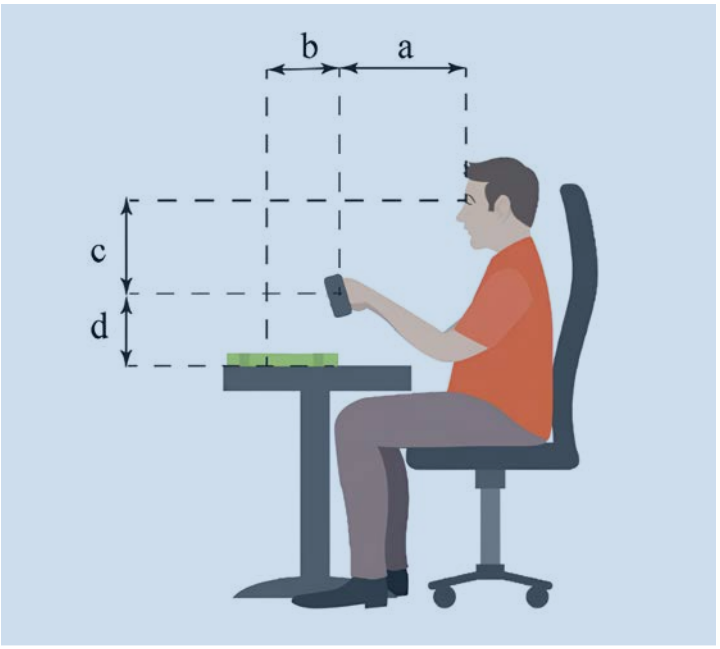
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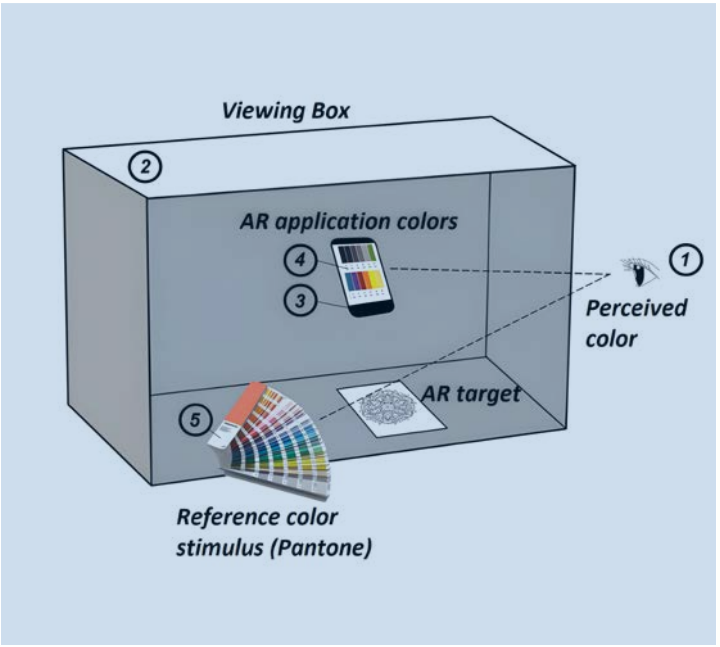
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Curating pedagogical change: A model for leadership and co-creation in student-led exhibition practice

ABSTRACT

This paper examines how pedagogical and operational strategies were put into practice while integrating a large-scale student exhibition, held as part of the European Design Awards festival, into the academic curriculum. The initiative was guided by experiential and project-based learning (PBL). It sought, above all, to connect classroom teaching with professional practice. In practice, the methodology tended to emphasize collaborative planning, structured team roles, and sustained staff engagement, grounded in principles of motivation and autonomy. These principles were evident in how students managed their own sub-projects. The main strategies involved creating dedicated teams for mentoring, curation, and logistics; introducing structured communication processes; and fostering an environment that promoted a sense of ownership among both students and staff. The results suggested a meaningful and lasting impact on both students and faculty. The project equipped students with industry-relevant skills and opened new professional opportunities. For faculty, this meant rethinking their role from knowledge deliverers to facilitators of hands-on, real-world learning, which encouraged more collaborative and student-led teaching methods. The institution also gained recognition within the European design community. In retrospect, the process itself proved to be a powerful driver of innovation, growth, and cultural change, despite challenges such as workload and resources. The study concludes that immersive, student-led projects are most effective when embedded into the curriculum, though their long-term sustainability depends on continued institutional support.

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KEY WORDS
co-creation, experiential learning, project-based learning (PBL), pedagogical transformation, transformational leadership

Introduction

The primary aim of organizing a student exhibition as an accompanying event of the European Design Awards festival was to integrate professional practice into the academic curriculum. This allowed the teaching team to bridge theory with real-world application (Kolb, 1984). The teaching team guided a cross-disciplinary group of students and staff, ensuring the event's success while gathering insights to establish a sustainable model for future student-led showcases. Built on mentorship and strategic planning, the effort not only equipped students with career-ready skills but also advanced institutional goals (Opoku, Appiah & deGraft-Yankson, 2020). It also contributed to a broader framework of public projects, with an impact that extended far beyond a single event.

The team faced complex logistical and creative decisions. By fostering a collaborative environment, members aligned around a shared vision and created a temporary but effective community of practice (Wenger, 1998). Swift, solution-focused meetings were held whenever unexpected constraints arose, leading to agile revisions of layout and workflow.

This approach, which emphasized problem solving, empowerment, and conflict management, proved critical in making operations more efficient and strengthening the overall impact of the exhibition (Bass & Riggio, 2006; Amabile & Kramer, 2011).

Recognizing that influencing and supporting staff was fundamental to achieving both pedagogical and professional objectives. Within the PBL framework, administrative and faculty members required inspiration, active engagement, and sufficient resources (Blumenfeld et al., 1991; Taneja, 2025). By deliberately creating an empowering environment, we aimed not only to support immediate roles but also to encourage long-term shifts, in line with principles of constructive alignment (Biggs & Tang, 2011).

Methods

Vision and Concept Development

We used a qualitative approach that included post-event reflective analysis, structured debrief sessions with staff and students, and a review of project documentation to explore the development process (Figure 1). The first step was to shape a guiding framework that reflected the European Design Awards' emphasis on creativity and innovation. Through collaboration, we worked with staff to embed the vision into teaching practice. This enabled more effective student mentorship and ensured a stronger alignment between exhibition goals and curriculum outcomes (Kaplanoglu & Dinç, 2019).

This process helped students develop industry-relevant skills while giving staff the chance to engage directly with experiential learning strategies (Wenger, 1998; Kong, 2021; Lave & Wenger, 1991). To foster inclusivity and co-creation, structured sessions were organized with students and staff to gather ideas about themes, presentation styles, and interactive elements.

This participatory approach, which is rooted in social constructivism (Vygotsky, 1978), encouraged staff to contribute to conceptual development directly rather than taking on a purely supervisory role. This promoted a sense of ownership and strengthened collaborative investment across the teaching and learning community.

Close collaboration with administrative staff ensured that vision development remained aligned with broader institutional goals. We gained strong commitment from faculty and administrators by articulating a clear and shared purpose. By maintaining a transparent and motivating environment, we reinforced a culture where all contributors felt valued and inspired to engage meaningfully (Kolb, 1984; Ryan & Deci, 2000).

Building and Managing a Strong Team

Balancing creativity, experience, and technical expertise was essential for building an effective team (Belbin, 2012). A key part of the process involved identifying, recruiting, and coordinating faculty members, mentors, and administrative staff. Ensuring broad participation and equity allowed all students at the Institute of Creativity and Innovation to present their work.

To adequately support students, it was important to define structured roles for staff that leveraged their individual strengths (Bass & Riggio, 2006).

To ensure effective collaboration and execution, responsibilities were divided among specialized teams (Northouse, 2021; Hattie & Timperley, 2007; Wenger, 1998; Biggs & Tang, 2011), each with clear objectives (Table 1).

Table 1

Team Structure, responsibilities, and impact

Team	Core responsibilities	Leadership approach	Key outcomes
Mentoring Team	Student guidance Constructive feedback Creative concept refinement	Empowerment-focused Encouraged initiative Autonomous problem-solving	Staff shifted from content deliverers to facilitators Adoption of PBL, flipped classrooms, structured debates Enhanced formative assessment skills
Curation Team	Exhibit selection Narrative construction Thematic coherence	Trust-based delegation Creative autonomy Regular check-ins	Cohesive exhibition narrative Enhanced curatorial skills among staff Strong thematic alignment with awards standards
Organizational Team	Logistics management Technical operations Administrative coordination	Structured oversight Clear deadlines Resource allocation	Seamless event execution Improved project management capabilities Technical proficiency development

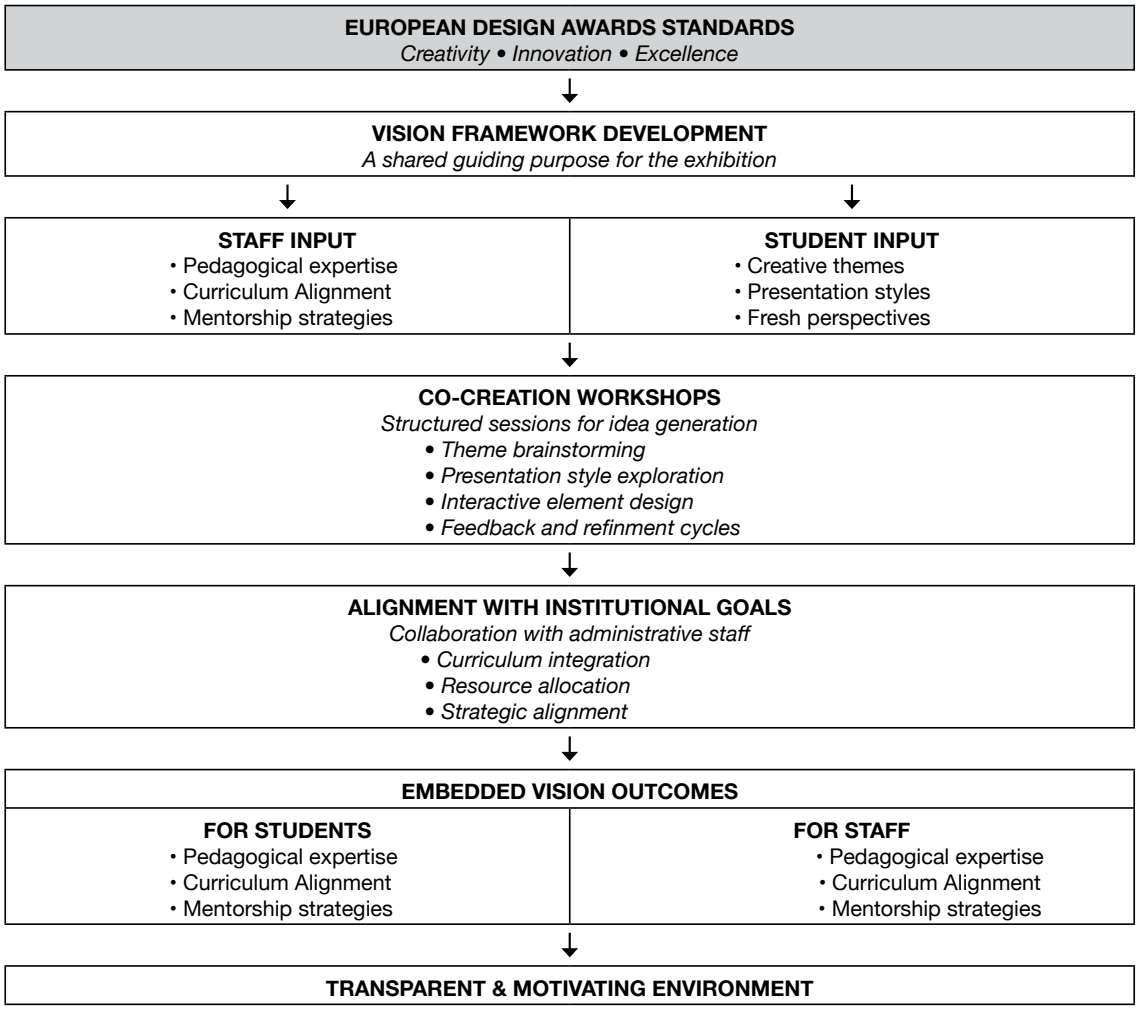
Meetings were held weekly to monitor progress and address any emerging challenges.

While delegating tasks, the focus was on motivating and empowering staff, encouraging initiative, autonomous problem-solving, and leadership development as well (Amabile & Kramer, 2011; Zhang & Bartol, 2010).

Reflective data obtained after the event revealed a notable shift in how staff perceived their professional roles.

Many transitioned from seeing themselves as content deliverers to facilitators of practical, real-world learning. Several staff members introduced structured debates, problem-based learning (PBL) scenarios, and flipped classroom models in their teaching based on their mentoring experience (Barrows, 1996). Staff also reported that providing iterative feedback during the collaboration enhanced their formative assessment skills, which they later integrated into their studio instruction time (Black & Wiliam, 1998).

We cultivated an innovative and accountable work environment while balancing guidance with trust in the team's ability to make decisions. As a result, staff morale improved, and many reported feeling more confident about tackling complex projects in the future (Ryan & Deci, 2000; Edmondson, 1999).



» **Figure 1:** *Vision development and co-creation process*

Influencing and Motivating Staff

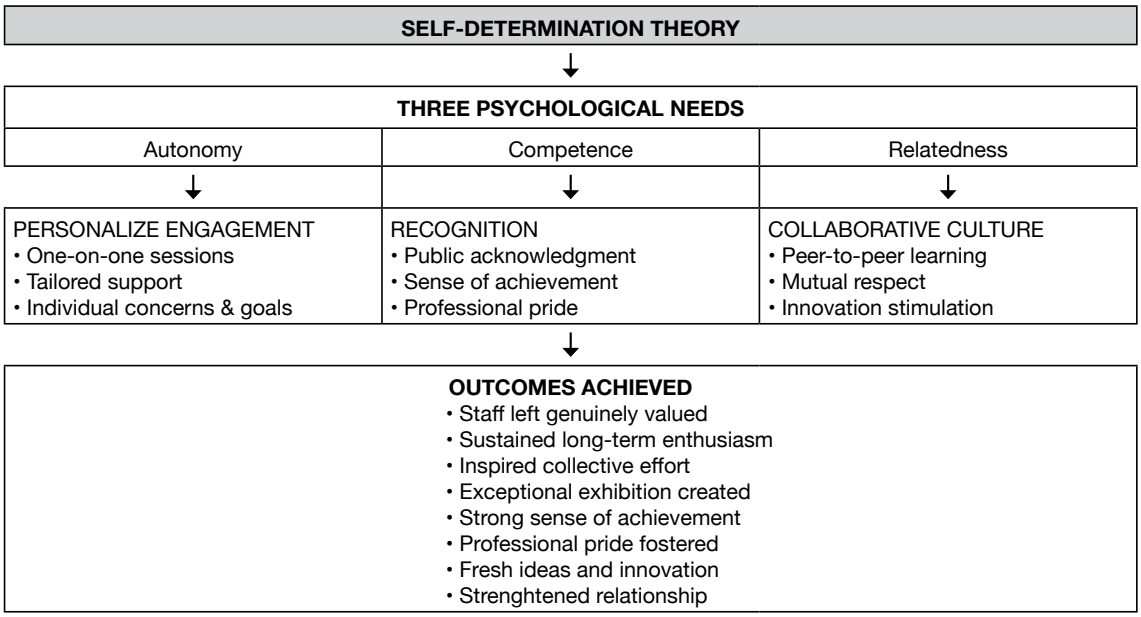
One of our key responsibilities during the project was keeping staff motivated and engaged.

Given the extensive scale of the exhibition and the prolonged preparation period required, maintaining long-term enthusiasm was critical (Kong, 2021). To address this, targeted strategies were implemented to foster and preserve motivation, guided by the principles of self-determination theory (Ryan & Deci, 2000). Figure 2 shows approaches that were implemented.

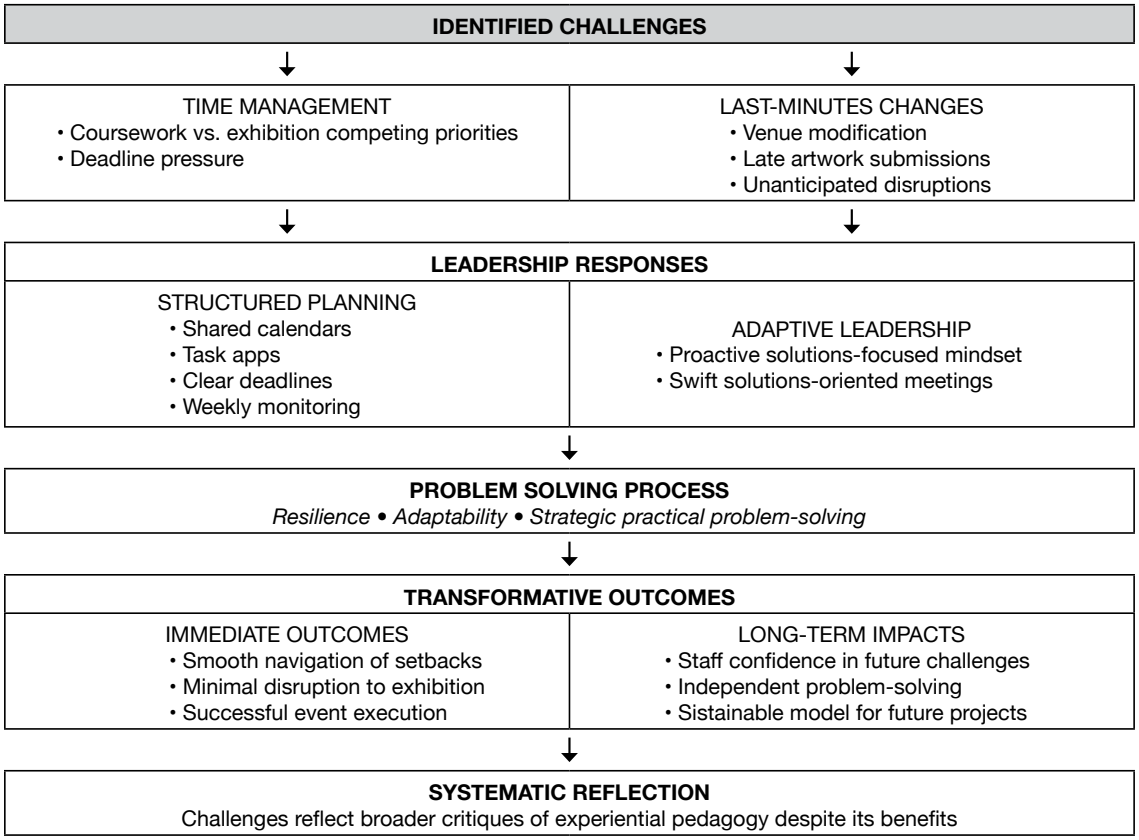
By consistently recognizing, supporting, and empowering staff, we kept them inspired and fostered the creation of an exceptional collective exhibition.

Overcoming Challenges and Problem-Solving

Several significant challenges (Zijlstra, Cropley & Rydstedt, 2014; Uhl-Bien & Arena, 2018) emerged during the project. Figure 3 shows how time management pressures and last-minute changes were addressed through structured planning and adaptive leadership.



» **Figure 2:** *Motivation strategy wheel aligned with Self-Determination Theory*

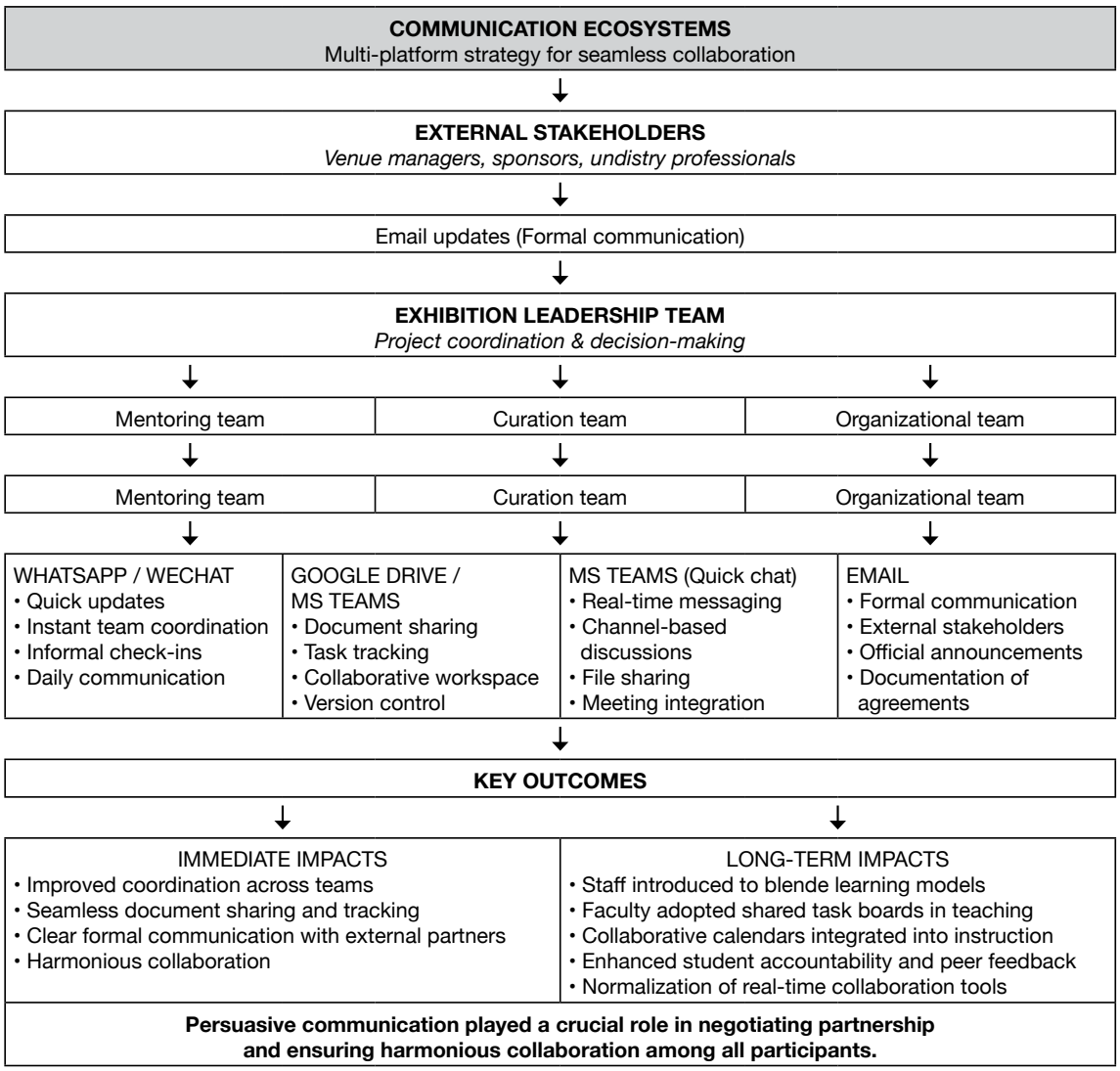


» **Figure 3:** *Challenge-Response-Outcome flow model*

These challenges reflected broader critiques of experiential pedagogy, in which educators often encounter systemic barriers despite its clear educational benefits. Through resilience, adaptability, and practical problem-solving, we supported staff in building the confidence to handle future challenges on their own.

Effective Communication and Management

Clear and consistent communication was essential for coordinating both across teams and with external stakeholders. To ensure seamless collaboration, several communication channels were established which is shown in Figure 4.



» **Figure 4:** *Communication ecosystem map*

Using these platforms, we not only improved coordination but also introduced staff to updated models of blended learning and project management (Garrison & Kanuka, 2004). Faculty members incorporated shared task boards and collaboration calendars into their teaching, helping foster student accountability and peer feedback. By doing so, we helped normalize the use of real-time collaboration tools in teaching practices. Persuasive communication was equally important, especially in negotiations to maintain harmonious collaboration among all participants.

Results and discussion

The exhibition day marked the shift from planning to execution (Figure 5). Our role transitioned from strategic leadership to hands-on operational management. This phase involved overseeing the final setup, ensuring technical systems functioned smoothly, and coordinating team efforts to keep operations running seamlessly. Maintaining a calm and authoritative presence was essential, as it instilled confidence in the team and enabled members to carry out their responsibilities effectively. The event successfully attracted industry professionals, journalists, and design enthusiasts, broadening its reach and impact.

After the event, reflection through structured debrief sessions with staff and students provided critical insights into successful practices and areas for improvement. Besides the immediate success of the exhibition, the initiative demonstrated notable long-term impacts. Staff reported substantial professional development in areas such as mentoring, event planning, and problem-solving. The project provided students with new professional opportunities. Furthermore, the institution achieved high recognition within the European design community and beyond.

Additional evaluations revealed a meaningful shift in pedagogical approaches among staff.



» **Figure 5:** *Exhibition space and poster presentation*

These changes included the adoption of co-creation methods in curriculum planning, an increased emphasis on formative, student-led critique sessions, and the implementation of diverse assessment methods such as portfolio reviews and live presentations.

These elements may be formally integrated into updated module descriptors and may contribute to the institution's ongoing quality enhancement process within its internal assurance framework.

This initiative achieved significant pedagogical transformation. Despite this, it is important to recognize that such constructivist approaches often encounter barriers related to workload, resources, and institutional preparedness. Our experience highlighted these constraints, especially in balancing academic commitments with exhibition demands, underscoring the necessity of sustained institutional support to ensure the long-term sustainability of such projects.

Conclusions

The successful leadership and curation of the European Design Awards exhibition were built on a clear strategic vision and a focus on motivating the entire team.

We brought students, faculty, and administrators together to handle every logistical detail, tackle challenges, and create an atmosphere where innovation thrived. Central to translating a shared vision into a successful event was the ability to inspire and direct collective efforts.

Staff were encouraged to assume ownership, which helped cultivate an environment conducive to creativity, collaboration, and excellence. As we aimed to go beyond mere delegation, the focus was shifted towards mentoring faculty and administrative teams to strengthen their leadership abilities.

This approach also fostered student participation and promoted a culture of shared accountability. This encouragement not only solidified the achievements of the exhibition but also reinforced connections between faculty, students, and other partners.

Looking back on this experience reveals the significant role of leadership and mentorship in the success of collaborative endeavours. Because we built trust and gave both students and staff real responsibility, people stayed motivated and committed to the project's goals.
The initiative confirmed the potential of leadership to generate meaningful educational experiences and opportunities for professional development.

The exhibition also served as practical training in using digital tools, equipping faculty to implement more interactive and student-driven instructional activities. Subsequent internal reviews noted a marked increase in instructors' confidence in digital pedagogy and student engagement in related courses.

The exhibition was more than just a display of art; it was a powerful experience. By empowering and mentoring everyone involved, it helped us all grow professionally. We left not just with a project, but with new confidence, leadership skills, and real-world experience that will shape our future work and studies.

What mattered most about the exhibition wasn't the opening night, but the process that led up to it. When we frame it as a core part of the curriculum, it drives innovation in teaching, gives students crucial professional development, and genuinely changes the institution for the better.

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Evolution and transform of the tone value meaning and metrics in standardizing the printing process control

ABSTRACT

Concept of the basic parameter of halftone printing - tone value is concerned in the historical context of improving the models of image printing. The multi-stage nature of a process is also taken into account in the light of solving the color communication problems of modern open and disconnected pre-press environment. The special attention is put for more accurate and different in their meaning and metrics interpretations and definitions of this term versions. The mathematically approved and experimentally confirmed examples of tone value presenting the stimulus like luminance Y of CIE XYZ or the perception thereof as CIE Lab lightness L are presented.

KEY WORDS
stimulus, perception, lightness, luminance, halftone

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Introduction and background

Having approved, in general, the draft of the new version of the lithography standard (International Organization for Standardization, 2023), developed by TC 130 “Printing technology”, the representatives of ISO member countries have put forward a number of general, technical, editorial comments and corrections in ISO/TC 130 N 5077.

For this reason, as well as due to the need to clarify the target values for novel "near neutral" calibration method the TC 130 has temporarily suspended this draft progress.

The proposed improvements did not however affect the cluster of terms unified within the tone value concept relating to the most important print image property.

With the emergence of new standards and the updating of existing ones, there was a need for more accurate, sometimes different in their meaning and metrics this term interpretations. To date, ISO TC130 documents have accumulated more than a dozen names of this term that have added or changed from version to version of the standard:

- tone value (data), digital tone value;
- tone value (printing), printed tone value;
- density tone value;
- tone value increase (TVI);
- tone value (printing forme), plate tone value;
- tone value (colorimetric);
- colour tone value (CTV), spot colour tone value (SCTV);
- delta colour tone value;
- near neutral CMY tone value;
- near neutral black tone value...

There was an attempt made in above draft, as well as in the previous standard versions, to streamline the list of these terms, hierarchically subordinating the particular terms to the senior ones by their indexing order in section 3 "Terms and definitions" of the document. Despite this, the most of interpretations remain rather uncertain, not always logical in a number of aspects and need some explanation or clarification. It’s below performed on the basis of historical review of printing calibration developments, analysis of process stages characteristics and image signal transforms, as well as by the use of some calculations and experimental data.

Densitometric and colorimetric calibration

According to basic binary (ink/no ink) principle of halftoning, the print tone measure is, historically, designated in a percent of the relative ink coverage within a unit image area. The intermediate, grey gradations on, for example, b/w print are, in turn, perceived due to the spatially additive mixture by the Human Visual System (HVS) of the halftone dot black and blank paper white portions.

With use of n process inks, the print color is similarly defined by the weighted sum of 2^n parts occupied within such area by blanks, ordinary ink layers and overlaps thereof. Following this logic, the temporal additively previewing of halftone color on the rotated Maxwell disk was suggested with dividing the latter onto 2^n sectors containing, for example, 2^3 (CMY) combinations of said portions (Nyberg, 1932).

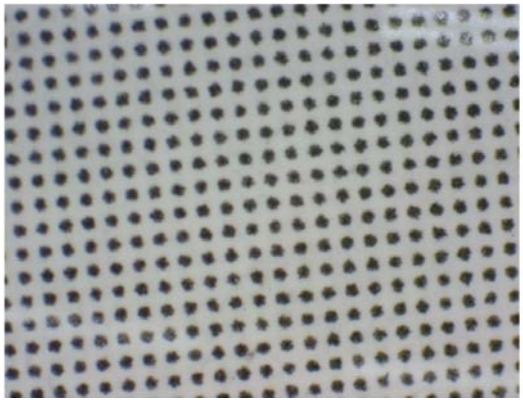
To estimate the expected reflectance or optical density of a halftone at its prescribed ink coverage in particular case of monochrome printing (n = 1) the formula was published to be thereafter widely used in the densitometric method of print control and calibration (Murray, 1936; Sheberstov, 1936). Following the same principle of partition area coverage, the generic model, applicable for the arbitrary number n of process inks and allowing the print color data prediction in various metrics, was next year published (Neugebauer, 1937).

All these, at first purely geometrical interpretations, were over time supplemented with taking into account the specific effects of the ink-substrate-light interaction on the result of printing:

- capture of light, scattered in a blank, by the edge of a halftone dot (Yule & Nielsen, 1951);
- ink film thickness dependence on the size of a dot (Byer, 1969);
- concomitant change in the reflection spectrum;
- multiple reflection/absorption of light within the print substrate (Yang & Kruse, 2000);
- variable effect of chromaticity of the latter on the color of a halftone tint, and the other factors.

Byer (1969) investigation has in particular shown that the ink film thickness on halftone dots sharply reduces at coverage lower 70%, which makes the densitometric estimation of a dot size rather doubtful.

Photograph of the halftone tint on figure 1 demonstrates, for example, the about twice greater visible coverage as compared to 6.5% of its densitometric calculation at ink solid of 1.55 and substrate of 0.1. It's visually evident from this figure that adding in blank area just of 5- 6 such dots will produce the complete, 100% coverage.



» **Figure 1:** *Micrograph of a halftone tint with the visual coverage over 10% against of its 6.5% as result of dot area densitometric calculation*

Additional errors arise due to the own noise of process and, in particular, the substrate roughness which causes the non-stable transfer onto it of the tiny dots and gaps.[1]

The use of densitometric estimation for printing process calibration is currently supplemented by the colorimetric one and the both of them stay operate with pairs of concepts/parameters, which, by virtue of physiology, very nonlinearly relate to each other. The former in these pairs refer to the stimulus affecting vision, and the latter to the perception as the sensation of this stimulus impact. In densitometry, such a pair consists of the reflection coefficient and its negative logarithm (optical density), while in colorimetry the similar roles play, for example, the luminance Y of XYZ and the Lab lightness L as the measure of luminance perception. However, the order of using these parameters in these methods turned out to be the opposite (Figure 2).

Coverage estimation

Densitometric		**Colorimetric**	
Perception ⟶ **Stimulus**		**Stimulus** ⟶ **Perception**	
(opt. density).	***(dot area, refl.)***	***(luminance)***	***(lightness)***

» **Figure 2:** *Opposite direction of the metrics replacement in two variants of data calculation for printing process calibration*

In the first method the dot area/absorption/luminance, i.e. stimulus is calculated from the perception-related optical density of a halftone tint. To the contrary, the, so-called, color tone value (CTV) of visually uniform Lab space is in the other one determined from the luminance Y (stimulus). Leaning towards the accustomed notion of ink coverage, the CTV name conceals this fundamental metrics difference relying upon its proper accounting in the curve calibration procedure.

[1] Except of the substrate (0%) and the ink solid (100%), the latest standards of 12647 series do not advice calculations in areas below 10% and above 90%.

Meantime, the term for basic print image parameter tone value proceed from the percent coverage principle stays generic in ISO12647 “Graphic technology…” series of standards since 1996 (International Organization for Standardization, 1996).

Characteristics of the process and its stages

From capturing an original to its print copy output the reproduction process encompasses the number of physical transforms of an image content. It starts from the light to electric signal conversion and completed by signal to substrate inking one. Each of these and intermediate signal transforms are characterized by the nonlinear relationship of their input and output values.

The transfer curve of each stage should be and is, in practice, optimized according to its own criterion. At image capturing it can, for example, comprise the maximal achievable dynamic range of a signal. In platemaking, such a criterion is the robustness of ink transfer on a substrate, as well as, on a press it can be the possible achievable tone range, color gamut...

Meantime, the standard does not recommend the criteria of optimization or related press settings, but, in consent to its title, teaches only to “Process control…”. It deals just with the calibration which would match the data of certain output profile or allows to produce and register the new one. Some of the initial on-press parameters can be only indirectly taken there from the particular set of multiple variants of Printing Conditions (PC).

However, just the ink supply can be in certain degree adjusted according to the color values of solids prescribed for the given PC. The other parameters of halftone printing stay passed by the standard relying upon the operator skills and experiences. It concerns of such important procedure settings as pressure on a press, volume and range of a K ink use (Kuznetsov & Ermoshina, 2016), as well as of the tone values of “white” and “black”.

The latters define the contrast, as the most predominant image property, comprising, in its turn, the base for the substantiation of a screen ruling value for the certain kind of technology (Kuznetsov, 1999). The achievable level of print image quality significantly depends on all of these parameters.

In the absence of optimization, it is not ensured that the own reproduction facilities of the process are realized in full scale. Instead of the optimal adjustment of the process itself, its correspondence to the output profile occurs primary.

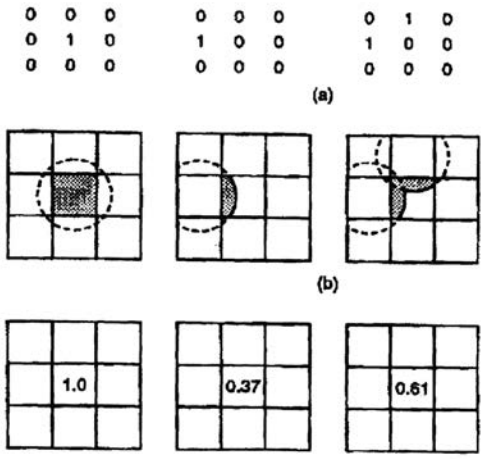
The ISO/TS 10128 does not help so much in this aspect as far as once again teaches just to the “Methods of adjustment… of a printing system to match a set of characterization data”. In such situation, the need for a document titled like "Optimal process organization for its further profiling or calibration..." may arise.

The task and result of the entire process is presented by the tone reproduction curve (TRC) connecting the tone value (data) and printed tone value (Kuznetsov, Schadenko & Vaganov, 2020). It follows from all intermediate curves which interrelation is used to demonstrate by the multi quadrant Jones diagrams (Kuznetsov, 2021). The issues of optimal shape and calibration of this curve are very relevant in today's open prepress environment and technical standards development (Birkett & Spontelli, 2018).

One of the main parameters of said calibration is the tone value increase (TVI)[2], which can be concerned as the sum of stepwise differences between:

- tone value (data) and tone value (printing forme);
- tone value printing forme and ink coverage on it;
- said coverage and printed tone value.

As figure 3 shows, the input-output non-linear connection at the first of above stages may result from the configuration incompatibility of a square cell in the recording signal bit map and round aperture exposing a plate (Carrara, Analoui & Allebach, 1992).



» **Figure 3:** *Element of the plate is partially exposed, even if it isn’t stipulated by the data tone value of an output bit map: a) bitmap; b) position of the beam when recording; c) tone value on the plate (adopted from Carrara, Analoui & Allebach, 1992)*

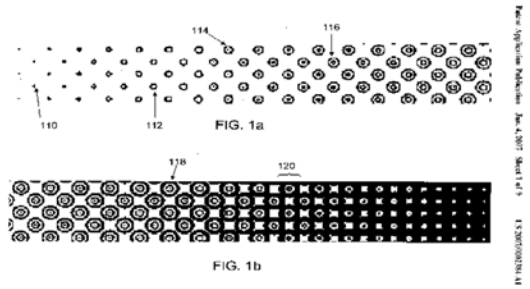
This discrepancy can be compensated due to the procedure of the, so-called, plate linearization by introducing corrections into the recording signal (Sanger, 2005).

[2] Earlier named as dot gain.

However, during the subsequent ink-to-plate transfer, the resulting ink coverage once again ceases to correspond to the tone values (forme) as soon as the adjacent ink menisci touch each other in mid- or three quoter tones. The effect of surface tension forces, which previously restrained the ink in the meniscus, changes here to the opposite, contributing to its fill-in the gaps.

At the last of these three stages, the physical reasons for the non-linear connection of the original and the resulting coverage are mostly due to the ink squeeze and absorption. TVI takes place here along the whole curve, since at a certain constant wetting angle, the meniscus ink volume grows faster than its size. It is believed, for example, that the ink layer thickness on a plate comprises about the tenth of a printing element diameter.

So, to make it more uniform over the coverage range it's proposed to perforate the halftone dots by the pin holes or concentric rings as shown in figure 4 (Samworth & Cadogan, 2007).



» **Figure 4:** *Halftone dots perforated by the rings to make their ink film thickness more uniform over the tone range (adopted from Samworth & Cadogan, 2007)*

It can be also concluded that, unlike theoretical one, the real TVI curve starts, instead of zero, from tone value (data) "white" which corresponds to some minimal, only just transferred and that is why not at all squeezed dot. Related to ink solid the end of this curve refers, in its turn, to the input data of a few percent lower than 100%.[3]

The TVI curve form and its extremum position are dependent on the geometry of a halftone dot (square, round, elliptical...) and that of a screen (stochastic, orthogonal, hexagonal, line wise...).

It is worthwhile to note in this connection that for a halftone formed not from dots, but by, for example, parallel lines of variable width the form of TVI curve substantially differs from those prescribed in standard to the particular PC. There is no place for ink to fill-in, because the solid is immediately formed when such lines touch each other.

[3] In earlier standard versions it was used to prescribe the effective dot area range as, for example, from 3-5% to 95-97%.

Due to these reasons the pressure setting according to such densitometric norm as print contrast

$$K = 100\ (D_S - D_{80})/D_S \qquad (1)$$

where D_S and D_{80} – densities of a solid and 80% halftone tint, looks appropriate only for orthogonal screen with round dots.

Image signal transforms

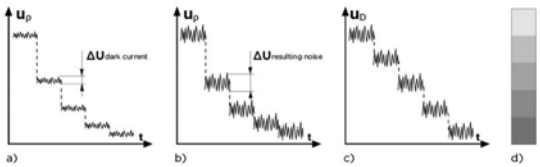
The transforms of an image signal content are sometimes encompassed by the data metrics replacement. For example, as far back as in analog scanners the signal of a light sensor closely related to object reflectance/absorption was used to right away transfer into somewhat perceptually uniform optical density values. Because ultimately, at the system output, there is used the signal of ink amount (dot area), so again associated with absorptions (this time on a print), the need for such a transform may seem not obvious and has attempted in explanation (Kuznetsov & Ermoshina, 2016).

The representation of an image signal most closely related to perception makes it more resistant to interference that accompanies any functional transformations of such a signal. Noises affect the image additive.

They are summarized of all generated at the subsequent stages: the dark current of a sensor, fluctuations in the electronic circuitry p~n transitions, quantization errors of analogue-to-digital (ADC), digital-to-analogue conversions and of forming the halftone dots from a discrete set of microdots. When such interference is concentrated within some part of a tonal range, its effect is most damaging.

Therefore, the signal is lead to uniform values at the very beginning, where the noise is still relatively small being comprised only of a sensor dark current. Effect of total process noise on the image, represented by such a signal, is, as shown in figure 5 (c), uniform over all reproduced tone range and less affect the resulting copy quality.

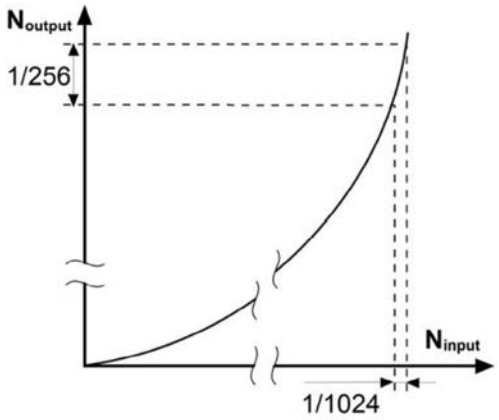
Otherwise, it is accumulated in the shadows diluting there the meaningful steps of gradation (Figure 5b).



» **Figure 5:** *Forms of reflectance U_ρ and density U_D signals for visually uniform tone scale (d): at the sensor output (a) and at the end of a channel without (b) and with the use (c) of logarithm transform*

Actuality of the luminance conversion into optical density or Lab lightness grows with the tone range increase of an original. Therefore, the signal is encoded in ADC of 10 and more digits. Reserve of quantization scale interval in the nonlinear conversion is needed to keep informative all the 256 levels of standard PDF/X eight-bit output. In the scanner, equipped, for example, with 30 bit ADC, each signal, captured behind the RGB filters, is quantized on a scale of the 2^{10} = 1024 levels.

On the part of tone curve transform with gradient of 4/1 the output eight-bit value stays, thanks to this reserve, informative being corresponded to at least one level of an input signal as schematically shown in figure 6.



» **Figure 6:** *To the "sufficiency" of the input signal bit depth for the nonlinear conversion*

High end scanners can use the 16-bit ADC in each color channel to process the originals of up to 4 units density range or directly supply such a signal to prepress software. That makes, for example, possible to provide without losses the necessary color corrections in CIE XYZ space prior to transition in perceptual CIE Lab one.

Backward transition to ink coverage/absorption has place just at the final stage in a RIP or printer driver due to inverse nonlinear connection of the halftone dot area with the amount of forming it microdots.

When defined as apparent intensity, does the tone value relate to stimulus or to perception thereof?

The generic meaning of term "tone value" is set in pp 3.3 of the above draft as area coverage – the ratio of ink covered area to the total area being measured, which metrically corresponds to the absorption coefficient or its inverse luminance affecting the Human Visual System (HVS).

But sensation is associated with one or another type of stimulus in a very non-linear way. Therefore, as an attempt to resolve the metrics conflict in the control scale patch assessment, the subparagraph 3.3.1 introduces the concept of apparent intensity (visual effect of the colorant (e.g. brightness, contrast, lightness) used to describe and measure the appearance of a patch). This term is used as an attribute in underlying definitions without its mentioning elsewhere over the text of a document. In the absence of such a term in CIE multilingual dictionary (International Commission on Illumination, 2020), its essence can be only indirectly judged from the notes and dimensions in this and the following subpoints. Initially, it is equated by such accepted in the CIE vocabulary words as brightness, lightness, which characterize the perception/sensation of luminance. So, it can be concluded that the apparent intensity stands for the perception and not for some kind of a stimulus force or intensity.

Only in the next, equilibrium pp 3.3.2 the term tone value, as number in the range of 0 to 1 or 0% to 100% that indicates the apparent intensity of a printed scale, is at last formulated. However, the first of these numerations characterizes the luminance Y of CIE XYZ, while the other, the linearly related to it coverage of pp. 3.3 and not at all the measure of their perception as, for example, the lightness L of CIE Lab. The latter is estimated in 1 to 100 units and is calculated from the luminance Y according to well-known formula

$$L = 116\,(Y/Y_{ref})^{1/3} - 16 \qquad (2)$$

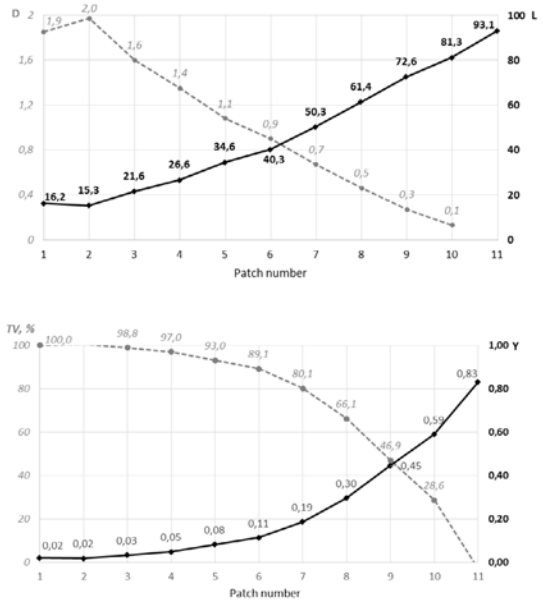
while the chromaticity coordinates a and b of CIE Lab are presented in units from-100 to +100.

Transformation of the signal of stimulus into a signal characterizing sensation changes the dimension. However, its presentation in the units of luminance or coverage (0- 1 or 0%- 100%) is not consistent with the noted therein facility of this term arbitrarily interpretation in practice and over the following text of the document.

It appears, for example, in clause 3.3.4 for term digital tone value- digital values for CMYK in the PDF/X document to be printed. When switching to L in a PDF/X file, the units 0 – 1 of Y or 0%-100% of CMYK coverage are nonlinearly quantized on the 0- 255 scale of an eight-bit code according, for example, to the above equation or by some other way which takes into account the considerations set forth in previous paragraph.

So, the luminance/coverage metrics of tone value to be encoded is different from metrics of content finally presented in such a file. To make sure of that is possible by printing from the PDF/X file the scale of ten patches uniformly divided within a range, as it may seem, at first glance, of a 100% of coverage, but, in fact, of 0 to 255

quantization levels of PDF/X byte. Measurements will show that not at all the relative dot area TV or luminance Y but the lightness L and the most part of optical density D values are linear along the scale (Figure 7).



» **Figure 7:** *Lightness (L) and optical density (D) values are linear along the visually uniform step wedge printed in equal data intervals from PDF/X file (upper) in contrast to the printed tone value TV or luminance Y (lower)*

These densitometric measurments where provided relative to the substrate through polarization filter with 45°/0° geometry and according to Status E, while the colorimetric estimation was relative to white, at black backing, 2°; D50; 45°/0° and without filter.

In case of b/w scale the CTV curve somewhat concides with that for L becouse of hereinbelow shown transform of CTV formula

$$SCTV = 100 \cdot \sqrt{\frac{(V_{x,t} - V_{x,p})^2 + (V_{y,t} - V_{y,p})^2 + (V_{z,t} - V_{z,p})^2}{(V_{x,s} - V_{x,p})^2 + (V_{y,s} - V_{y,p})^2 + (V_{z,s} - V_{z,p})^2}} \quad (3)$$

where subscripts t, p and s are correspondingly related to the halftone tint, paper and ink solid.

All V, as set in SCTV standard (International Organization for Standardization, 2017), are there calculated, similar to lightness L of CIE Lab, from the luminance Y of CIE XYZ according to formula (2). So, the equation (3) presents in fact the quotient of differences in lightness (ΔL)

$$SCTV\ (b/w) = 100 \cdot \frac{(V_{y,t} - V_{y,p})}{(V_{y,s} - V_{y,p})} = 100 \cdot \frac{L_t - L_p}{L_s - L_p} \quad (4)$$

Assuming the lightness of a substrate $L_p \approx 100$ and of an ink solid $L_s \approx 0$, it gives

$$SCTV\ (b/w) = 100 - L_t \quad (5)$$

As result, the multiplier 100, initially intended for normalizing the SCTV in percent, has vanished and, with taking into account the lightness (L) measure from 0 to 100 units, this parameter comprises somewhat as the “darkness” of a halftone tint.

This fact and above curves also confirm that the numeration, usually set along scale patches, is linearly related to such specific kind of a color attribute which is however declared for SCTV in “percent” confusing it with the habitual ink coverage. If such scales where organized at the equal step of an ink coverage/percentage they would look strongly non-uniform.

Encoded data interpretation should follow the steps sequence with priority of defining the method of encoding over its metrics (Giorgianni & Madden, 2008). Table 1 relates to encoding specification where the colorimetric method is applied to CMYK values with the perceptual CIE Lab metrics instead of CIE XYZ.

Table 1

Steps hierarchy of encoding specification for the PDF/X and SCTV

1	encoded property of an image	CMYK ink amount (% of coverage)
2	method of encoding	colorimetric
3	encoding metrics	CIE Lab
4	units	0 – 100 of Lab
5	normalization	0 – 255 quantization levels

So, as the result of an image signal transform, there arises the fundamental difference between metrics of the tone value to be encoded, specified in percentage of coverage, and of what the such kind of a file does in fact present.

Tone value increase

Subordinating the subsequent ones from 3.3.7.1 to 3.3.7.6, the pp 3.3.7 printed tone value is also designated as apparent intensity, as if to indicate this parameter perceptual nature and to put aside those related to the coverage or luminance.

Such metrics noncompliance right away reveals in the following points. For example, the density tone value (pp 3.3.7.1), once again defined as apparent intensity, does comprise the halftone dot percentage calculated with Murray formula and most likely characterizes the stimulus but not the appearance thereof.

Such lacking of metric conformance straight away arises for the term 3.3.7.2 tone value increase (TVI).

It's defined there as the difference between a density tone value and the digital tone value if allowing to subtract the measured data from its nonlinearly conversed one.

To the contrary, applying the attribute of apparent intensity looks just rightful for the colour tone value (CTV) in 3.3.7.3, as far as it's calculated on the basis of perceptually uniform CIE Lab dimensions. It is also reminded there to distinguish the color tone value from the colorimetric tone value (according to ISO 12647-1) calculated directly from the XYZ coordinates.

Hence, in contrast to the calculation of TVI according to clause 3.3.7.2, the metrics of decreasing and subtracting in 3.3.7.4 for the delta colour tone value: ΔCTV = CTV – T, where T is the digital tone value according to 3.3.4, quite coincide. There is also put attention that such way calibrated scales are visually uniform.

Moreover, the ΔCTV calibration aims are set in table 2-5 of the document, unlike TVI, in the Lab metric by the prescribed, both positive and negative, deviations from the digital tone value. So, it is hardly appropriate, as proposed in the Notes to clause 3.3.7.3, to estimate ΔCTV in a percent as well as to characterize it in relation to some linear curve by analogy with densitometric TVI, while, in fact, the required up or down shift from target CTV is there dealt.

Conclusion

Tone value is historically estimated by the relative inked area on a halftone print. Image printing models, originally based on this purely geometric premise, were over time supplemented accounting the number of physical and physiological interaction factors inherent in plate-ink-paper and light-print-vision systems.

This parameter versions are used today in the transfer function presentations for a variety of the printing process physical stages and image signal transforms, which are often inherent in changes of the method, metric and normalization in a signal encoding.

The numbers from 0 (lightest) to 100 (darkest) used to be set beside the patches of calibrating scales directly relate to the perceptive color attribute such as "darkness" (100 -Lightness) which makes these scales visually uniform.

So, the SCTV and CTV measurement in percent isn't expedient as far as their values are in the metrics of perception instead of that of habitual ink coverage, i.e. stimulus.

In tone value definitions it can be also recommended to deliver from the apparent intensity attribute due its rather indefinite, in this light, interpretation.

In the offset printing standard, it is, in common, advisable to formulate the definitions of tone value versions in such a way that the ranges of numerical values correspond to both the type and nature of the metrics and the method of their coding. This will allow to unambiguously interpret the meaning of numeration put beside the patches of control scales as an argument for the measured calibration functions.

There are the number of important process adjustment parameters which are advisable to be recommended by such a document for ensuring the complete use of a printing process facilities.

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Evaluating the reliability of spectrophotometer for print quality control

ABSTRACT

This study investigates the measurement system variability of a spectrophotometer, used for color control in the printing industry. A Type 1 Gage Study and Gage R&R was conducted for the Nix Spectro 2 spectrophotometer to evaluate the precision and accuracy in measuring color values of Cyan, Magenta, Yellow, and Black (CMYK) on 10 printed samples. The study assesses both repeatability and reproducibility to determine the overall measurement system capability. The results revealed high repeatability and low bias with Cg and Cgk metrics greater than 1.33, %Contribution below 1% and %Study Variation under 10%, thus confirming the reliability and suitability of Spectro 2 for color measurements. The findings shall aid the printers, quality control team, and designers in the optimization of color management workflows, ensuring consistent print quality.

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type 1 gage study, gage R&R, spectrophotometer, repeatability, reproducibility, print consistency, color management, quality control, process capability

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Introduction

Brands need to connect, communicate, and build trust with their consumers to maintain brand loyalty. The brand identity depends on the consistency of product and package printing as it conveys ideas and connects with potential consumers. Color is an integral part of brand identity and has an impact on consumers' emotional state. Hence, color control is paramount in the printing industry, where consistency and accuracy are critical for meeting client expectations, minimizing production waste, and easier brand recognition and loyalty.

These colors are printed on various substrates, like absorbent and non-absorbent, with different types of inks and printing processes. Maintaining color consistency is a challenge due to several process variables in the color management workflow across design, prepress, ink room and printing machine. Spectrophotometers play a vital role in providing quantitative measurements of color values and enable printers to monitor and adjust ink densities, tone value increase or dot gain, and other key quality metrics.

However, the reliability of these measurements is fundamental. Inconsistent measurements shall misguide the printers leading to incorrect adjustments of process parameters, higher color deviations, increased waste, and dissatisfied customers.

The ability of the color measurement system to consistently measure accurate colors directly impacts the validity of data-driven decisions, for example, pass-fail decisions by printing press operators or quality control teams. The variations in the color measurement systems arise from different sources like the instrument, the operator, and the printed sample (part). Evaluating the measurement system is essential to minimize these variations. A Type 1 Gage Study serves as a crucial analytical method for evaluating the color measurement systems. It is the first step in a comprehensive measurement system analysis (MSA) and lays the foundation for more detailed studies that consider other sources of measurement variation. It focuses solely on the gage (measurement device), assessing the repeatability and bias of a single measuring instrument to ensure the reliability of the data for the process (Muelaner, n.d.).

Repeatability refers to the extent of variation in measurements when a single part is measured repeatedly by the same operator, using the same instrument, and under consistent environmental conditions. Bias on the other hand compares the accuracy of the measuring instrument to a known standard (Minitab, n.d.). A Type 1 Gage study assesses a measurement device's capability for consistent readings under the same conditions. This makes it an excellent initial assessment to ensure the stability and precision of the gage itself before moving on to more complex analyses involving multiple operators or parts. It helps to determine if the measurement device, such as the Spectrophotometer, is capable of discriminating differences in color being measured. Type 1 Gage Study involves data collection, statistical analysis with metrics such as Cg (repeatability) and Cgk (bias) to quantify the gage's capability, and run chart to visually assess the measurement variation and identify any patterns or trends (SPC for Excel, 2024).

Gage R&R (Repeatability and Reproducibility) quantifies the variability originating from the measuring instrument (repeatability) and the operators (reproducibility) (Minitab, 2017). Reproducibility describes the extent of variation in measurements when multiple parts are measured by different operators and instruments on the same sample (American Society for Quality, n.d.; Soares et al., 2022; Burdick, Borror & Montgomery, 2003). Gage R&R is expressed in percentage and quantifies the proportion of total observed process variability attributable to the measurement system. If the Gage R&R% is below 10%, the measurement system is adequate and reliable while between 10% to 30% may be acceptable depending upon the specific application. The measuring system is unacceptable if it exceeds 30% and requires improvement (Hessing, n.d.; Mikulová & Plura, 2018; Automotive Industry Action Group, 2010; SAE Industry Technologies Consortia, 2022). Gage R&R study is performed by the Analysis of Variance (ANOVA) method as well as the Average and Range method. ANOVA method is preferred over the Range method as the latter does not support the computation of confidence interval. Incorporating the confidence intervals for the measurement standard deviation and the discrimination ratio (β) into the decision-making process offers a more robust and informative approach. Moreover, a limitation of the Average and Range method is its inability to account for interaction effects between operators, parts, and the measurement gage (Senvar & Firat, 2010; Čepová et al., 2018; Healy & Wallace, 2011).

Effective color communication requires correct color scale, CIE illuminant, CIE standard observer, instrument geometry, sample preparation, and sample presentation (MyColorDoc.com, 2018). ISO 13655:2017 defines color measurement conditions including M0, M1, M2 and M3, along with D50 illuminant, 45°/0° or 0°/45° instrument geometry for printing and packaging industry (International Organization for Standardization, 2017).

ISO 15790:2004 describes how to use certified reference material and report the combined uncertainty of color measurement systems in printing industry (International Organization for Standardization, 2004). Studies on uncertainty of color measurements have been reported by Burns & Berns (1997) and Gardner (2000).

Tarasov & Milder (2020) evaluated the accuracy of the ColorMunki and i1 Pro spectrophotometers by color difference and reflectance comparisons. An acceptable accuracy with the magnitude of color differences below 0.45 ΔE76 was observed for both devices. Sharma, Leung & Adams (2017) evaluated the inter-instrument agreement of ten commercial spectrophotometers used in the printing industry across various substrates. Wyble & Rich (2007) compared twelve spectrophotometers evaluating traditional color difference metrics with the multidimensional methods outlined in ASTM E2214 for short-term, medium-term, and long-term repeatability. A comparative study by Sanderson (2015) on Konica Minolta and X-Rite handheld reflectance spectrophotometers revealed that the consistency of the measurements across various colors, textures, and materials was dependent on the measurement procedure and the instruments' geometric design. Novotny (2011) assessed the measurement accuracy of Gretag-Macbeth Spectrolino, Techkon SpectroDens and X-Rite 530 spectrophotometers on rough and smooth substrates. Spectrolino using diffuse illumination showed better accuracy on rough and texture substrates while Techkon SpectroDens and X-Rite 530 using directional illumination exhibited better accuracy on smooth coated substrates. An inter-instrument agreement study by Nussbaum, Hardeberg & Albregtsen (2011) with six color-measuring instruments on three different substrates evaluated by polynomial regression showed consistent performance of the model across all three substrates. However, the inter-instrument agreement can be further improved by 50% with the characterization model. Centore (2016) assessed the repeatability of six spectrophotometers on 290 samples by the Coefficient of Variation (CoV) method and identified surface geometry of the instrument as the major source of variation.

This study evaluates the measurement variability of the Nix Spectro 2 instrument using a Type 1 Gage Study and Gage R&R for CMYK printed samples, examining both repeatability and reproducibility.

Materials

Substrate

In this study, the samples printed on both absorbent and non-absorbent substrates with Gravure, Flexography, and Digital printing processes were used (Table 1).

Table 1
Substrates and Printing Processes

S. No	Substrate	Printing Process
1	12 µ PET	Gravure
2	85 GSM High Gloss	Flexography
3	80 microns Vinyl	Digital (Wide Format Ink Jet)
4	Vinyl Lamination	Digital (Wide Format Ink Jet)
5	Vinyl	Digital (Wide Format Ink Jet)
6	Texture16	Digital (Electrophotography)
7	350 GSM Ivory	Digital (Electrophotography)
8	300 GSM Art paper	Digital (Electrophotography)
9	270 GSM Ensemble	Digital (Electrophotography)
10	170 GSM Art paper	Digital (Electrophotography)

Layout Design

Cyan, Magenta, Yellow, and Black (CMYK) solid patches of size 4 mm x 4 mm were generated for the measurement analysis (Figure 1). These are widely used colors in the printing industry.



» **Figure 1:** *CMYK Solid Patches*

Experimental Process

Type 1 Gage Study

Type 1 Gage Study was performed first to check the precision, capability, and accuracy of spectrophotometer. The analysis was limited to Nix Spectro 2 instrument. It did not include comparisons with other instruments such as X-Rite, Techkon, or Konica Minolta which will be covered in the next phase of this research. For the present study, the same part of CMYK solid patches were measured 50 times on each substrate by the same operator using the Nix Spectro 2 instrument, having 45°/0° geometry and a 2 mm aperture (Nix Sensor, n.d.). M1 measurement mode with the D50 illuminant and 2-degree observer angle as per ISO 13655:2017 was used for all the measurements.

Before the experimentation, the Nix Spectro 2 was calibrated using the manufacturer-supplied white tile. The instrument measured the known reflectance of the tile to set the reference white, and successful calibration was confirmed in the Nix Print Pro software.

The objective of this exercise was to assess the consistency of the Spectro2 instrument when measuring CMYK patches multiple times by the same operator. The variations in the readings of an identical CMYK patch evaluated the repeatability of the instrument while the Study Variation to the Tolerance and the true value of the instrument were assessed by Bias.

The mean L*a*b* values of 50 measurements for each patch (CMYK and the substrate) were considered as the target. Color difference CIEDE2000 (ΔE00) between the target and the individual measurements was calculated. Further, the reference (true value) for the Type 1 Gage Study was established and the tolerance limits were set at 3.5 for CMY, and 5.0 for K.

From Figure 2, the Run Chart for CMYK shows that all the ΔE2000 measurements are within the tolerance limits without any presence of outliers. The observations indicate the absence of unusual variations and outliers. The random distribution of data around the reference line shows no specific trends in the ΔE2000 values. A standard deviation less than 0.1 for CMYK indicated good repeatability.

As shown in Equation (1), the Gage Capability Index (Cg) for Repeatability compares the gage's spread (6 x standard deviation) to % Tolerance. The Cgk metric shown in Equation (2), considers both the repeatability (spread) and the bias (accuracy) of the Spectro 2 instrument.

$$Cg = \frac{\left(\frac{K}{100}\right) x\, Tolerance}{L\, x\, s} \quad (1)$$

$$Cgk = \frac{\left(\frac{K}{200}\right) x\, Tolerance - \left|\bar{X}g - Xm\right|}{L\, x\, s} \quad (2)$$

K = Tolerance % (20 is default)
s = Standard Deviation of Measurements
L = No. of standard deviations that represent the entire process spread (6 is the default)
$\bar{x}_g$ = Mean of Measurements
x_m = Reference Value

From Figure 3 and 4, it is evident that the Cg value was higher than 1.33 for CMYK on all the substrates, indicating that Spectro2 is precise enough as measurements are very close together compared to the acceptable variation. The Cgk (Repeatability and Bias) values are also above the benchmark of 1.33 and confirm that lower bias is not negatively impacting the overall capability of Spectro 2. The higher average Cg and Cgk metrics were observed for 85 GSM High Gloss (4.39 and 4.37), 300 GSM Art paper (3.39 and 3.37), and 170 GSM Art paper (3.18 and 3.15) indicating excellent measurement system capability. Black exhibited lower Cg/Cgk values than other colors for the majority of the substrates printed by digital process.

This may be due to micro-variations in the same patch due to banding, graininess, pigment loading, etc.

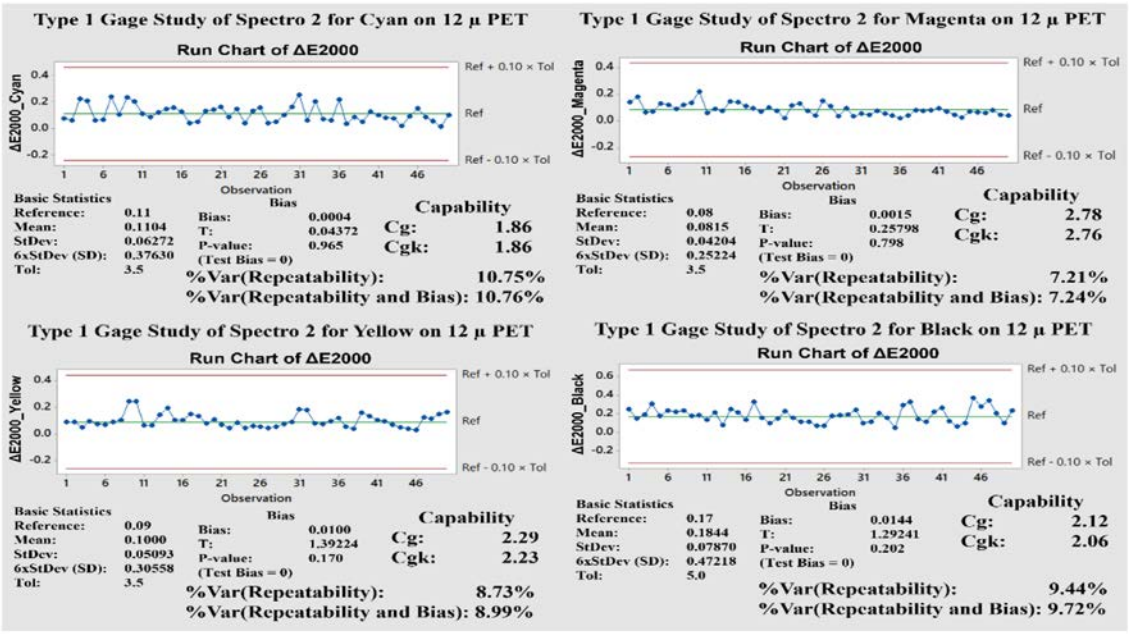
The %Var (Repeatability) values below 10% are considered excellent while between 10% to 20% are acceptable depending on the application. For the values above 20%, the measuring instrument needs to be evaluated.

Figure 5 shows (Repeatability) denoted by %VarR for CMYK on all the substrates. Figure 6 provides %Var (Repeatability and Bias) represented as %VarR and Bias. All the values are below 15% indicating minor total variability and bias and the instrument fitness for use of color measurements. Excellent repeatability was observed for 85 GSM High Gloss, 300 GSM Art paper, 170 GSM Art paper, Vinyl, and 12 µ PET substrates. The remaining substrates showed acceptable repeatability. The higher micro-print inconsistencies in Black led to higher values of %Var (Repeatability) and %Var (Repeatability and Bias) as compared to Cyan, Magenta, and Yellow.

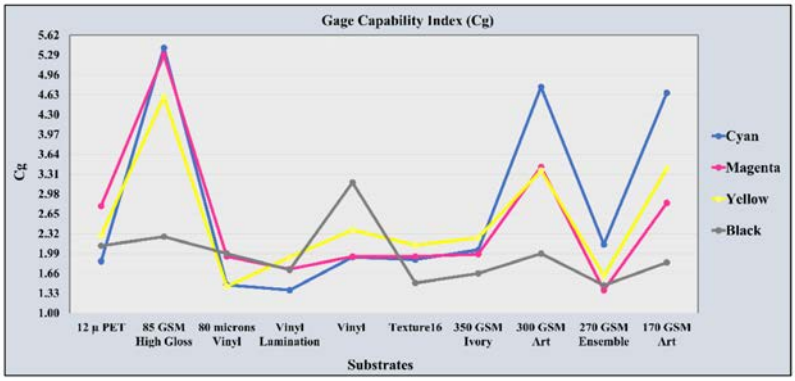
This precision and repeatability for Black measurements is still acceptable.

Bias is the difference between the average of observed measurements and the reference or true value. The systematic error refers to the consistent shift in measurements either above or below than the true value. The P-value for bias (Figure 7) determines the statistical significance of systematic error in the Spectro 2 instrument. The significance level (α) was kept at 0.05 and the null hypothesis of bias = 0 was tested.

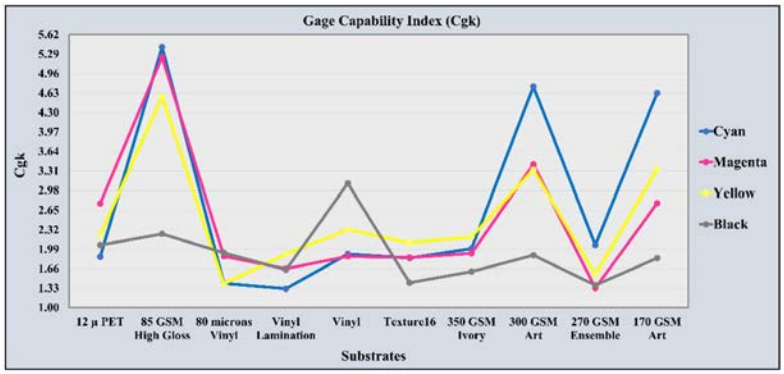
From Figure 6 and 7, it is evident that there is no statistical significance of bias for colors on any of the substrates as the p-value>0.05. Although the CMYK measurements on all the substrates exhibited good accuracy, the Black measurements on Texture 16, Vinyl Lamination, and 270 GSM Ensemble were close to the significance level of 0.05. It was due to the larger variation in the data set from the true value.



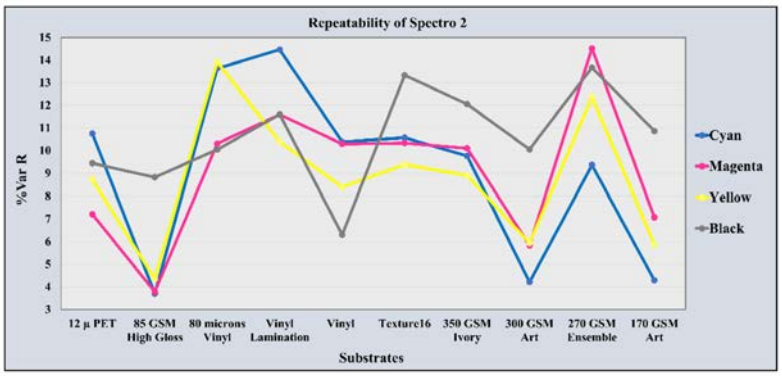
» **Figure 2:** *Type 1 Gage Study of Spectro 2 for CMYK on 12µ PET*



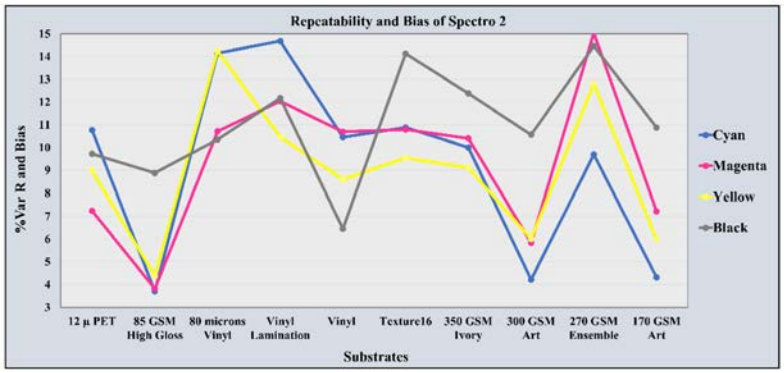
» **Figure 3:** *Gage Capability Index (Cg) of CMYK for Substrates*



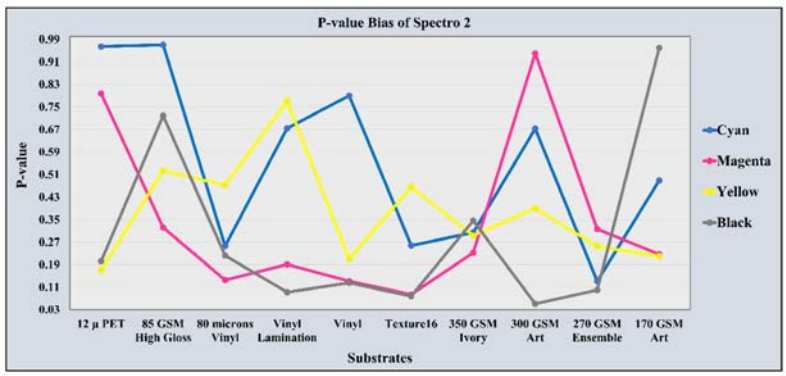
» **Figure 4:** *Gage Capability Index (Cgk) of CMYK for Substrates*



» **Figure 5:** *Repeatability of Spectro 2 for Varying Substrates*



» **Figure 6:** *Repeatability and Bias of Spectro 2 for Varying Substrates*



» **Figure 7:** *Bias P-value of Spectro 2 for Varying Substrates*

The accuracy of Spectro 2 was significantly influenced by the substrate surface characteristics. The smoother substrate 12 µ PET, 85 GSM High Gloss, and Art papers (300 GSM, 170 GSM) consistently resulted in higher p-values, indicating more robust accuracy. Conversely, the substrates with comparatively lower smoothness such as the Vinyls, Texture 16, and 270 GSM Ensemble resulted in lower p-values and accuracy.

Gage R&R

The Crossed Gage R&R Study was conducted on 10 different parts of CMYK patches with 3 operators and 3 replicates, thus a total of 90 measurement data per color. The L*a*b* values specified for the premium coated paper on white backing in ISO 12647-2:2013 (International Organization for Standardization, 2013) were considered as a reference for CMYK. The ΔE2000 was calculated between the reference and the individual measurement. The Nix Spectro 2 instrument was used with the same settings as the Type 1 Gage Study. The objective of this exercise was to evaluate the variation due to the instrument, operator, or process. The ANOVA method was used for the Gage R&R Study.

The Two-Way ANOVA (Tables 2 to 5) for CMYK shows that the p-values for parts and the part-operator interaction are less than the significance level α=0.05, indicating a statistically significant effect for these factors.

In contrast, the p-value >0.05 for the operator in Cyan, Magenta, Yellow, and Black indicates no statistically significant difference among the average measurements provided by the operators, hence the null hypothesis is rejected.

Table 6 shows %Contribution of variance components for CMYK solid patch measurements by Spectro 2 instrument. The %Contribution of Total Gage R&R is less than 1% of the Total Variation for Cyan (0.29%), Magenta (0.90%), Yellow (0.60%), and Black (0.92%). This reveals that Spectro 2 spectrophotometer is highly capable of distinguishing part differences.

Lower Repeatability variance for CMYK (0.16% to 0.48%) indicates that there were no significant measurement variations, confirming the consistency of Spectro 2.

Lower Reproducibility variance (0.13% to 0.57%) indicates minimal effect of operator on measurement variation with individual operator effect impacting not more than 0.04%. The contribution from Operator * Parts interaction was 0.12–0.53% due to differences in the surface properties of the substrates which is still in the acceptable limits. The lower %Contribution of operators and its interaction with parts confirms that operators are well trained for measurements and do not introduce meaningful measurement bias.

Part-to-Part variation (>99%) was major contributor to overall variation for all the colors. This higher contribution confirms that the variation exists due to substrates and printing processes, and not measurement error. A clear distinction in Parts indicates the reliability and accuracy of Spectro 2 for color measurements of CMYK.

Table 2

Two-Way ANOVA with Interaction of Spectro 2 for Cyan

Source	DF	SS	MS	F	P
Parts	9	680.861	756.512	1765.1	0.000
Operator	2	0.164	0.0819	1.91	0.177
Parts * Operator	18	0.771	0.0429	3.14	0.000
Repeatability	60	0.818	0.0136		
Total	89	682.615			
α to remove interaction term = 0.05					

Table 3

Two-Way ANOVA with Interaction of Spectro 2 for Magenta

Source	DF	SS	MS	F	P
Parts	9	419.568	46.6187	932.779	0.000
Operator	2	0.069	0.0347	0.693	0.513
Parts * Operator	18	0.9	0.05	3.147	0.000
Repeatability	60	0.953	0.0159		
Total	89	421.49			
α to remove interaction term = 0.05					

Table 4

Two-Way ANOVA with Interaction of Spectro 2 for Yellow

Source	DF	SS	MS	F	P
Parts	9	272.028	30.2253	734.615	0.000
Operator	2	0.144	0.072	1.75	0.202
Parts * Operator	18	0.741	0.0411	4.933	0.000
Repeatability	60	0.5	0.0083		
Total	89	273.413			
α to remove interaction term = 0.05					

Table 5

Two-Way ANOVA with Interaction of Spectro 2 for Black

Source	DF	SS	MS	F	P
Parts	9	363.065	40.3406	458.099	0.000
Operator	2	0.275	0.1376	1.562	0.237
Parts * Operator	18	1.585	0.0881	5.536	0.000
Repeatability	60	0.954	0.0159		
Total	89	365.88			
α to remove interaction term = 0.05					

Table 6

Variance Component of Spectro 2 for CMYK

Source	%Contribution (of VarComp)			
	Cyan	Magenta	Yellow	Black
Total Gage R&R	0.29	0.90	0.60	0.92
Repeatability	0.16	0.48	0.25	0.35
Reproducibility	0.13	0.41	0.35	0.57
Operator	0.02	0.01	0.03	0.04
Operator* Parts	0.12	0.41	0.32	0.53
Part-To-Part	99.71	99.10	99.40	99.08
Total Variation	100.00	100.00	100.00	100.00

Table 7

Gage Evaluation of Spectro 2 for CMYK

Source	(%Study Variation)			
	Cyan	Magenta	Yellow	Black
Total Gage R&R	5.41	9.47	7.76	9.60
Repeatability	4.02	6.96	4.97	5.94
Reproducibility	3.62	6.42	5.95	7.55
Operator	1.24	0.84	1.75	1.91
Operator* Parts	3.40	6.37	5.69	7.30
Part-To-Part	99.85	99.55	99.70	99.54
Total Variation	100.00	100.00	100.00	100.00
No. of Distinct Categories	26	14	18	14

Table 7 shows the %Study Variation that compares the measurement system variation to the total variation. As per the Automotive Industry Action Group (AIAG), the measurement system is acceptable if the %Study Variation (%SV) of Total Gage R&R is below 10%. The %SV of Total Gage R&R for Spectro 2 was well below the acceptance criteria for Cyan (5.41%), Magenta (9.47%), Yellow (7.76%), and Black (9.60%). This indicates that Spectro 2 is adequate and reliable for accurately measuring the CMYK colors.

The lower repeatability variation for CMYK color measurements (4.02 to 6.96%) shows that Spectro 2 contribution was less in overall measurement variation. The lower reproducibility variation (3.62% to 7.55%) shows minimal influence of operators on color measurement variation with individual operator effect ranging from 0.84% to 1.91%.

The interaction between parts and operators ranging from 3.40% to 7.30% can be attributed to the surface characteristics of varying substrates printed by different printing processes. Overall, the individual effect of operator and its interaction with parts shows minimal impact of operators on color measurement variation.

As per the AIAG guidelines, the measurement system should have at least 5 number of distinct categories to be acceptable. Spectro 2 has exceeded this minimum requirement with Cyan (26), Magenta (14), Yellow (18), and Black 14) indicating the detection of small differences in parts. This shall help in pass/fail criteria for process control and quality monitoring in print production.

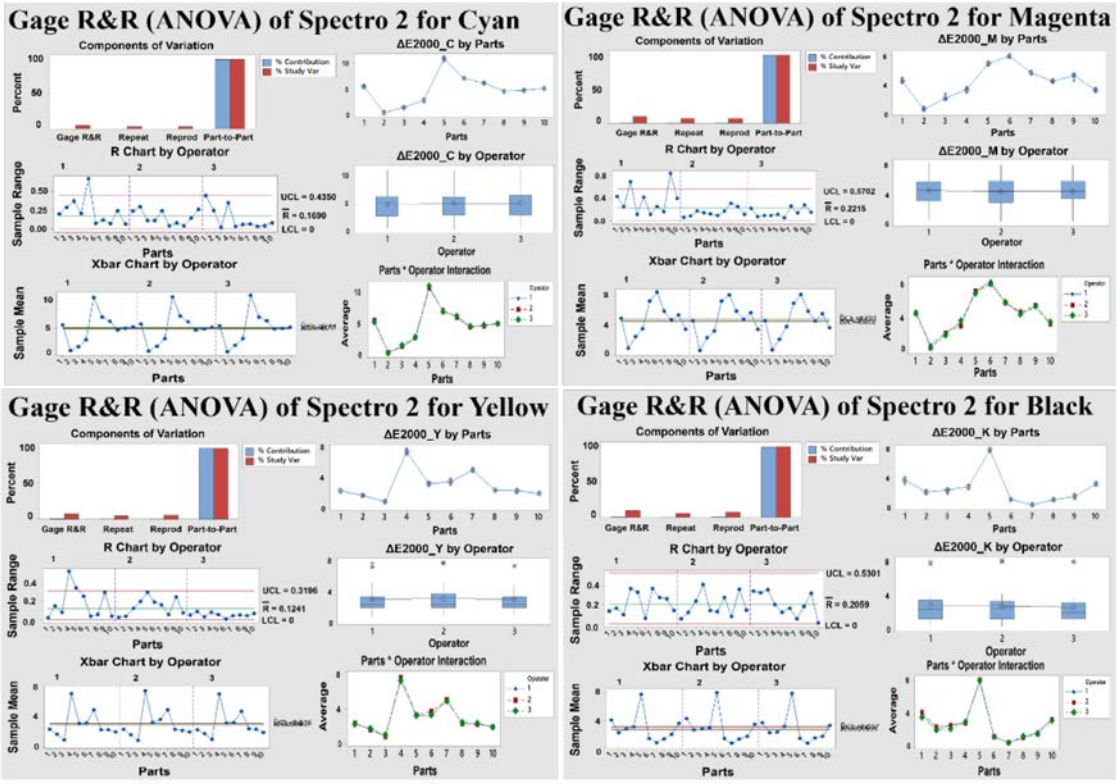
The Components of Variation and ΔE2000 by Parts in Cyan, Magenta, Yellow, and Black (Figure 8) show that much of the variation is due to the parts. The R chart shows a minor inconsistency in measurements by Operator 1 for Cyan, Magenta, and Yellow, although the magnitude is negligible and do not affect the quality output.

Majority of the data points are within the upper and lower control limits indicating that measurement variation within the operators is stable. The differences in measurements between the operators are small as compared to parts, as seen by ΔE2000 by the operator for all the 3 colors. The box plot of ΔE2000 by operators for CMYK shows that there is a marginal difference in measurement variation and no significant bias in the readings by the 3 operators. All the data points are falling outside the control limits as seen in the X-bar chart shows the variation mainly due to parts.

This means that Spectro 2 is efficient enough to detect the differences in the mean ΔE2000 values of all the colors which is necessary for print quality control. The interaction between parts and operators shows overlapping of lines for all the parts measured by 3 operators. This suggests similar methods employed by the operators for the measurement of data. The graph exhibits good repeatability and reproducibility and is effective in distinguishing parts with consistent performance by Spectro 2, hence is fit for the intended use.

Result and Discussion

The performance of Spectro 2 spectrophotometer was assessed using both Type 1 Gage and Gage R&R studies. Type 1 Gage Study was conducted to evaluate the inherent bias and precision of the Spectro 2 with the same operator measuring 50 times for each CMYK solid patch. The Cg and Cgk values were found to be above 1.33 signifying low bias and high precision. The %Var (Repeatability) and %Var (Repeatability and Bias) of the system were within acceptable limits, indicating Spectro 2 as an acceptable measurement system.



» **Figure 8:** *Gage R&R of Spectro 2 for CMYK*

Furthermore, to evaluate the variation due to operators and parts, Gage R&R Study was conducted. The %Contribution of Total Gage R&R, and %Study Variation of Total Gage R&R, for CMYK were well below the acceptance limits while the number of distinct categories above the threshold limit. The scope of this work includes intra-instrument reliability of Nix Spectro 2 measurement system. The consistent performance of Nix Spectro 2 can be attributed to its fixed measurement geometry and measurement conditions, standardized white tile calibration, spectral measurement approach, and controlled measurement methodology. The findings of this study proved the suitability of Spectro 2 for color measurements of CMYK in print production, quality control, and decision-making.

Conclusion

Color perception is subjective, hence measuring and maintaining print quality during color reproduction is required. Several Spectrophotometers are used in the printing industry for color measurement. In this study, reliability and precision of Nix Spectro 2 was evaluated. Both the Type 1 Gage Study and the Gage Repeatability and Reproducibility (R&R) confirmed that Spectro 2 is capable of measuring CMYK colors with high precision and reliability. The findings of this study shall provide confidence to the stakeholders in the printing supply chain to use Spectro 2 for color measurement, quality control and process optimization. It offers the brand owners, print convertors, ink manufacturers, and suppliers a practical approach for selecting a spectrophotometer suitable for their operational use. The future scope involves evaluation and comparison of different spectrophotometers used in printing industry.

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The redefinition of Indonesian pop music album covers from the 1980s on Spotify

ABSTRACT

This study aims to critically redefine the ontological and graphic function of 1980s Indonesian pop music album covers remediated on the Spotify platform. Employing a qualitative case study approach grounded in post-digital theory, this research investigates how visual artifacts originally designed for tactile analog media adapt to, and survive within, an immaterial algorithmic ecosystem. Findings reveal that these album covers have evolved into dynamic hybrid artifacts. Rather than erasing physical limitations, the digital interface deliberately preserves analog imperfections such as manual letraset typography, CMYK halftone dots, and paper grain. This preservation creates a compelling "haptic visuality" that actively dismantles conventional dichotomies, including analog versus digital, physical versus virtual, and human versus machine. Crucially, the study identifies the socio-cultural phenomenon of algorithmic flattening. Spotify's curation mechanisms (e.g., compressed thumbnails and curated playlists) strip away the intense New Order-era socio-political hierarchies that historically divided Pop Kreatif (urban elite) and Pop Cengeng (censored melancholic pop). Ultimately, while this digitalization democratizes access and fosters transgenerational nostalgia through a renewed digital "aura," it simultaneously risks reducing profound local histories into commodified "retro" or "vintage" aesthetic tags within the global streaming landscape. This research offers vital insights for graphic design and digital culture studies regarding the continuity, resilience, and transformation of cultural memory in the post-digital age.

KEY WORDS
post-digital, graphic design, album covers, Indonesian pop music, 1980s, Spotify

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Introduction

Digital technology fundamentally transforms the contemporary media landscape, not merely altering how information is accessed, but fundamentally redefining the practices of graphic design and visual culture. In the contemporary digital ecosystem, visual objects no longer stand alone as independent physical entities; rather, they are integrated into screen-based interfaces. This phenomenon demands a paradigm shift from static design consumption to visual experiences curated by algorithmic platforms (Lupton, 2017). Streaming platforms like Spotify act as digital exhibition spaces where cultural artifacts, including album cover designs, undergo a process of remediation—a process wherein new media appropriates, modifies, and represents the characteristics of older media (Eskilson, 2019). In this process, the graphic design of the past is challenged to maintain its visual identity and communicative power amidst the compression and standardization of digital formats.

Furthermore, digitalization compels a reevaluation of materiality within graphic design. When a physical design artwork is transformed into a digital medium, it acquires "screen materiality," where physical, tactile interaction is replaced by optical interaction mediated

through pixels and backlit screens (Drucker, 2020). The criteria for visual aesthetic appreciation are now heavily contingent on how formal design elements—such as typography, color saturation, and composition—can survive and remain legible when drastically reduced into digital thumbnails or navigational icons (Kane, 2019). This shift in scale and the loss of physical tactility require visual artifacts to adapt, forcing a continuous negotiation between the preservation of original aesthetic beauty and the functional demands of digital interface usability.

Despite living within the dominance of instant, screen-based interfaces, humans continue to exhibit a longing for the organic sensations and material traces of physical objects. This alienation from tactile objects has given rise to the phenomenon of "offline romanticism," where users actively seek the remnants of the past within contemporary visual formats (Humayun & Belk, 2020).

In recent visual culture studies, the tendency to retain analog imperfections—such as visible paper textures or slightly faded colors—within digital mediums is viewed as a form of aesthetic resistance against the sterile visual cleanliness of modern technology (Paul, 2023). This exact condition brings us to the understanding of the post-digital era, where the boundaries between the physical and the digital dissolve, creating a hybridized space where graphic design from the past is not merely archived, but revitalized and imbued with new socio-cultural meanings.

In contemporary digital society, individuals evaluate imagery through a lens of "aesthetic authenticity"—the extent to which a digital representation replicates the optical depth and tonal richness of the physical world (Hoy, 2017). The appreciation of visual representations now hinges on their capacity to deliver immersive sensations that mimic haptic experiences. This pursuit drives the demand for digital design that increasingly mirrors physical interactions, even within virtual environments. Consequently, the transition to digital platforms necessitates a reevaluation of how we engage with cultural artifacts, as digitalization has redefined the formal criteria for a design's validity, shifting the focus from the durability of ink and paper to the fidelity of the pixel and screen-light.

This paradigmatic shift significantly impacts music album covers, prompting critical questions regarding their formal transformation. Historically, album covers function as essential visual media that utilize color theory, typography, and layout to represent musical content and capture the zeitgeist of an era (Sakrie, 2006). They operate through a complex visual hierarchy that guides the viewer's eye across a 12x12 inch canvas (Sgourev, Aadland & Formilan, 2023). In the current era of platformization—exemplified by Spotify—this large-scale format undergoes a drastic deconstruction. Album covers are now reduced to miniaturized thumbnails, often serving as secondary icons within a fast-scrolling interface.

This transformation raises a vital design issue: the visual hierarchy and legibility of the original cover are severely challenged. Direct interactions with the physical artifact disappear, and the aesthetic experience is now mediated by the constraints of the "thumbnail grid," where intricate details are often lost to visual compression.

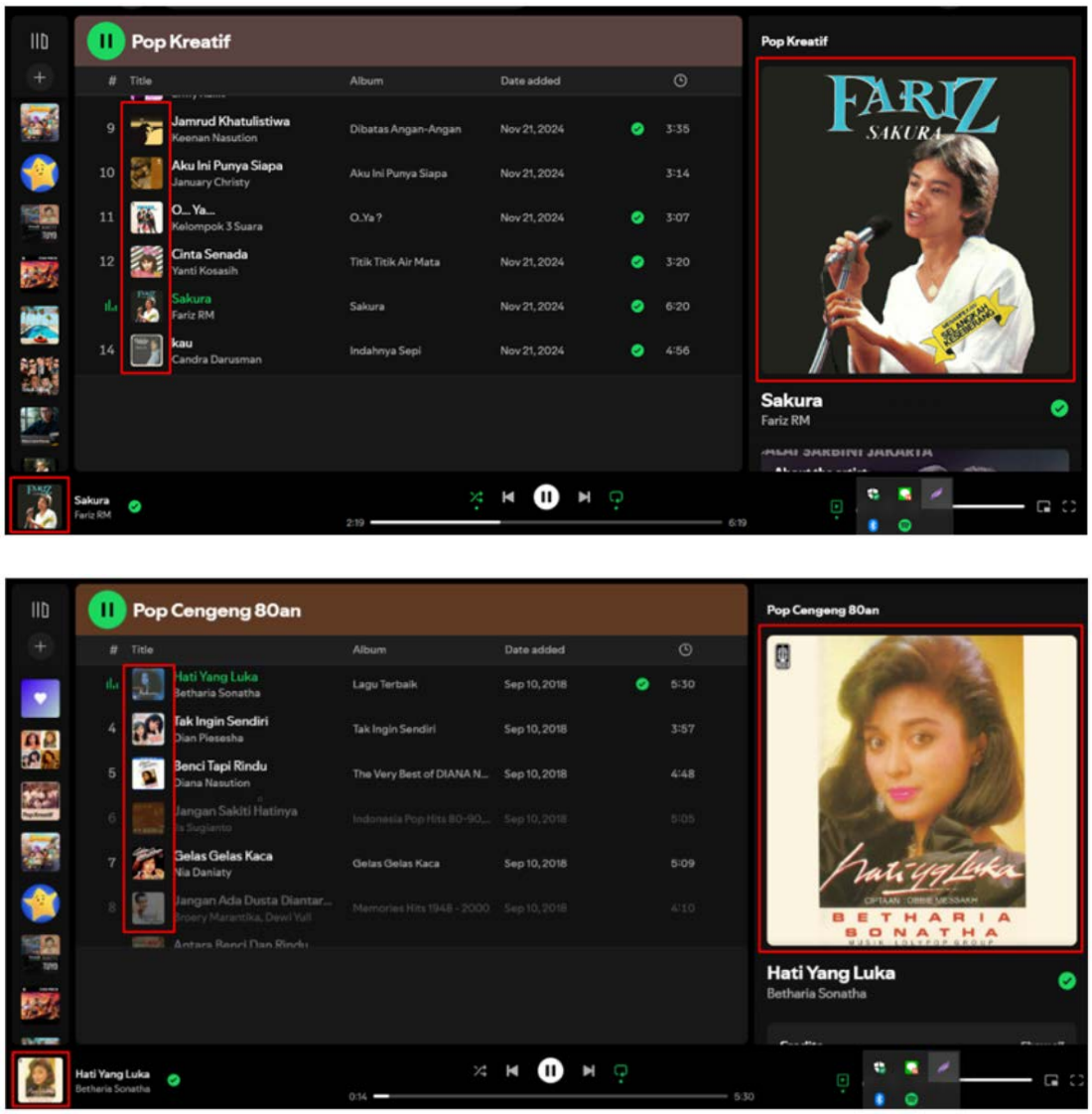
Amidst this digital dominance, a counter-movement emerges: a return to analog visual cues, driven by a desire for "visual grounding." This resurgence stems from a saturation with the rapid, ephemeral nature of digital thumbnails, leading to a yearning for the "haptic aesthetics" of the past (Humayun & Belk, 2020).

This movement responds to the visual fatigue caused by the endless stream of high-definition, frictionless imagery (Berry & Dieter, 2015). This behavior manifests in "neo-analog" design practices, which intentionally re-introduce "obsolete" elements—such as halftones, film grain, and manual lettering—to reclaim a sense of distinct materiality and emotional weight (Cramer, 2014). Such practices reflect a quest for a more personal visual experience, rejecting the digital efficiency that often flattens the depth of artistic expression (Nacher, 2018).

Within the framework of post-digital design, the visual world is no longer seen as a binary between "real" and "virtual," but as a continuum of materialities. The longing for profound visual experiences serves as an antithesis to the "fragmented scanning" typical of contemporary digital consumption (Ioannidis & Costa, 2019). Unlike the focused gaze required for physical art, digital interfaces often promote a superficial engagement (Citton, 2017).

The post-digital perspective, therefore, invites us to perceive technology not as a replacement for the old, but as a versatile infrastructure for archiving and re-narrating the aesthetics of the past (Cramer, 2014; Berry & Dieter, 2015). In this context, the Indonesian pop music album covers from the 1980s emerge as a significant case study. Often hailed as Indonesia's "golden age," the 1980s produced iconic pop works distinguished by a specific visual identity: a dominance of musician portraiture captured in distinctive poses, vibrant color palettes, and the extensive use of manual typographic techniques like Letraset (Sakrie, 2015; Dewanto, 2025).

The digitalization of these artifacts on Spotify presents a critical site for exploring the renegotiation of analog heritage within digital mediated networks. This research adopts a post-digital perspective and formal visual analysis to examine how these covers—originally designed for a tactile, physical format—survive and "resonate" as digital thumbnails. The significance of this study lies in redefining "visual aesthetic appreciation practices," which refers to the shifted ways audiences interact with miniaturized, screen-based representations that are rapidly consumed and algorithmically curated.



» **Figure 1:** *Screenshot of examples of Indonesian pop music album covers from the 1980s on the Spotify platform (desktop version). Top: "Sakura" album by Fariz RM (1980). Bottom: "Hati yang Luka" album by Betharia Sonata (1987). (Source: Spotify)*

Research Design and Methodology

Research Design

This study employs a qualitative case study design to conduct an in-depth analysis of visual textual elements within their original analog and remediated digital contexts. A qualitative approach is chosen because it aligns perfectly with the objective of comprehensively describing, interpreting, and evaluating specific visual phenomena over mere numerical representation (Creswell & Creswell, 2018; Sambeka & Ali, 2024). In the realm of graphic design research, this qualitative method enables a profound exploration of how formal aesthetic choices—such as typography, color saturation, and layout—carry cultural and historical weight when translated across different media. Following the guidelines proposed by Leedy and Ormrod, this case study is bounded and structured to systematically evaluate the formal transformation of Indonesian pop music album covers from the 1980s within the contemporary digital ecosystem of Spotify (Muratovski, 2016).

Post-digital theory serves as the primary conceptual framework, providing a nuanced lens that views digital technology not as a novel disruption, but as an integrated infrastructure that continually archives and interacts with analog remnants (Cramer, 2014; Berry & Dieter, 2015). By synthesizing this theory with formal visual analysis, the research design effectively deconstructs the hybridity of these artifacts, bridging the disciplinary boundaries between media studies and graphic design to reveal how physical formats maintain their communicative power as digital thumbnails.

Sample Selection and Data Collection

To address previous methodological limitations and ensure a rigorous qualitative visual analysis, this study focuses on a concrete, clearly defined sample. The data consists of exactly 6 (six) Indonesian pop music album covers released between 1980 and 1989, accessed as digital thumbnails via the Spotify desktop application. The sample was determined using a purposive sampling technique designed to represent the two most dominant and culturally significant pop music sub-genres in Indonesia during that decade:

- Creative Pop
  3 album covers from highly productive musicians known for their experimental and progressive approaches, e.g.: “Sakura”- Fariz RM (1980), “Bossanova Indonesia”- Rafika Duri (1982), “Indahnya Sepi”- Candra Darusman (1981).
- Melancholic Pop
  3 album covers representing the massive commercial success of sentimental pop, e.g.: “Tak Ingin Sendiri”- Dian Piesesha (1984), “Kisah Kasih di Sekolah”- Obbie Messakh (1986), “Hati Yang Luka”- Betharia Sonata (1987).

The selection criteria for these 6 specific albums are based on the book of “Musisiku”(Ginting *& Sakrie*, 2007) and “Musisiku 2”(Komunitas Pencinta Musik Indonesia, 2009), which are: (1) Released during the 1980-1989 period; (2) Achieved high commercial success and profound cultural impact, ensuring their status as collective memory artifacts; and (3) Visually demonstrate a clear transition from a physical analog print (originally cassette formats) to a digital thumbnail representation on Spotify.

Formal Visual Analysis and Analytical Framework

To effectively bridge the post-digital theoretical framework with the discipline of graphic design, the analysis of the 6 selected album covers is operationalized through formal visual analysis. Rather than merely cataloging production techniques, this method evaluates the formal aesthetic and compositional qualities of the covers as they appear to the contemporary digital viewer. The visual analysis assesses four specific graphic design criteria:

- Typography
  The structural adaptation and digital legibility of analog lettering (such as Letraset) when compressed into a thumbnail.
- Color and Saturation
  The translation of the vibrant 1980s color palettes onto backlit digital screens.
- Composition and Visual Hierarchy
  How the spatial arrangement—specifically the dominance of musician portraiture—survives the constraints of the digital interface.
- Digital Reproduction of Analogue Materiality
  The visible retention of physical imperfections (e.g., paper textures, halftone dots, or faded edges) within the digital file.

These four graphic design criteria are then systematically analyzed through the three stages of the post-digital analytical framework. Post-digital theory is chosen as the analytical lens because it challenges binary distinctions between analog and digital, emphasizing hybridity—the blending of physical and virtual elements—and ambiguity in media experiences (Berry & Dieter, 2015).

This theory is integrated by applying its core concepts to the case study, allowing for a systematic deconstruction of how 1980s album covers are recontextualized (repositioned within new digital frameworks) and renegotiated (their meanings actively reshaped through user interactions and platform affordances) in the post-digital era. Key terms such as "recontextualization" (the relocation and adaptation of artifacts to new environments), "renegotiation" (the ongoing reinterpretation of cultural meanings), and "redefinition" (as defined above) are used consistently throughout to maintain conceptual clarity.

- Stage 1: Recontextualizing the Object/Phenomenon in the "Post-digital Condition".
  This stage examines how the formal elements—specifically the composition, visual hierarchy, and color palettes of the 6 album covers—adapt when relocated from physical cassette packaging to Spotify's thumbnail grid. It involves identifying these covers not as entities that are purely "digital" or "analog," but as artifacts navigating a new algorithmic environment where digital technology is integrated and "taken for granted" (Cramer, 2014).

- Stage 2: Deconstructing Binaries and Identifying Ambiguity/Hybridity.
  This stage analyzes how specific formal design choices—such as the digital reproduction of analog materiality (e.g., paper textures) or the legibility of manual typography (Letraset)—blur traditional dichotomies, including physical versus virtual and old versus new. This highlights the hybridity and ambiguity that frequently characterize the post-digital media experience (Berry & Dieter, 2015).

- Stage 3: Critical Analysis of Digitality Narratives and Socio-Cultural Implications.
  This stage evaluates how the persistent analog aesthetics (e.g., color saturation and the dominance of musician portraiture) of these 1980s covers challenge dominant narratives of digital progress, efficiency, and complete dematerialization.

This in-depth analysis requires adopting a reflective stance toward the broader socio-cultural implications, exploring how these visual elements actively renegotiate cultural meaning and evoke nostalgia within the global streaming landscape (Cramer, 2014).

Review and Synthesis of Literature

This section synthesizes existing literature on post-digital aesthetics and music album covers in the digital era, with a particular focus on Indonesian pop music from the 1980s. By integrating interdisciplinary perspectives from graphic design, media studies, and visual culture, this review establishes a conceptual foundation for understanding how analog media remnants, such as album covers, are recontextualized and renegotiated in post-digital conditions.

Post-Digital Aesthetic

The concept of post-digital aesthetics refers to the deliberate blending and interaction of digital and analog elements in art and design, reflecting the omnipresence of digital technology in contemporary visual culture. This aesthetic often involves the hybridization of digital and analog techniques, creating a seamless blend that challenges the boundaries between the physical and the virtual (Woo-Jung & Choon, 2022).

Within graphic design, there is a notable trend toward incorporating tangible, physical materialities—such as visible paper textures or manual print imperfections—alongside digital elements, which repositions digital creation within a new haptic aesthetic framework (Fernandes-Marcos & Pereira, 2022).

The post-digital artifact involves the conflation of medium and media, where the formal design parameters of an artwork (e.g., typography, color, and composition) and its networked, communicative status are intimately intertwined. This has led to the development of new formal traits and processes in contemporary visual communication (Frew, 2023).

Therefore, post-digital aesthetics represent a significant shift in how design is created and experienced, offering new possibilities for visual expression that embrace the remnants of the analog past to reflect the complexities of contemporary culture. This aesthetic not only challenges traditional boundaries but also opens up new possibilities for artistic expression and interaction. By understanding these key aspects, this article tries to gain a comprehensive view of the post-digital aesthetic concept and its impact on the case studies.

Album Covers in the Digital Era

The digital era has significantly transformed the music industry, fundamentally altering the functional and aesthetic role of graphic design in album covers. Despite the shift from physical formats to digital music consumption, album covers remain a crucial visual touchpoint in attracting listeners and shaping their perceptions. In the digital age, these covers must function effectively within the constrained interfaces of music streaming platforms. High-impact designs, characterized by strong visual hierarchy and legibility at thumbnail sizes, are essential for standing out in a crowded digital marketplace (Chang & Chiu, 2025). Furthermore, the design of these covers is heavily influenced by their socio-political, economic, and technological contexts (Chae & Kim, 2022).

Interestingly, the phenomenon of "digital nostalgia" has emerged, where the formal design cues of historical album covers evoke a sense of the past, appealing directly to consumers' emotions and collective memories. This nostalgic appeal is particularly potent in the digital landscape, where the aesthetics of obsolescence and analog materiality are deliberately highlighted to counter digital sterility (Jordan, 2024). Moreover, technological shifts—such as algorithmic curation on streaming platforms—offer new opportunities for value creation by recontextualizing historical artworks for modern audiences (Darvish & Bick, 2024). The persistent relevance of these visual artifacts, coupled with a resurgence in physical album sales in some markets, suggests a complementary rather than replacement relationship between digital and physical formats (Lee et al., 2020). Consequently, album covers remain a multidimensional aspect of the music industry; they are not merely promotional tools, but enduring visual artifacts whose graphic forms continue to mediate cultural and emotional responses in both physical and digital realms.

Results and Discussion

The post-digital era signifies not only the normalization of digital technology in daily life but also an ontological shift that reframes our understanding of visual culture through hybrid media forms. In this evolving landscape, conventional boundaries such as analog-digital, physical-virtual, and past-present become profoundly blurred, creating a hybridized space laden with aesthetic ambiguity where physical tactility is continuously renegotiated into screen materiality. The 6 (six) selected Indonesian pop music album covers from the 1980s serve as primary visual case studies that perfectly encapsulate this complexity. On Spotify, these graphic artifacts act as a vital bridge between analog nostalgia and digital functionality. They transition from tangible, historical prints into contemporary, algorithmic thumbnails, forcing formal design elements to adapt while continuously mediating collective cultural memory.

Recontextualizing Indonesian Pop Music Album Covers from the 1980s in the Post-digital Condition

The repositioning of an album cover from a material object—originally manifested in analog cassette inserts or vinyl sleeves—to the Spotify platform drastically alters its formal graphic function. Observing the 6 selected samples, ranging from the experimental pop of Fariz RM (*Sakura*, 1980), Candra Darusman (*Indahnya Sepi*, 1981), and Rafika Duri (*Bossanova Indonesia*, 1982) to the sentimental melancholia of Dian Piesesha (*Tak Ingin Sendiri*, 1984), Obbie Messakh (*Kisah Kasih di Sekolah*, 1986), and Betharia Sonata (*Hati Yang Luka*, 1987), the album cover now stands as a dialectical intersection. It is a negotiation between past analog materiality (e.g., printed paper textures, manual typography) and present digital immateriality (e.g., 50x50 pixel dimensions, backlighting, and interface metadata).

As seen in Figure 2 below, the visual aesthetics of these covers reflect traces of Indonesia's social, cultural, and technological conditions during the 1980s. However, when Spotify's interface reproduces these covers as miniaturized thumbnails, it necessitates a severe retranslation of their composition and visual hierarchy. In their original physical dimensions (e.g., a standard cassette j-card), these covers allowed viewers to explore intricate background details. In the post-digital condition of a screen, the visual hierarchy is forced to adapt. The dominance of the musician's portraiture—a hallmark of 1980s Indonesian pop design explicitly visible across all 6 samples in Figure 2—becomes the absolute focal point required to survive the compression of the digital grid. Spotify reframes the album cover artifact by miniaturizing it, yet it paradoxically relies on its vibrant color saturation and distinct analog poses to retain a nostalgic "aura" against the platform's sterile dark-mode interface.

This recontextualization reveals a new perspective where these artifacts are not merely digitized relics but actively evolving visual entities. Consequently, the album cover undergoes a complete functional transformation. It no longer serves as a protective physical casing but emerges as a "visual gateway." The legibility of its colors and facial compositions must prompt users to "click," thereby granting access to audio archives and evoking collective memories of the 1980s. This post-digital interpretation reveals how graphic design not only alters our interactions with cultural artifacts but actively reshapes our relationships with time and memory.

Furthermore, the technological infrastructure governing the presence of pop music album covers warrants deeper examination as part of this recontextualization. By employing Spotify's curation algorithms, which record and implement personalization logic, the platform generates new contextual meanings. For example, the algorithm aggregates these historical visual artifacts and juxtaposes them in playlists titled "Creative Pop" or "80s Melancholic Pop" (See Figure 3).

In this algorithmic context, the graphic design of the album cover transcends its standalone visual form as a static physical casing, evolving into an active, clickable node within a vast digital information network. The persistent analog aesthetic of the 1980s—characterized by its manual typography, high-contrast portraiture, and vibrant color saturation—serves as a vital visual anchor in this fluid, data-driven dynamic. It actively unites contemporary users, historical artists, and nostalgic romanticism through the mechanism of screen materiality. Ultimately, this remediated visual artifact far surpasses its original analog function; it now operates as a continuous mediator of cultural memory, seamlessly weaving the tactile heritage of Indonesian pop into the everyday consumption patterns of the global streaming landscape.



» **Figure 2:** *The visualization of Indonesian pop music album covers from the 1980s on the Spotify platform. Top (left-right): "Sakura" - Fariz RM (1980), "Bossanova Indonesia" - Rafika Duri (1982), "Indahnya Sepi" - Candra Darusman (1981). Bottom (left-right) : "Tak Ingin Sendiri" - Dian Piesesha (1984), "Kisah Kasih di Sekolah" - Obbie Messakh (1986), "Hati Yang Luka" - Betharia Sonata (1987). (Source: Spotify)*



» **Figure 3:** *The "Creative Pop" (top) and "80s Melancholic Pop" (bottom) playlists, which users can locate in the search column and save to their favorite playlists. (Source: Spotify)*

Deconstructing Binaries and Identifying Ambiguity/Hybridity

This stage actively seeks to dissolve the tension of binary oppositions that have conventionally shaped our standardized understanding of media: analog versus digital, physical versus virtual, old versus new, and human versus machine. The post-digital stance eschews these rigid dichotomies, embracing ambiguity and hybridity as the constitutive characteristics of contemporary visual culture.

Consequently, the critical task of this elaboration stage is to identify how the formal graphic elements of the 1980s Indonesian pop music album covers on Spotify actively obscure and dismantle these conventional boundaries. Rather than viewing these digitized covers merely as static remnants of a bygone era, we must analyze them as dynamic interfaces where tangible print heritage collides with algorithmic display. By dissecting specific design choices—such as manual typography and retained paper textures—we can reveal how the physical past is continuously renegotiated within the digital present.

This analog-digital relationship can be recognized as an unstable binary opposition, where meaning remains incomplete and exists in a state of suspension (*différance*, drawing on Derrida's theoretical framework)—its meaning will never be fixed or universally agreed upon, continually evolving with time and subsequent technological contexts.

The Indonesian pop music album covers from the 1980s visually allude to their "original form" (such as physical cassette j-cards or vinyl sleeves), which physically no longer exists within the digital ecosystem of Spotify, yet they establish a new, authentic visual presence. By translating physical wear and manual typography into illuminated pixels, the graphic design of the music album cover transforms into an "open text." Its aesthetic meaning is perpetually rewritten through user interactions, responsive interface updates, and screen resolution variations across different devices.

The deconstruction commences with a rejection of reducing the album cover to an artifact aligned solely with either the analog or digital realm. On the Spotify platform, these album covers emerge as digital simulations that deliberately preserve the imperfections of analog print aesthetics. As highlighted by the red squares in Figure 4, subtle visual anomalies are evident across both the Creative Pop and Melancholic Pop genres.

For instance, the visible CMYK halftone dots on Rafika Duri's portrait (Creative Pop) and the faded print edges and paper grain on Betharia Sonata's and Dian Piesesha's covers (Melancholic Pop) are digitally reproduced. These retained flaws generate a compelling illusion of materiality within an entirely immaterial platform. By meticulously preserving these analog artifacts—which would normally be perceived as printing errors or signs of decay—Spotify's digital interface paradoxically enhances their authenticity as historical objects. This "tactile" visuality functions not as a technical failure, but as a deliberate graphic strategy to evoke a sense of haptic nostalgia in contemporary listeners navigating a sterile screen.

Moreover, this hybridity is distinctly articulated in the album cover's function as a temporal bridge between "new" and "old." On one hand, its graphic design—characterized by the bold, emotive lettering of Melancholic Pop or the experimental layouts of Creative Pop—evokes nostalgia for the collective memory of the 1980s, frequently romanticized as the golden era of the Indonesian pop music industry. On the other hand, Spotify situates these historical visuals within the framework of post-digital music consumption, governed by streaming logic, dark-mode interfaces, algorithmic personalization, and playlist preferences.

This ambiguity fosters a productive tension in the user experience: are they engaging with an authentic cultural artifact from the past, or a synthesized "retro" aesthetic reformulated to cater to contemporary listeners' visual preferences? The post-digital condition subtly compels us to acknowledge that the answer encompasses both simultaneously, thereby resisting binary simplification.



» **Figure 4:** *The imperfections of analog aesthetics (indicated by red square), which digitally reproduce an illusion of analog materiality. Top (left-right): "Sakura" - Fariz RM (1980), "Indahnya Sepi" - Candra Darusman (1981), "Bossanova Indonesia" - Rafika Duri (1982). Bottom (left-right) : "Tak Ingin Sendiri" - Dian Piesesha (1984), "Kisah Kasih di Sekolah" - Obbie Messakh (1986), "Hati Yang Luka" - Betharia Sonata (1987). (Source: Spotify)*

This deconstruction offers a fresh perspective that reframes these covers as embodiments of post-digital fluidity, where analog print imperfections fundamentally enhance digital authenticity rather than oppose it. The subsequent endeavor is to dismantle the binary divide between humans and machines. The original Indonesian pop music album covers from the 1980s are profound products of human creativity.

They were meticulously crafted by graphic designers, photographers, and art directors collaborating with manual tools—such as Letraset dry-transfer type, physical cut-and-paste layouts, and darkroom photography—that exemplify high "craftsmanship" consistent with the technological advancements of their time. Yet, on Spotify, these highly tactile, human-made objects are mediated, compressed, curated, and disseminated by non-human, algorithm-driven systems.

This dynamic does not reflect a hierarchical relationship (where machines are subordinate to humans, or vice versa) but rather a deeply symbiotic one. The Indonesian pop music album covers from the 1980s constitute inseparable hybrid entities: the tangible imprint of human creativity (authentic manual design) converges with machine logic (algorithmic curation and pixel grid rendering) and is animated by user behavior (scrolling and clicking).

The "soul" resonating within these music album covers hinges entirely on this exact hybrid interplay between human craftsmanship and machine distribution. Consequently, the ontological question that emerges shifts from "What is a music album cover?" to "How does the graphic materiality of the album cover manifest and survive within the post-digital condition?"

Narratives of Digitality and Socio-Cultural Implications of 1980s Pop Music Album Covers

This concluding in-depth analysis critically aims to elucidate how the Indonesian pop music album covers from the 1980s engage with—and frequently challenge—dominant narratives surrounding digital technology. Narratives such as linear progress, absolute efficiency, or complete dematerialization are not accepted uncritically. Instead, the researcher strives to interrogate them to reveal their embedded social, cultural, and political implications.

The prevailing narrative often portrays digitality as a democratizing force that revolutionizes access and eradicates physical/material constraints. At first glance, the digitalization of the 1980s Indonesian pop music catalog on Spotify appears to substantiate this narrative. Recordings once confined to physical media formats (vinyl records, cassettes) now enjoy boundless accessibility. However, rather than abolishing materiality, digitalization generates new materialities and revitalizes analog graphic aesthetics as visual commodities. Through their retained analog visual cues, these covers serve as instruments of symbolic resistance against the threat of total dematerialization. This evidence underscores that digital technology does not invariably erase the old; rather, it provides a versatile infrastructure for archiving, recontextualizing, and re-narrating the romanticism of the past.

The socio-cultural implications of this post-digital phenomenon are particularly compelling, especially concerning the emergence of transgenerational nostalgia. Younger generations, unacquainted with the physical tactility of cassette tapes, can now readily connect with the cultural heritage of preceding generations via the familiar interface of streaming platforms.

The “aura” of the artwork paradoxically re-emerges in a transformed ecosystem. This new aura no longer derives from the uniqueness of a physical print but from its immaterial capacity to evoke emotional resonance within a digital grid.

This new aura is actively sustained and manipulated by the platform's infrastructure, revealing a profound socio-cultural shift through algorithmic flattening. Historically, during Indonesia's New Order era in the 1980s, the music industry was sharply divided by socio-political hierarchies. Pop Kreatif (represented by artists like Fariz RM) was celebrated as the sophisticated sound of the urban intellectual class. In stark contrast, Pop Cengeng or Melancholic Pop (represented by Betharia Sonata or Obbie Messakh) faced severe government censorship in 1988 for allegedly "weakening the national morale" with its deeply sentimental lyrics and aesthetic. Yet, by systematically embedding these visual artifacts into curated environments—such as Spotify’s "Pop Kreatif" and "Pop Cengeng 80an" playlists (See Figure 3)—the platform strips away this intense historical hierarchy. The algorithm repackages these historically conflicted genres into identically sized, 50x50 pixel digital playlists, transforming a once-heated national political debate into adjacent, commodified "retro moods" for global digital consumption.

This structural integration demonstrates how the graphic covers negotiate commodification. Packaged and labeled merely as "80s" content, they face inevitable political ramifications. On one level, the digitalization elevates local Indonesian culture onto the global entertainment stage. Conversely, it risks severe cultural reduction.

Laden with local socio-historical struggles, these visual artifacts are reduced to mere aesthetic labels within a landscape perpetually craving exotic content. Post-digital critique compels us to reconsider: who ultimately controls this narrative? Do global platforms like Spotify, driven by commercial algorithms, now serve as the primary curators of Indonesia’s pop cultural heritage?

Philosophically, this inquiry prompts deep reflection on the interconnectedness of human memory and algorithmic curation. Our cultural identity is never static; it is perpetually reconstructed through efforts to reinterpret the past in response to present challenges. The 1980s Indonesian pop music album covers on Spotify emerge as significant visual sites within this narrative reconstruction. Yet, the resulting narratives are replete with dialectical tensions: between preservation and exploitation, historical authenticity and digital simulation, and organic memory versus algorithmic nostalgia.

Table 1

The key concepts and implications of the article’s findings

Main Theme	Key Concepts	Implications
Recontextualization	• Transformation from physical (vinyl, cassettes) to digital (thumbnails). • Shift from static images to interactive gateways. • Retention of analog aesthetics (e.g., decorative typography, vibrant color) in a digital format. • Integration into Spotify's algorithmic ecosystem.	• Album covers evolve from passive objects to dynamic, clickable elements. • Digitalization alters but preserves nostalgic value. • Technology reshapes cultural engagement and visual memory.
Deconstructing Binaries	• Hybrid identity blending analog print and digital pixels. • Simulacra preserving analog imperfections (halftones, scratches). • Temporal bridge between past and present. • Symbiosis of human craftsmanship and machine logic.	• Challenges rigid dichotomies (analog/digital, old/new, human/machine). • Fosters ambiguous, perpetually evolving visual meanings. • Reflects the aesthetic fluidity of the post-digital condition.
Narratives of Digitality	• Democratization through global accessibility. • Risk of commodification (e.g., algorithmic flattening into ""retro"" labels). • Transgenerational nostalgia. • Tension between historical preservation and commercial exploitation.	• Digital platforms archive and simultaneously commodify local culture. • Raises critical issues of authenticity and narrative control. • Connects generations while risking the reduction of socio-political history.

Through this synthesis of theoretical perspectives and visual analysis, the redefinition of 1980s Indonesian pop music album covers on Spotify emerges as a pivotal conceptual outcome (summarized in Table 1). These covers have been fundamentally transformed from static, physical packaging into dynamic, hybrid entities that re-frame our engagement with cultural memory in the post-digital era.

Originally tangible objects bound to the limitations of print technology, these covers have been remediated into clickable visual nodes. Their hybrid identity dismantles traditional boundaries, proving that analog imperfections actively enhance digital authenticity. Socio-culturally, while this digitalization democratizes access and fosters transgenerational connections, it simultaneously risks flattening rich, politically charged cultural histories into easily consumable aesthetic tags. Ultimately, the graphic design of these album covers transcends its original commercial purpose; it becomes a multidimensional mirror reflecting how a society navigates the delicate tension between preserving its localized tactile past and surrendering to a globalized, algorithm-driven future.

Conclusion and Future Research Directions

The primary findings reveal that Indonesian pop music album covers from the 1980s have evolved into dynamic hybrid artifacts, effectively bridging their tangible analog origins with their immaterial digital existence. This evolution actively dismantles traditional dichotomies such as analog-digital, physical-virtual, and human-machine. Within the post-digital condition—where digital technology integrates seamlessly into daily life—the role of the music album cover transcends mere visual packaging to become an interactive interface. By retaining and even amplifying analog graphic aesthetics—such as manual Letraset typography, visible CMYK halftones, and high-contrast portraiture—within a compressed pixel grid, these covers generate a renewed, haptic "aura." This condition overwhelmingly confirms that digitalization does not merely reproduce or archive cultural artifacts; it actively remediates them, imbuing them with new contextual significance.

On Spotify, these album covers function as digital simulacra, deliberately preserving the imperfections and physical decay of print media to create a compelling illusion of materiality within a sterile digital ecosystem. Their hybridity serves as a temporal bridge connecting the collective memory of the 1980s with contemporary streaming logic. Crucially, this research highlights the socio-cultural phenomenon of algorithmic flattening. Historically opposed genres—such as the politically scrutinized Pop Cengeng (Melancholic Pop) and the urban-elite Pop Kreatif—are stripped of their New Order-era socio-political tensions. Spotify's algorithms repackage these heavily coded historical artifacts into adjacent, identically sized playlists. Consequently, while this digitalization fosters transgenerational nostalgia and connects today's youth with the tactile heritage of the past, it simultaneously risks reducing profound cultural histories into commodified "retro" aesthetic tags for global consumption.

In summary, this research enriches the intersection of digital culture studies, graphic design, and the Indonesian pop music industry. By synthesizing post-digital frameworks with rigorous visual analysis, it contributes to design discourse by demonstrating how formal visual elements can be renegotiated to maintain communicative power in compressed digital formats. For contemporary graphic designers, this study offers actionable insights into "hybrid materiality" strategies. It proves that the deliberate simulation of analog imperfections (e.g., subtle scratches, paper grain, or faded colors) is a powerful mechanism to enhance emotional engagement, authenticity, and user retention in an era dominated by algorithmic curation. Furthermore, it advances the study of digital cultural artifacts by providing a robust analytical model for examining other analog-to-digital transitions in global media contexts.

Ultimately, through the post-digital lens, the 1980s Indonesian pop music album covers on Spotify transcend their status as mere digital image files; they embody multidimensional reflections of post-digital existential complexity. They invite critical reflection on how society navigates the delicate tension between preserving organic memory and surrendering to technological curation. Building on this theoretical synthesis, future studies could empirically examine user interactions with these album covers through survey analysis or UX methodologies to quantify aesthetic appreciation in post-digital contexts. Additionally, comparative research across other Southeast Asian music eras or streaming platforms like Apple Music could explore regional variations in visual hybridity and commodification. Finally, investigating AI-driven generative redesigns of analog artifacts may reveal emerging trends in automated cultural mediation, significantly extending the discourse on the ethical implications of design and digital heritage preservation.

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Modeling color transformations in augmented reality applications using multidimensional linear regression

ABSTRACT

Recent years have seen rapid adoption of augmented reality (AR) in e-commerce, enabling consumers to visualize products such as clothing, furniture, and cosmetics within real-world contexts using smartphones. While AR improves engagement and reduces return rates, accurate color reproduction remains a critical challenge affecting consumer trust and purchase decisions. Color distortions arise from smartphone display technologies, ambient lighting conditions, and viewing geometry. This study investigates color perception distortions in mobile AR and proposes a multivariate linear regression model to predict and compensate for color shifts. Device-displayed colors defined in CIE Lab space were mapped to visually perceived colors using empirical data obtained from controlled user experiments with standardized Pantone color references. The proposed model achieved an average color difference of ΔE = 3.17, which lies within commonly accepted industry tolerances, though it remains insufficient for high-precision color-critical applications. Additionally, ergonomic factors such as user posture and smartphone orientation were examined to minimize viewing-angle-induced color distortions. The results demonstrate that simple, interpretable regression models can improve AR color fidelity when combined with ergonomic optimization, while also highlighting the need for larger datasets and more advanced modeling approaches for commercial-grade deployment.

KEY WORDS
augmented reality, color perception, multivariate linear regression, smartphone displays, color calibration in AR

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Introduction

The COVID-19 pandemic accelerated the shift to online shopping, pushing consumers to seek remote ways to browse and buy products. Augmented reality (AR) emerged as a key tool, enabling users to virtually try on clothes, preview furniture, or test cosmetics – bridging the gap between online and in-store experiences.

Augmented reality has allowed buyers to lower the barrier between online and offline shopping, making the choice of goods convenient and more confident. As users grew accustomed to these benefits, companies continued to invest in AR innovation. (Wedel, Bigné & Zhang, 2020; Negm, 2025; Fritz, Hadi & Stephen, 2023).

A key feature of AR is its ability to blend real-time camera images with preloaded virtual objects. Accurate color rendering is essential for realism – color distortions from angle changes break immersion and make virtual elements appear unnatural. (Morimoto et al., 2017; Gegenfurtner, Weiss & Bloj, 2024; Finken et al., 2025). This is especially noticeable when the user constantly moves smartphone changing the angle of view. This phenomenon is explained by the main technologies of modern smartphones: OLED (Organic Light-Emitting Diode) and LCDs (Liquid-Crystal Displays). In 2025, OLED smartphone display shipments are expected to exceed 1 billion units. Apple plans to switch to OLED displays in all iPhone models starting in 2025, ditching LCD (Reuters, 2024; StartUs Insights, 2025).

Color distortions in such screens occur because when viewed at an angle, light from pixels passes through more display layers and changes direction. The best OLED screens have nearly perfect viewing angles, though a slight change can still be seen (StartUs Insights, 2025; Luo, 2016).

Thus, the problem of inaccurate color reproduction in augmented reality applications has real causes, and it can lead not only to lower user interest in viewing content, but also to financial losses if the application is part of an online sales system where color is important for consumers.

This paper solves the problem of modeling the transformation of color stimuli observed on smartphone screen as elements of an augmented reality application.

Related works

Research into improving color accuracy in augmented reality applications has been ongoing for many years (Abbasi et al., 2024; Wu et al., 2021; Zhang, Murdoch & Bachy, 2021; Kim et al., 2016; van Krevelen & Poelman, 2010). The importance of this problem, its impact on sales through augmented reality applications, and possible distortions in how visualized data is perceived in fields like medicine or education have led many researchers to study different ways to solve it. Murdoch (2023) evaluated the applicability of the CAM16 color perception model in an AR environment using an optical simulator. Objective measurements were taken using an AR optical simulator, and a psychophysical experiment on color matching was carried out for different foreground and background combinations. Color perception in AR was compared with that on a regular screen. One of the tasks where color perception of augmented reality content is extremely important – visual assessment of pH using test strips – is considered by Lee, Zhan & Wu (2019). They propose a smartphone-based solution that combines a dedicated color chart and a new color correction algorithm. The algorithm uses a spatially varying first-order regression model to accurately correct color based on both absolute luminance and scale.

To study differences in spectral sensitivity among observers, Zhai & Chen (2021) used a viewing box with neutral lighting conditions and participants compare the visible colors of eight base sets. This approach, where a specially designed mixed reality application with sample test colors is used and participants view the augmented reality content under controlled viewing conditions, was also applied by Zhang et al. (2023). In this research virtual reality technology was used to create realistic environments that could be changed in real time. Participants chose the object that most closely resembled a pre-determined achromatic standard.

Gil Rodríguez et al. (2024) describes a controlled metameric matching experiment using daylight reproduction and different display technologies. The study examines how the background correlated color temperature (CCT) affects color perception in AR. The experiment performs color matching between an AR RGB prototype and a reproduction of the daylight spectrum. The experiment examined different background CCTs and luminance levels.

Diaz-Barrancas et al. (2023) presented an AI-based chromatic aberration adjustment system based on a modified U-Net architecture designed for real-time applications in VR/AR. The system adapts to changing lighting conditions in real time. It overcomes the limits of traditional methods like histogram equalization and gamma correction, which do not handle fast lighting changes well.

It can be concluded that much attention is given to the practical aspects of color perception. Researchers develop prototypes, run user experiments, and record changes in color perception under different lighting conditions, display types, backgrounds, and display settings.

Despite many experimental studies, there's a lack of theoretical models that systematically explain color distortions in AR. Color perception in AR is influenced by factors like display transparency, chromatic adaptation, psychological context, and scene layout – making it difficult to formalize and insufficiently studied. Most models also assume fixed lighting and viewing, limiting their use in dynamic AR environments. To advance AR, we need formal models tailored to its specific conditions to enhance system calibration and color accuracy.

To address this, we propose using multivariate linear regression, which examines how multiple independent variables affect a dependent outcome. While newer methods like neural networks and decision trees exist, many still build on linear regression. Its main advantage is interpretability – models are transparent, easy to visualize, and widely applicable – making linear regression a reliable and practical approach even today (Montgomery, Peck & Vining, 2021).

In studying the features of color display in mixed reality technologies, regression analysis methods are also used: in the papers (Kim et al., 2016) the nonlinear nature of color distortion is represented using localized regression methods. Secondly, the distortion is modeled in the CIE XYZ color space, a device-independent format, based on empirical color measurements.

This paper proposes to build and train a multivariate linear regression model that will describe the color transformation of images displayed by augmented reality applications. The predictor and response variables are proposed to be coordinates of the device-independent color space.

Visual assessment of colors perceived by users is proposed to be carried out using specially developed test image objects that will be included in the augmented reality application and shown to the experiment participants under standardized daylight conditions provided by a viewing box.

Methodology

Studying the characteristics of color perception in augmented reality (AR) applications goes through several sequential stages. The main goal of such research is to understand how users perceive the colors of virtual objects superimposed on the real world and what factors can cause distortions.

The first stage involves developing the AR application itself. Due to the specifics of display technologies colors on a smartphone screen can appear different depending on the viewing angle. This is important in augmented reality applications, as the user constantly moves the smartphone to view virtual objects from different angles.

Therefore, the next stage of research is to determine typical user positions while interacting with an AR application. To achieve this, specialized experimental studies are conducted. During these experiments, user posture, head position, and the tilt and orientation of the smartphone are recorded.

The third stage involves developing the special test objects. These are typically color charts with pre-defined color values. Test charts are integrated directly into the augmented reality app. Users view them on the device screen, select the closest from the color standard patches and researchers evaluate how accurately the colors are displayed. The results are recorded and analyzed. Mathematical models can then be built using this data to describe how color distortions occur.

Multidimension linear regression is often used for this purpose. It could describe connection between colors in AR application and on-screen visible colors. This creates a model that predicts distortions and, if necessary, corrects the displayed colors. In general, the linear regression model can be written as

$$h(x) = a + b_1 x_1 + \ldots + b_d x_d = a + b \cdot x \quad (1)$$

where $x=(x_1,x_2,\ldots,x_d)$ – vector of input values – chart color coordinates in AR content, $b=(b_1,b_2,\ldots,b_d)$ – vector of model coefficients, a – free member. The main task in constructing such a model with optimal values of the coefficients b. They must ensure the minimization of a certain approximation quality criterion, Q.

In general, this requirement is written as the solution to an optimization problem:

$$b^* = Q(b, x) \quad (2)$$

In this paper as criterion the sum of squared errors is adopted. $Q(b,x) = \sum_{i=1}^{d} \left(h(x_i, b) - y_i\right)^2$

The $y=(y_1,y_2,\ldots,y_d)$ – the desired response vector of color coordinates of on-screen visible colors.

When input data are represented as sets of vectors $X=(x_1,x_2,\ldots,x_n)^T$ and $Y=(y_1,y_2,\ldots,y_n)^T$ accordingly, a generalized multivariate linear model is used. In this case, the data are conveniently written as matrices:

$$Y_{n\times d} = X_{n\times(p+1)} B_{(p+1)\times d} \quad (3)$$

The input matrix $X_{n\times p+1}$ contains three coordinates for each of n chart color patches in AR content; the output matrix $Y_{n\times d}$ contains the corresponding output values – three coordinates of n on-screen visible colors. The model selects a coefficient matrix B^* that minimizes the root-mean-square error between the predicted and visible color values:

$$B^* = argmin\, Q(B) = argmin \|H(X, B) - Y\|^2. \quad (4)$$

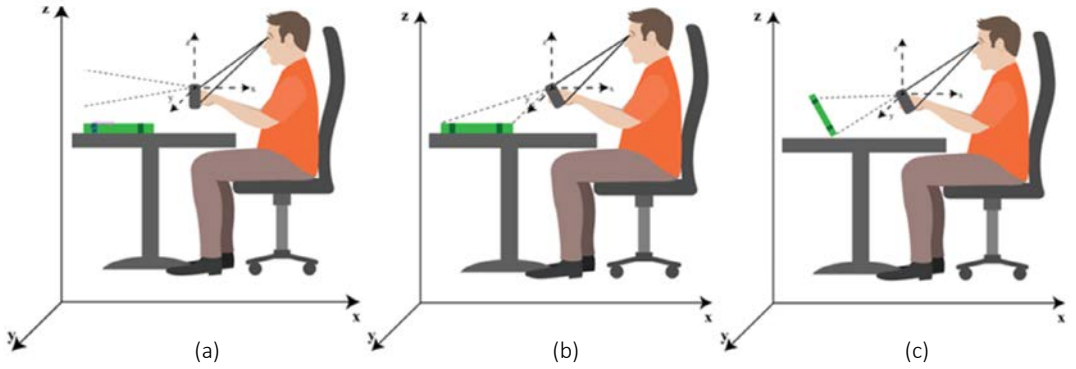
The main goal of this work is to determine the parameters B^* of a multidimensional linear regression model. This model should accurately describe the relationship between the color coordinates of fragments of the color chart used in the AR app content and the color coordinates the user perceives on the smartphone screen. Comparing these values allows us to identify potential color display distortions..

Results

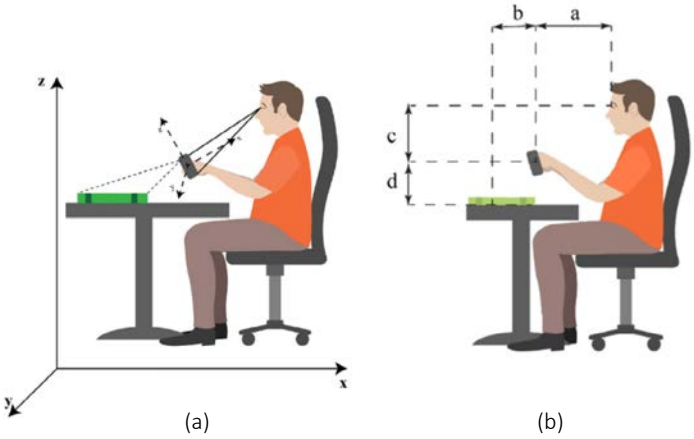
Studying the user's working posture while viewing augmented reality applications on a smartphone

Consider a user sitting and using an AR app with a smartphone and a printed marker on a table (Figure 1). In the default setup (Figure 1a), the phone is vertical and the marker lies flat, forcing the user to view the model from above at an angle.

This hinders interaction and reduces color accuracy. To improve perception, either the phone's angle or marker position should be adjusted (Figure 1b, c), ideally making the marker parallel to the screen to minimize color shifts. Since tilting the marker is impractical without support, the setup in Figure 1b is the most feasible.



» **Figure 1:** *Human posture model and options for placing a gadget or image-tag: a) the marker is horizontal, the smartphone is vertical; b) the marker is horizontal, the smartphone is tilted; c) the marker is tilted, the smartphone is tilted*



» **Figure 2:** *Human posture model and a) convenient placement of the phone; b) image-marker and measurement parameters: distance from eyes to phone a, distance from phone to marker b, height of phone relative to marker d, and height of phone placement relative to eye level c*

For optimal AR use and color fidelity, the model's orientation in virtual space must match the smartphone's tilt relative to the marker. Figure 2 a show an ideal setup, while Figure 2b lists required measurements: user height, arm length, eye-to-phone distance (a), phone-to-marker distance (b), phone height above the marker (d), and phone height relative to eye level (c). To determine the model virtual position, a series of experiments was conducted with the participation of 15 people.

Each participant was given a marker image and a device with an installed augmented reality application. The task was to place the gadget in a position that allows them to comfortably view the virtual model. The following anthropometric indicators were measured: participant height, arm length, distance from eyes to phone *a*, distance from phone to marker *b*, height of phone relative to marker *d*, and height of phone relative to eye level *c* according to Figure 2 b. The height of the table is the same – 74.5 cm. The data entered in Table 1.

Table 1 (part 1)

Results of a study of anthropometric indicators of users viewing an augmented reality application while sitting

Person №	Height, cm	Arm length, cm	Distance from eyes to phone a, cm	Distance from the phone to the mark b, cm	Height of the phone relative to the eyes c, cm	Height of the phone relative to the mark d, cm
1	170	71	33	10	18	21
2	163	68,5	24	9	17	17
3	173	68	32	8	23	16
4	160	67,5	27	13	23	18
5	161	67,5	32	12	16	21
6	158	66	26	10	18	18
7	168	68	29	13	17	18

Table 1 (part 2)

Results of a study of anthropometric indicators of users viewing an augmented reality application while sitting

Person №	Height, cm	Arm length, cm	Distance from eyes to phone a, cm	Distance from the phone to the mark b, cm	Height of the phone relative to the eyes c, cm	Height of the phone relative to the mark d, cm
8	160	66	25	15	20	18
9	155	66	23	8	16	19
10	169	67,5	31	11	16	18
11	157	67	27	12	16	20
12	158	65	24	11	17	17
13	158	65,5	24	12	16	19
14	164	66	24	12	17	17
15	172	70	29	9	19	17

Calculations of geometry of the human body position, showed that the virtual model should be placed in the scene at an angle of 43 to 46 degrees. The distance between AR camera and marker image and model in the virtual scene along the X axis is 37 units, and along the Y axis – 36 units. When adjusting the model's tilt angle, it was discovered that a difference of 2 – 3 degrees does not have a critical impact on result, so the model in the virtual space of AR application was rotated at an angle of 43 degrees.

After that, participants tested augmented reality applications again. According to the test results, it was found that desired effect was achieved in developed applications. As soon as user picked up gadget and launched the application, he/she no longer had to move the phone or marker to find a convenient viewing angle according to the diagram in Figure 2 a.

Development of test objects with color samples

The design of image layouts used as content for augmented reality applications is performed in the RGB color space. This color space is hardware-dependent and represents color reproduction on emissive devices such as computer monitors and smartphone screens. In contrast, human color perception is more accurately described by the CIE Lab color space (International Commission on Illumination, 2004). The RGB and CIE Lab color spaces are nonlinearly related through the intermediate CIE XYZ color space (Hunt, 2004):

$$X = 0.49R + 0.31G + 0.20B \quad (5)$$

$$Y = 0.1769R + 0.8124G + 0.01063B \quad (6)$$

$$Z = 0.00R + 0.01G + 0.99B \quad (7)$$

$$L = 116f\left(\frac{Y}{Y_n}\right) - 16 \quad (8)$$

$$a = 500\left(f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right) \quad (9)$$

$$b = 200\left(f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right) \quad (10)$$

$$f(x) = \begin{cases} x^{\frac{1}{3}} & x > 0.008856 \\ 7.787x + \frac{16}{116} & x \leq 0.008856 \end{cases} \quad (11)$$

and X_n=96.4212, Y_n=100, Z_n=82.5188 – color coordinates of the white point D50.

To ensure accurate color reproduction across different devices, color theory and color reproduction practices rely on so-called color profiles. These profiles are based on interpolation tables and are standardized by the specifications of the International Color Consortium (ICC) (International Color Consortium, 2022; International Color Consortium, 2023).

On each device, the color transformations defined by equations (5–11) are performed automatically by dedicated software modules. Consequently, the transformation from the RGB color coordinates of augmented reality content to the CIE Lab coordinates of the colors perceived on a smartphone screen is inherently nonlinear.

In this paper, it is assumed that colors are displayed on the smartphone screen in the augmented reality application has specified RGB_{App} values. According to standard color management models, these values are related to the corresponding Lab_{App} coordinates through equations (5 – 11) (Hunt, 2004).

For the experiment, the selected colors were presented as a chart consisting of uniform color patches. The Pantone Solid Color Set – Formula Guide was used for RGB_{App} (Pantone, 2025) color selection (Figure 3).



» **Figure 3:** *Color palettes for an augmented reality application*

Table 2 (part 1)

Pantone colors for augmented reality applications and their coordinates

Pantone patches for application	Color coordinates of patches						Pantone patches for application	Color coordinates of patches					
	L_{App}	a_{App}	b_{App}	R_{App}	G_{App}	B_{App}		L_{App}	a_{App}	b_{App}	R_{App}	G_{App}	B_{App}
412 PC	19	5	5	55	43	39	358 PC	82	-28	30	165	219	146
447 PC	22	-2	2	50	53	50	406 PC	80	2	2	202	196	194
411 PC	36	6	5	98	82	72	579 PC	83	-11	20	197	213	169
404 PC	49	2	7	124	115	105	698 PC	86	12	0	237	207	215
402 PC	68	2	5	173	165	157	713 PC	83	17	29	251	195	153
7496 PC	53,5	-20,9	51	118	136	29	7492 PC	79,5	-16,4	36,4	191	204	128
5405 PC	40	-8	-19	62	100	126	7544 PC	55	-3,1	-8,4	118	134	146
520 PC	30	34	-28	104	47	115	7516 PC	43,4	24,6	36	153	85	43
484 PC	37	47	36	159	45	32	7459 PC	58,9	-16,8	-22,8	66	152	181
152 PC	61	44	77	231	111	0	7406 PC	80,8	1,8	82,2	241	196	0
102 PC	91	-7	100	250	230	0	7417 PC	53,8	55,3	43,1	224	79	57
121 PC	89	2	57	251	219	110	702 PC	57	47	9	213	100	124
711 PC	47	65	36	211	41	57	603 PC	89	-8	64	237	226	94
627 PC	15	-17	2	3	45	35	564 PC	78	-18	-4	152	204	201
676 PC	35	61	-2	163	0	89	528 PC	57	33	-39	167	116	205
690 PC	27	36	-5	109	35	72	472 PC	70	25	37	228	153	105
581 PC	38	-4	39	96	90	18	435 PC	77	6	-1	200	186	192
5545 PC	43	-15	2	74	109	98	381 PC	84	-22	82	200	219	0
457 PC	62	4	68	178	146	0	116 PC	85	7	93	255	206	0
485 PC	49	68	52	220	36	31	1795 PC	47	68	45	216	31	42
418 PC	38	-2	6	90	91	81	214 PC	45	72	7	208	0	99
Black 3 PC	16	62	65	33	39	33	260 PC	24	37	-25	95	29	95
349 PC	35	-43	18	0	98	51	2597 PC	24	50	-55	89	5	141
322 PC	39	-46	-19	0	111	122	285 PC	48	-3	-58	0	119	212
1545 PC	21	19	26	81	38	11	3288 PC	44	-61	1	0	126	100
165 PC	63	61	75	255	95	0	399 PC	58	-5	72	153	141	0

Table 2 (part 2)

Pantone colors for augmented reality applications and their coordinates

Pantone patches for application	Color coordinates of patches						Pantone patches for application	Color coordinates of patches					
	L_{App}	a_{App}	b_{App}	R_{App}	G_{App}	B_{App}		L_{App}	a_{App}	b_{App}	R_{App}	G_{App}	B_{App}
1935 PC	44	69	23	203	4	71	Wm Gy 11 PC	42,4	3,9	5,5	110	98	89
255 PC	29	40	-25	112	38	108	469 PC	27	19	26	97	52	24
295 PC	17	-2	-39	0	45	98	660 PC	45	2	-51	41	109	193
343 PC	30	-31	5	0	83	62	716 PC	65	42	70	241	124	14
303 PC	18	-15	-22	0	52	77	7547 PC	10,8	-1,1	-9	19	30	41
455 PC	36	2	37	101	84	21	7476 PC	31,4	-18	-8,7	13	82	87
5115 PC	21	21	-8	75	37	62	7528 PC	75,8	2	8,1	197	185	172
7512 PC	48,4	21,7	48,9	166	99	27	7440 PC	55,7	25,1	-18,6	162	119	166
7455 PC	40,9	14,4	-47,1	58	93	174	725 PC	35	30	46	132	59	0
605 PC	81	-5	99	224	202	0	7423 PC	-18,6	52,6	4,2	224	98	135
112 PC	55	2	62	153	128	0	631 PC	69	-27	-23	72	184	210
161 PC	27	18	27	97	53	23	694 PC	66	24	3	202	144	156
1817 PC	24	26	12	94	39	40	569 PC	48	-41	-4	0	132	120
202 PC	31	45	16	137	32	52	555 PC	39	-31	8	19	105	78
2593 PC	35	48	-43	126	43	151	505 PC	27	34	6	110	38	57
274 PC	13	28	-47	33	18	101	4485 PC	32	6	31	93	71	24
3005 PC	44	-23	-60	0	118	204	Pro Yel PC	90,6	-7,2	89,4	254	221	0
369 PC	61	-45	61	79	166	0	137 PC	75	32	87	255	159	0
454 PC	84	-2	10	213	211	191	159 PC	53	45	61	205	88	6
553 PC	25	-16	6	33	66	50	185 PC	50	76	42	234	4	55
583 PC	71	-16	75	171	180	0	2582 PC	48	51	-50	162	76	200
639 PC	56	-38	-42	0	154	207	2655 PC	55	28	-46	145	115	211
141 PC	83	6	53	239	200	104	2718 PC	53	7	-52	84	126	217
182 PC	81	26	0	248	184	203	3262 PC	66	-58	-15	0	186	185
155 PC	87	4	22	236	214	175	360 PC	69	-49	49	85	190	71
2562 PC	73	24	-26	207	165	228	422 PC	69	0	-1	169	170	171
263 PC	84	9	-14	216	203	235	Cl Gy 10 PC	42	-0,7	-3,4	99	102	106
291 PC	80	-9	-20	164	206	236	532 PC	17	1	-10	38	42	57

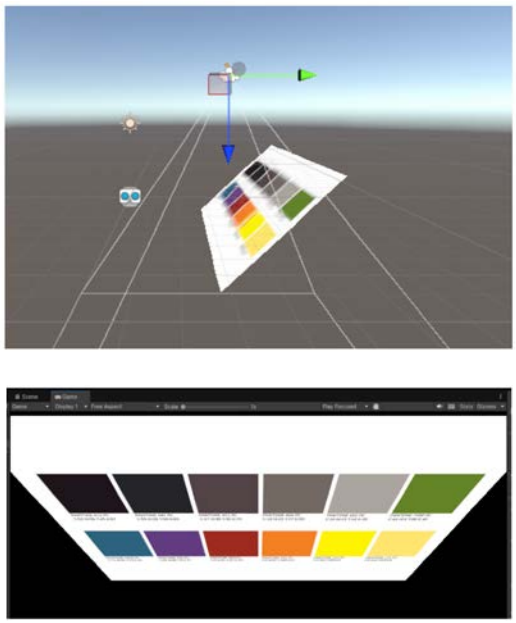
The nine palettes contain 108 colors; they are selected in such a way as to provide uniform distribution in the CIE Lab color space. Five colors in grayscale, saturated and light shades, and midtone gradations are presented here. The color coordinates of the samples are given in Table 2.

Developing an augmented reality application for visual assessment of colors

During development, there was a need to refine the scene geometric parameters to correctly bind a content virtual model to real world. The Unity (Unity Technologies, 2025) environment – a tool designed for creating games and mobile applications – was chosen to develop the augmented reality application.

The development of the augmented reality application in the Unity environment consisted of the following stages: creating a new project and setting the required parameters; adding and configuring a marker image; creating a plane model and specifying its dimensions, position, and viewing angle; placing the plane above the marker at an angle of 43° to improve viewing comfort (Figure 2a); applying the pre-prepared color chart image to the plane model; saving the final version and exporting it in a format compatible with the Android platform.

Initially, all virtual objects were positioned perpendicular to the camera, at a standard scale, and at zero distance from it. During compilation and testing, the smartphone had to be held at a right angle to the marker, which limited the field of view and reduced user comfort. Adjusting the distance between the device and the marker to fully fit the model within the screen further increased user discomfort. To address these issues, the object containing the color chart image (Figure 6a) was rotated by 43° relative to the marker surface. As a result, the augmented reality application, when the smartphone camera is pointed at the marker, displays the color chart at an inclined angle, significantly improving usability and visibility (Figure 4).



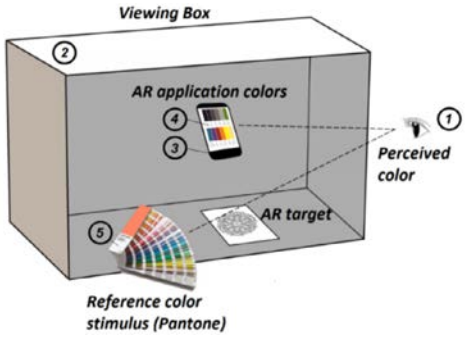
» **Figure 4:** *Rotating the surface of the test object under a cut of 43°*

Visual assessment of test object colors in augmented reality application on smartphone

Under controlled daylight conditions and using a viewing box, the augmented reality application displaying a test object was shown on the smartphone screen in real time. Participants were instructed to observe the image on the smartphone display and visually compare it with a Pantone reference palette, selecting the colors that appeared most similar.

The Pantone Solid Color Set – Formula Guide (Pantone, 2025) was chosen as the reference because its color samples have well-defined color coordinates and are available in physical form for direct visual comparison. Prior to conducting the study, all materials and equipment required for the experiment were prepared in advance.

The following items were used in the experiment: an observer (1), a device with a daylight lamp, a viewing box Just Normlicht Color Viewing light PJC/CVL 5E (2), a smartphone Galaxy A32 (3), an image with labels (4), a Pantone color chart (5) (Figure 5). The Just Normlicht Color Viewing light viewing box allows color evaluation under several standardized illumination conditions, including: D50, D65, F1 – F12, A. The D50 light source is used for experiment.

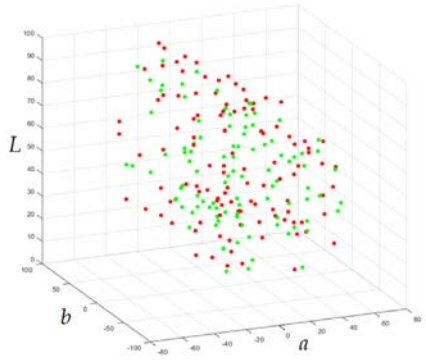


» **Figure 5:** *Scheme of the experiment*

The color coordinates of Pantone Lab $_{Perceived}$ reference patches that visually matched the colors of the test object displayed in the augmented reality application on the smartphone screen were measured using a Gretag-Macbeth Eye-one spectrophotometer.

Multivariate regression model for color transformations in augmented reality application

As a result of the experiment, for each color patch of the test image (which formed the content of the augmented reality application), the visually closest matching Pantone color was selected. Figure 6 illustrates the color coordinates of the test image patches Lab$_{App}$ green dots) and the corresponding Pantone reference colors Lab$_{Perceived}$ (red dots). It is evident that all colors are perceived with some degree of distortion during visual observation.



» **Figure 6:** *Color coordinates Lab$_{App}$ of color patches of image that was the content of augmented reality application (green dots) and visually similar colors Lab$_{Perceived}$ from the Pantone samples (red dots)*

It was hypothesized that Lab_{App} and $Lab_{Perceived}$ color coordinates are related through a linear transformation F. The graphs in Figure 7 show the dependencies of data points

$$\left(L_{Perceived}, a_{Perceived}, b_{Perceived}\right) = F\left(L_{App}, a_{App}, b_{App}\right) \quad (12)$$

and indicate that the transformation F can indeed be approximated as linear.

In this context, the input values (predictors) of a multivariate linear regression model are represented by the set of color coordinates Lab_{App}, while the training values (responses) are the corresponding color coordinates $Lab_{Perceived}$. The model $H: Lab_{App} \rightarrow Lab_{Perceived}$ approximates the target transformation F by minimizing the following least mean squares functional:

$$Q = \sum_{i=1}^{l} \left(H\left(Lab_{App}, B\right) - Lab_{Perceived}\right)^2. \quad (13)$$

where *B* is the vector of model parameters.

The model H is trained using the least squares method. This approach is justified by the nature of the problem, as matching colors in the Lab color space naturally aligns with minimizing Euclidean distances.

In fact, in color reproduction practice, color differences are typically quantified using the Euclidean distance formula (International Commission on Illumination, 1995):

$$\Delta E_{12} = \sqrt{\left(a_1 - a_2\right)^2 + \left(b_1 - b_2\right)^2 + \left(L_1 - L_2\right)^2} = \\ = \sqrt{(\Delta a)^2 + (\Delta b)^2 + (\Delta L)^2}. \quad (14)$$

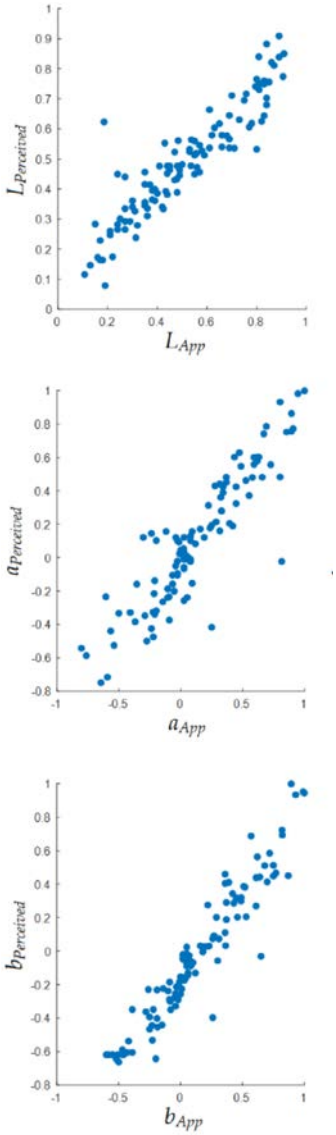
Within this framework, the optimal model parameters minimize the color difference between the augmented reality image content and the colors as perceived by the user on the smartphone screen. The coefficients of the multivariate regression model were determined using two approaches. First, they were estimated via ordinary multivariate normal maximum likelihood estimation applied to the functional in (13). Second, the coefficients were obtained using

$$Q = \sum_{i=1}^{l} \left(H\left(Lab_{App}, B\right) - Lab_{Perceived}\right) C_0 \left(H\left(Lab_{App}, B\right) - Lab_{Perceived}\right) \quad (15)$$

the least squares method with covariance weights (CWLS), which minimizes the objective function

given a fixed covariance C_0.

Additionally, a constraint on the admissible convergence of the log-likelihood objective function was applied to ensure stability. The results of training the model using both algorithms are summarized in Table 3.



» **Figure 7:** *Dependency of color coordinates $L_{Perceived}$, $a_{Perceived}$, $b_{Perceived}$ from L_{App}, a_{App}, b_{pp}*

Table 3

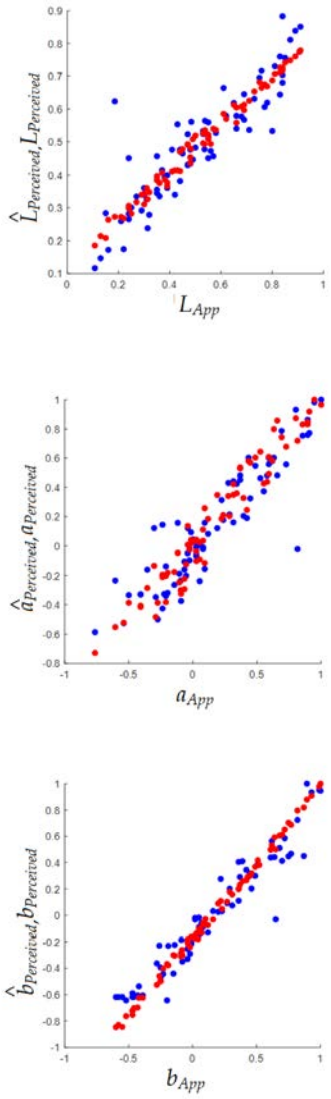
Results of training the multivariate regression model using the ordinary multivariate normal maximum likelihood estimation method and using the least squares method with covariance weights

Algorithm	Number of iterations	Average color error ΔE	The value of the log-likelihood objective function L
Ordinary Multivariate Normal Maximum Likelihood Estimation Method	50	12.6429	-863
	100	13.0471	-832
	150	3.1724	-862
	200	12.5789	-836
Least squares with covariance weights	50	10.1067	-14992
	100	19.7215	-12583
	150	26.5584	-11451
	200	32.1161	-15320

Since in this task the color difference is the most important criterion for assessing the model quality, the best option is recognized as one that provides training of model by the method of usual multivariate normal maximum likelihood estimation over 150 iterations with an average color error ΔE=3.1724. Model weight vector:

$$\boldsymbol{B} = \begin{pmatrix} 0.0299 \\ -0.0246 \\ 0.7591 \\ 0.1337 \\ 0.0371 \\ 0.8361 \end{pmatrix} \quad (16)$$

Figure 8 shows the color coordinates calculated using learned model $h(Lab_{App},B)=\hat{L}\hat{a}\hat{b}_{Perceived}$.



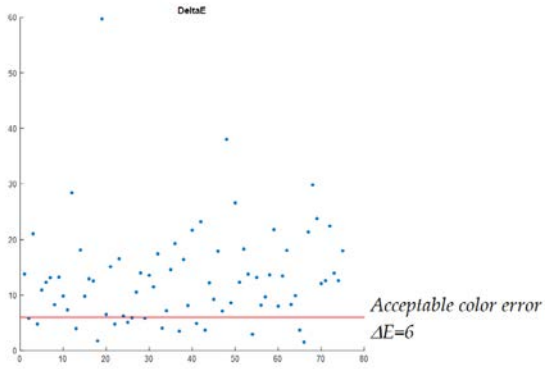
» **Figure 8:** *Dependency of color coordinates $L_{Perceived}$, $a_{Perceived}$, $b_{Perceived}$ from L_{App}, a_{App}, b_{App} (blue dots) and dependency of color coordinates $\hat{L}_{Perceived}$, $\hat{a}_{Perceived}$, $\hat{b}_{Perceived}$ from L_{App}, a_{App}, b_{App} (red dots)*

Typical tolerances in the graphic arts industry usually range between 2 and 6 ΔE. Figure 9 shows the color errors of the predicted colors calculated based on the trained model with coefficients (16). There are 15 colors in the acceptable error range.

Discussion

Experiments measured user posture while viewing AR applications, allowing the placement of 3D models in the virtual space to minimize color distortions caused by viewing angles.

A custom test object – a color chart with predefined colors – enabled objective user-based observation. Color comparisons between the AR app on a smartphone and Pantone samples were conducted in a viewing box under standardized lighting, improving result reliability and reducing variability.



» **Figure 9:** *Color errors for colors predicted by trained model*

The study shows that color distortions in smartphone AR follow consistent patterns that linear models can approximate. The multivariate regression reduces average color error within industry tolerances.

However, color perception is inherently nonlinear and varies across hue regions. This limitation is especially evident for highly saturated colors, where perceptual shifts differ in magnitude and direction. Unlike professional color management systems that rely on thousands of reference samples, this study was constrained to 108 colors, limiting predictive precision.

While neural network approaches could potentially model nonlinearities more accurately, they require substantially larger datasets and longer experimental sessions, making them impractical for this study. The chosen linear regression approach offers transparency, interpretability, and feasibility, making it suitable as a foundational solution.

Limitations of the Study

This study demonstrates that multidimensional linear regression can model color transformations in augmented reality (AR) applications, but several limitations affect its practical use. One key limitation is the small dataset: the model was trained on 108 color samples from nine Pantone palettes to ensure uniform distribution in CIE Lab space. While sufficient to capture general distortion trends, this dataset is much smaller than those used in professional calibration systems and may miss subtle nonlinear effects, especially in highly saturated colors or near the display gamut edges. Expanding to 1,500 – 2,000 samples could improve accuracy.

Another limitation is the use of a single smartphone model. While this reduced variability and ensured consistency, it limits generalization, as different devices vary in display technology, primary colors, gamma, and calibration.

Future studies should include multiple devices to capture device-specific distortion patterns, possibly requiring separate models or adaptive calibration.Experiments were conducted under controlled D50 lighting, which does not reflect real-world conditions where users encounter mixed and dynamic lighting affecting perception. Additionally, linear regression can only approximate perceptual trends; human color perception is inherently nonlinear, so some colors are predicted inaccurately.

Alternative methods – polynomial regression, regularized regression, support vector machines, decision trees, random forests, and neural networks – can model more complex transformations. Support vector machines seem most promising for future research. The study also did not account for individual differences in perception. Overall, the model serves as a baseline but needs refinement and broader testing for high-precision AR applications.

Improvements and Achievements of the Paper

This paper makes several meaningful contributions to the study of color perception and calibration in augmented reality applications by combining empirical experimentation, ergonomic analysis, and interpretable mathematical modeling into a unified framework (Table 4).

This work highlights the integration of user posture and viewing geometry into AR content design. By analyzing anthropometric data and identifying consistent, comfortable viewing positions, the study shows that spatial arrangement of 3D objects can reduce color distortions, complementing algorithmic corrections.

Table 4

Summary Table of Workflow and Results

Stage	Description	Output
Ergonomic study	Analysis of user posture and phone orientation	Optimal viewing angle (43°)
Test object design	Pantone-based color charts	108 reference colors
Visual experiment	AR vs. Pantone comparison under D50 lighting	Perceptual color pairs
Modeling	Multivariate linear regression	Color transformation matrix
Evaluation	ΔE (CIE 1995)	Mean ΔE = 3.17

A controlled perceptual dataset was also created, linking AR-displayed colors to perceived colors under standardized conditions using Pantone references. Though limited in size, it provides a solid empirical basis for modeling color transformations and bridging device-dependent color specifications with human perception.

Additionally, a multivariate linear regression model in CIE Lab space was developed. Unlike black-box approaches, it is interpretable, showing how color components contribute to distortion, achieving an average ΔE of 3.17, within accepted industry tolerances.

Methodologically, the study presents a complete workflow for AR color calibration, including application development, ergonomic optimization, controlled assessment, and modeling. It establishes pathways for improvements such as dataset expansion, cross-device validation, and hybrid modeling, providing a foundation for better color fidelity in mobile AR.

Conclusions

The rise of AR has reshaped online retail by enhancing interactivity and reducing return rates through product visualization. However, accurate color representation remains a challenge, especially in industries like fashion and cosmetics where color fidelity is essential. Color distortions often stem from differences in device displays, lighting, and viewing angles.

This study introduces a multivariate linear regression model to predict and correct AR color shifts, using 108 color patches compared under standardized conditions. The model achieved a mean ΔE of 3.17, showing promise in estimating color deviations. By analyzing posture and viewing angles using anthropometric data, the study proposed ways to improve visual comfort and color fidelity. Despite the model's simplicity and

interpretability, its limited data set restricts precision for professional use. Neural networks may offer better results but require more extensive data.

Future work should expand color samples, include varied devices, and explore hybrid models combining regression with deep learning. Personalized AR interfaces based on ergonomic and perceptual profiles may further enhance accuracy and comfort. This research provides a solid base for improving AR realism and reliability in commercial and broader applications.

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Reflections of the Y2K trend in graphic design: An analysis of a digital aesthetic

ABSTRACT

The Year 2000 (Y2K) aesthetic brought about a significant transformation in graphic design with the rapid development of digital technologies in the late 1990s and early 2000s. The aesthetic that emerged during this period created a visual language reflecting both technological and cultural optimism by incorporating elements such as neon colors, metallic surfaces, glitch effects, and futuristic typography. This study demonstrates that the Y2K movement goes beyond being a temporary trend and plays a determining role in shaping modern graphic design. While digital tools and software innovatively transformed design processes, the Y2K aesthetic created a unique form of expression by blending the aesthetic codes of the past with the design language of the digital future. The research examines the nostalgic resurgence of the Y2K aesthetic today and the visual codes reflected in graphic design products resulting from the popularity it gained through social media dynamics. The results emphasize how the Y2K aesthetic has been reshaped in both cultural and aesthetic contexts in the digital age, the innovative elements this process contributes to graphic design, and its potential future effects.

KEY WORDS
Y2K, graphic design, digital culture, typography, visual culture, digital aesthetics

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Introduction

Social media has enabled individuals to interact and produce content in online environments with the rapid development of information technologies, initiating a new era in the societal reach of graphic design (Castells, 2010). While the proliferation of Web 2.0 technologies has transformed social media into a platform where individuals express themselves, it has also influenced the marketing strategies of businesses and accelerated the evolution of visual communication (Kirtiş & Karahan, 2011; Sevindik, 2024).

Technological advancement has reshaped design practices extending from early 20th-century modernist movements to the present (Armstrong, 2009: pp.127-132; Heller & Vienne, 2012: pp.10-15); specifically, the Year 2000 (Y2K) trend, which emerged in the late nineties and early 2000s as a style reflecting the technological optimism of the millennium, has been influential in a wide area ranging from posters to typography (Yang, 2023: p.1; Souza Junior, 2024: pp.5-7).

The Y2K aesthetic was born from the cultural and technological context created by the “Millennium Bug” (Y2K Bug) crisis during a period spanning from the late 1990s to the early 2000s (Yang, 2023). Souza Junior (2024) defines Y2K typography as "display fonts with a futuristic and technological appearance" and states that the Y2K aesthetic offered an innovative language in graphic design with the rise of digital fonts (p. i).

Features such as bright colors, metallic textures, and 3D effects are the fundamental elements defining Y2K; these features are embodied in the pop culture products of the period, for example, in the *Backstreet Boys - Larger than Life* music video (Atmosphere font) and the *Equilibrium* movie poster (Mata font) (Souza Junior, 2024: pp.5-7).

Yang (2023) states that the Y2K style created a similar effect in fashion design, offering a futuristic vision with circuit board patterns and LED lights in Alexander McQueen's 1999 Givenchy collection (p. 2). The Y2K aesthetic was shaped in graphic design through posters and typography with an approach that boldly explored the possibilities offered by technology (Heller & Vienne, 2012).

The appearance of Y2K in graphic design gains meaning in a context where digital technologies transformed design processes. Manovich (2001) emphasizes that new media recoded visual culture through principles of numerical representation and modularity; as a reflection of this transformation, Y2K presents a futuristic style characterized by neon colors and pixelated textures. Armstrong (2009), on the other hand, states that the standardized tools of digital software restructured design aesthetics as "metamedia" (pp.127-132). Studio 2AM (2023) defines the key features of Y2K graphic design as "bright metallic colors, bold typography, glitch effects" and emphasizes that these elements create a nostalgic retro-futurism in 3D modeling. For instance, the use of Ray Larabie's *Neuropol X* typeface in the *Grand Theft Auto* logo strengthened Y2K's influence in pop culture (Souza Junior, 2024: p.54). The Y2K influence in fashion appeared with red latex outfits in Britney Spears' *Oops I Did It Again* music video; similarly, the style found expression in graphic design with vibrant colors and technological motifs (Yang, 2023: p.2).

The Y2K movement has gone beyond being merely a temporary trend in graphic design; it has combined the search for universalism of modernist movements (e.g., Bauhaus's typographic innovations) and postmodernist experimentalism (e.g., Weingart's bold approaches) with a digital aesthetic (Armstrong, 2009: pp.32-49, 77-81). However, the impact of Y2K aesthetics on graphic design, particularly in the context of posters and typography, has not been sufficiently addressed in academic literature (Souza Junior, 2024: pp.9-10). Today, the repopularization of Y2K as a nostalgic mainstream draws attention with examples such as Lady Gaga reflecting the Y2K style with metallic and semi-mechanical elements on the cover of her *Chromatica* album released in 2020 (Yang, 2023: p.3). The Y2K style has found wide resonance on social media with over 90 million views on Xiahongshu and 630 million Y2K-tagged videos on TikTok, leading designers to question both their individual and collective roles (Yang, 2023: p.4; Studio 2AM, 2023; Armstrong, 2009: pp.98-101).

This study aims to examine the appearance of the Y2K movement in graphic design and analyzes how the Y2K aesthetic was shaped as a digital language through elements such as posters and typography. Thus, it aims to reveal the cultural and aesthetic reflections of Y2K's resurgence on graphic design.

Literature review

Deciphering the effects of the Y2K movement on graphic design requires examining the origins of this aesthetic within the axes of technological determinism and cultural context. Emerging in the late 1990s and early 2000s, the Y2K aesthetic represents a critical threshold in the history of graphic design as a visual language reflecting the technological optimism and digitization excitement created by the millennium. In the literature, this period is defined as a hybrid structure where elements such as neon colors, glitch effects, metallic textures, geometric abstractions, and futuristic typography are used together (Heller & Vienne, 2018; Müller, 2018; Paul, 2023).

The integration of digital technologies into design processes is one of the fundamental factors in the shaping of the Y2K aesthetic. Lupton (2014), in her work *Type on Screen*, emphasizes that the proliferation of graphic design software pushed designers toward more experimental pursuits in screen-based projects. According to Lupton, digital tools broke the functionalist and simple structure of modernist design, opening the doors to a bolder, more complex, and layered aesthetic understanding for designers.

Supporting this view, Eskilson (2023) discusses in *Digital Design: A History* how technological developments in the early 2000s gave birth to the "Digital Print" and "Web 1.0" aesthetics. Eskilson states that the pixelated textures and techno fonts specific to Y2K marked a turning point where technology transformed from a mere tool into a "design subject." Similarly, Drucker & McVarish (2020) state that with software such as Adobe Photoshop and Illustrator dominating design processes between 1997 and 2004, futuristic fonts like *Neuropol* were used as tools for technological perception management.

The visual language of Y2K demonstrated simultaneous development not only in printed materials but also in web design and digital art. Webflow (2023) notes that elements of Y2K aesthetics in web design, such as "blobby" (fluid) shapes, shiny textures, and bold typography, infiltrated poster designs by feeding off hip-hop and rave culture. This transitivity coincides with Manovich's (2001) principle of the "modularity of new media"; an aesthetic code produced on digital platforms could easily be adapted to print media. Paul (2023), examining the impact of digital art on graphic design in the 1997–2004 period in *Digital Art*, argues that neon colors and glitch effects were an effort to "aestheticize digital error."

The cultural and nostalgic dimension of the movement is associated by Yang (2023) with the chaotic yet hopeful atmosphere created by the "Millennium Bug" (Y2K Bug) crisis. According to Yang, the curiosity that Generation Z feels today toward the technology of the 2000s has enabled this aesthetic to return as a nostalgic "revival."

For instance, the metallic textures on Dua Lipa's *Future Nostalgia* (2020) album cover or the semi-mechanical elements on Lady Gaga's *Chromatica* album are concrete examples of this nostalgic resurgence in pop culture (Yang, 2023; Müller, 2018). Müller (2018) notes that while the pixelated textures in *The Matrix* (1999) poster reflected the "futurist" perspective of the period, current examples (e.g., Charlie XCX's *Brat* album cover) reinterpret this aesthetic in a retro-futurist context.

Consequently, while these studies in the literature address the Y2K movement from the perspectives of technological innovation, cultural context, and nostalgic resurgence, the specific implications of this aesthetic on graphic design—particularly at the intersection of posters and typography—have not been examined in sufficient depth with a holistic perspective.

This article aims to fill this gap in the literature by analyzing how the Y2K aesthetic was shaped as a digital language and its reflections in contemporary design practices.

Aim and scope of the research

This research aims to examine the reflections of the Y2K movement on the graphic design discipline through poster designs, focusing on visual language, typography, and color usage. The primary goal of the study is to reveal how this aesthetic, which emerged in the late 1990s and early 2000s, was constructed as a digital visual language and the transformation it undergoes today. In this direction, the scope of the research is limited to the relationship of designs produced with Y2K aesthetics to graphic design principles (hierarchy, composition, balance) and their interaction with digital culture.

Method

Research Model

This study is a qualitative research designed to examine graphic design artifacts produced within the scope of the Y2K movement. Qualitative research focuses on the process of meaning-making by examining phenomena in their natural settings with a holistic approach and in depth (Yıldırım & Şimşek, 2016).

Accordingly, the research covers the historical period of the Y2K aesthetic (1997–2004) and its contemporary resurgence (post-2020), addressing visual and aesthetic elements through a case study design. Based on the sub-questions derived from the literature review, the visual language and cultural interaction created by the Y2K aesthetic were analyzed using a descriptive approach.

Research Questions

In line with the primary aim of the research, answers were sought for the following research questions (RQ) to analyze the Y2K aesthetic:

RQ 1: How is color usage (saturation, contrast, temperature) constructed in designs made within the scope of the Y2K movement?

RQ 2: How do the visual elements (photography, illustration, texture, effect) used in the designs reflect the Y2K aesthetic?

RQ 3: What evaluation can be made regarding the composition and hierarchy structure of designs possessing Y2K aesthetics?

Limitations

The research covers visual design products produced in the process extending from 1997 to the present regarding the Y2K aesthetic. The primary limitations of the research are as follows:

The research is limited only to poster and typography-oriented designs within the broad spectrum of graphic design; web interfaces or motion graphics are excluded.

The analysis is limited to 11 visuals determined by the purposive sampling method. Although these limitations restrict the universal generalizability of the findings, the study offers an in-depth cross-section for making sense of the visual codes of the Y2K aesthetic.

Instrument Development

A "Visual Content Analysis Form" was developed by the researcher to systematically collect and analyze the data. This form was prepared based on aesthetic criteria in the literature and consists of four main categories: (1) Color Usage, (2) Typographic Approach, (3) Visual Elements/Texture, and (4) Composition/Layout. Thanks to the developed form, the aesthetic attributes of each poster were evaluated through a standard template, ensuring the comparability of the data.

Data analysis

The qualitative visual content analysis technique was applied in the analysis of the data. While Krippendorff (2018) defines content analysis as a research technique that makes replicable and valid inferences from texts to the contexts of their use, Rose (2016) emphasizes that applying this method to visual materials systematically decodes cultural and aesthetic meanings. In this context, the selected 11 posters were examined individually in terms of color palettes, typographic preferences,

glitch/texture effects, and composition setups. The obtained data were processed into the "Visual Content Analysis Form" and then interpreted by grouping them thematically, utilizing inductive thematic coding principles (Braun & Clarke, 2008). During the analysis process, the focus was on the meaning and aesthetic integrity created by the visual language rather than statistical generalizations (Yıldırım & Şimşek, 2016).

Population - Sample

The population of the research consists of all graphic design products reflecting the effects of Y2K aesthetics and digital culture. The sample of the study consists of 11 posters determined by the purposive sampling method, specifically utilizing criterion sampling. In qualitative research, purposive sampling is highly recommended for selecting "information-rich cases" that deeply illuminate the research question rather than seeking statistical generalization (Patton, 2015; Creswell & Poth, 2018).

Furthermore, as Rose (2016) emphasizes in visual methodologies, selecting images based on predefined structural criteria is crucial for ensuring analytical validity and systematic rigor. In accordance with this methodological framework, the selection criteria were defined to ensure visual diversity and representativeness. Accordingly, the sample includes designs that: (1) exhibit high interaction rates on digital design platforms (such as Behance and Pinterest) within the Y2K tag; (2) clearly demonstrate the hybrid use of typography and image; and (3) cover both the original era (1997-2004) and the contemporary revival period (post-2020). When selecting the sample, criteria were observed such that the designs distinctly carry the characteristic features of Y2K (neon colors, futurism, digital textures). In this way, the historical transformation and current reflections of the aesthetic were handled with a comparative perspective.



» **Figure 1:** *Examined Y2K Designs*

Examined Y2K Designs *(Sources: Bornx Design, 2023; Vultaggio, 2024; Graphicindex, n.d.; Valeriarv16, n.d.; Revna1634, n. d.; Arina, n. d.; Sofya, n. d.; Jennie, n. d.; Rawpixel.com, 2022; Hyerinalorav, n. d.)*.

The selection of posters was made considering not only visual aesthetics but also the cultural and technological elements of the Y2K movement. Since the Y2K aesthetic presents a visual language shaped by the impact of digitalization and technological progress, these posters best represent the effects of the period's cultural structure and digital world.

To ensure the transparency and systematic rigor of the visual selection process, the complete metadata of the analyzed posters—including their creators, titles, publication years, and source platforms—are presented in Table 1.

Table 1

Metadata of the Analyzed Y2K Posters

Poster ID (Grid Position)	Designer / Creator	Title / Context	Year	Source / Platform
P1 (Top Row, 1)	Arina (Арина)	Cyber Y2K	n.d.	Pinterest
P2 (Top Row, 2)	Valeriarv16	Y2K Poster Ideas	n.d.	Pinterest
P3 (Top Row, 3)	Bornx Design	Y2K Aesthetic Poster Templates	2023	Behance
P4 (Top Row, 4)	Sofya (Софья)	Y2K	n.d.	Pinterest
P5 (Mid Row, 1)	Vultaggio, A.	Poster Design: Freedom	2024	Behance
P6 (Mid Row, 2)	Jennie	Yves Tanguy Poster	n.d.	Pinterest
P7 (Mid Row, 3)	Bornx Design	Y2K Aesthetic Poster Templates	2023	Behance
P8 (Mid Row, 4)	Revna1634	Y2K Poster	n.d.	Pinterest
P9 (Bottom Row, 1)	rawpixel.com	Retro Advertising Poster Design	2022	Freepik
P10 (Bottom Row, 2)	Graphicindex	Y2K Magazine Cover Inspiration	n.d.	Pinterest
P11 (Bottom Row, 3)	V., H. A.	Hiring Trainee Poster by Hyerin	n.d.	Pinterest

As detailed in Table 1, cataloging the specific digital origins of each artifact not only fulfills the requirement for methodological reproducibility but also grounds the subsequent visual analysis within a verifiable dataset.

Findings

The analysis conducted on the visual elements of 11 posters associated with the Y2K aesthetic has revealed the strong influence of digital culture on graphic design. Common features among the examined posters include neon color accents, futuristic typography, glitch effects, and digital collage techniques. The findings obtained are detailed below under the headings of color, typography, visual elements, and composition.

Color Usage in Design

Color usage, as one of the most distinctive components of the Y2K aesthetic, assumes both an aesthetic and psychological function in design. Color selection in design is a strategic decision that manages the viewer's perception and carries cultural codes. The literature emphasizes that characteristics such as temperature, coolness, and saturation of color are decisive in creating the desired atmosphere in design.

In the context of the Y2K aesthetic, colors are used not merely as decorative elements but as indicators symbolizing "digital optimism" and "technological future." Table 2 presents the distributions regarding the color characteristics of the examined designs.

When Table 2 is examined, it is observed that the "Medium Saturation (Pastel)" (N=7) category is predominant in terms of color saturation, whereas "Neon Color Usage" (N=7) is at a high level. This finding reveals an interesting characteristic of the Y2K aesthetic: While "soft/pastel" (soft-digital) tones are preferred for the background or general atmosphere in designs, "high neon" accents are used in focal points and typographic elements. In other words, a pastel digital dreamscape is constructed together with sharp neon lights.

Regarding contrast, a "Strong" contrast is preferred in the vast majority of designs (N=9). This strong contrast is achieved particularly through neon pink, blue, and green tones placed on black or dark backgrounds, thus imparting a "glowing screen" effect to the designs.

In the color temperature balance, the prominence of the "Warm-Cold Balanced" (N=7) option indicates that the Y2K aesthetic is not confined to a single color group but rather uses a hybrid of warm (energetic) and cold (technological) tones. Consequently, the color palette exhibits a hybrid structure synthesizing nostalgic softness with futuristic brightness.

Table 2

Findings Related to Color (Saturation, Contrast, Temperature, etc.)

Color Saturation	**N**
Low Saturation	0
Medium Saturation (Pastel Colors)	7
High Saturation (Vibrant Colors)	4
Total	11
Color Contrast	**N**
Strong	9
Medium	2
Weak	0
Total	11
Color Temperature	**N**
Cold Colors Dominant	1
Warm- Cold Balanced	7
Warm Colors Dominant	3
Total	11
Neon Color Usage	**N**
High	7
Medium	4
Weak	0
Total	11

Typography Usage in Designs

Typography, as one of the cornerstones of visual communication, conveys aesthetic and functional messages through the meaningful arrangement of letters and symbols (Şahin, Kılıç, & Denli, 2021). In the context of the Y2K aesthetic, typography has transformed from being merely readable text into an "image-oriented" form reflecting the speed and technology of the digital age. While Kahraman (2014) states that typography underwent radical transformations under the influence of futurism, Sevindik & Karapekmez (2022) emphasize that writing evolved into a tool for visual experience. In this context, the typographic preferences in the examined posters are summarized in Table 3.

According to the analysis results, "Digital" (N=11) and "Futuristic" (N=6) qualities are evident in the aesthetic structure of fonts across the entire sample. This indicates that designers used typography as the primary tool to establish the "cyber" identity of the period. The fonts used generally evoke computer interfaces with their angular, modular, or pixelated structures.

Table 3

Typographic Findings

Aesthetic Structure of Font	N
Futuristic	6
Digital	11
Nostalgic	2
Typography as Design Object	**N**
Yes	4
No	7
Total	11

Another striking finding is the use of "Typography as a Design Object." In some of the examples (N=4), text went beyond its readability function and acted as the main visual (image) of the composition. Interventions such as bending, stretching, or volumizing letters with 3D effects transformed typography from a message carrier into an "experience space."

In terms of letter spacing (tracking) data, it was observed that "Standard" spacing was preferred in all examples. This finding is significant because, no matter how experimental and futuristic the fonts themselves are, keeping the letter spacing standard shows that designers did not want to sacrifice readability entirely while creating "controlled chaos."

Usage of Visual Elements in Design

The Y2K aesthetic possesses a rich visual repertoire that carries the visual reflections of the digitizing world into graphic design. While Karaçeper (2018) emphasizes the impact of digital technologies on the use of glitches and textures, Atabey (2025) draws attention to the functional integrity of visual elements. In the Y2K design language, visuals are constructed on a plane where the boundary between reality and virtuality is blurred. Table 4 presents the distribution of visual elements used in the designs.

Data in Table 4 reveals that the most dominant visual characteristic of the Y2K aesthetic is "Glitch Texture" (N=9). Rather than metallic or pixelated textures, the use of effects symbolizing digital corruption (glitch), scanning errors, and signal losses reflects this aesthetic's fascination with "imperfect technology."

Furthermore, the presence of photography in all posters (N=11), yet their manipulation with intense effects (N=11), supports the concept of "processed reality." Photographs are presented not in their pure forms but in a digitized form through color filters, noise, and collage techniques. Illustration usage (N=8) generally assumed a supportive role for photographic elements through vector drawings and abstract forms.

Table 4

Findings Related to Visual Elements

Photography Usage	N
Yes	11
No	0
Total	11
Illustration Usage	**N**
Yes	8
No	3
Total	11
Texture Usage	**N**
Metallic Texture	1
Pixelated Texture	1
Glitch Texture	9
Effect Usage	**N**
Yes	11
No	0
Total	11

Composition Status

Composition in Y2K designs seeks a balance between classic grid systems and the dynamic structure of the digital age. While Urano et al. (2021) emphasize the importance of visual hierarchy, Do & Kim (2016) draw attention to the perception of movement in digital design. Table 5 summarizes the composition setups of the examined designs.

When composition data is examined, an almost equal distribution is observed between Asymmetrical (N=6) and Symmetrical (N=5) layouts.

This indicates that the Y2K aesthetic does not adhere to a single layout rule; it sometimes leans towards central/symmetrical setups mimicking web interfaces and sometimes towards an asymmetrical/collage logic creating dynamism.

A "Balanced" composition and a "Strong" hierarchical structure were detected in all designs (N=11). Although the Y2K style gives a visually chaotic and crowded (maximalist) impression, analysis results prove that a solid hierarchy lies beneath this chaos. The relationship between the headline, visual, and side elements is constructed to convey the message without tiring the viewer's eye.

Consequently, composition structures present the chaos brought by digital aesthetics by disciplining it with the fundamental principles of graphic design (balance and hierarchy).

Table 5
Findings Related to Composition Setup

Layout Status	N
Asymmetrical	6
Symmetrical	5
Total	11
Balance Status	**N**
Balanced	11
Unbalanced	0
Total	11
Hierarchical Structure	**N**
Strong	11
Medium	0
Weak	0
Total	11
Letter Spacing	**N**
Wide	0
Tight	0
Standard	11
Total	11

Conclusion and discussion

This study examined the visual codes of the Y2K aesthetic, which played a determinant role in graphic design in the late 1990s and early 2000s, and analyzed the movement's relationship with digital culture and its nostalgic resurgence today. The research results reveal that the Y2K aesthetic goes beyond being merely a periodic "trend" and serves as a structural transformation tool in shaping modern graphic design. This language, established through neon colors, metallic surfaces, and futuristic typography, has transformed the possibilities offered by technology to graphic design into an aesthetic norm.

The obtained findings indicate that the visual identity of the Y2K aesthetic is built upon the "harmony of contrasts." Specifically, the use of neon accents and futuristic typography constructed on pastel/soft backgrounds symbolizes the "technological optimism" of the period, whereas the widely used glitch effects and pixelated textures are interpreted as visual representations of the "uncertainty and chaos" brought by digitalization.

Therefore, rather than offering a flawless vision of the future, the Y2K aesthetic has developed a hybrid narrative language that simultaneously reflects both the glittering (utopian) and the erroneous/broken (dystopian) faces of technology.

A critical outcome of this research lies in its methodological contribution to visual design studies. While graphic design analysis is often perceived as inherently subjective due to its reliance on personal interpretation and aesthetic appreciation, this study demonstrates how such subjectivity can be structured into a scientifically grounded evaluative framework. By operationalizing abstract visual codes—such as categorizing color saturation levels, typographical hierarchy, and specific texture usages—through a standardized "Visual Content Analysis Form," the subjective aesthetic experience was translated into observable, systematic, and thematic data. This transformation from subjective perception to objective categorization not only ensures the analytical validity of the research but also proposes a robust, replicable model for future studies seeking to evaluate visual culture phenomena on a scientific basis.

The most significant output of the research in the contemporary context is the repopularization of this aesthetic in the post-2020 period through the concept of "digital nostalgia." The concentration of Y2K-tagged content on social media platforms (TikTok, Pinterest, etc.) demonstrates the aesthetic longing felt by Generation Z for a past they did not experience (anemoia). As seen in the example of Lady Gaga's Chromatica album cover mentioned in the study, the Y2K aesthetic has secured a strong place in mainstream media today by being reinterpreted with modern design tools. This situation proves that the movement is not a static past but a dynamic visual culture that continues to evolve.

Consequently, the Y2K movement has blended the aesthetic codes of the past with the design vision of the future by boldly using the innovative tools offered by digitalization in the graphic design discipline. This aesthetic language has shaped the viewer's perceptions in the digital age and succeeded in transforming technological developments and societal transformations into a visual experience. In this context, various perspectives can be developed for future research. The scope of the study can be expanded to comparatively examine the reflections of Y2K aesthetics not only in graphic design but also in other disciplines such as cinema, fashion, music, and the gaming industry. Furthermore, focusing on how contemporary designers reproduce this aesthetic with modern tools such as artificial intelligence (AI) and 3D modeling is important for understanding the impact of technical processes on aesthetics. Finally, analyzing the social media dynamics and the consumption habits of young generations, which play a central role in the repopularization of the aesthetic, on a sociological ground will contribute to the visual culture literature.

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