denomination, while the reverse presented attributes, artistic works, or achievements associated with the depicted individual. For example, the banknote featuring France Prešeren included references to Zdravljica, while the Jože Plečnik banknote depicted the façade and floor plan of the National and University Library (Banka Slovenije, 2021). In addition to sophisticated graphic design, the banknotes incorporated tactile relief elements to assist visually impaired users and differed in size according to denomination. Typography was based on the Friz Quadrata typeface (Figure 2).

The tolar served as Slovenia's national currency and legal tender from 1992 until the adoption of the euro in 2007. The selected portraits represented some of the most important figures in Slovenian cultural and scientific history, including Primož Trubar, Janez Vajkard Valvasor, Jakob Gallus, Jurij Vega, France Prešeren, Rihard Jakopič, Ivana Kobilca, Jože Plečnik, and later Ivan Cankar. Together, these motifs empha-

sized the cultural, artistic, and intellectual identity of the Slovenian nation (Banka Slovenije, 2025).



» **Figure 2:** *Sample V2, Slovenian 10-tolar banknote, issued during the period when the tolar served as the national currency of Slovenia (1991–2007)*

1.1.3. EURO (2007 -)

On 1 May 2004, the Republic of Slovenia joined the European Union and expressed its intention to become part of the euro area. On 1 January 2007, the euro was introduced in Slovenia, replacing the Slovenian tolar. With the adoption of the common European currency, monetary policy became integrated into the European Central Bank (ECB) system, while the Bank of Slovenia became part of the Eurosystem. The national side of the Slovenian euro coins was designed by Miljenko Licul.

The euro is the official currency of Slovenia and has been in use since 1 January 2007. Before its introduction, Slovenia was required to meet the convergence criteria established for membership in the Economic and Monetary Union. The first series of euro banknotes was designed by Robert Kalina of the Austrian National Bank, who won the European design competition in 1996. Each denomination represents a characteristic architectural style from European history.

The €5 banknote (Figure 3) symbolizes Classical Antiquity, €10 Romanesque architecture, €20 Gothic architecture, €50 the Renaissance, €100 Baroque and Rococo styles, and €200 the iron and glass architecture of the nineteenth century. The front side depicts windows and gateways as symbols of openness and cooperation among European nations, while the reverse side features bridges representing communication and connection within Europe and beyond. The twelve stars of the European Union symbolize harmony and unity. Banknotes differ in size and colour and incorporate numerous security features, including microprinting, infrared elements, and features visible under ultraviolet light (European Central Bank, 2023).



» **Figure 3:** *Sample V3, 5-euro banknote, circulating in Slovenia since the adoption of the euro in 2007*

The second series of euro banknotes, entitled Europa, takes its name from the portrait of Europa, a figure from Greek mythology. While retaining the architectural concept of the first series, it introduces a refreshed visual identity. Designed by Reinhold Gerstetter, the series employs stronger colours, softer forms, and three-dimensional bridge designs, making it easier to distinguish from the first generation of banknotes. In addition to aesthetic improvements, the Europa series incorporates more advanced security features that significantly increase protection against counterfeiting (European Central Bank, 2023). The national side of Slovenian euro coins features important personalities, cultural symbols, and elements of Slovenia's natural and historical heritage. The €2 coin depicts the poet France Prešeren together with the inscription “May all nations live”, while the €1 coin features Primož Trubar and his famous motto “To stand and withstand”. Other motifs include Mount Triglav, Lipizzaner horses, Plečnik’s Cathedral of Freedom, the Sower, the Prince’s Stone, and a stork. Designed by Miljenko Licul in collaboration with Maja Licul and Janez Boljka, these motifs collectively express Slovenia’s national identity, history, and cultural heritage.

2. Methods

2.1. Objectives

The main objective of this research was to investigate how technological advancement, mass production, and the degree of actual wear are reflected in the properties of banknote paper. We aimed to determine whether modern production standards, represented by sample V3, have resulted in a significant improvement in material homogeneity compared with older banknotes (V1 and V2), which circulated during periods of economic pressure. Standard methods were employed to determine the basic, surface, structural, and optical properties of the paper. An optical microscope was used for image analysis, providing a deeper insight into the obtained measurements.

2.2. Hypotheses

Based on the visual inspection, tactile assessment, and historical background of the samples, the following hypotheses were formulated and subsequently evaluated in the conclusion:

1. **Hypothesis 1:** Sample V3 will exhibit the best physical properties, as it represents the highest level of modern papermaking technology.
2. **Hypothesis 2:** Sample V2 will show the weakest performance, as it already appears the most fragile during initial handling, indicating significant mechanical fibre degradation and loss of structural strength.
3. **Hypothesis 3:** Due to rapid mass production and the influence of inflationary periods, samples V1 and V2 will exhibit greater variability and non-uniformity in the measured properties than sample V3.

2.3. Challenges and Methodology of the Research Process

During the research, we encountered several challenges related to data interpretation. Due to the lack of official technical data, which are treated as confidential information, a direct comparison of absolute values (e.g., grammage values) was not possible. Therefore, the analysis was based on relative comparisons between the individual samples. An additional challenge was the influence of banknote wear. When interpreting the results, it was necessary to distinguish between the intrinsic quality of the paper and changes in its properties caused by use and material ageing. Another important aspect of the study was the selection of an appropriate methodology.

Because legal regulations prohibit damaging currency and because the integrity of the samples had to be preserved, only non-destructive measurement methods were employed. The chosen methods enabled a comparative analysis using different approaches, ranging from macroscopic measurements to microscopic fibre imaging and analysis. The experimental work was carried out in several stages. The first stage involved the determination of the basic properties of the samples, the second focused on surface properties, the third on structural properties, and the fourth on optical properties. During the measurements, particular attention was paid to an adequate number of test specimens and to the correct identification of the upper (A) and lower (B).

2.3.1. Description of Testing Methods

For the three selected samples, the following properties were determined in accordance with standard testing methods. Basic properties: grammage, thickness, density, and specific volume, Surface properties: Bendtsen roughness and Bendtsen porosity. Structural properties: sound pulse propagation velocity; Optical properties: opacity.

3. Results and discussion

3.1. Basic Properties

The analysed banknote samples differed in their basic properties (Table 1). Since official banknote grammage data are not publicly available and are considered confidential, it was not possible to calculate the exact deviations from the specified values.

Nevertheless, the measurements provided important insight into the actual grammage values of the analysed samples. Sample V1 exhibited a grammage of 89.0 g/m² with the lowest coefficient of variation. Sample V2 reached a grammage of 91.5 g/m² and showed the highest coefficient of variation (CV = 3.24%), which may be attributed to mechanical wear and the uneven distribution of fibres within the paper structure. Sample V3 achieved the highest grammage, namely 100.8 g/m².

Table 1
Results of grammage, thickness, density, and specific volume measurements

		G [g/m²]	d [mm]	r [kg/m³]	n [m/kg³]
V1	1.	90,23	0,102	884,6	0,00113
	2.	87,84	0,115	763,8	0,00131
	S_x	89,0	0,109	824	0,00122
	$\bar{x}$	1,7	0,009	85	0,00013
	CV	1,90	8,47	10,36	10,43
V2	1.	89,41	0,108	827,9	0,00121
	2.	93,6	0,127	737	0,00136
	S_x	91,5	0,118	782	0,00129
	$\bar{x}$	3,0	0,013	64	0,00011
	CV	3,24	11,43	8,21	8,25
V3	1.	98,79	0,114	866,6	0,00115
	2.	102,79	0,112	917,8	0,00109
	S_x	100,8	0,113	892	0,00112
	$\bar{x}$	2,8	0,001	36	0,00004
	CV	2,81	1,25	4,06	3,79

Although no substantial differences in thickness were observed among the investigated samples, V2 was the thickest sample and also exhibited the highest coefficient of variation (11.43%). Variations in thickness result from the internal structure of the paper and the degree of mechanical wear, both of which directly influence the thickness of individual specimens.

Sample V1 was the thinnest, although it also displayed considerable variability. The best results were obtained for sample V3, where the coefficient of variation was only 1.25%.

The highest density was measured for sample V3 (892 kg/m³), reflecting its high compactness and increased fibre content. At the same time, this sample was the most homogeneous and consistent, achieving the lowest coefficient of variation (4.06%), which indicates greater material uniformity. In contrast, sample V2 exhibited the lowest density (782 kg/m³). Combined with its greater thickness and higher coefficient of variation (8.21%), this confirms that the fibres in this paper are less tightly bonded.

The highest specific volume was recorded for sample V2 (0.00129 m³/kg), which is a consequence of its lower density and uneven thickness resulting from the paper structure itself. The lowest specific volume was measured for sample V3 (0.00112 m³/kg), indicating that the material contains the fewest air voids between fibres and is therefore the densest and most compact of the analysed samples.

3.2. Surface Properties

3.2.1. Roughness

As shown in Table 2, a two-sidedness of the material can be observed in samples V1 and V3. In sample V1, the difference between sides A and B amounted to 5.19%, while in V3 it was 3.33%. Despite these differences, both samples still reflect a relatively homogeneous paper structure.

The roughest and most uniform profile was exhibited by sample V2, where the roughness values on both sides were identical (2175 ml/min). The complete absence of two-sidedness in this sample indicates a high degree of mechanical wear. In contrast, sample V3 exhibited the smoothest surface, with roughness values ranging between 1500 and 1550 ml/min. Sample V1 showed the highest standard deviation on side A (126 ml/min) and side B (150 ml/min), further confirming the uneven distribution of fibres and the effects of mechanical paper wear.

3.2.2. Porosity

The porosity of the paper, presented in Table 2, depends on the degree to which the paper structure is filled with fibres, sizing agents, and fillers (Rutar, 2002). All of these parameters significantly influence the physical properties and usability of the banknote.

The lowest level of porosity was determined for sample V3 (9 ml/min), confirming that the sample is dense, compact, and contains a minimal proportion of air voids between fibres (Table 2). In contrast, sample V2 exhibited the highest porosity (55 ml/min), indicating the presence of larger pores that allow air and liquids to pass more easily through the material.

As a result, such paper is somewhat softer to the touch, while higher porosity may negatively affect the visibility and durability of security features, such as watermarks (Rutar, 2002).

Table 2

Results of Roughness and Porosity Measurements

		H_B [ml/min]		P_B [ml/min]	
		A	B	A	B
V1	1.	2000	1700	15	20
	2.	2200	2000	10	10
	3.	1900	2000	20	10
	4.	2000	2000	15	10
	S_x	2025	1925	15	13
	$\bar{x}$	126	150	4	5
	CV	6,21	7,79	27,22	40,00
V2	1.	2300	2400	30	90
	2.	2000	2100	25	70
	3.	2100	2200	60	30
	4.	2300	2000	65	30
	S_x	2175	2175	45	55
	$\bar{x}$	150	171	20	30
	CV	6,90	7,85	45,36	54,55
V3	1.	1400	1500	5	10
	2.	1600	1700	7	15
	3.	1700	1400	10	5
	4.	1500	1400	10	5
	S_x	1550	1500	8	9
	$\bar{x}$	129	141	2	5
	CV	8,33	9,43	30,62	54,71

3.3. Structural Properties

3.3.1. Sound Propagation Velocity

Anisotropy plays a significant role in determining the physical and mechanical properties of the investigated material. As shown in Table 3, the machine direction (MD) is considerably more pronounced than the cross direction (CD) in all analysed samples, confirming the oriented structure of the material. This indicates that the fibres are predominantly aligned in the machine direction, providing the material with greater tensile strength and mechanical stability along that axis. Sound propagation velocities measured in the MD ranged from 0.49 to 0.55 km/s, whereas significantly lower values were recorded in the CD, approximately 0.35 km/s.

Such pronounced yet balanced anisotropy in the machine direction (MD) is particularly important for the service life of banknotes, as they are continuously

exposed to various mechanical stresses during circulation, including folding, rubbing, and handling, as well as numerous environmental influences such as moisture, temperature fluctuations, and contact with liquids. The oriented fibre structure provides increased resistance to mechanical damage and contributes to maintaining the structural integrity of banknotes throughout their period of use.

It was found that the anisotropy values of all analysed samples, despite originating from different periods of banknote production, were comparable and consistent. Based on these results, it can be concluded that the banknotes examined were produced in accordance with strict and uniform manufacturing standards throughout the different historical periods. This confirms that banknote paper production has been technologically well controlled over time and adapted to meet the requirements for high mechanical durability, tensile strength, structural stability, and long-term circulation performance.

Table 3

Results of Sound Wave Propagation Velocity Measurements

C [km/s]		
V1	MD	0,49
	CD	0,35
V2	MD	0,54
	CD	0,34
V3	MD	0,55
	CD	0,35

3.3.2. Opacity

As shown in Table 4, sample V2 exhibited the highest opacity on side A (99.17%), followed by sample V1 on side B (97.40%). In sample V1, a larger difference between sides A and B was observed (3.25%), whereas sample V3 transmitted the greatest amount of light. At the same time, V3 exhibited the lowest coefficient of variation, indicating exceptional material homogeneity.

The slightly lower opacity of sample V3 may be the result of a deliberate technological solution intended to improve the visibility of security features, such as watermarks.

However, additional measurements on a larger number of samples would be required to confirm this hypothesis conclusively. Nevertheless, the opacity of all analysed samples was sufficiently high (Table 4) to prevent unwanted show-through of printing from the opposite side. This ensures a clear visual separation of graphic elements and is essential for high-quality double-sided printing (Rutar, 2002).

Table 4

Results of Opacity Measurements

OP [%]			
		A	B
V1	x_{min}	86,97	90,27
	x_{max}	98,24	100,48
	S_x	94,15	97,40
	$\bar{x}$	4,44	4,14
	CV	4,72	4,25
V2	x_{min}	97,40	90,40
	x_{max}	103,47	99,06
	S_x	99,17	96,17
	$\bar{x}$	2,58	3,49
	CV	2,61	3,63
V3	x_{min}	94,19	94,28
	x_{max}	96,99	95,82
	S_x	95,35	94,90
	$\bar{x}$	1,24	0,73
	CV	1,30	0,77

3.3.3. Optical Microscopy

In sample V1, the microscopic image (Figure 4) reveals a loosened fibre network with noticeable voids or pores. The fibres are distributed rather randomly, and signs of paper ageing are visible, with individual fibres being less interconnected, which explains the higher roughness of the material.



» **Figure 4:** *Optical Microscopy (V1)*

In sample V2, the structure is uneven, and the effects of mechanical wear are clearly visible in Figure 5.



» **Figure 5:** *Optical Microscopy (V2)*

Figure 6 of sample V3 reveals an exceptionally dense, tightly interwoven, and homogeneous cotton fibre structure. Voids between fibres are almost imperceptible, confirming the low porosity (9 ml/min) and high density of the material. The surface is smooth and compact, resulting from the advanced calendering and finishing processes used in modern banknote production.



» **Figure 6:** *Optical Microscopy (V3)*

4. Discussion

Based on the measurements performed, significant differences among the selected banknotes were identified, and all proposed hypotheses were confirmed.

Sample V3 exhibited the best overall properties across all measured parameters. With the highest density, lowest porosity, and exceptional homogeneity, it represents the highest-quality and most technologically advanced material included in the study, providing maximum durability and high resistance to environmental influences. Sample V2 displayed the weakest material properties. Its high roughness, low density, and microscopically visible fibre loosening are direct consequences of extensive mechanical wear.

Compared with V3, samples V1 and V2 showed greater variability in the measured values. This may be attributed to the effects of mass production during periods of inflation and to uneven material wear. However, additional measurements on a larger number of samples would be required to confirm this assumption conclusively. The study demonstrated that material quality, long-term use, and mechanical stress significantly alter the structure of banknotes.

While sample V1 occupies an intermediate position with relatively good dimensional stability, the modern production standards represented by sample V3 provide an optimal balance between opacity, necessary for the visibility of security features, and stiffness required for reliable machine processing.

5. Conclusions

This study examined the relationship between the visual design and material properties of three historically distinct banknotes: the Yugoslav dinar, the Slovenian tolar, and the euro. Although all analysed samples were produced from cotton fibres, significant differences were identified in their physical, structural, surface, and optical characteristics.

The results confirmed all three research hypotheses. The contemporary euro banknote (V3) achieved the highest density, the lowest porosity, and the greatest material homogeneity, demonstrating the advantages of modern papermaking technologies, stricter quality-control procedures, and advanced security-printing standards. In contrast, the Slovenian tolar (V2) exhibited the most pronounced signs of mechanical degradation, including increased roughness, lower density, and a more open fibre structure. The Yugoslav dinar (V1) occupied an intermediate position, showing evidence of ageing while maintaining relatively stable structural properties. Microscopic analysis supported the quantitative measurements and revealed a clear relationship between material compactness, wear resistance, and long-term circulation performance. The study demonstrated that prolonged use, environmental exposure, and mechanical stress significantly influence the physical condition of banknotes, regardless of their original production quality.

Beyond their monetary function, banknotes also represent important artefacts of visual culture. The analysed currencies reflect three different political, cultural, and economic contexts: the socialist identity of Yugoslavia, the nation-building period of independent Slovenia, and the supranational visual identity of the European Union. Their designs illustrate how graphic communication, symbolism, and security requirements have evolved alongside technological innovation. The findings further suggest that the future development of euro banknotes will continue to be shaped by the balance between visual communication, security, sustainability, and durability.

The forthcoming new generation of euro banknotes, currently being developed by the European Central Bank, indicates that banknote design remains an active field of innovation despite the increasing importance of digital payment systems. Future issues are expected to introduce new visual themes, improved security features, and environmentally conscious production processes, while continuing to fulfil their role as both secure payment instruments and carriers of European cultural identity. The research confirms that the evolution of banknotes is not merely a history of money but also a history of graphic design, materials engineering, and technological progress. As such, banknotes remain valuable objects for interdisciplinary research at the intersection of design, culture, and material science.

6. Acknowledgments

Associate Professor dr. Klemen Možina.

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