International Circle
of Educational Institutes
of Graphic-Media
Technology & Management

56th IC Annual Conference

02–05 September 2025

iarigai IC
2025 PARDUBICE

56th IC Annual Conference

CONFERENCE PROCEEDINGS

02-05 September 2025

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Pardubice, Czech Republic, September 2025

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iarigai IC
2025 PARDUBICE

51th Conference of iarigai | 56th Conference of IC

International Research Conferences of iarigai & International Circle

02-05 September 2025 | Pardubice, Czech Republic

PROGRAM

51st International Research Conference of iarigai
Advances in Printing and Media Technology
"AI and Robotics Changing Graphic Arts"

iarigai IC 2025 PARDUBICE

56th Conference of the IC
"Steps towards New Initiatives in Print-Media Education, Technology and Economics"

Pardubice, Czech Republic, 2–5 September 2025

PROGRAMME OUTLINE

The schedule of the 2025 iarigai & IC joint event includes two days for plenary sessions with opening and keynote talks, and parallel sessions with presentations of submitted papers.
This year, the conference also hosts the live final of the global iarigai/IC Charity Cloud Printing Competition for printing technology students, where the best two will produce packaging jobs on Cloud Sinapse Flexo simulators.
Besides networking during coffee breaks and lunches, all participants are invited to the welcome reception on Tuesday and the conference dinner on Thursday. The programme concludes on Friday with the conference tour to Litomyšl.

TUESDAY 2ND SEPTEMBER

16.00–19.00	iarigai Board meeting (Board members only)
19.00–21.00	**Welcome reception** + Registration

WEDNESDAY 3RD SEPTEMBER

08.00–09.00	Registration
09.00–10.45	**Plenary session – Opening + Keynotes + Group photo iarigai**
10.45–11.15	Coffee break
11.15–12.15	**Parallel sessions – iarigai**
12.15–13.30	Lunch
13.30–14.30	**The Sinapse Packaging Productivity Contest Live Final**
14.30–15.00	Coffee break
15.00–15.30	**Plenary session – Keynote**
15.30–17.00	**Parallel sessions – iarigai**
17.00–17.15	Break
17.15–18.45	iarigai General Assembly (member representatives only)
18.45–19.30	iarigai Board meeting (Board members only)

THURSDAY 4TH SEPTEMBER

08.00–09.00	Registration
09.00–10.30	**Plenary session – Opening + Keynotes + Group photo IC**
10.30–11.00	Coffee break
11.00–12.15	**Parallel sessions – IC**
12.15–13.30	Lunch
13.30–14.20	**Parallel sessions – IC**
14.20–14.50	Coffee break
14.50–16.05	**Parallel sessions – IC**
16.05–16.20	**Plenary session – Wrap up + Invitation to 2026 conferences**
16.20–16.30	Break
16.30–17.30	IC General Assembly (member representatives only)
19.00–22.00	**Conference dinner**

FRIDAY 5TH SEPTEMBER

8.30–16.00	**Conference tour**

FULL CONFERENCE PROGRAMME

TUESDAY 2ND SEPTEMBER

16.00–19.00	iarigai Board meeting (Board members only) | Room C2
19.00–21.00	**Welcome reception** and registration

WEDNESDAY 3RD SEPTEMBER

08.00–09.00	Registration	
09.00–09.30	**Opening session – iarigai** | Room C1	
09.00–09.15	Opening of the conference ***Tomáš Syrový**, Conference Director*	
09.15–09.30	Welcome address ***Fritz Bircher**, President of iarigai*	
09.30–10.30	**Session 1** | Room C1	
09.30–10.00	**KEYNOTE – Ultra-high-resolution printing for industrial and bio applications** ***Tomáš Těthal**, IQS Group*	
10.00–10.30	**KEYNOTE – The impact of automation and digitalization on technology purchasing decisions** ***Jana Slováková**, KOMFI*	
10.30–10.45	Group photo – iarigai	
10.45–11.15	Coffee break	
11.15–12.15	**Session 2A** | Room C1	**Session 2B** | Room C2
11.15–11.45	A dynamic compression study on nip pressure variation in flexo post-printing ***Li Yang** and Hans Christiansson*	Circular Large Format Printing ***Fons Put** and Willem Uyttendaele*
11.45–12.15	Mitigating Print Stripiness in Flexographic Post-Print: The Role of Pressure Distribution and Surface Topography ***Sofia Thorman**, Hans Christiansson and Anckie Eriksson*	Investigations into the substitutability of conventional coatings with coatings based on renewable raw materials in graphic printing ***Insa-Marie Wickel**, Philipp Wüst, Edgar Dörsam and Andreas Blaeser*
12.15–13.30	Lunch	

13.30–14.30	**Special session – iarigai & IC** | Room C1	
13.30–14.30	**The Sinapse Packaging Productivity Contest Live Final**	
14.30–15.00	Coffee break	
15.00–15.30	**Session 3** | Room C1	
15.00–15.30	**KEYNOTE – AI in flexographic printing** ***Petr Blaško**, SOMA*	
15.30–17.00	**Session 4A** | Room C1	**Session 4B** | Room C2
15.30–16.00	Inks based on cellulosic materials for stretchable printed electronics *Marie Goizet, Julien Bras, Guillaume Krosnicki and **Aurore Denneulin***	Tipografia Lousanense – A Legacy of 140 Years in Graphic Arts Heritage ***Miguel Sanches**, Luís Mota Figueira and Ana do Carmo*
16.00–16.30	Comparison, Evaluation and Development of Bio-Based Screen-Printing Inks ***Philipp Wüst**, Thorsten Euler, Marcus Bischoff, Dieter Spiehl, Edgar Dörsam and Andreas Blaeser*	Carbon black pigments: a carbon footprint assessment ***Jules De Bardonneche**, Jérémy Manifacier, Agnès Boyer and Anne Blayo*
16.30–17.00	Wetting behavior of laser-structured metallic surfaces for potential use in offset lithography ***Felix Knödl**, Philipp Wüst, Edgar Dörsam and Andreas Blaeser*	–
17.00–17.15	Break	
17.15–18.45	iarigai General Assembly (member representatives only) | Room C2	
18.45–19.30	iarigai Board meeting (Board members only) | Room C2	

THURSDAY 4TH SEPTEMBER

08.00–09.00	Registration	
09.00–09.15	**Opening session – IC** | Room C1	
09.00–09.10	Opening of the conference ***Tomáš Syrový**, Conference Director*	
09.10–09.15	Welcome address ***Anastasios Politis**, President of IC*	
09.15–10.15	**Session 5** | Room C1	
09.15–09.45	**KEYNOTE – Trends, strategies and materials in packaging** ***Ladislav Hurdálek**, Packaging Innovation Expert*	
09.45–10.15	**KEYNOTE – Beyond Industry 4.0: the people and technology strategy in packaging** ***Martin Hejl**, Thimm Obaly*	
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10.30–11.00	Coffee break	
11.00–12.15	**Session 6A** | Room C1	**Session 6B** | Room C2
11.00–11.25	Digital transformation of the graphic arts industry: opportunities and challenges in the era of Industry 4.0 ***Gerasimos Vonitsanos**, Antonios Tsigonias and Marios Tsigonias*	Comparative analysis of the quality of accurate printing, using digital printing systems ***Daiva Sajek**, Virginijus Valčiukas, Gitana Ginevičienė and Vidas Vainoras*
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11.50–12.15	Bridging print technology and additive manufacturing: a new interdisciplinary study program ***Lutz Engisch***	Development of pouch for time temperarture indicators ***Madhura Mahajan** and Rambabu Atluri*
12.15–13.30	Lunch	

13.30–14.20	**Session 7A** | Room C1	**Session 7B** | Room C2
13.30–13.55	Understanding the effects of image customization on response rates for direct mail campaigns ***Kevin Howell***	Alginate blends as a bio-based adhesive for bookbinding application ***Lukas Jenner***
13.55–14.20	Automatic Colorization of Grayscale Images Using Convolutional Neural Networks: a Small-Scale Study ***Aleš Hladnik*** *and Mihael Lazar*	Thermally conductive composites for FFF 3D printing with hybrid filler – the influence of individual fillers and the amount of filler ***Petr Roudný****, Jana Kašparová, Čestmír Drašar and Tomáš Syrový*
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14.50–16.05	**Session 8A** | Room C1	**Session 8B** | Room C2
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15.15–15.40	Enhancing Quality and Standardisation in Flexographic Printing: the need to embrace Big Data ***Enn Kerner***	Teaching the History of the Book through Applied Letterpress Printing: A Classroom Experience ***Kenneth Macro***
15.40–16.05	Environmental Accounting as a key parameter for the implementation of Sustainability strategies in the Printing & Packaging Industry ***Christos Sarigiannidis*** *and Bassilis Boutsinas*	Visual Communication for a Theatrical performance: What can Digital Printing do? *Charalambos Sepentzis, Sofia Strati, Marios Tsigonias, Antonios Tsigonias and* ***Anastasios Politis***
16.05–16.20	**Closing session – iarigai & IC** | Room C1	
16.05–16.20	**Wrap up and invitation to the iarigai & IC conferences 2026**	
16.20–16.30	Break	
16.30–17.30	IC General Assembly (member representatives only) | Room C2	
19.00–22.00	**Conference dinner**	

FRIDAY 5TH SEPTEMBER

8.30–16.00	**Conference tour to Litomyšl**

The conference programme as of 21 August 2025. The up-to-date version and additional information are available at the conference website:
https://fcht.upce.cz/en/fcht/iarigai-ic

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Preface

Dear IC members,
Dear colleagues and friends of the Graphic Communication, Print, Media and Packaging fields,

The 56th Annual Conference of the IC – the International Circle of Educational Institutes of Graphic-Media Technology and Management, has taken place at ETH, Pardubice, Czech Republic, on 2-5 September 2025. Following the tradition of the last years the IC Conference has been jointly organized with iarigai. The joint iarigai/IC conferences have been organized in Warsaw Poland (2018), Athens Greece (2021), Clemson/Greenville USA (2022), Wuppertal Germany (2023) and Zurich, Switzerland (2024).

iarigai – the International Association of Research Organizations for the Information, Media and Graphic Arts Industries and IC – the International Circle of Educational Institutes of Graphic-Media Technology and Management are among the most prominent research and educational organisations for print-media and packaging fields worldwide.

The joint organization of the conferences has been proved quite successful, bringing together the three pillars of Research, Industry and Education in the Graphic Communication, Print-media and Packaging fields.

At this digital edition of the Conference Proceedings of the IC, you will find the full papers or abstracts from the colleagues that participated in person or from distance and presented their scientific work at the conference.

Please follow our website at: https://www.internationalcircle.net/
and our LinkedIn site at: https://www.linkedin.com/company/international-circle/,
for more information and updates on the activities of the IC.

Prof. Dr. Anastasios E. Politis
Chairman of the IC

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Bridging Traditional Print Technology and Additive Manufacturing: Designing an Interdisciplinary Bachelor Program for Future Engineers

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Abstract

The printing and packaging industry is undergoing a paradigm shift. Traditional 2D technologies increasingly merge with additive manufacturing (AM) and functional surface engineering, creating novel opportunities as well as urgent challenges for education and workforce development. Industry stakeholders have repeatedly emphasized a clear technical skills gap in these emerging domains, while universities experience declining numbers of qualified applicants for conventional graphical printing study programs. To address this demand, HTWK Leipzig has developed 3D Printing and Functional Surfaces (B.Eng.), a new interdisciplinary bachelor program that bridges engineering and printing sciences.

The article outlines the motivation for this initiative, the development process, the curriculum design, and the expected outcomes. Special emphasis is placed on lessons learned during program conception, on the embedding of the study program into institutional research structures, and on perspectives for collaboration with other universities and industry. It is argued that the new program provides a model for future-oriented engineering education by bridging traditional printing expertise with the dynamic field of additive manufacturing.

Keywords: 3D printing, functional surfaces, additive manufacturing, interdisciplinary education, competence development, curriculum design, sustainable production.

Introduction

"Additive manufacturing is currently suffering from a skills shortage… there remains a shortage of multidisciplinary educational programmes aimed at producing the next generation of AM professionals, ..." [1]

The printing industry has historically been a cornerstone of industrial production, communication, and cultural development. Conventional processes such as gravure, offset, screen and flexographic printing have provided efficient mass production of media and packaging for decades. Yet in the last 20 years, the scope of printing has expanded dramatically. Today, printing technologies are applied not only to newspapers or packaging but also to electronics, biomedical devices, energy systems, and smart materials.

In parallel, additive manufacturing (AM) evolved from prototyping to industrial-scale production. Its ability to enable a seemingly free definition of geometries, mass customization and resource-efficient design makes AM a disruptive technology. Functional surfaces, which are achieved by coatings and local structuring, further extend application scenarios, from packaging barriers to electronic sensors [2].

This convergence of 2D and 3D technologies creates both opportunities and challenges. On the one hand, it allows for entirely new product categories and industrial applications. On the other hand, it requires a workforce that is well-trained in traditional mechanical design, printing fundamentals as well as advanced digital technologies. Existing programs in printing and packaging technology often fail to attract sufficient applicants, and industry consistently reports a lack of graduates with the right interdisciplinary skill set. Yet existing educational programs often fail to prepare graduates adequately for the new challenges ahead [3].

The bachelor program 3D Printing and Functional Surfaces (B.Eng.) at HTWK Leipzig has been designed in response to recent advancses in the field as well as the unknown challenges of the future. It offers students a comprehensive scientific background as well as practical skills in additive manufacturing, surface functionalization, and digital process management. The program's objective is to prepare engineers who are adept at connecting established printing methodologies with innovations in additive technologies. As Singh et al. (2025) observe: "Emerging educational programmes must integrate both technical skills and hands-on exposure to AM technologies if they are to address the existing skills gap." [3].

Background and Motivation

Decline in Qualified Applicants

A key driver for the development of the new program was the declining number of qualified applicants to existing printing and media technology programs. Although the number of applications remained relatively high on paper—with roughly 130 qualified applications for 25 study places—many candidates lacked the specific technical preparation required. Furthermore, demographic changes and regional competition for STEM students exacerbate the situation.

The risk was clear: without modernization, traditional study programs would become increasingly unattractive, threatening both enrollment numbers and the reputation of the discipline.

Changing Student Demographics

The demographic profile of enrolled students revealed important insights. Approximately three-quarters were not fresh from high school but had already pursued vocational training or even started another degree. Their average age was around 24 years, and the majority were male.

This profile has advantages and disadvantages. On the positive side, many students brought practical experience, strong motivation, and clear career orientation. They valued the reputation of HTWK Leipzig and had an affinity for STEM topics. At the same time, the pool was too narrow to sustain future enrollment, and the gender imbalance limited diversity and perspectives within the program.

3D Printing as an Attractive Entry Point

In contrast to the declining appeal of traditional print technology, 3D printing enjoys strong societal visibility. It is present in schools, vocational training centers, makerspaces, and even private households. Tech-savvy young people perceive it as future-focused, creative, and empowering. For this reason, 3D printing serves as an excellent entry point to attract new audiences.

However, the 3D printing process alone does not provide the depth of an engineering education. To ensure sustainable career opportunities, students require a comprehensive curriculum that combines AM with mechanical design, functional surfaces, material science, sustainability, and digital process management. The challenge, therefore, was to design a program that uses 3D printing as a "hook" while embedding it in a rigorous academic framework.

Development Process

The conception of the program followed a multi-step, collaborative approach.

1. **Interdisciplinary Cooperation:** Several faculties contributed expertise, including Media and Computer Science, Engineering, Natural Sciences, as well as the Institute for Print and Packaging (iP^3). This cooperation ensured that the program covered a broad range of disciplines.
2. **Industry Involvement:** From the very beginning, industry partners were invited to advisory boards. Their input shaped the curriculum by identifying relevant technologies, applications,and skills. Letters of intent (LOIs) confirmed industrial demand and commitment.
3. **Accreditation:** To ensure compliance and quality, the program was aligned with ASIIN accreditation standards and the German Qualifications Framework (QF-EHEA). This step guaranteed that graduates would meet national and European requirements for engineering programs.
4. **Strategic Positioning:** The program supported HTWK Leipzig's institutional strategy of raising the proportion of engineering programs to 70%, thereby enhancing the university's profile in applied sciences as well as the current realignment of the research infrastructure to facilitate multi-material additive manufacturing.

Lessons learned:

One key lesson from the program's development was the importance of aligning with accreditation frameworks at an early stage, as this practice helps to prevent the need for expensive and time-consuming changes further down the line. At the same time, it reduces barriers of acceptance for different management layers. While interdisciplinary collaboration introduces greater complexity to the development process, it ultimately serves to strengthen the unique identity of the program. Involvement from industry partners proved essential in securing both credibility and practical relevance, ensuring the curriculum met contemporary professional demands. Furthermore, advocacy within the university played a critical role, as it helped to overcome internal resistance and secure the necessary resources for success. Finally, it became clear that a careful balance must be achieved between making the program attractive from a marketing perspective and maintaining rigorous academic standards. This experience provides valuable guidance for other institutions considering similar program developments.

Curriculum Structure and Competence Development

The curriculum is structured around five pillars:

Engineering and Natural Sciences: Students study mathematics, physics, and material sciences. These courses provide the analytical and technical foundation necessary for engineering practice.

Additive Manufacturing Technologies: Core modules introduce polymer, metal, insulator and hybrid printing processes. Students learn not only how to operate AM systems but also how to design parts for manufacturability and sustainability.

Process Management and Digitalization: Courses on workflow management, automation, and AI-based quality control prepare students for digitalized production environments.

Sustainability and Smart Materials: Students explore circular economy, eco-design, and advanced functional materials (e.g., conductive, insulating, barrier). Sustainability and smart material choices permeate the curriculum, forming the foundation of engineering, additive manufacturing, and industry collaboration.

Industry Collaboration and Practice: Practical phases, projects, and lab work ensure that students apply their knowledge to real-world challenges.

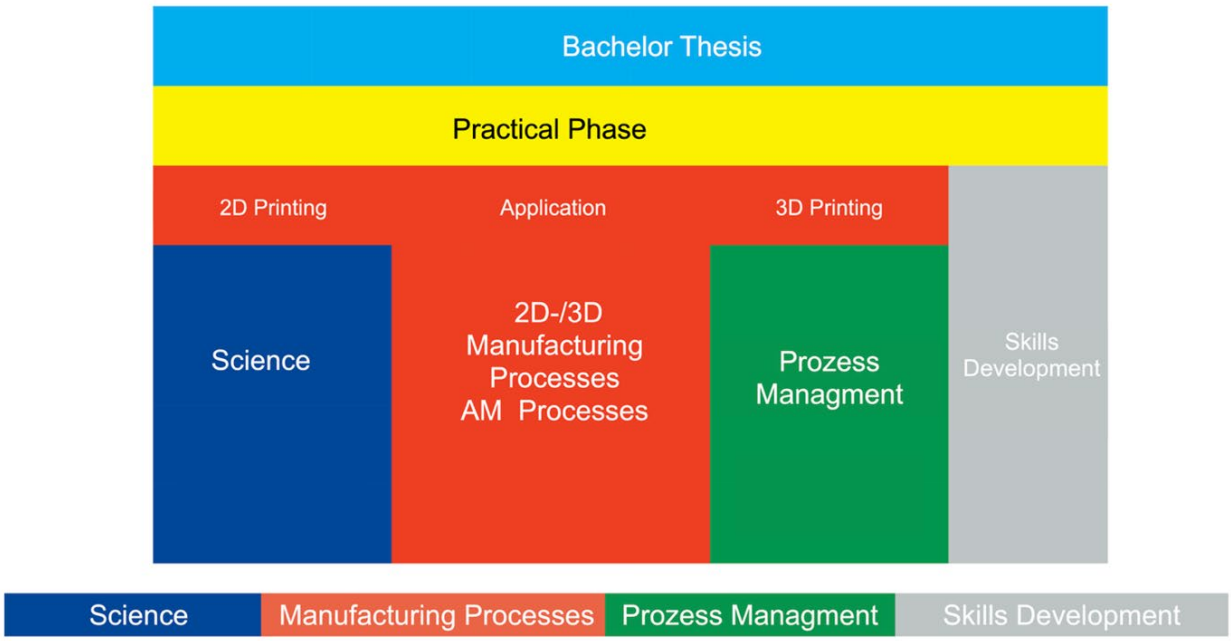

Figure 1. Curriculum of the New Program – A top-level view.

The curriculum progresses logically from fundamentals in the first two semesters, through technological specialization in semesters three and four, to application-oriented projects in semesters five and six. Flexibility is provided through elective modules, which include topics such as factory planning, logistics, marketing, and occupational safety.

Expected learning outcomes include:

- The ability to design and optimize additive manufacturing and surface processes.
- Expertise in applying sustainability principles to industrial contexts.
- Skills in managing digital workflows, automation, and quality assurance.
- Experience in interdisciplinary teamwork and problem-solving.

This competency-based approach ensures that graduates are prepared not only for current industry demands but also for future developments in rapidly evolving technology fields.

Practice Orientation and Industry Links

Practical training is integrated from the very first term. Laboratory courses enable students to experiment with materials, processes, and measurement methods. Project-based learning fosters creativity

and team spirit. A dedicated internship term immerses students in industrial environments, providing valuable professional experience and challenge the application of the knowledge in the real world.

Internationalization is also emphasized. Mobility windows in the 2nd, 3rd, and 6th terms allow students to study abroad, participate in exchange programs, or complete internships with international companies. This strengthens language skills and intercultural competence.

Two institutional initiatives support the practical and research-oriented focus:

CS² – Center for Smart Surfaces: A research center focusing on coatings, additive processes, and material functionalization. It addresses applications such as printed electronics, diagnostic systems, and sustainable packaging. Students can participate in projects and theses here.

AM³ – Additive Multi-Material Manufacturing: A cross-university, open research hub focusing on additive technologies in the powder bed fusion (PBF-IR) and material extrusion (MEX), giving the students the opportunity to work on fundamental research projects.

X-LAB: An interdisciplinary innovation hub at HTWK Leipzig that integrates 2D and 3D printing technologies. It serves as a learning space for students, a platform for collaboration with external partners, and a driver for creative experimentation.

Together, **CS², AM³** and **X-LAB** anchor the program in fundamental and applied research as well as industrial collaboration, ensuring that students apply their knowledge in the real world and benefit from cutting-edge projects. The bachelor program is not a stand-alone initiative but is embedded in HTWK Leipzig's broader institutional strategy. The **iP³ Institute** plays a central role in coordinating interdisciplinary research on printing and packaging. The CS², AM³ and X-LAB provide infrastructure and expertise that link teaching and research.

A new master's program, *Sustainable Printing and Packaging (M.Eng.)*, is in development to provide continuity for bachelor graduates. It focuses on process innovation, change management, and sustainability. Together, the bachelor and master programs create a coherent educational pathway.

Expected Impact and Career Opportunities

The program is expected to have multiple impacts:

- To manifest printing technologies as a generic manufacturing technology.
- Closing the skills gap at the interface of printing and AM.
- Preparing graduates for manufacturing sectors such as healthcare, mobility, packaging, energy, and smart materials.
- Supporting industrial innovation by providing skilled engineers.
- Strengthening the reputation of HTWK Leipzig in engineering and applied sciences.

Career opportunities include product development, process engineering, quality assurance, R&D in materials, and project management. Graduates will be versatile engineers, capable of working across disciplines and adapting to technological change.

Conclusion

The bachelor program **3D Printing and Functional Surfaces (B.Eng.)** demonstrates how traditional disciplines can evolve to meet the needs of a rapidly changing technological landscape. By combining rigorous scientific foundations with innovative content and strong industry links, it offers a model for future-oriented engineering education. The program bridges printing heritage and additive futures, ensuring that students not only master the fundamentals of engineering but also acquire the skills required to drive industrial transformation.

Despite these strengths, the program faces challenges. Recruiting sufficient students in a competitive environment remains a central task, while sustaining interdisciplinary teaching requires careful resource planning. Rapid technological advances necessitate continuous curriculum updates, and long-term success will depend on maintaining strong ties to industry. Looking forward, HTWK Leipzig aims to expand international partnerships with other universities, exchange curricula, and initiate joint projects. Building a global network in additive manufacturing and functional printing will benefit students, researchers, and industry alike, contributing to a new generation of engineers equipped to address the challenges of sustainability, digitalization, and innovation.

In this way, the program **bridges printing heritage and additive futures.**

References

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[2] Cheng, C., & Gupta, M. (2017). *Surface functionalization of 3D-printed plastics via initiated chemical vapor deposition*. Beilstein Journal of Nanotechnology, 8, 1629–1636.

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Author's biography

Lutz Engisch studied chemistry and material sciences at Chemnitz University of Technology, completing his PhD in 2004 on chemical vapor deposition and instrumental analysis. He led the Department of Digital Printing at the Institute of Print and Media Technology, with research stays in Sweden (STFI Packforsk) and Australia (QUT Brisbane). Later, as Head of R&D at SWG Frankenberg, he advanced direct laser gravure and light-cylinder technologies. Since 2011, he has been Professor at HTWK Leipzig, currently serving as Vice Dean of Research and Director of the Institute iP³ Leipzig.

Ingo Reinhold is a professor of coating technologies at the University of Applied Sciences (HTWK) in Leipzig. He holds a diploma degree in Print- and Media Technology from the Chemnitz University of Technology and earned his Ph.D. in industrial inkjet printing at the Royal Institute of Technology (KTH) in Stockholm, Sweden. From 2008 to 2021, he worked at Xaar's Advanced Application team in Stockholm, focusing on industrial functional printing processes and inkjet printhead design. He leads the DFTA Competence Center Digital Printing Leipzig (CCD) and pursues research opportunities with the Leipzig Center for Smart Surfaces as well as the Leipzig Center for Additive Multi-Material Manufacturing.

PackPrint Science – The Hellenic Center for Research and Education on Packaging, Print and Graphic Communication: A Sector-Oriented Initiative from Greece

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Abstract

Print media and packaging industries are undergoing a significant period marked by rapid evolution in diverse domains, including aspects such as business & management, workflow & production, as well as technological innovation involving novel systems and equipment with advanced applications of specific software.

A substantial body of research in conjunction with events such as Drupa 2024 indicates a compelling need for intensified collaboration among industry and companies, research institutes and educational organizations, with the objective of implementing continuous reforms to the existing curricula and improvement of study programs in the print-media, graphic communication and packaging fields. Consequently, a comprehensive and systematic approach to the development of curricula and study programs at all levels, entails the indispensable involvement of the industry and research domains.

A recently presented procedure of particular interest entails the development and implementation of strategies for the holistic development of all individuals associated with the industry. The present study delves into this strategy as a novel, sector-based, holistic approach in education and training the development of human capital within the graphic communication, printing, and packaging sectors/fields.

In light of the aforementioned evidence, this paper presents and analyzes the brand-new formed PackPrint Science initiative. PackPrint Science, established in Greece in 2024 as an initiative by prominent print media and packaging industrial and research associations, emerged as a crucial response to the evident dearth (nearly non-existent to be precise) professional training and higher education within the print-media and packaging fields in Greece.

PackPrint Science represents a comprehensive approach to Human Capital Development on a national scale for a specific industrial sector. The initiative's objective is to consolidate the three pillars of the print-media and packaging industries, namely the industry and the companies, the research organizations and the educational institutes, fostering a collaborative environment conducive to education and training for the sectors in Greece. Furthermore, the study delves into the

concrete steps required towards the seamless integration of this holistic approach for the optimal training and education in both printing and packaging sectors.
The most salient distinction of these holistic approach vis-à-vis traditional settings resides in the sector's role as the pivotal starting point for the education design. This approach entails the classification into different levels, predicated on the human capital needs and the pertinent education at all levels. PackPrint Science exemplifies an effective holistic Human Capital Development strategy, fostering collaboration among all individuals and organizations within the relevant sectors and fields.

Keywords: Print-media & Packaging fields, Holistic human capital development strategies, Sector-based education and training, Hellenic PackPrint Science initiative.

Introduction

Printing, finishing and packaging represent the core pillars that facilitate effective communication of brands, goods and services. It is imperative to acknowledge that within the conventional structure of print-media industries, print constitutes the primary product, employed as an integral component of the communication process. (Politis, 2019).

According to Nils Enlund (2013), the multidisciplinary engineering and scientific field of Graphic Arts Technology (GAT) comprises established and emerging technologies, and encompasses principles and practices from diverse scientific disciplines. (Enlund, 2013).

Recent advancements encompass hybrid printing and finishing technologies, application of advanced materials, printed electronics, Augmented Reality (AR) technology, Variable Data Printing (VDP), functional printing (e.g., functional packaging, 3D printing), advanced multicolor printing and digital textile printing. (Politis, 2019).

In addition, notable examples of innovative application in the printing industry, concern AI-powered workflows, cloud-based print management systems, data-driven eco-management, utilization of recycled materials, biodegradable inks, LED-UV curing systems, and closed-loop recycling standards, employment of robots and automated guided vehicles (AGVs) for heavy-duty and repetitive tasks, and utilization of IoT-connected machinery' analytics for predictive maintenance purposes. (Reed, 2025).

The aforementioned trends and innovations should be examined via the scope of digitalization in printing production (e.g., Industry 4.0, 3D printing), underscoring the prevalence of printing and packaging industry in the digital age, albeit with major alterations in research, industry, and education. (Politis, 2018)

The transition towards digital workflows precipitated the emergence of new professions, interdisciplinary teamwork-based competencies, and hybrid skill sets (e.g., combination of technical, creative, management, business competencies). However, the existing educational programs appear to be deficient in addressing such competencies. (Politis & Gatsou, 2016).

Despite the restructuring of the academic curricula and the emergence of new courses during the last decades, most of the educational and training institutions grappled to adapt. Concurrently, there was proliferation of in-house training and specialized seminars on print media systems, machines, and technologies. (Politis & Gatsou, 2016) (Sofias & Politis, 2024).

It is noteworthy that the most prominent scientists and researchers in the print-media education and research community participated in Drupa 2024 via the International Circle (IC) and HELGRAMED booth at the drupa next age - dna hall. The majority of inquiries posed by attendants focused on employment opportunities, revealing deficiencies in educational and training establishments, culminating in diminished rates of competitive personnel skills, as well as indicated significant gaps in educational and training frameworks, alongside a decline in the possession of hybrid personnel skill-sets to be employed at all levels within the pertinent sectors. (Sofias & Politis, 2024)

Figure 1. Requests by Greek printing companies for personnel during their visit at the Internaional Circe / HELGRAMED booth at drupa 2024 Hall 7.0 - dna (source: drupa 2024)

Indeed, a noteworthy example of dwindling (nearly non-existent) educational and training frameworks can be observed in Greece, providing the impetus for the establishment of the PackPrint Science initiative in 2024 by prominent print-media and packaging industrial and research associations.

Pack Print SCIENCE
Hellenic Center of Research, Development & Education for Packaging, Printing & Graphic Communication

Figure 2. PackPrint Science.
(source: https://www.packprintscience.org/).

PackPrint Science embodies a national holistic Human Capital Development (HCD) strategy, aiming to consolidate the three pillars of the print-media and packaging industries (e.g., industry and companies, research organizations, and educational institutes) to foster a collaborative environment conducive to education and training for all individuals within the relevant sectors and fields in Greece. (PackPrint Science, 2024).

Print-media & Packaging sector

According to the Printing Global Market Report 2025 by the Business Research Company, the estimated market value is projected to reach $402.75 billion by 2029, exhibiting a compound annual growth rate (CAGR) of 4.0%. The factors contributing to this growth encompass increased sustainability commitments, e-commerce demands for smart packaging, a surge in remote work models, higher personalization rates, innovations in hybrid printing technologies, and advancements in 3D printing. (The Business Research Company, 2025).

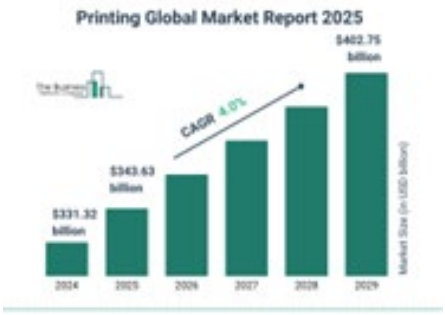

Figure 3. Printing Global Market Report 2025 by the Business Research Company. (source: https://www.thebusinessresearchcompany.com/report/printing-global-market-report).

Indeed, the marked decline in conventional print-media production, and the rise of online shopping, catapulted packaging into a rapidly expanding sector, thus rescuing the majority of print operations in turn. (Dabo, 2025). Furthermore, the global packaging printing market forecasts indicated an annual CAGR of 4.6% from 2025 to 2034, primarily due to escalating e-commerce demands for high-quality and aesthetically pleasing packaging. (GMI, 2025).

Figure 4. The GMI Global Forecast (2025 - 2034) of Packaging Printing Market. (source: https://www.gminsights.com/industry-analysis/packaging-printing-market).

In addition, the intricacy of printing processes, adherence to entrepreneurial principles, and continuous technological advancements enable the leveraging of AI's transformative capabilities, via AI real-time decision-making, and AI data-driven predictions towards novel ROI (return on investment) strategies. (Metcalf, 2025).

The digital transformation in the printing industry is driven by Industry 4.0 technologies, facilitating operational efficiency, mitigating downtime, and augmenting customer experience. (Mopria Alliance, 2025). As such, Industry 4.0, may be identified as the social, industrial, and technological transformative potency precipitated by the digital transformation. (Richnák & Čambalíková, 2022).

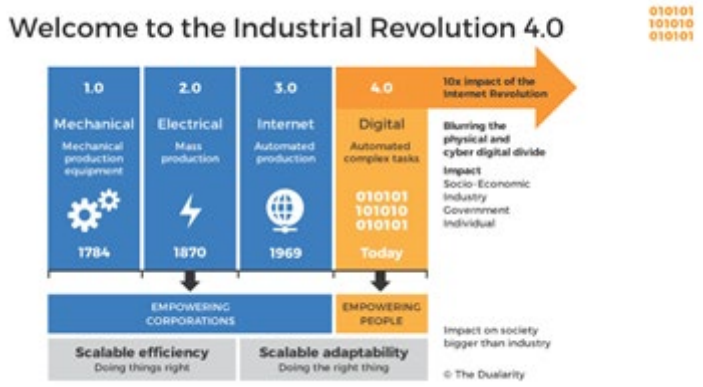

Figure 5. Industrial Revolution: Industry 1.0 to Industry 4.0.
(source: https://www.linkedin.com/pulse/industry-40-fourth-industrial-revolution-driving-karan-mehta).

The integration of AI facilitates the implementation of diverse AI fields (e.g., ML, natural language processing or NLP, optimization, and utilization of robotics and expert systems) across production planning and control (PPC), quality management (QM), maintenance management (MM), and supply chain management (SCM). (Bin Masod & Zakaria, 2024).

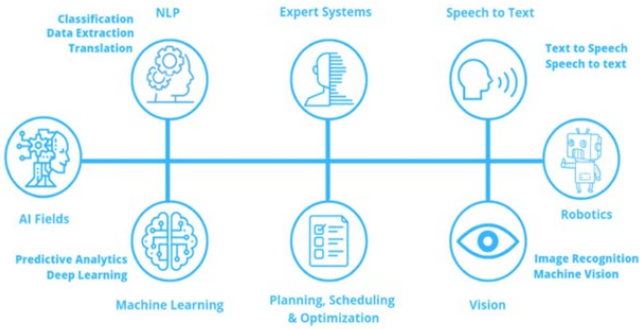

Figure 6. The AI fields.
(source: https://www.researchgate.net/figure/The-seven-fields-of-AI_fig1_357238467).

Key concepts include the utilization of cyber-physical systems (CPS), cloud computing, cognitive computing, the Internet of Things (IoT), ML, virtual reality (VR), 3D printing, simulation, big data, radio frequency identification (RFID), cyber-security, machine-to-machine interaction, utilization of robots and drones, nanotechnology, enterprise intelligence, automation, and AI integration. (Mopria Alliance, 2025) (Richnák & Čambalíková, 2022).

Figure 7. The 11 pillars of Industry 4.0.
(source: https://www.researchgate.net/figure/The-eleven-technology-pillars-of-Industry-40_fig1_366580564).

It is imperative to note that Adam Page, the vice president of Smithers' reports, conducted an analysis and suggested that AI integration within the printing and packaging industry is subdivided into three distinct waves, occurring between 2023 and 2025. Indeed, the advent of ChatGPT in 2023 enabled the utilization of machine learning (ML) capabilities, ushering in the 1st wave via the form of Predictive AI. (Page, 2025).

Conversely, the 2nd wave emerged in 2024 due to the proliferation of Generative AI, augmenting the realm of human-machine interaction, and ushering in the 3rd wave via the form of Agentic AI during 2025. Furthermore, Page's analysis was chiefly informed by the key findings of the Post-Drupa Technology Forecast for Print and Printed Packaging to 2034 Report by Smithers. (Page, 2025).

The primary emphasis of Drupa 2024 centered on automation, advanced workflow solutions, advancements in MIS, innovations in inkjet technology, trends in 3D printing and printed electronics, and the integration of AI. (Quirk, 2024) (Smithers, 2024).

Indeed, Industry 4.0 portends disruptions in employment opportunities, necessitating the acquisition of hybrid skill sets. Furthermore, enterprises are progressively transitioning towards Industry 5.0 (Fifth Industrial Revolution), a paradigm shift towards a wider spectrum of efficiency, automation, personalization, and precision. (Gryczka, 2024).

Figure 8. The Human-Centric shift from Industry 4.0 to Industry 5.0.
(source: https://antgrasso.medium.com/industry-5-0-will-bridge-automation-to-human-machine-collaboration-63e170cffe3d).

Industry 5.0 aims to enhance personalization and efficiency through an anthropocentric approach, thereby emphasizing the significance of HCD as a crucial element in the production processes. (Gryczka, 2024). Furthermore, Sofias & Politis (2024) suggested that predominant concerns among attendees pertained to employment opportunities, thereby underscoring educational and training insufficiencies, and diminished rates of competitive personnel skills. Indeed, they underscore the necessity of implementing a novel HCD approach, predicated on addressing the needs and requirements concerning education and training within relevant sectors. (Sofias & Politis, 2024).

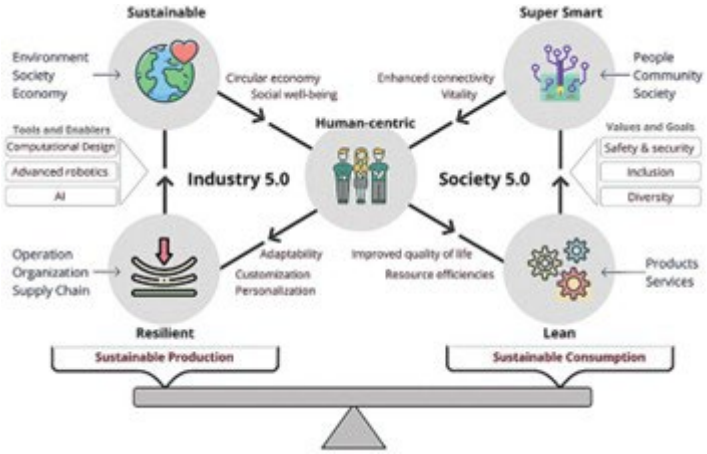

Figure 9. Industry 5.0 is an integrated approach to HCD, focusing on sustainable production and consumption. (source: https://www.researchgate.net/figure/An-integrated-industry-50-society-50-perspective-The-human-centred-element-is-the_fig1_390597184).

According to Sofias & Politis (2024), the novel sector-based holistic HCD strategy should differ from all conventional approaches, being rather anthropocentric and enabling the holistic development of all individuals in all levels of the print-media and packaging sector, particularly by addressing efficiently the emerging needs and requirements identified in related fields. (Sofias & Politis, 2024).

Human capital development – HCD in the printing & packaging sectors

The printing industry is undergoing a period of significant transformation, precipitated by technological advancements that impact production processes and organizational structure of enterprises, products, and their market dynamics. Indeed, a salient feature is the shift from a manufacturing-oriented model to a service-oriented approach, precipitating changes in companies and the Human Capital (HC) involved. (Politis, 2004).

Employees in the printing and packaging sector are subject to the aforementioned alterations, thereby impacting competencies and requirements, thus precipitating the imminent role of soft skills within the information era. (Politis, 2004). Indeed, soft skills are associated with emotional intelligence (EQ), thus modulating thought and behavior. (Peterson, 2017).

The fundamental basis for all operational activities that determines an enterprise's viability and success resides in Human Resources (HR). However, contemporary perspectives often constrain Human Resource Management (HRM) and Human Resource Development (HRD) solely to three main facets: recruitment, compensation, and legislation. (Richman, 2015).

Figure 10. The 7 elements of HRD with a HR department.
(source: https://www.workhuman.com/blog/human-resource-development-hrd/).

The implementation of HRM and HRD strategies has been predominantly observed within large-scale enterprises, with most of HRM solutions being customized for medium-sized and large enterprises. Furthermore, the HCD strategies lack the consideration they merit, notably within micro-sized, small, and medium-sized entities, as well as sole proprietorships and independent contractors. Indeed, HC is a pivotal factor within development strategies, focusing on relationship and customer management, EQ, and networking. (Politis, 2004).

The concept of HC, traced to 18th-century work by the economist Adam Smith, endeavors to elucidate interrelationships and dynamics among employees within enterprises and organizational frameworks. Furthermore, Papadopoulos (2003) posits that HC enables the development of information capital, which is valuable solely within specific business strategy, encompassing IT applications and associated technological infrastructure. (Politis, 2004).

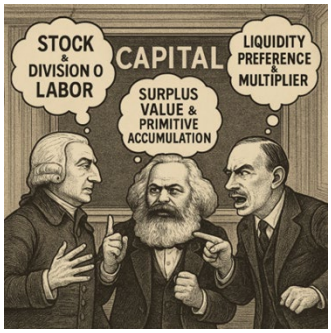

Figure 11. Mike Munger juxtaposing Smith's economic perspective with that of Marx, elucidating capital allocation. (source: https://www.adamsmithworks.org/speakings).

The transition from a product-centric sales model to a service-oriented paradigm has led to the emergence of knowledge and information as pivotal resources, thus necessitating novel management theories, regarding the enhancement and exploitation of knowledge, as well as its effective utilization and quantification. Indeed, it is imperative to differentiate the various forms of intellectual capital and to map out the interrelationships among them. (Politis, 2004).

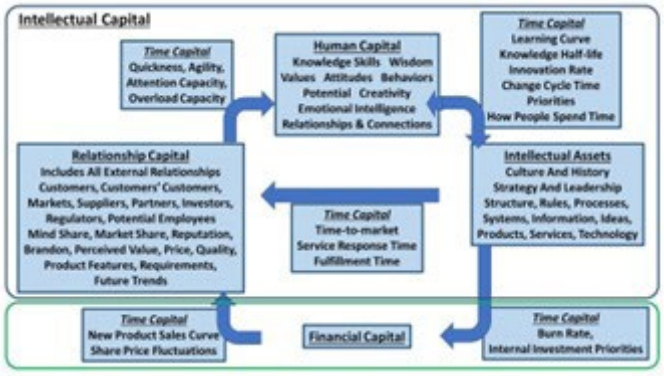

Figure 12. Forms of intellectual capital.
(source: https://businessinnovationmanagement.com/browse-content/book-table-of-contents/chapter-23-knowledge-management-and-intellectual-capital/)

Scandia AFS (1996) proposed the concept of intellectual capital as an accumulation of knowledge, competencies, HC, and structural capital. HC signifies the set of skills, knowledge, and experience possessed by an organization's personnel, which should be utilized, enhanced, and established via organizational processes. (Politis, 2004).

As a result, the unprecedented transformations within the global economy and the escalating levels in attaining competitive advantage, necessitates a reevaluation of the HRD paradigm within a holistic, global context. Furthermore, there is an imperative need to ascertain the efficacy of current HRM and HRD within operational environments or transitioning towards the establishment of an innovative sector-oriented holistic HCD strategy. (Politis, 2004).

Definition and characteristics of a HCD holistic strategy

According to Penkala (2021), the definitions of HC provide a framework for comprehending the term through the lenses of expenditures, resources, or investments. Nevertheless, the principal emphasis must be placed on the employees' qualifications, social aptitudes, and attitudes in relation to the prevailing organizational environment. Indeed, the concept of innovation is associated with the proliferation of novel products, services, practices, and business models, thus precipitating the necessity of shifting towards a holistic HCD approach. (Penkala, 2024).

The term HCD may be defined as the set of strategic initiatives and approaches meticulously designed to enhance an organization's workforce levels of intellectual aptitude, practical skills, as well as fundamental ethical values and behavioral traits. Indeed, HCD is promoting the long-term viability of the circular and sustainable economy. (Atiku & Lawal, 2021).

Figure 13. The model of HCD impact on labour productivity.
(source: https://www.researchgate.net/figure/The-model-of-human-capital-development-impact-on-labour-productivity-made-by-authors_fig1_325604029).

Prudent investment in HCD, coupled with effective utilization of HC, redounds to the benefit of employees, and employers. Furthermore, HCD enables the efficient transition into a sustainable economy, while strategic HCD interventions must be meticulously aligned with sustainable development goals. (Atiku & Lawal, 2021).

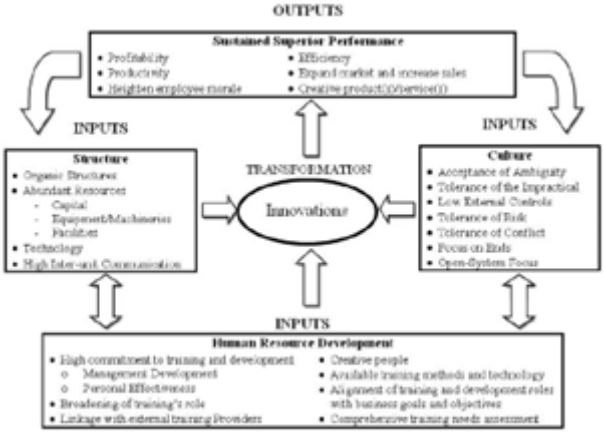

Figure 14. The operational framework on HCD for innovation.
(source: https://www.researchgate.net/figure/Operational-Framework-on-Human-Capital-Development-for-Innovation_fig1_228667689).

As Politis (2024) posits in the presentation "The Future of Print-Media Education: A Sector-Oriented Holistic Approach" held at Drupa 2024 in the dna stage, the inherent intricacy of print businesses is typified by the interplay of business and management, technological advancements and automation, data and digitalization, circular economy and sustainability, and relevant customers, suppliers, materials, markets, and products. According to Politis (2024), there is an emerging need to think and act in a non-conventional manner, and to transition towards the formation of a holistic strategy for HCD.

In addition, Politis (2024) posits that the holistic HCD strategy should embrace an anthropocentric framework, be conceptualized and implemented within companies and sectors, as well as involve all stakeholders and players within company and sector levels, and consider education and training at their full dimensions, by providing directions and suggestions for curricula and programs based on learning outcomes. (Politis, 2024).

Figure 15. The picture is a collage made from screenshots obtained from the presentation "The Future of Print-Media Education: A Sector-Oriented Holistic Approach" by Anastasios Politis, held at the Drupa 2024 exhibition in the dna hall. The picture presents the most notable examples of sector councils on a global scale.

Politis (2024) initially has identified a multitude of considerations for Europe, encompassing disparities in national education systems, job profiles, task descriptions, occupation standards, entry requirements for education, and levels of skills and competencies. (Politis, 2024).

It is imperative to note that the proposed HCD strategy should be based on the convergence of different components (e.g., recruitment, education and training), and common job profile descriptions. The primary objectives of this initiative entail the integration of disparate, albeit inherently interconnected elements into a unified platform to facilitate a comprehensive holistic HCD approach. Indeed, according to Politis (2024), notable examples of policies for the HCD in the industry include the sector councils. (Politis, 2024).

Politis (2024) further emphasizes the existence of significant examples of actions by social partners, organizations, and/or associations, manifesting either via partnerships between confederations, cantons, and professional organizations, or via the cooperation between host companies, VET schools, and industry training establishments. (Politis, 2024).

Prominent examples of noteworthy initiatives for HCD in the European printing industry include the project by EGIN, Intergraf, and UNI Europa graphical and packaging in 2014 and in 2015, as well as the EU project on Jobs and skills (2009). Indeed, significant incidents are also being reported from various locations around the world. (Politis, 2024).

Figure 16. The picture is a collage made from screenshots obtained from the presentation "The Future of Print-Media Education: A Sector-Oriented Holistic Approach" by Anastasios Politis, held at the Drupa 2024 exhibition in the dna-next hall. The picture presents notable examples of actions by social partners' organizations and/or associations, and noteworthy initiatives for HCD in the European printing industry, as well as significant incidents being reported from various locations around the world.

Politis (2024) concludes his presentation by underscoring the pivotal role of the Drupa exhibition for inspiring and aspiring individuals in all positions and levels within the printing and packaging sector. By tracing back to Drupa 1977, Politis (2024) highlights the importance of the potential attaining of national and international initiatives towards novel, sector-oriented, holistic approaches to HCD strategies during Drupa 2028. (Politis, 2024).

Case study from Greece – The PackPrint Science initiative

The establishment of the PackPrint Science Center in 2024 has become imperative to address the shortage of skilled personnel, and to ameliorate the challenges related to research and development, which are frequently encountered by employees, businesses, and the Packaging, Printing, and Graphic Communication industries in Greece. (PackPrint Science, 2024).

The primary mission of the PackPrint Science initiate is the comprehensive analysis and evaluation of HC requirements, in addition to the strategic implementation of meticulously tailored educational and training programs. Indeed, the primary objective of these programs is to nurture the next-gen of professionals within the domains of Packaging, Printing, and Graphic and Communication Industries. (PackPrint Science, 2024).

The PackPrint Science initiative is predicated on the collaboration of scientific and professional associations in pertinent sectors, including: ELSET (Hellenic Labelers Association), HELGRAMED (Hellenic Union of Graphic Arts and Media Technology Engineers), and FESPA HELLAS ASSOCIATION (Association of Screen, Digital &Textile Printing Professionals). (PackPrint Science, 2024).

The PackPrint Science Center represents a sector-oriented organization that is dedicated to the comprehensive growth and development of three distinct sectors in Greece: Packaging, Printing and Graphic Communication - Graphic Arts. It is imperative to note that center's emphasis is given on the HCD,

through the design and implementation of novel, meticulously defined educational and training programs, in topics and subjects of the relevant sectors, addressing the prevailing demands and needs arising at all levels. (PackPrint Science, 2024).

The establishment and subsequent administration of the PackPrint Science Center signifies a coherent progression and development of the sustained and collaborative efforts of various professional and scientific associations and bodies, operating within the domains of design and production of packaging materials and media, printing, and the extensive field of graphic arts and graphic communication. (PackPrint Science, 2024). The position of the PackPrint Science Center, is illustrated in Figure 17.

Figure 17. The position of the PackPrint Science Center in relation with the graphic communication, printing and packaging sectors in Greece. (source: Anastasios Politis, Marios Tsigonias, Avgerinos Chatzichrissos: "Education in printing and packaging and the role of industrial and research associations" Presentation at the Packaging Inspiring Stage conference, GlobalPack exhibition, Athens 8 November 2025).

The PackPrint Science Center extends an open and continuous solicitation for collaboration with relevant stakeholders, including but not limited to associations, employees, individuals, young people, institutions, businesses, schools, and educational organizations. Indeed, the purpose of this initiative is to support research, development, and training in the packaging, printing, and graphic communication sectors, on a national scale. (PackPrint Science, 2024).

The center's overarching objective is twofold: first, to promote interdisciplinary research and development, and second, to provide educational and training opportunities for individuals engaged in the domains of Packaging, Printing, and Graphic Arts. Such initiative is predicated on the principle of collaborative endeavors with diverse stakeholders, including individuals, entrepreneurs, and businesses, all of whom attain a particular and vested interest in the aforementioned disciplines. (PackPrint Science, 2024).

The primary objectives of the centre are the advancement of relevant sectors, enterprises, and HC through research and innovation in entrepreneurship and production, contingent upon new technologies, quality, exports, and principles of the circular economy. Furthermore, emphasis is placed on the enhancement of education and training for all categories of individuals in the packaging, graphic arts, and printing sectors, as well as for partner companies and sectors associated with packaging and printing within Greece. (PackPrint Science, 2024).

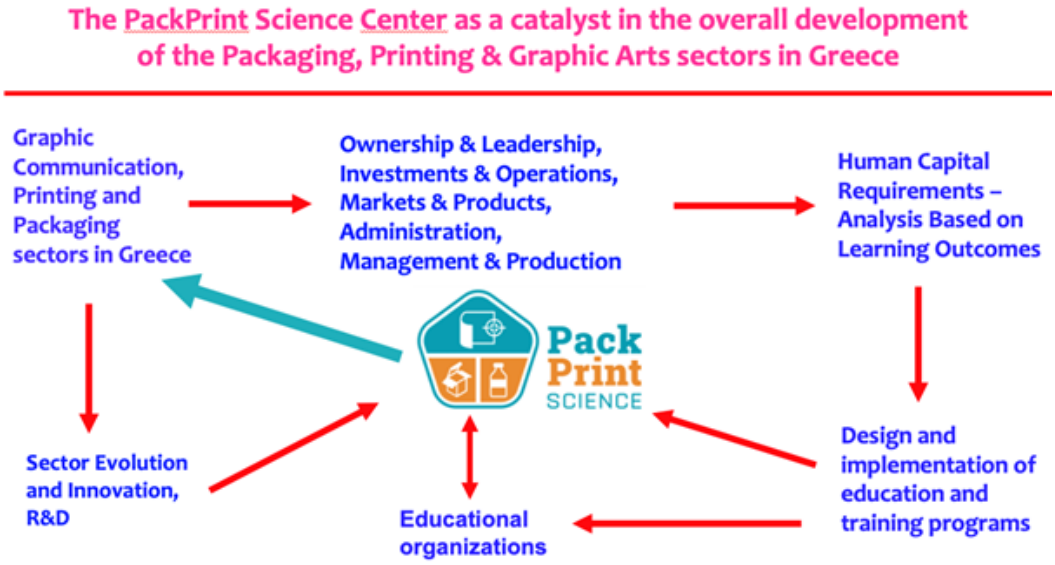

Figure 18. The interactions and workflow of PackPrint Science Center within the graphic communication, printing and packaging sectors in Greece. (source: Anastasios Politis, Marios Tsigonias, Avgerinos Chatzichrissos: "Education in printing and packaging and the role of industrial and research associations" Presentation at the Packaging Inspiring Stage conference, GlobalPack exhibition, Athens 8 November 2025).

The PackPrint Science Centre has established an ambitious agenda, with a commitment to actively engaging in both domestic and international research and development initiatives. In addition to these initiatives, the center places significant emphasis on orchestrating a diverse array of awareness-raising activities and events, encompassing conferences, workshops, and exhibitions, among others. These initiatives are meticulously designed to promote the growth and advancement of associated sectors and businesses. (PackPrint Science, 2024).

Finally, the PackPrint Science Center is committed to fostering innovation within pertinent sectors, while primary emphasis is focused upon the advancement of the national Packaging, Printing, and Graphic Communication sectors, thereby facilitating an in-depth coverage of those domains within Greece. The impending procedures, projects, and initiatives have the potential to influence the future of national industries regarding research and development in education, training, and continuing education. This outcome is attributable to the initiative's character as a holistic, sector-oriented HCD initiative for the Packaging, Printing, and Graphic Communications Industries in Greece. (PackPrint Science, 2024).

Conclusions

The print-media and packaging industries are navigating an era of substantial transformative shifts across multiple domains, ranging from business and management to workflow and production. Indeed, technological innovation is a hallmark of the current era, manifesting in the form of novel systems and equipment that leverage sophisticated software applications.

The printing and packaging industry continues to thrive within the digital era, albeit with major alterations in the fields of research, industry, and education. (Politis, 2018). Indeed, the contemporary landscape is predicated on the disruptive principles of Industry 4.0, digitalization and digital transformation, alongside the concepts of sustainability and circular economy, as well as lean-based continuous improvement.

The HCD strategy aims to enhance an organization's workforce levels of intellectual aptitude, practical skills, ethical values and behavioral traits. Furthermore, HCD enables the efficient transition into a sustainable economy, while strategic HCD interventions must be meticulously aligned with sustainable development goals. (Atiku & Lawal, 2021).

Indeed, the conclusion of the current paper suggests that PackPrint Science is an innovative and meticulously designed framework of a national holistic HCD strategy, aiming to consolidate the three pillars of the print-media and packaging industries in order to foster a collaborative environment conducive to education and training for all individuals within the relevant sectors and fields in Greece.

Upon closer examination, the PackPrint Science research agenda, suggests the potential of attaining a more vigorous, efficient and financially prosperous future towards fostering innovation within pertinent sectors. Indeed, the collective actions, presentations, projects, and seminars, are poised to contribute to the establishment of novel educational and training opportunities in the foreseeable future. (PackPrint Science, 2024).

Furthermore, such procedures, projects, and initiatives have the potential to influence the future of national industries regarding research and development in education, training, and continuing education, as well as address the needs of all individuals in all levels of the relevant sectors, primarily on a national scale, but also on an international level.

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Industry 4.0 and the Graphic Arts Sector: Technologies, Applications, and Emerging Challenges

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Abstract

The ongoing digital transformation driven by the Fourth Industrial Revolution (Industry 4.0) is reshaping the graphic arts industry through the convergence of advanced technologies such as artificial intelligence (AI), big data analytics, the Internet of Things (IoT), robotics, cloud computing, digital twins, and extended reality (XR). These innovations enable new levels of automation, customisation, and operational intelligence across design, printing, packaging, and post-production processes. This paper investigates the technological evolution within the graphic arts sector, with a focus on how these tools are enhancing workflow efficiency, supporting cross-media integration, and enriching user engagement through immersive and data-driven experiences. In addition to identifying opportunities, the study highlights persistent challenges such as high implementation costs, cybersecurity risks, infrastructure limitations, and the urgent need for workforce upskilling. The analysis concludes that sustained innovation and digital readiness are critical for graphic arts companies seeking to maintain competitiveness and relevance in a rapidly evolving industrial landscape.

Keywords: Industry 4.0, graphic arts, digital transformation, artificial intelligence, IoT, big data, robotics, augmented reality, cloud computing, printing, packaging

1. Introduction

The Fourth Industrial Revolution (Industry 4.0) marks a profound and transformative era defined by the convergence of advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics, big data, and cloud computing. Unlike previous industrial revolutions, it is distinguished by the fusion of technologies across the physical, digital, and biological domains, fundamentally reshaping economies, industries, and societal systems (Schwab, 2017). The digital transformation envisioned in Industry 4.0 fundamentally reconfigures traditional manufacturing by integrating intelligent technologies across organisational boundaries, setting new benchmarks for efficiency, adaptability, and networked value creation (Schumacher et al., 2016). Industry 4.0 offers significant potential to enhance productivity and innovation in manufacturing systems, yet it also presents challenges in technological integration and workforce transformation (Mrugalska & Wyrwicka, 2017).

One of the main challenges in Industry 4.0 lies in the effective integration of digital technologies—such as cyber-physical systems (CPS), IoT, and cloud computing—to optimise production speed, accuracy, and quality, while ensuring these systems remain adaptive, resource-efficient, and socially sustainable

(Sony & Naik, 2020). Automation through robotics and interconnected systems enabled by Industry 4.0 technologies has improved production efficiency in various manufacturing sectors by reducing labour needs, development times, and resource waste (Qin et al., 2016). Intelligent manufacturing, a core component of Industry 4.0, enables higher quality and scalable production by integrating IoT, CPS, and cloud computing, allowing systems to adapt dynamically and maintain consistency across large-scale operations (Zhong et al., 2017).

Industry 4.0 also redefines business operations, prompting companies to adopt innovative models that leverage connectivity, real-time data analysis, and automated workflows (Xu et al., 2018). For the Graphic Arts Industry, the transition toward Industry 4.0 demands the development of digitally skilled workforces proficient in data analytics, IoT, and AI tools. As technologies such as CBS and cloud computing become embedded in printing, packaging, and finishing workflows, organisations must reshape job roles and upskill employees to operate in interconnected, automated environments. This shift—often called Print 4.0 or Finishing 4.0—requires integrating digital capabilities across traditionally analogue processes, enhancing flexibility, efficiency, and customisation in production (Politis, 2018).

Although Industry 4.0 technologies offer significant opportunities for transformation within the printing industry, their adoption remains uneven, particularly among smaller enterprises, due to limitations in financial resources, knowledge gaps, and outdated technological infrastructure (Trochoutsos & Sofias, 2022).

This paper examines key technologies and structural shifts defining Industry 4.0 and their impact on the graphic arts industry. Additionally, the paper addresses the growing pressure for sustainable practices in printing and packaging, highlighting both the challenges and opportunities presented by Industry 4.0.

2. Technological Landscape

The Fourth Industrial Revolution introduced advanced technologies that redefined operations in industries, especially in the graphic arts industry. Core technologies enable new efficiencies, automated processes, and enhanced customer engagement. The shift toward a digital framework has enabled the industry to move away from traditional practices, supporting an adaptable, future-focused approach that encourages continuous innovation and responsiveness to consumer demands (Schwab, 2017). However, each technology brings specific challenges, including adoption costs and workforce training requirements (Mrugalska & Wyrwicka, 2017).

Artificial Intelligence and Big Data Analytics

AI-powered automation and industrial big data analytics enable companies to systematically analyse customer behaviour and machine performance, tailoring services to user needs while optimising production. This data-driven approach, supported by predictive and adaptive informatics tools, fosters informed decision-making, enhances operational efficiency, and improves user experience across self-aware, self-maintaining systems in the Industry 4.0 environment (Lee et al., 2014).

The Internet of Things (IoT)

IoT connects devices, creating a real-time production monitoring network for predictive maintenance (Xu et al., 2018). The ability to predict maintenance needs and monitor performance in real-time streamlines production, supporting flexibility and responsiveness (Zhong et al., 2017).

Robotics and Automation

Robotics has increased production speed and precision in the graphic arts industry (Campilho & Silva, 2023). Robotics facilitates consistent, scalable production by minimising errors and reducing labour costs, which is crucial for maintaining quality standards (Qin et al., 2016; Matheson et al., 2019). Furthermore, robotics improves safety in production environments by handling tasks that could pose risks to human operators (Liang & Cheng, 2023).

Cloud Computing

Cloud-based platforms support agile project management, real-time collaboration, and scalable data storage by leveraging virtualisation, resource sharing, and distributed networks. These systems enhance responsiveness to production demands and streamline complex decision-making processes. By enabling Manufacturing-as-a-Service (MaaS) and promoting service modularity, cloud computing is critical in advancing Industry 4.0 transformation (Xu et al., 2018).

Augmented Reality (AR)

Augmented reality (AR) enhances customer engagement by overlaying virtual elements onto the physical world in real time, allowing users to visualise products in realistic settings. Through interactive features, immersive visual content, and location-aware delivery, AR transforms product trials and information search, reshaping consumer behaviour and enriching shopping experiences across retail and digital channels (Javornik, 2016).

Digital Twins

Virtual replicas of physical systems offer transformative potential in the graphic arts sector. By simulating production processes, press performance, and even customer interactions with packaging, digital twins enable predictive analytics, real-time optimisation, and reduced downtime. For example, in prepress workflows, a digital twin can model how changes in ink or substrate affect the final output, minimising trial-and-error and waste (Fuller et al., 2020).

Extended Reality (XR)

An umbrella term that includes AR, VR, and MR expands the possibilities of user interaction. In VR-based prototyping, designers can virtually experience a print product's scale, texture, or packaging interaction before production. Mixed Reality (MR) can overlay interactive layers on print machinery interfaces, enhancing training and maintenance (Bekele et al., 2018).

3. Applications in Printing and Packaging

Industry 4.0 technologies have transformed workflows in printing and packaging, enabling high customisation, increased precision, and efficiency improvements across processes. IoT, AI, and AR are the primary technologies driving innovation within these areas.

Cross Media and Printing

Cross-media integration, driven by digital capabilities, enables content adaptation across various platforms, ensuring cohesive and flexible branding across print and digital media. In graphic arts, cross-media integration has allowed companies to manage a unified brand presence while catering to digital-first consumer preferences (Politis, 2018). The graphic arts industry can now quickly provide consumers with physical printed materials and matching digital campaigns, enriching the customer experience across multiple channels.

Augmented Reality (AR) in Printing

The adoption of AR in printing offers a new level of engagement, creating a seamless bridge between digital and physical media. By allowing consumers to interact with printing through smartphones or tablets, AR brings dynamic and immersive experiences to printed materials, such as previewing product packages or accessing additional digital content. This fusion of AR with print media increases engagement and enhances the value and appeal of printed materials (Margaritopoulos & Georgiadou, 2019).

AI-Driven Printing

Artificial intelligence significantly impacts printing by automating previously manual tasks and streamlining image processing, predictive maintenance, and workflow management. AI systems enhance production efficiency, reduce the likelihood of human error, and improve overall production quality. Furthermore, AI's data analytics capabilities allow companies to analyse customer feedback and adapt their strategies accordingly, supporting the creation of targeted and high-impact printed media campaigns (Russom, 2011).

3D Printing for Customisation

3D printing brings unique capabilities to the graphic arts industry by enabling the creation of customised prototypes and complex structures with precision. This technology is precious for packaging, where companies can prototype designs and adjust quickly, minimising waste and production costs. In addition, 3D printing can produce high-quality, customisable, small-batch items that cater to niche markets and enable rapid adjustments to meet consumer preferences (Gebler et al., 2014).

IoT and Smart Packaging

IoT has introduced the concept of smart packaging, which utilises sensors to track environmental conditions, monitor product integrity, and improve supply chain visibility. In the graphic arts industry, IoT-enabled packaging solutions allow companies to control temperature, humidity, and other variables during transit, ensuring that products reach consumers in optimal condition. This technology benefits manufacturers and consumers by reducing spoilage, streamlining logistics, and improving product transparency (Zhong et al., 2017).

Digital twins and XR implementation

Together, digital twins and XR technologies enhance technical performance and contribute to the industry's broader digital transformation by aligning operational workflows with immersive, data-driven

systems. Their integration into printing and packaging processes signals a shift toward intelligent production environments where simulation, real-time control, and immersive visualisation converge. These technologies empower companies to deliver more customised, efficient, and engaging experiences across the print and packaging lifecycle, reinforcing their strategic importance in the evolving Industry 4.0 landscape.

4. Challenges and Prospects

Despite challenges from global economic crises, the COVID-19 pandemic, and digital media's rapid rise, the printing industry is still in progress. Instead, it shows signs of stabilisation and growth in specific sectors, such as packaging and labels. While traditional areas like newspaper and book publishing are seeing slower declines or stability, the industry is adapting. By embracing digitisation and automation, printing can coexist alongside digital media, leveraging its strengths in a changing landscape (Gamprellis et al., 2021).

Data Privacy and Cybersecurity

Adopting Industry 4.0 technologies like IoT and cloud computing brings new data privacy and cybersecurity challenges. As companies expand their use of connected devices and digital storage systems, they face increased cyberattacks and data breach risks. Ensuring robust data security measures is essential to protect customer information and business data (Boyes et al., 2018).

High Adoption Costs and Economic Barriers

The high costs associated with adopting Industry 4.0 technologies present a significant barrier, especially for smaller companies. Implementing IoT systems, robotics, and AI-driven platforms often involves substantial initial investments and ongoing expenses for maintenance and upgrades. In economically challenged regions, financial constraints further limit the capacity to adopt these technologies, widening the digital divide between companies with varying resources (Horváth & Szabó, 2019).

Integration Complexity

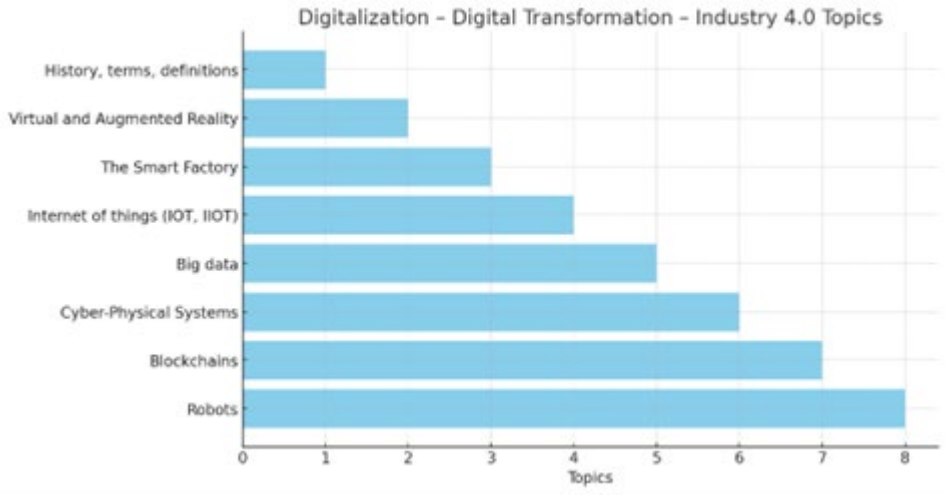
Integrating new technologies with existing systems presents technical challenges, particularly when legacy equipment or outdated processes are involved. Traditional machinery often lacks compatibility with digital and automated systems, necessitating expensive upgrades or complete replacements. Furthermore, implementing advanced technologies requires specialised knowledge, leading to a reliance on skilled technical support for installation and maintenance (Schumacher et al., 2016).

Prospects for AI-Driven Personalisation and Smart Packaging

Future advancements in AI and IoT are expected to drive further personalisation and customisation within the graphic arts sector. AI-powered analytics can enable companies to produce personalised packaging that responds to customer needs in real-time. Similarly, smart packaging, supported by IoT sensors and AR technology, allows consumers to interact with products innovatively, transforming packaging into a dynamic marketing tool that provides real-time product information (Zhong et al., 2017).

5. Insights on the Adoption and Challenges of Industry 4.0 Technologies in Graphic Arts

Automation, robotics, and big data analytics emerged as priorities, particularly optimising workflows and enabling innovative cross-media applications. This strong preference for advanced digital tools highlights the industry's readiness to leverage these technologies for greater productivity and improved quality. The findings by Vonitsanos (2023) underscore that the Graphic Arts industry is positioned to benefit significantly from adopting technologies aligned with Industry 4.0, particularly in digitalisation, automation, and data analytics. These technologies enable cross-media strategies, improved workflow efficiency, and enhanced print quality, offering a competitive edge for companies willing to invest in these advancements. Nevertheless, organisations must address usability and data security challenges for successful integration, provide adequate training, and ensure the technology aligns with industry standards. The overall positive feedback on content inclusiveness and clarity of new technologies suggests that the graphic arts industry is receptive to digital transformation but requires a well-structured approach to navigate the complexities of Industry 4.0 (Vonitsanos et al., 2023).



Prioritisation of Topics in Digitalisation and Industry 4.0 Transformation (Vonitsanos et al, 2023).

User feedback on technology adoption reflected generally positive satisfaction levels, especially in content clarity and comprehensiveness. However, feedback indicated mixed experiences regarding functionality, with some users suggesting the need for added support to maximise usability. While the majority found the technologies transparent and beneficial, certain aspects, such as seamless functionality and ease of use, were noted as areas for improvement. These findings suggest that as the industry moves toward a digital framework, successful implementation may depend on addressing usability concerns and ensuring robust support systems (Trochoutsos & Sofias, 2022).

6. Conclusions

The 4th Industrial Revolution introduced advanced technologies, significantly affecting the graphic arts industry. These innovations, from AI and IoT to big data analytics and augmented reality, drive transformative changes that enhance customisation, operational efficiency, and consumer engagement. Embracing digital transformation is advancing the graphic arts industry's operational capabilities and preparing it to meet evolving consumer needs with agility and innovation. This future-focused approach supports

the industry's growth trajectory, paving the way for sustained relevance in an increasingly digital landscape.

However, adopting these new technologies is challenging. The high costs associated with implementation and complex integration processes pose barriers, especially for smaller enterprises. Additionally, data privacy concerns and workforce training requirements highlight the need for a comprehensive strategy to manage these challenges effectively. Despite these obstacles, the graphic arts industry's resilience and adaptability underscore its potential to thrive amid the ongoing technological shifts of Industry 4.0.

Looking to the future, continuous investment in scalable technologies and a commitment to digital literacy will be crucial in maintaining competitiveness. Trends such as AI-driven personalisation and smart packaging hold exciting opportunities for companies seeking to strengthen their market position. Ultimately, as the graphic arts sector continues its digital transformation, it is well-positioned to leverage Industry 4.0 for sustainable growth and relevance in an increasingly connected global market.

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Teaching the History of the Book through Applied Letterpress Printing: A Classroom Experience

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Abstract

In our currently over-indulgent world of digital media, the highly crafted and pragmatic beauty of the old and forgotten letterpress printed book meticulously and laboriously constructed through complex processes of early printing technology remains completely elusive to the modern-day student. In a recently developed academic course concentrating on applied letterpress printing and physical examination of selected past printed books (representing the incunabula period through the industrial revolution), students were exposed to the intricate and arduous processes of book printing and their history. As a requirement for the course, students prepared their own printing projects by determining the finished size of their project, selecting paper, choosing ink, selecting woodcuts, identifying and picking type (and size) from a multitude of type cases, setting the type, securing it into a chase using furniture and quoins, and locking it into an applicable hand or jobber letterpress press. Their finished output was generated through their manual operation of the press itself. The final deliverable was a brief presentation of each of their prints along with constructive dialogue about their experience, and their newly found appreciation for the publishing and physical existence of an old book.

Through this class demonstration, application and theory were combined. Students today are rarely given an opportunity to hold—let alone physically examine—an old, printed book. Special collections and rare book departments in libraries rightfully guard their artefacts of incunabula (1440-1501) and rare books printed during the 16th and 17th centuries. As many academics most assuredly have access to these collections, the question remain, how often are these books made available to students within their institutions? How often are students permitted to physically examine these works, page by page? As evidenced through this class, students that were given opportunities to print their own leaves using the same methods and processes of the very printers who printed the observed books, gained valuable insight, and above all, an enlightened appreciation for the discipline of printing and the old, printed book itself. The importance of teaching printing history through the physical examination of old books and demonstrating actual letterpress printing is tantamount to our discipline's success. Because without it, everything gets lost in the realm of digital space and becomes meaningless and forgotten-- Vanitati et oblivioni fiebat.

Keywords: Teaching, Printing History, Letterpress Printing, Old Printed Books

I thought to have given the Exercises the Title of The Doctrine of Handy-crafts;
but when I considered the true meaning of the word Handy-crafts,
I found the Doctrine would not bear it, because Handy-craft signifies
Cunning or Sleight, or Craft of the Hand which cannot be taught by Words,
but is only gain'd by Practice and Exercise…

Joseph Moxon (1680)

Preface

Mechanick Excercises or
the Doctrine of Handy-Works (Volume I)

1. Introduction

As soon as the package arrived, I immediately set forth in opening it. Dazed and filled with emotion, I began to unwrap the bubble plastic that surrounded the new and beautiful "old' book that I had ordered from a rare book seller. Finally, it had arrived. The book was a 1698 printed version of the fifth edition of Joseph Moxon's "*A Tutor to Astronomy and Geometry. Or, an easie a speedy way to know the USE of both the Globes, Celestial and Terrestrial.*" Of the three available volumes that were exhibited on the market, this 1698 edition one was the latest edition of Moxon's work to be discovered and printed by his son James Moxon, at the Sign of the Atlas on Warwick Lane, London, England. Because its condition was considered "fair", it was the most affordable. Such books of this classification usually contain moderate wear and tear. This edition was comprised of many pages that were "foxed" or discoloured and deteriorated. Hence its affordability.

Now to many people the purchase of an old book would not raise any level of excitement. Nor would it appeal to others in our materialistic digitized and AI-driven society. After all, it's just an old book. But to me, it is a treasure to add to my collection of old, rare, damaged, off-cast, mis-fit collection of books. Books that may have suffered a different fate such as possibly being left orphaned on a shelf with other unwanted degrading books of "not-so-good" condition, or to be tossed out into a hopper only to be dumped in a landfill, or, with any hope, to be placed in a second's store with hopes of being found by a empathic collector and book-saver as myself. Unfortunately, libraries today in organizations and educational institutions are "debulking" their collections through this method of cleansing.

In recent years, our Library at the California Polytechnic State University (Kennedy Library) contacted our department (Graphic Communication) to inquire our interests in housing multiple physical bound versions of popular industry and research magazines, periodicals, and journals in which to house in our collection. The reason for the request was to accommodate for their renovation project for refurbishing and repurposing once highly contested shelving space to make room for newly needed study carrels (large integrated, technologically advanced student and faculty meeting spaces). As a result, Administration of the Library invoked a "purge notice" which required the removal of such material. Space once required to house such collections, have been repurposed due to the minimized need for physical books resulting from the heightened increase in digital databases and repositories made available everyone in the institutional community online. Of course, the Graphic Communication department received the books in good faith and entered them into our Raymond J. Prince Graphic Arts Collection (https://grc.calpoly.edu/special-collections/rjpgac) which currently houses collections from the former Wadewitz library (complete with Frank Preucil, Richard Fisch, and various other pioneer's private collections of valuable research papers and books that contributed greatly to the early lithographic print revolution) and, once associated with the PIA/GATF library that formerly resided in Sewickley, Pennsylvania at PIA's headquarters.

As the technological utopian quest for modernity continues to shake the walls of the educational institution—and rightfully so—so goes the future of books (Caperida, 2024). Much has been written about the demise of the printed book, and the print applications therein, as anyone in the graphic communication industry; corporations, companies, and scholars, can attest, the debate continues ad infinitum. But the purpose of this paper is not to debate the role of the library, the future of the book, or even printing. It's a call to graphic communication educators and practitioners alike to bring awareness to the importance of book history as it is legitimized with the classroom through teaching the value of print using historic methods of production, i.e. letterpress printing. For if "we" do not do this, who will? And, as the technological advancements over time echo by, what will come of tactile senses experienced through the touch of an old book. The significant experience of smelling it, touching the old vellum cover, rubbing your fingers upon the rag-based linen sheet impressed with figures and letters galore. Observing the type-metal impression of a letter imprinted on one side and slightly embossed on the reversed side. The unique cuts of the letters that had been poured into the matrices and casted into the moveable type that composed the page. The composition of the inks and their ability to set text in an impression that lasted throughout the ages. The folded signatures that were gathered and bound and then cut to form the book. And, the handwritten notes that were inscribed within the inner margins to address the thoughts of the owner or reader who once possessed the book. The digitized page, as flawless as it may be, still doesn't provide for the tactile senses experienced by those of yesteryears. The appreciation for history, just as seeing a fossilized bone from a prehistoric dinosaur display ignites a fire of interest from within the observer standing before it, so does the same happen in the presence of an old, printed book. Supplementing the experience with stories of provenance inevitably generate questions surrounding who owned it? when did they own it? who would have read it? why would they have read it? where would this book have originated? Who printed it? Who paid to have it printed? Why did they print it? Who was the author?

The purpose of this paper is to provide further insight into a recent instructional class that was developed to achieve this objective. To ignite a catalyst within college students in engaging upon the appreciation of the old book through the creation of printed pages using equipment within a letterpress museum housed with the Graphic Communication Department at the California Polytechnic State University—or within your institution. Before the old book becomes forgotten and devalued. Vanitati et oblivioni fiebat. We—as scholars and practioners of Graphic Communication programs—must take the lead in paying homage to our predecessors who invented, developed, improved, and engaged in the craft that brought millions of publications of demacritized knowledge to civilized societies for the purposes of enhancing the human condition. And, to understand the craft for which these practitioner's perfected through the physical observation of their output—in the forms of books, periodicals, pamphlets, and pages—insures the value of their work as it lies within the graphic communicaiton discipline.

LITERATURE REVIEW

The Book is Back

In the early 2000's, students were flocking to ebooks to gain access to their course materials. Online textbooks were more affordable, easily produced, and therefore more profitable to publishers trying to push the printed version. Over time, however, more and more academic studies have revelead an interesting change in this mode (Caperida, 2024; Palsdottir & Einarsdottir, 2017; Subaveerapandiyan & Sinha, 2021; et al). According to Pálsdóttir and Einarsdóttir (2016), two scholars from the University of Iceland (2017), report that participants in a study prefer academic material in a printed format rather than electronic. Clearly, Millennials and GenZ have a significant advantage on older generations regard-

ing digital literacy skills (Subaveerapandiyan and Priyanka Sinha, 2021), however their research reveals that "Students are willing to read whatever the source is, print or digital, but are highly comfortable with digital media-based reading" (17). However, when surveying preferences of students for reading in bed or for recreational pleasure, 62.2% preferred printing materials in the form of books and magazine (16).

Similarly, in an article written by Lidia Altamura (2024), Turning the Page: What Research Indicates about Print vs. Digital Reading, reports that "the use of digital devices shows a small negative relationship with reading outcomes" and that are reported significant advantages in the benefits of print reading (18). "For young children," writes Altamura, "we estimate that those who spend ten hours reading print books or magazines in their free time will exhibit six to eight times higher levels of reading comprehension than do children who spend the same amount of time reading digital devices" (20). Digital media inevitably conjures up distractions, i.e. animated ads, incoming emails, newsfeed badges, etc. Hence, "studies on media preference indicate that we prefer to read printed books because we feel able to concentrate and read in a more attentive manner" (21), reports Altamura. In a study conducted by Carnegie Mellon University (Riffe, 2017) posits that Millennials have tendency to prefer printed materials for academic reading. "They found students reading the digital format engaged less meaningfully with the text—swiping back and forth and skimming more frequently—and started to write their summary during their first reading, writes Riffe, "When reading print, however, students engaged with the entire text before beginning to summarize and recalled the material with less difficulty." A simply lessoning of distractions could be inferred, and an unspoken identification with the tactile presence of paper and the natural familiarization with reading in an analogue fashion…meaning, turning the page by hand could enhance the experience overall. "The low cost of digital-only materials", posits Riffe, "means it is unlikely instructors will return to exclusively as assigning print readings. But the research demonstrates that not all students are learning effectively from the digital materials." Sweden has created an initiative to re-introduce printed textbooks to the classroom, as instructors place newly heightened awareness on "printed books, quiet reading time, and handwriting practice and devoting less time to tablets, independent online research and keyboarding skills" (Peale, 2023). In reporting on an interview involving the Swedish Karolinska Institute, Peale reports that a spokesperson representing Karolinska reported, "We believe the focus should return to acquiring knowledge through printed textbooks and teacher expertise, rather than acquiring knowledge primarily from freely available digital sources that have not been vetted for accuracy." Hence the defection to printed materials.

Letterpress is Also Back

More importantly, there has a great rise in the interest in letterpress printing and the book arts. Countless communities have developed awareness in the discipline through online forums, websites, social media, conferences and fairs. The International Printing Museum in Los Angeles, California has an annual fair every fall (https://www.printersfair.com/) with over 100 vendors and 5,000 attendees. Similarly, the San Jose Printers' Guild holds a Bay Area Printers' Fair and Wayzgoose event every Spring (https://www.sjprintersguild.com/) which hosts local letterpress printers and book artists that is held in a historic park. Because of enhanced interests, both venues sell old letterpress equipment to budding and growing press houses, artists, and hobbyists alike. As such, with heightened awareness, many academic programs have subscribed to developing curriculum surrounding the history of printing, the mechanics of printing, and the awareness around the value and history of the book.

In an Wired article written by Glenn Fleishman (2017) "How Letterpress Printing Came Back from the Dead", he writes, "Yet today letterpress is in the throes of a full-blown revival. In 2000, a flatbed proof press, often used in teaching and for posters, cost Boxcar Press Founder Harold Kyle about $100. By 2005, the price rose to a few thousand. Today, if could pursuade someone to part with it, you might pay

$15,000." (3). Antiquated letterpress equipment (and applicable sundries) that once existed in in the basements of highschool and post-secondary institutions were other sold-off, donated, or moved into permanent storage within the confines of their institutions hidden archives. Because of the "awareness movement," small handpresses, letterpress jobbers, and flatbed presses have been uncovered and brought back out into the art and inudstrial labs for teaching, instruction, and experiementation. Glenn Fleishman (2017) reports on a literature professor (Andrew Rippeon) at Hamilton College in Clinton, New York, "who teaches his students how to handset type in a letterpress studio while also nudging his protegés to advance the craft" One student in his Rippeon's class allegedly became captivated by ornamental type created by Louis Pouchée in the early 1800s, that he recreated 3Dprint images of Pouchée's original ornate wood blocks and used them in one of his college letterpresses projects. In support of Fleishman's report, a comprehensive survey conducted by Cooper, Gridneff, and Haslam (2023) on the history of letterpress education in the UK and Ireland, they found that although many traditional institutional print programs had diminished over the course of thirty years, the use of letterpress education actually increased in the last two decades within art and graphic design programs. They write, "Letterpress provides today's graphic design students with a direct link to the process of reproduction key to the historical dissemination of knowledge through the printed book. For students who are familiar with digital type through word processing the origins of terminology including typeface, size, columns, kerning, leading and alignment are made real through metal. The letterforms of type can be traced back to calligraphy, notation and writing systems leading to the origins of the alphabet." It is apparent, that other disciplines supplementary to the traditional graphic arts program, have seemed to absorb the mechanical technology and consequently written it into their curricula, disciplines such as art and design, English and literature studies, early modern history, and library sciences (rare book collections). In an attempt to remain relevant within the changing landscape of technological evolution, traditional graphic communication and graphic art programs inevitably "moth-balled" their letterpress labs along with the curriculum that once supported them therein.

Finally, as mentioned above, is that some labs in educational institutions have actually equipped labs with letterpress equipment and opened up to the public in order to advocate the exploration of letterpress printing and the awareness of (and tie to) old books. At Baylor University in Waco, Texas, the Book Arts and Letterpress Lab (https://library.web.baylor.edu/bookartsletterpresslab), part of the Jesse H. Jones Library Baylor Book Arts Collection, provides for a hands-on experimental experience for students of all majors. Featureing a "variety of resources and tools to learn and explore many aspects of the art and history of the book and offers hands-on experiences in composing and hand setting moveable type, operation historic printing presses, and exploring a variety of book arts related activies" (Admin. Baylor, 2025). These opportunties serve in the form of:

1. Support the integration of literacies and active learning experiences in the technologies of communication, printing, and book history;
2. Serve as a working model of historical printing practices that ushered in a pivotal chapter in the creation, documentation, and dissemination of knowledge and human expression;
3. Provide a space where users can experiment and create their own expressions rooted in the rich heritage of the book and printed communications.
4. Serve as an experiential studio in which to learn about the history and craft of book arts and letterpress printing; and
5. Inspire learning and creativity for the entire campus and students of all disciplines (Admin. Baylor, 2025).

Similarly to Baylor, the California Polytechnic State University in San Luis Obispo, California houses a letterpress musuem (circa 1850-1950) named the Shakespeare Press Museum – Charles Palmer Collection which serves under the Department of Graphic Communication. Residing on the first floor of Building 26, the Shakespeare Press Musuem (https://shakespearepressmuseum.org/) also provides experiential opportunities for students to explore in the mechanics of letterpress printing using various peices of authentic equipment used during the California "Gold Rush" period. A student-run enterprise, students can work on projects "hands-on" along with student curators during applied open hours.

Combining Letterpress and the Rare "Old" Book

In the world of rare books there are a select grouping of schools domestically and abroad that are specifically developed to integrate the mechanical reproduction of old and rare books, but more importantly, the identification, classification, conservation and repair, and research pertaining to provenance and manufacturing. London Rare Books School Insitutie of English Studies School of Advnaced Studies University of London (https://ies.sas.ac.uk/study-training/summer-schools/london-rare-books-school), The Rare Book School Univerty of Virginia (https://rarebookschool.org/rbs-news/), and UCLA California Rare Book School (https://www.calrbs.org/), all provide hands-on educational courses in the areas above. Other similar programs exist undeer the auspices of libraries and special collections such as that in the Tisch Library of Tufts University in Boston, Massuchussetts.

In an article pertaining to the course work offered by RBS written by Suchak and Bromley (2019) for the University of Virginia, the provide an excellent summary of one of the programs: " [it] examines the inextricable bond between technological and cultural contexts of typography and printing: the evolution of ideas about graphic expression of thought and language; the revolution of ideas about printing as an art; and the very concept, as we now understand it, of graphic design." Such programs are so well developed that any student/professional/educator can enroll in a week-long hands-on course to enhance their knowledge and extend their skills in teaching whilst immersing themselves in rare books and manuscript artifacts. Laura Ferguson (2024), a writer for Tufts NOW magazine reports that Chris Barbour, a professor within Tisch Library's Special Collection laments that "students want to touch and see history, and they find that deeper connection in these books. It's history that they can hold in their hands." And, because many students today are quite oriented with graphic design and, perhaps have advanced skill sets and interests within, they best identify with typography especially as it applies to printed matter. Ferguson (2024) writes, "There's also a great authentic quality to typography as an object when it is an old book because the font is making an imprint in the paper, giving it form and depth. That impression sometimes surprises students who are not accustomed to thinking of fonts as having dimensionality." The printed page, complete with impression (both type letter and ornament) expressed by the color of ink and severity of the impression, and the ability to touch it, completes the experience and propels a sense of meaning as it exemplifies the historicity surrounding the book. This is education at its' best and so needed within all grades and levels of the educational norm.

In his compelling paper *Printing-Practice-as-Research: Using Letterpress for Research and Teaching Early Modern Literature (2024)* Julian Neuhauser leads the reader through an applied experiment involving the teaching of Shakespeare through the exploration of printed pages within 16th century books. Through prompted discussions on the technology used to manufacture and produce the books, revelations were presented on behalf of the students in his class about how the content was interpreted, engaged, and how it affected the 16th century audience for which it was written and published. He writes, "Taken together with practice's ability to create exciting opportunities to engage with key ideas about early modern book history, materiality, labour, culture, and society, the development of more nuanced interpretive framework also grants the participant with an expanded understanding of the cultural artifact that is, for

instance, the Shakespearean text." Through the use of the old and physical book, the miraculous transcendence of the participating student to a time foreign to their own, opens a deep appreciation for not only the author, the content, and the community, but for the printers and publishers alike.

Similarly, in the exploration of old physical books, the concept of provenance is invoked as well. Jansted and Kelly (2014) submit that in a Renaissance Book History project conducted in Canada, "[s]tudents were taught that the past survives through objects and through remakings. Holding a sixteenth-century book that had seventeenth-, eighteenth-, nineteenth-, and twentieth-century owners before it came into our hands makes explicit that the past lives in the present." And, hence, the more that the old book is referenced and studied, and handled, and engaged, the more the educational value is purveyed. "Having fewer materials at our disposal," writes Jansted and Kelly (2014), "invites our students to think about legacy in multiple ways: how works survive, how they are collected and transmitted, the transformations they undergo across time and through media." Long live the forgotten old physical book.

Coupling this activity with the hands-on mechanical discipline of letterpress printing only solidifies the educational deliverable, the goal of teaching history with history and giving the student a much more in-depth introduction to the lives of those who printed and published the book, an invaluable experience. Mattson Gallager (2019) writes, "Print practice generates a sort of performative, embodied knowledge about and expressed by the objects and materials of printing. Ornament, alongside the alphabet, participates in the printing process, and may be extended from a form of 'enhancement' into an active site of communication. The printed matter presented here (an applied case study examined explained within in his article *Knowing/Showing/Doing*) uses ornament to illustrate and record aspects of print practice that cannot adequately be communicated through or represented in text." To further express this point, from an ink manufacturer vendor's website (https://letterpressink.com/) the owner inscribes, "Letterpress printing also offers a sense of connection to the past. It is a craft that has been passed down through generations, with each printer adding their own unique touch. By continuing this tradition, printers are keeping alive a piece of history and preserving a craft that might otherwise be forgotten." *Vanitati et oblivioni fiebat*.

THE CLASS – A PRACTICUM

In 2022, I was accosted by the director of our University Honors Program at Cal Poly. The Honors program is a supplemental curricular extention for applicable students to explore opportunities outside of their particular chosen fields of interest. As such, students are presented with multiple courses from multiple disciplines for which they find interesting and passion. They goals are to equip themselves with skills and leadership experience applicable to their post-grad career. Through this program they are encouraged to seek out life-shaping experiences such as study abroad, research, or civic leadership to make the most of their time at Cal Poly.

Known for my interest in the history of printing, the history of the book, and as the curator of the Shakespeare Press Musuem, I was asked to develop a ten-week, one-unit course entitled: "*Vetus Libro Renasciture - Bringing Life Into an Old Book* :A Light Seminar on the History, Character, and Value of Old printed Books."

The course expectations were defined as such with the following rhetoric:

> What's the oldest printed book you have ever held? How did it come in to being? What significance did it bring to humanity? What of it now? In this seminar, we will study the history of letterpress printing and the creation of the printed book. We will learn about the industriousness of printers

who brought life to books, and we will explore books of old in physical form for purposes of awareness, fascination, and enlightenment. Additionally, we will spend time in the Shakespeare Printing Press Museum in a hands-on practicum involving the setting of type and letterpress printing.

Because Cal Poly is currently a ten-week quarter system, the distribution of content and applied lab time had to be carefully considered. For the inaugural class (Fall 2023) the course was assembled as such and then slightly adjusted to allot for one additional workshop/lab session:

Class Schedule – HNRS 299 – 14 students

WEEK #1: Lecture – "Introduction – What is a book to you?"	
WEEK #2: Lecture - "The BOOK and its Components" (scroll/codex/manuscript)	WTS1
WEEK #3: Lecture - "The Printers: Who were they?" Incunabula	WTS2
WEEK #4: SPM Workshop #1 (introduction to SPM/Chappel Rules)	
WEEK #5: SPM Workshop #2 (design and type selection)	WTS3
WEEK #6: SPM Workshop #3 (paper selection)	
WEEK #7: SPM Workshop #4 (Printing Day #1)	
WEEK #8: LIBRARY VISIT: A Look at Rare Books at Cal Poly	WTS4
WEEK #9: SPM Workshop #5 (Printing Day #2)	
WEEK #10: SPM Workshop #6 (Printing Day/Clean-up)	WTS5
FINALS WEEK: Final Project	FP

Because letterpress printing is a time-consuming art, I opted to allot six (6) hours dedicated to the introduction to the lab and equipment therein, the preparation of their designs, the selection of type, the placement of type, the fundamentals of operating a press, selecting substrates and ink, and the execution of the printing itself. In the first class of 14 students, I provided three options as a final project not anticipating everyone's interest in actually setting type and/or printing their own output. As such the three options were:

CLASS FINAL PROJECT OPTIONS

Option 1: Letterpress Printing Project

All students will engage in a letterpress-typesetting activity. However, the final project can be the creation of a one-page piece that exhibits the use of multiple typefaces, ornaments, and/or woodcut graphics. The piece can be a greeting card, a small poster exhibiting poetry or quotations, a keepsake or memorial. The piece will require a small written summary that will include the typeface chosen, the woodcut used, and ornamentals chosen to supplement the piece, the paper selected, and the meaning behind the content displayed. One page report submitted with a sample of the final printed piece.

Deliverable: One (1) page summary complete with an attached picture of the final output.

Option 2: Interest Paper

Students may choose a book to research, analyze, or review. A report will be submitted that explains the book, the date printed, the printer who printed it, the content therein, and the provenance con-

tained in the book or the history of the book as to the people who have owned it (a family heirloom, a relative's book, a grandmother's recipe book, a digital book discovered online, etc.).

Deliverable: Two-three-page report complete with pictures attached.

Option 3: Library for Museum Report

Students can write a report on a museum or library that they have visited in which old and rare books were displayed. Student will write about the history of the museum; the collections and the collectors; and the book (or books) that were encountered, experienced, or displayed. Student will write about what knowledge they gained about libraries and books of the past, their value, and meaning.

Deliverable: Two-three page report complete with attached pictures.

WEEKLY THOUGHT STIMULATORS (WTS)

In addtion to the final report, the students were assigned to five (5) on-line wiki-based discussions using prompts that were applicable to the discussions and demonstrations we engaged in during lecture and lab. The prompts were identified as Weekly Thought Stimulators (WTS) and consisited of the following (taken directly from CANVAS LMS):

WTS #1 Prompt: "Old Books"

Fittingly, in that we will be talking about "old books" throughout the rest of this quarter, I feel it most apropos to begin learning about your experiences with old books.

Therefore, I would like for you to comment (to the best of your knowledge) on the following questions:

1. What has been the oldest printed book you have encountered in your life? Did you see it in a library, museum, or in someone's study somewhere? Tell us about your experience...elated, euphoric, "a religious experience?" or bored, disgusted, and discouraged that you couldn't swipe the pages away on your iPhone?

2. Do you have a special book in your family (extended) that brings meaning to your elders? A religious book, a book written by a distanced family member/author? a First Edition of a now famous book?

WTS #2 Prompt: "Listen to the Historian"

After having introduced you to some of the history of the book and some printing this past week, I thought it apropos to introduce you to the history of printing (which we will talk about on W) and to Gutenberg as well.

I am asking you to watch two videos (both are 20 minutes each) that are hosted by Mark Barbour, the Executive Director for the International Printing Museum in Carson, Ca. Mark is a graduate of GRC (from the 80s) and was actually a student curator for the Shakespeare Press Museum.

His is a great presenter and will show you the methods, techniques and tools used to print and make type as he walks you through his museum in Carson. It will help us upon our visits to the Shakespeare Press Museum beginning next week (Week #5).

For the deliverable of this assignment, I would like you to watch the videos and jot down two or three facts or topics that he covers that you find interesting and elaborate briefly why you were drawn towards them.

For instance, perhaps you didn't know about how type was formed and that Gutenberg perfected the formula for type metal - made of lead, tin, and antimony...and how that provided effectiveness and efficiency for setting type for the making of books.

WTS #3 Prompt: "Letterpress Printers and Book Artists?"

For this week's Thought Stimulator, I wanted you to research different letterpress printers (or Book Arts people) who exist today.

Identify one artist, printer, or company and report on them (who they are, why they do what they do, what they do) and then upload a sampling of their work (a pic).

Are they using lead type? Are they using wooden type? Are they using wood cuts? Are they carving linoleum blocks? What allures you to their work? What do you appreciate about their work?

WTS #4 Prompt: "In Search of an Old Book (digitatized version)"

As I am intrigued with old and rare books, and, the class is called "Bringing Life back into an Old Book," I would like for you to perform a search for a digital version of an old, printed book inclusive of incunabula--printed before 1501--or a broadsheet ballad (or book) before 1650. There are many places to search these days in that many institutions (and Google) have digitized the treasures.

Note to READER: Here are excellent resources used in the development of this class:

Kirschenbaum, Matthew; Haselberger, Mallory; Starr, Britt; & Kraus, Kari. (2023). "Meet the (book) beetle: Teaching with a tabletop letterpress." In M. Pangallo & Emily B. Todd (Eds.), Teaching the history of the book (pp.330-336); University of Massachusetts Press

Carter, Matt. (2023). "Book history online, or, how I learned to stop worrying and love the ROM." In M. Pangallo & Emily B. Todd (Eds.), Teaching the history of the book (pp.186-194). University of Massachusetts Press

Attar, Karen. (2023). "The London Rare Books School". In M. Pangallo & Emily B. Todd (Eds.), *Teaching the history of the book* (pp.323-329). University of Massachusetts Press.

Baumann, Rebecca. (2023). "The librarians of babel: Teaching the history of the book to future professionals". In M. Pangallo & Emily B. Todd (Eds.), *Teaching the history of the book* (pp.157-165). University of Massachusetts Press.

You can try here:

Early English Books Online: (A ProQuest database that you can access from Cal Poly Library Portal)

There is the English Broadside Ballad Archive
https://ebba.english.ucsb.edu/ Links to an external site.

Here you can find printed books and music with woodcuts and soundtracks of how the music would be sung at the time. It is a cool site.

You can search different libraries too:

- *The Library of Congress: (https://www.loc.gov/rr/rarebook/digitalcoll.htmlLinks to an external site.)*
- *Cambridge University Library*
- *Oxford Bodleian Library*
- *Huntington Library Digital Archives*

- *British Library Digital Archives*
- *University of Texas (Harry Ransom Center)*
- *Folger Shakespearian Library*
- *and others...*

Deliverable: *Conduct some research on any site for a book or a ballad that was printed between 1460-1650. Once you locate it, provide a brief report on it. Provide a picture and explain, if you can: When was it printed? Who is the author? Who is the printer? Where was it printed? Is there a wood cut? Who produced the cut? What type of font (typeface was used)? What is the book/poem/song/ballad about? Additionally, what drew you to this piece? What do you think about the digitized version? Is it the same as having the original artifact in front of you for examination?*

WTS #5: "The Rare Book Schools"

Two weeks ago, we met an archivist from the Special Collections at our library.
She showed us several archived pieces from the Kennedy Special Collections and Archives and she spoke about preservation procedures and processes used in maintaining and repairing pieces within the collection.
As we conclude this class, I wanted to bring to your attention two prominent programs/institutions that provide insight and training in these areas.

They are the California Rare Book School (based out of UCLA)
https://www.calrbs.org/Links to an external site.

The Rare Book School (based out of the University Virginia)
https://rarebookschool.org/Links to an external site.

For this WTS, I want you to investigate one of these institutions and look at the types of courses and services they provide and then answer the following questions:

1. *What value do these schools/programs bring to the world of printed literature, old books, and manuscripts?*
2. *Are there any courses or programs that caught your eye that perhaps you found interesting? If so, why?*
3. *Upon the completion of this short course, has your awareness of the "old book" been enhanced? Positively? or negatively?*

RESULTS

Overall, both classes (Fall 2023 and Winter 2025) were successful and well-received (see Appendix 3: EVALUATORY COMMENTS FROM HNRS 299 for a sampling of remarks provided after the class closed). Every student walked away having learned significant knowledge about the production of old physical boooks. As such they are most aware, at the minimum, of the existance of old pysical books and are consciously awakened to the need to preserve, archive, and make available to all readers, scholars, and bibliophiles alike. Moreover, their affinity for letterpress printing was evidenced by seven of the sixteen students who participated in the Winter 2025 cohort to volunteere as curators for the new year (2025-2026). Additionally, four (4) of the participants volunteers to assist with press operation demonstrations at the San Jose California Printers' Guild Printers' Fair this past April 2025.

Some notes on class structure

In the first class (Fall 2023), all fourteen students decided to do the first option for their final project and complete the entire letterpress experience by choosing a design, selecting type, selecting ornaments, selecting woodcuts, and setting the type within a chase where they imprinted their images using ink on a chosen substrate. Everyone worked diligently and often willingly stayed stayed past their allotted and came in during normal museum open hours to work with student curators. Having not anticipated an unanonymous response to engaging in the letterpress project, I was only assisted by one student from the musuem and had to manage multiple presses that all required minimal repairs. As a result, in the second class, I offered the three original offers for final project within the first class meeting and surveyed their choices and, there too, all sixteen (16) of the participants unanonymously chose the first option of the letterpress project. As such, I recruited three additional student curators and scheduled a production plan for the use of applied letterpress and flat-table presses. I also limitede the amount of type selection and imaging size that they could set in order to diminish time constraint pertaining to mis-aligned type, inappropriate chase set-ups, and to equalize the loads on five different presses in which to minimize time requirements. As it were, many students—being the perfectionists that they are—opted to come in during two extended open lab hours offered during our finals week period.

For a sampling of answers submitted for WTS prompts, see Appendix 1: SAMPLE RESPONSE FROM WTS PROMPTS.

This was an incredible class to teach. More so, because the majority of the students were not Graphic Communication majors (there was one, who, interestly, was in the process of switching out of the Graphic Communication major and into the Graphic Arts and Design major). The represenation of student majors covered the entire spectum from engineering, architecture, English literature, history, agriculture, animal science, business, and education. As such, it was invigorating leading the discussions, perusing their submissions from the Weekly Thought Stimulator prompts, and, most importantly seeing their faces as they completed the letterpress output and reading their final papers/presentations (for a sampling of student final reports and presentation of printed output, see

Appendix 3: SAMPLING OF FINAL PROJECT PRESENTATIONS.

CONCLUSION

It is easy to brush off the importance of books today, for an average run of any newly published and "viral" books starts around 30,000 printed books. Harry Potter and the Philosopher's Stone generated over 120 million copies over the course of several translations and edition. And, interestingly, a first edition can fetch upwards of $200,000. The rest, well, not so much. The determination of what makes for the classification of a "rare book" has to do with availability, amount printed, the amount of editions released, the date for when it was first printed, provenance (who owned a specific edition), and who printed it. According to the Rare Book and Special Collections Division at the United States Library of Congress, a "rare book" is defined as a book published prior to the year 1801. They write: "This date represents roughly the period when the Industrial Revolution transformed printing techniques, allowing for faster, cheaper production of books and other printed matter in larger quantities" (https://ask.loc.gov/rare-books-special-collections/faq/305834). If more are printed, then the lesser the value of the book as more remain distributed. There are rare books that remain archived in private collections that re of great value, and, often unobservable to the public. There are also many rare books that exist in public institutions that can be viewed, but only with the possession of an academic credential or the authorized access of administrators convinced that the project warranting access is deemed appropriate or valid.

Thus, the common student or interested party, for that matter, is slightly at a disadvantage as viewing any or all these treasures. Hence, the ability for a book to be forgotten or become rendered meaningless, becomes a more self-fulfilling prophesy—or rather, reality.

At the beginning of this paper, I most excitingly revealed the scene of the delivery and opening of the newly acquired old and rare book to be added to my collection. To be able to touch it, smell it, turn the pages, feel the indentation of the metal type protruding through the back of the page, to feel the texture of the linen-based substrate and the brittleness of the vellum cover conjured up a multitude of thoughts pertaining to the time of publication. The author would have had to have met with the printer with the original manuscript to sort through logistics of sourcing the paper and ink, determining the type selection and the quantity of the correct sizes and styles of the font required. Additionally, the size of the final deliverable along with the impositioning of pages required to determine the sizes of signatures, and the thickness of the bind. Questions pertaining to imagery would have had to have been considered as well and if they were to be created by metal sorts, a copper etching, or a wood block. And then the determination of costs required by either the author, the benefactor, the publisher, and/or the printer would have had to been considered. And lastly, what went through my mind was, who owned this, who touched this, who referenced this material, and what was this book's story. Did it survive a fire? A war? A plague? Was it taken? Sold? Acquired as a family heirloom? The experience of interacting with an old and rare book ignites a fantasy of intellectual inquisition, reflection and heavy ponderance. Is this not the results of a great educator too?

Joseph Moxon, the 17th century printer/author/publisher/mathematician/maker-of-globes, Fellow of the Royal Society, and Royal Hydrographer to the King Charles II of England, was first-and-foremost a printer. Someone who especially understood the craftsmanship required to purvey the makings of a printed page, a magnificent engraving, a beautiful type punch and letter, and/or an outstanding book, was the first to bring awareness to the process of the craft that makes the discipline of printing "ours" (and by ours, I mean those employed within the industry of print and the education therein). So enthralled was he that he authored a book entitled "*Mechanick Exercises: The Whole Art of Printing*" in 1684, that expanded his first book (Volume I) dedicated to the tradesman employed with in the *Handy-Crafts* (1680). His raison d'etre was to democratize this knowledge so that it would be: 1) acknowledged and a contribution to the development of society; and 2) so that it would never be forgotten. The quote exhibited at the beginning of the paper explores his thoughts on the those craftsmen who passed down their skills to the youth under their tutelage…"Handy-craft signifies

Cunning or Sleight, or Craft of the Hand which cannot be taught by *Words*, but is only gain'd by *Practice and Exercise…*" (Moxon, 1680). As educators, which must follow his lead and teach our students to appreciate the art of the book through practical exposure to the real thing, the physical books and through the experimentation of the very equipment that produced it.

One of the students from HNRS 299 class wrote in her evaluation of the course:

> "My awareness of the 'old book' has been enhanced significantly through this course. Before, I did not care about old books because no one had ever suggested to me that I should care about them, but after hearing about Ken's enthusiasm for old books for the last ten weeks, I have started to become infected with the excitement. Now, I am reflecting on all of the trips and tours I have taken where I probably missed seeing a cool old book because I did not know to be looking for them. If I get the chance to see some old books in the future, I will now be able to appreciate when and where they were printed, who the printer was, and what materials were used. I have also gained an awareness of and appreciation for the bookbinders, artists, and woodblock carvers who also participated in the artistry of making a book."

Our lesson is to bring awareness of the beginnings of our craft and the importance that is has had in the development of society, civilization, and knowledge. We do this through the exploitation of old and rare books coupled with the hands-on experimentation engaging the mechanical processes used to create these treasures. Only until we have all accepted this call-to-action as a newly formed mantra, will we be able to abolish "meaningless and forgotten."

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APPENDIX 1: SAMPLE RESPONSE FROM WTS PROMPTS

WTS #1 Prompt: "Old Books"

Student #1: "The oldest printed book I have encountered in my 19.8 years of life was the book that was passed around during the first day of class. If I remember correctly that book was printed in 1516. I think it's the oldest thing I've encountered, period. I decided to take this class because I thought the magic of books was all about what was printed rather than the how, when, where, and by who. So, when I was able to hold that book in my hands and run my finger along the pages, I admired the work that was put into creating something that was able to last for hundreds of years."

Student #2: "Truthfully, the oldest printed book I've ever encountered was the one we held in class last week. However, apart from that, the oldest book I encountered was probably a book from the 1800s. I came in contact with this book when I was at my uncles house in Mexico. He's a retired lawyer so he loved collecting old looking books. I was going through his Library and found a withered and dishevelled looking book. It was in Spanish so I could read most of it but I don't quite remember what it said. I thought the book interesting. I felt like having an old book sometimes makes the person who had it look astute and professional in a way. I think old books hold two stories, the one that is literally written in the book, and the one it tells through its appearance and condition."

Student #3: "Since I come from a family of musicians the oldest book I have encountered is sheet music book printed in 1786. This music book is titled Graduel de Frejus and was printed in Paris by Cl. Simon. This music book was brough by my parents over 30 years ago to use as the music sheet for their wedding. The last time I came across this book was a month ago in my parents' book archive. When I first saw this book, I have to say I was quite intrigued because its cover stood out from the other modern book surrounding it. The Graduel de Frejus has a leather and zinc cover which has such a wonderful feel and smell, in addition, all of the pages are in perfect condition which awed me in amazement that such an old book could be in such good condition."

WTS #2 Prompt: "Listen to the Historian"

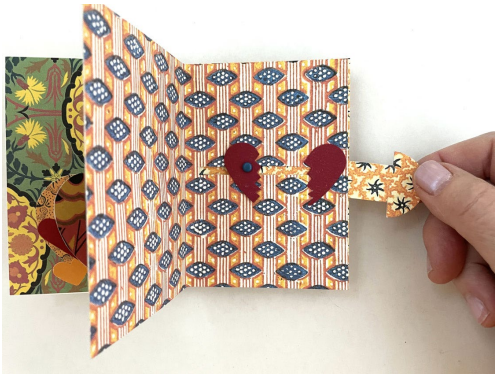
Student#1: "From the first video, I found the process of making the individual letters interesting. To create each letter, metal must be filed to an exact shape, which took around an entire day to complete. Then, a matrix was created and used as a mold to replicate the letters. This video taught me that Gutenberg's molding device was the most impressive invention of his printing process because his printing press, while important, was just a variation of an existing machine. I did not realize how crucial metal selection was to the making of the letters; however, I learned that Gutenberg's alloy prioritized a low-temperature melting point in order to save money and time. I appreciate Gutenberg's process because I understand how much effort it takes to create precise forms from my experience making intricate models for my architecture studio."

Student #2: I found it incredibly interesting how the molds were made for the letters. I wouldn't have even thought of the specific heights for the molds being important or the way the molds come apart to remove the letter being made. And the fact that he could manufacture the letters down to a tolerance of accuracy of 100th of an inch is also incredible. That in and of itself was very interesting, along with the fact that it would have taken Gutenberg somewhere between five and ten years to perfect the metal being used for the casting really puts into perspective the amount of time and thought that had to go into advancing the printing process. Additionally, that people used these advances for 400 years to follow really emphasizes the importance and thought going into this process, where it would not have to be changed for so long. Furthermore, I was fascinated by the fact that uppercase and lowercase letters were named that way because of the way they were stored in a case this way with one particular font and size. I also found it interesting that they changed from this way into having the most common letters in the middle, with the uppercase on the right side after so many years of organizing the type the other way and what ramifications it would have on the printers having to try and learn to use these letters now that all of their spots were switched.

WTS #3 Prompt: "Letterpress Printers and Book Art Printers"

Student #1: "Kit Davey is a delightful popup bookmaking artist. Her art is extremely sustainable as she only uses recycled or found materials, from flea markets, garage sales, library sales, and the dumpsters. She has taught book arts in community colleges in the Bay Area where I am from and has amassed a considerable following on Instagram of 251k. Her work has been shown at various Bay Area museums including San Jose Museum of Quilts and Textiles and the De Saisset Museum. I found her work through exploring the San Jose Printers' Guild's website as she was an exhibitor for 2024's Bay Area Printers' Fair & Wayzgoose.

What draws me to her work is first and foremost are the use of eclectic patterns and interactivity through pull and push tabs. Her medium of choice (bookmaking and paper art) is an art that can only be fully experienced tactilely. Secondly, I love how local and how accessible her art is as she also offers several free and paid resources online if I so desire to learn how to make the kind of crafts that she does. Kit Davey inspires me to incorporate found objects and vintage pieces to create something truly new and unique."



WTS #4 Prompt: "In Search of an Old Book (digitatized version)"

Student #1: "The ballad I found is called The Chronycle of all the Kynges, regarding all of England's kings after William the Conqueror up until it was published, sometime between 1530 and 1561. There is not much info on who wrote or printed it, or where it was printed, but the first woodcut seems to be part of the title, followed by a colon, and though it is not super clear, it could be an indicator of who wrote or printed it. There are 11 woodcuts in total, one which depicts William the Conqueror and another with a crown above a rose, which I think I have seen associated with the Protestant Reformation, which would match the timeline. Another woodcut is just the letter T, the first letter of the main body of text, and the other 7 woodcuts are each a depiction of a figure displaying a specific trait, like prudence and charity. I compared the font to 1456 Gutenberg Bold, and it was quite similar, which I thought was pretty neat. I was drawn to this ballad because it is about history, and England's kings, which I find quite interesting and have studied before. I also thought it was pretty telling that they have little idea about its origins, but the document itself is pretty solid evidence of when it is from.

I like that I can see the digitized version and that there are a variety of tools that are helpful for transcribing it and for breaking down its components. It's definitely not the same as having the original artifact in front of you, if only because I love the look and feel of old books and documents, and being able to get an up-close experience can be very revealing (and exciting). As a history major, I love old things, being able to touch them, feel them, interact with them as they used to be, so though I'll accept digitization for convenience if it is the best way to access rare material, I prefer examining it myself.

I think physical libraries will remain necessary, if only because some things simply are not the same online. Many books are more interactive or are of more use to someone permanently as a hard copy. For example, I think children will always need to start with beautiful, tactile books that are creative and specifically designed for their use. I think that many people still love flipping through books, that some books even encourage this in their format, and that not every book is as straightforward as a pdf or Ebook can portray. I specifically prefer to read textbooks and educational material online so it is easier to search, but I like having fiction books that I can carry around with me and physically handle. There are also different needs that can be filled by both formats, which are more or less accessible for various populations. "

WTS #5: "The Rare Books Schools"

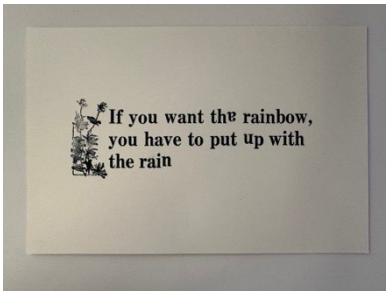
Student #1: RBS educates professionals and those that are just curious in the history, care, and management of rare books and manuscripts. They are trying to help ensure that these cultural artifacts are preserved for future generations and teach people a thing or two. They train individuals in special skills like bookbinding, archiving practices, and conservation techniques. The Rare Book School plays a crucial role in maintaining the physical integrity of these items.

The class that caught my eye was I-30. Advanced Seminar in Book Illustration Processes (Terry Belanger). This course dives into the evolution of book illustration techniques from early printing to 19th-century innovations like wood engraving and lithography. It focuses on how different illustration processes were developed and refined over time, offering hands-on examination of illustrated books from different historical periods. The course is particularly intriguing because it highlights the artistry and technical skill behind book illustrations, giving participants a deeper appreciation for visual storytelling in printed works.

My awareness of the "old book" has been significantly enhanced in a positive way. Learning about historical book illustration processes and the evolution of printing techniques grew my appreciation for the craftsmanship involved in book production. Understanding the intricate work behind early illustrations sheds light on how books were more than just holders of knowledge. They were also artistic and technological achievements. This knowledge makes old books feel even more valuable as cultural artifacts, preserving both information and artistic value through time.

APPENDIX 2: SAMPLING OF FINAL PROJECT PRESENTATIONS

Student #1: Final Project Reflection



I was recommended to take this course by fellow Honors students, especially students in the Graphic Communication major that have great things to say about your teaching style and this course. Coming into the class, I did not know what to expect, since I've never personally used a printing press or gone to a press museum. However, this class has taught me a lot about the history and intricacies of printing presses, and how people are revolutionizing the printing press to develop more creative and colorful artwork.

When I first started out on the press, I had trouble deciding which font I'd like to use. My quote is one of Dolly Parton's, so I wanted to keep it classy and fun to be consistent with her character. For this project I used Century Bold. I picked the font because it felt comfortable and casual, and reminded me of her folk style through the imperfectly sized, differentially

spaced letters. I used a simple black color for the print because I wanted it to blend into my room easily and go with the existing color palette I have. I also added a graphic of a small flower next to the quote as well, which reminds me of another adage about how no plants or animals bloom throughout the entire year. Both the Dolly Parton quote and the flower are testaments to the seasonality of life, and the motivation for working through tough times. I also found an error in my type—I used the letter "A" instead of the letter "E" for one of the words, but I think that it further emphasizes the message of this piece that perfection does not equal beauty, and there's beauty in imperfection.

Grabbing the letters was fun; I tested myself, based on the given chart, to find the letters as fast as possible and I got a pretty good grip on the locations of different letters. I also recently learned that the reason we call them "uppercase" and "lowercase" is because of the letters' relative location in the drawer. Getting to see that fun fact come to life was neat! Once I got to composing, I was very excited to see my piece come together. Placing the letters backwards was surprisingly easy, but first recognizing the letters before placing them was difficult (but a fun game). Finding the furniture was tedious work, especially because my piece is long and required additional pieces of leading to fill in cracks. However, once I put in the final piece of leading and we cranked the coins, it was ready to go! Once we printed it and I got to see my final product, I was happy with the way it turned out! I had a lot of fun with this project and appreciate the opportunity to have visited the Shakespeare Press Museum.

Our trip to Crandall Hall made me appreciate the history and culture of bookmaking as well. Having the opportunity to interact with print books of varied age and designers. Seeing how they played with color, design, and font was so interesting, especially when the design was used to inform the tone of the story (e.g. a fairytale book looking extremely medieval). One of my favorite pieces was the music box book, which used differently placed holes based on weather reports to create sound. I also loved the nature guides because the plant sketches were colorful and beautiful to look at. I did not know that Crandall Hall existed before this class, so it was fun learning about all the resources on campus that I didn't know existed.

Coming into Cal Poly, I didn't think that I'd have the opportunity to learn about the art of letter pressing, nor did I think I'd get to explore it through my own creative vision at the Shakespeare Press Museum. This has been an extremely rewarding class, and I appreciate the opportunity to have taken it!

APPENDIX 3: EVALUATORY COMMENTS FROM HNRS 299

Fall 2023

Student #1: "Super fun and educational, something I never would have learned otherwise"

Student #2: "The course was amazing. I loved earning about the printing press and how to actually handprint. It gave me a be appreciation for books and the people that not only wrote them but printed them later."

Student #3: "This was such a fun course. I especially enjoyed being able to complete my own printing and learning about the books that Cal Poly has."


: The Cronycle of all the Kynges : that haue
Reygned in Englande : Sythe the Conquest of Wyllyam Conqueroure . And
Sheweth the Dayes of their Croynation. And holde many Yeres
They dyd Reygne . With the Dayes of their Death.
And where they were buryed.

Wylliam Conqueroure.

¶ Wyllyam Conqueroure.

¶ Wyllyam Rufus.

¶ Henrye the fyrste.

¶ Stephen his Cosen.

¶ Edwarde the Thyrde.

¶ Rycharde the Seconde.

¶ Henrye the Fourth.

¶ Henrye the fyfte.

¶ Henrye the Sixte.

¶ Edwarde the Fourth.

PRVDENTIA

FIDES

CARITAS

SPES

IVSTITIA

TEMPER

FORTITVDO

Student #4: "I came into the seminar knowing next to nothing about the history of printing, and now I'm leaving with prints of my own from the Shakespeare Press Museum! This seminar was so much fun each week and I'm so glad I took it."

Student #5: "I was hesitant to sign up for this course, but it provided a unique learning experience that I thoroughly enjoyed. It was really cool to be able to use the Shakespeare press machines and learn more about the production of old books. Interacting with the old books and printed materials brought the experience to life."

Student #6: "Such a great class!!! My major doesn't really have a lot of "learn by doing" aspects, so this class was a great way to get my hands dirty. It was really well structured, and I think it was a great combination of printing our creations while also learning about the history behind printing and old books. I really liked it when Ken brought in old books for us to hold and went over some of the history. It was also great when we were able to talk to Laura Sorveti and read through different types of older books and newspapers. Absolutely well-structured and executed class. The WTS were a great touch and made me think and research aspects of letter printing I hadn't before."

Student #7: "I liked learning about the history of printing and especially going into the Shakespeare Press Museum. It gave me a much deeper appreciation on the history of printing and the development of modern printing/books."

WINTER 2025

Student #1: "I had a great time learning about printing and the existence of the SPM."

Student #2: "This is consistently a great seminar to take and my overall favorite. The only downside is how early it was, so I didn't show up sometimes, but anytime

I did show up it was such a blast. We got to learn so much about the history of printing through a learn by doing process."

Student #3: "Great course! Super fun and educational, something I never would have learned otherwise."

Student #4: "The course was amazing. I loved earning about the printing press and how to actually handprint. It gave me a be appreciation for books and the people that not only wrote them but printed them later."

Student #5: "It was hard to complete in a 50-minute format, and not having multiple experts there to help made it stressful in the final weeks to complete the printing project. I did thoroughly enjoy the course, though, and would take it again. Such a cool class!

Development of Pouch for Time Temperature Indicators

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Abstract

Around 30% of pharmaceutical products are wasted because the cold chain is not properly maintained during storage or transport. When medicines or vaccines are exposed to unsuitable temperatures, they can lose their effectiveness and may even become harmful to the human body. At present, most pharmaceutical products do not have any clear indicator to show whether they are still safe to use. Changes in temperature can cause unwanted chemical reactions in these products, which makes them unsafe for consumption. To solve this problem, there is a need for a label or pouch that can show if the product has been kept within the correct temperature range. A Time Temperature Indicator (TTI) is one such solution that helps monitor product quality and safety. In this work, a diffusion-based TTI was developed to show whether a product is still fit for use. Different types of TTIs were studied, and the diffusion-based one was found most suitable for pharmaceutical applications. Once the TTI is activated and placed on a product, it starts working if the surrounding temperature rises above the normal level. The diffusion of ink within the indicator acts as a signal of temperature change. However, some challenges were noticed—such as bulging of the TTI, long diffusion time, and difficulty in using it on small-sized packages. To reduce the bulging problem and improve its performance, thinner (low-micron) films were used, which gave better and more reliable results.

Keywords: Time Temperature Indicators (TTI), Diffusion, pouch

1. Introduction

The diffusion-based TTIs consist of a porous membrane that contains a temperature-sensitive material, such as a dye or a chemical compound. The membrane acts as a barrier, allowing the diffusion of the temperature-sensitive material in response to changes in temperature. As the temperature increases, the material diffuses through the membrane at a rate that is directly proportional to the temperature. Pharmaceutical companies attach these TTIs to their products' packaging or containers, providing a visual indication of temperature exposure over time. The indicator changes color or displays a specific pattern as the temperature exceeds certain thresholds or accumulates over time. This visual change serves as an alert for potential temperature abuse, enabling timely actions to prevent product damage or loss of efficacy.

The currently used TTIs use a variety of materials and absorption and diffusion methods. The interaction of inks and fluids with porous and fibrous materials has been a subject of extensive research due to its relevance in printing, packaging, and cold chain monitoring. Studies on synthetic nonwoven fabrics such as polypropylene and polyester have shown that ink absorption is influenced by fabric porosity, ink viscosity, surface tension, and contact angle, with solvent-based inks generally penetrating faster

than water-based inks, while surfactants can enhance water-based ink absorption [1]. The rate of fluid absorption in porous media is governed by capillary action, pore size, fluid viscosity, and gravity, where smaller pores slow down liquid penetration, and larger pores facilitate faster absorption [2]. Additives such as salts also significantly affect ink behavior; for instance, calcium chloride reduces absorption but increases surface print density, whereas sodium chloride enhances ink penetration, providing insights for optimizing ink performance on nonwoven sheets [3]. Computational simulations and modeling approaches, including lattice-Boltzmann methods and surface energy-based models, have demonstrated that higher porosity, larger pore size, lower contact angle, and higher substrate surface energy all contribute to faster and more efficient liquid penetration [4][5]. Beyond printing, time-temperature indicators (TTIs) have been developed to monitor cold-supply chains for food, vaccines, and medical supplies. Advanced polymer nanofilm-based TTIs are capable of irreversible, full-spectrum color changes that record permanent temperature history, are sensitive to threshold temperature and time, and even retain functionality after physical damage through self-healing properties, ensuring reliability in logistics and storage applications [6][7]. Several studies have advanced the application of Time Temperature Indicators (TTIs) in cold chain and intelligent food packaging. Poor cold chain management causes major spoilage in perishables like dairy, meat, and fish, while TTIs effectively visualize time–temperature history to enhance monitoring and reduce waste [8]. TTIs have shown high accuracy in predicting shelf life during fresh food transport, maintaining correlation with sensory quality parameters [9]. They play a key role in ensuring safety and transparency, especially when integrated with RFID systems for real-time tracking, and are vital components of intelligent packaging that help estimate freshness and safety despite cost and calibration challenges [10][11]. Diffusion-based TTIs have been developed to monitor microbial quality in non-pasteurized products, where color change correlates with microbial growth kinetics [12]. Thermochromic inks offer a low-cost solution for visual freshness indication and real-time monitoring [13]. Studies on temperature-dependent reaction kinetics have further contributed to developing responsive materials for intelligent packaging [14]. TTIs generally remain reliable under moderate but not extreme temperature fluctuations, emphasizing the importance of appropriate indicator selection [15]. For packaging compatibility, PET/LDPE laminates produced from recycled adhesives have proven suitable for integrating TTIs [16], while multilayer films exhibit good thermal stability and flexibility under varying conditions [17]. Optimization of seal strength in laminated and blended films ensures integrity in cold chain packaging [18][19], and improvements in sealing under contamination further enhance microbial safety and TTI reliability in real-world transport conditions [20].

Diffusion-based time-temperature indicators (TTIs) offer several advantages for the pharmaceutical industry. They provide a cost-effective, reliable, and non-invasive method for monitoring temperature exposure without requiring power or external equipment. TTIs deliver real-time information on temperature excursions, enabling immediate corrective actions, and can be customized to meet specific product and temperature requirements. These features make them suitable for vaccines, biologics, drugs, and other temperature-sensitive products, helping to prevent degradation and maintain supply chain integrity.

Currently, TTI pouches are made from PET/EVOH materials, but they face issues such as bulging. The diffusion rate of the current design is limited to 2 days, which needs to be extended to 30 days. Additionally, the pouch size has been reduced from 2.5 × 5 cm to 1 × 1 cm, and proper selection of pouch material is critical. Laminates such as PET/FG–Nano clay/LDPE and PET/EVOH/LDPE have been successfully produced using adhesive laminators with computerized control systems, offering improved performance for TTI applications.

Methodology

The Time Temperature Indicator was prepared using a pouch. Several materials for the pouch were tested for heat seal ability, flexibility, flatness, printability etc. Following materials were used during the experimentation work.

Selection of Material

a) PET + EVOH (Ethylene Vinyl Alcohol)
- The pouch was initially made using a 12-micron PET layer and a 68-micron EVOH layer.
- The PET layer served as the printing surface for the Time–Temperature Indicator information.
- However, the EVOH layer did not provide satisfactory sealing when exposed to higher temperatures.
- In addition, EVOH showed undesired interaction with the smart ink contained within the Time–Temperature Indicator pouch.

b) PET + LDPE (Low-Density Polyethylene)
- The outer layer consisted of 12-micron PET, chosen for its flexibility and smooth surface.
- The inner layer was 75-micron LDPE, selected for its excellent heat-sealing capability.
- Surface tension of the PET film was checked using dyne pens to ensure good printability.
- The PET layer gave superior printing results compared to the previous material combination.

Printing Trials

The initial sample trials were carried out using the screen-printing process. The pouch design required five colors, all of which were special shades. During the first color print, registration was achieved smoothly. For the remaining four colors, a transparent film was used to maintain accurate registration since the pouch size varied slightly. To ensure stability during printing, the laminated samples were cut into individual pouch sizes and mounted on paperboard sheets. Figure 1 is the screen printed sample on PET/LDPE laminate.

Figure 1. Screen Printed sample on PET/LDPE laminate

The next trials of printing of the Time–Temperature Indicator (TTI) pouch was successfully carried out using the HP Indigo 6K digital press. The pouch dimensions were easily adjusted on the HP Indigo, which delivered high-resolution print quality. This machine employs electrophotographic toner based

inks and uses the CMYK color process for printing. The TTI pouch was produced using the sandwich printing technique. In the third printing trial, the HP Indigo 6K digital press was again used for printing the TTI pouch. This trial was conducted to incorporate certain design and material modifications. During earlier tests, the ink on the pouch showed signs of piling when stored in the freezer, so a protective coating was applied to prevent this issue. Additionally, minor adjustments were made to the design, such as increasing the font size and adding a white patch beneath the blue patch.

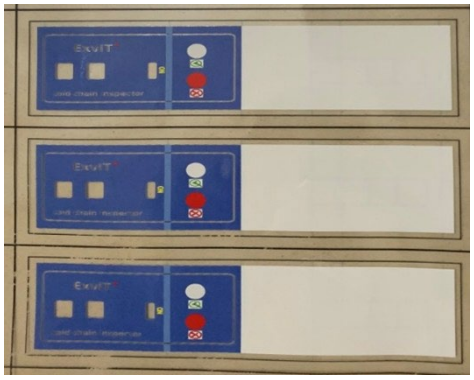

Figure 2. Printed sample on Digital Press

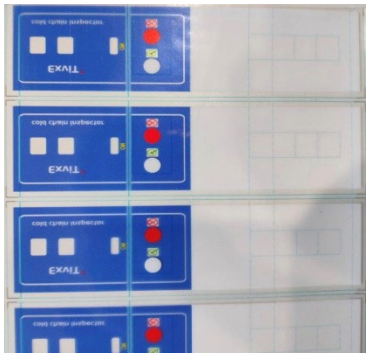

Figure 3. Samples printed on HP Digital press with sandwich printing

Resizing the pouch:

1. The previous size of the pouch 5x3.5 cm (LxB). This size was not suitable for every type of pharmaceutical application.
2. After modification, size of the pouch was changed to 5x2.5 cm (LxB). This size of pouch was more suitable for every application.

Designing of the Pouch:

The design of the Time–Temperature Indicator pouch was created using CorelDRAW software. In the screen-printing method, six colors—Red, Blue, Green, Yellow, White, and Light Blue—were used in the layout. However, in digital printing, only a white patch was used as a special color, while all other colors were produced using CMYK process inks. The printing was executed on the HP Indigo 6K Digital Press.

Instruments used

A Thickness Gauge Meter is an instrument used to measure the thickness of different materials. It is commonly applied in manufacturing and engineering industries. The device operates using a probe or sensor that is placed on the surface of the material, providing either a digital or analog reading of its thickness.

Figure 4. Thickness Gauge Meter

A Dyne Pen, also known as a surface tension test pen, is used to determine the surface energy or surface tension of materials. It is widely utilized in printing, coating, and adhesive manufacturing industries. During testing, a droplet of dyne solution is applied to the surface of the material. If the droplet spreads and wets the surface, it indicates high surface energy (low surface tension), whereas if it beads up, the surface has low energy (high surface tension).

Figure 5. Dyne Pen

The Deluxe Automatic B.O.D. Incubator Machine (Biological Oxygen Demand Incubator) is primarily used in microbiology and pharmaceutical laboratories. It maintains a controlled temperature environment for conducting BOD tests and various pharmaceutical evaluations, ensuring accurate biological and chemical analyses.

Figure 6. Deluxe Automatic B.O.D. Incubator Machine

Result and Analysis

Material Selection

Initially, a laminated PET + EVOH material was used; however, it was observed that the EVOH layer did not seal properly during the sealing process. Therefore, the material combination was changed to PET + LDPE. LDPE provided excellent sealing properties, while PET offered a good surface for printing. With this combination, high-resolution printing and better sealing performance were successfully achieved.

Bulging Problem

One of the main challenges in developing the Time–Temperature Indicator (TTI) pouch was the bulging effect. The bulging issue primarily depended on the GSM (grams per square meter) of the material. Various GSM values such as 107, 105, 90, 74, and 87 were tested. It was found that with PET + LDPE combinations, the bulging problem was reduced, but at higher sealing temperatures, the material tended to melt. On the other hand, using higher GSM materials increased the bulging significantly. Among all, the 87 GSM material provided the best balance — although the bulging issue was not eliminated, it was considerably minimized compared to other GSM samples.

Pouch Resizing

The next objective was to reduce the pouch size from 3.5 × 5 cm to 2.5 × 5 cm (L × B). Since the TTI pouch is intended for use on vaccine bottles, which are relatively small, the earlier size was not suitable for individual bottles. Reducing the size itself was not difficult; however, the challenge arose because the wicking sheet and absorbent sheet used inside the pouch were of standard dimensions. When placed in the smaller pouch, very limited space remained for proper sealing, making the process more delicate.

Printing Trials

Initially, the screen-printing method was used for printing the TTI pouches. However, several issues were encountered, such as registration errors, ink bleeding, ink selection difficulties, and failure in both tape and nail scratch tests. These problems were addressed through different corrective techniques, but

fine image reproduction remained difficult, especially after reducing the pouch size, as the text and design elements became too small for screen printing.

To overcome these limitations, printing was shifted to a digital process using the HP Indigo press. This method provided fine image quality, faster production, and allowed for double-sided (sandwich) multicolor printing. During testing, however, it was observed that the printed ink layer tended to peel off when the pouches were stored in the freezer at 2–4 °C. After consulting with industry experts, it was recommended to apply a protective coating over the printed surface, which effectively prevented ink removal under low-temperature conditions.

The newly developed Time–Temperature Indicator (TTI) system was designed and evaluated based on its functionality, material performance, print quality, sealing effectiveness, and ink diffusion behavior. The optimized pouch design, with a reduced size of 5 × 5 cm, led to significant material savings during production. This compact and uniform structure improved handling efficiency, enhanced sealing accuracy, and ensured better compatibility with various product packaging formats.

The selected laminate structure consisted of a 12 µm PET outer layer for printing and a 75 µm LDPE inner layer for sealing. This combination provided excellent flexibility, durability, and sealing strength. Surface energy testing using dyne pens showed a value of ≥ 44 dynes/cm, confirming strong ink adhesion on the PET surface. Printing was performed using the HP Indigo 15K digital press with a sandwich printing method, involving three key print layers — black graphics, a white opaque base, and CMYK colors. The resulting print quality was high-resolution, producing vivid and easily distinguishable visuals that remained clear even when viewed through transparent or curved packaging.

Functional testing demonstrated that the redesigned TTI system performed reliably and accurately. It showed no false activations under controlled cold chain conditions, and the ink diffusion behavior upon temperature breach was consistent and irreversible. This confirmed the indicator's ability to provide a dependable visual record of temperature exposure.

Summary and Conclusion

The new TTI system offers a cost-effective, user-friendly solution for cold chain monitoring. It eliminates the need for complex electronic devices while providing a tamper-proof visual record of thermal history. Its compact design, superior print quality, and optimized material combination make it highly suitable for integration into pharmaceutical, food, and medical packaging. The indicator is particularly valuable in sectors that demand strict regulatory compliance and product integrity. By reducing the risk of using temperature-compromised products and minimizing losses due to spoilage, this project contributes significantly to sustainable packaging and safer global supply chains. The successful completion of this project highlights the potential for continued innovation in the field of intelligent packaging systems.

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Understanding the effects of image customization on response rates for direct mail campaigns

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Need

The increase complexity in working with highly personalized images in variable data printing has revealed many opportunities and challenges at the same time. It is important to quantify the value added to direct mailpieces.

Overview

This presentation will address a direct mail campaign with a mature non-profit organization. The issue at hand is retention of members that were previously active and recognized as leaders in the organization. The direct mailpiece consists of a 6x9 duplex mailpiece mailed to permanent addresses of almost 400 members who had not renewed their dues for the year 2025. The recipients were randomly selected into 6 groups that received different styles of customization. The results will show the variation in the response rates overall and within each group.

Major points

Differences in highly individualized images for production

- Masking Text
- Nodes and Paths
- Fill Paths
- Character Based
- Tiles

Direct Mail Campaign

- Overall Response Rate
- Response Rate per Method of Customization
- Return on Investment

Abstract Proposal

This presentation will address workflow of image generation and mailpiece construction. The presentation will also include a description of a direct mailpiece campaign. PTI is a Marcom company, which is a Ricoh Portfolio company. PTI is the developer of Fusion Pro Variable data software and Fusion Pro Expression is an image personalization solution. Expression creates highly personalized images from a data set that goes beyond variable data. The software generates an unlimited number of images using 5 distinctly different techniques that yield very different looking images. The presentation will explain and demonstrate each of the 5 techniques in detail. The presentation will also report on response rates of each of the mailpieces along with a mailpiece with no custom imaging. The mailpiece with no customization serves as a control group. The five methods of generating custom images serve as test cases to determine if there is an increase in response rate with any of the methods. The results will inform the industry of best use of the technology to increase response rates from a direct mail campaign.

Enhancing Quality and Standardisation in Flexographic Printing: the need to embrace Big Data

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Abstract

The most valuable asset of a printing company lies with the optimal technical performance of the printing machine, and this must be given the highest priority in ensuring quality. Whilst flexographic (flexo) printing for flexible packaging has seen significant growth, notably with the integration of ECG, itself reducing costs by minimising the need for spot colour inks and supporting sustainability by reducing ink waste, many companies still lack the in-house expertise to manage the complexity of Big Data required for ECG implementation, often relying on third-party advisors. This article explores advancements and challenges in flexographic (flexo) printing, particularly those related to managing quality and achieving standardisation requirements when implementing Extended Colour Gamut (ECG) printing, often reverting to third-party support. The core challenge lies in the plethora of variables reported by the flexo printing machine, forming the record of running performance long term, effectively summing to constitute a repository of Big Data. In the context of this paper, Big Data refers to the extensive array of physical and chemical variables mining and recorded by the flexographic printing machine throughout its operational lifecycle. Big Data, in this sense, provides the foundation for process optimisation, predictive maintenance, quality assurance, and colour standardisation across production runs. Other variables, such as printing plates, double-sided adhesive tapes, and anilox rollers, play an important role in the process, they are regarded as consumables with significantly shorter lifespans compared to the printing machine itself, and their impact on quality can be more readily judged and corrected in real time. Unlike other printing methods like offset, which benefit from clear ISO guidelines to achieve standardisation, flexo printing in comparison lacks a formal standardisation process, making it difficult to maintain consistent control of image quality and colour reproduction arising from factors such as pressure settings and image raster adjustment. To eliminate this contradiction, a corresponding process has been initiated in cooperation with market leaders and FOGRA, which will be launched in 2025.[3] Companies need to tackle these challenges by establishing internal capabilities for handling their machine reported Big Data, including machine fingerprinting and monitoring of critical variables within the production process. To adopt ECG effectively, companies need to assess factors such as data availability, internal plate production, and compliance with quality standards. The significance of skilled in-house engineers who are experts in colour management, quality control, and data analysis cannot be underestimated. As digitalisation advances in flexo printing, the role of these professionals becomes vital for maintaining consistent quality and operational efficiency through the control of Big Data, requiring a comprehensive understanding of the entire value chain and precise control over all variables in the printing process. The article concludes that with appropriate standards and in-house expertise, companies can successfully implement ECG, ensuring the quality and consistency of their printed products worldwide. This is reflected already in those cases where companies successfully implement ECG printing systems.

Keywords: Flexographic (flexo) Printing Technology, Process Standardisation, Colour Management, Machine Fingerprinting, Continuous Quality Control, Big Data.

Introduction

Modern technologies in flexible packaging printing have reached new heights with the implementation of an extended colour gamut. The latest digital inkjet technology streamlines this process, as advanced printhead nozzles enable precise pixel manipulation and complete control over process colour ink application on various substrates.

For advertising and publications printed using offset technology, process monitoring has been achieved to a high standard by adhering to ISO 12647-2 [6] and Process Standard Offset (PSO) [7] requirements. These standards outline comprehensive value-chain datasets and colorimetric values specific to each printing technology.

In contrast, this standard-based advantage is absent when discussing meeting the quality requirements in gravure and flexographic (flexo) printing. This is particularly evident in the specific issue of how well print providers can control image raster Colour Value Increases (CVI) and their relation to the applied pressure on printing forms and substrates. We are consistently confronted with the challenge of assessing how effectively these processes can be standardised to ensure a unified value chain and repeatable production outcomes in daily manufacturing. While these ongoing challenges are often disregarded, flexo printing for flexible or corrugated packaging continues to lack progress in standardising processes, leaving many companies to depend on in-house management and external expertise to analyse and define suitable colour spaces for their key investments, including those for new printing machines. Only a few major players in the global flexible packaging market appear to be positioned to value their assets fully by controlling their flexo printing machine reported Big Data, thereby minimising risks associated with third parties.

This article discusses the advancements and challenges in flexographic (flexo) printing technology, particularly those related to managing Big Data to provide full process control when implementing Extended Colour Gamut (ECG) printing.

This article aims to address the following issues:

1. Do flexo printing companies manage their value chain and printing machine reporting Big Data, and if so, how?
2. Are flexo printing companies fully aware of their most critical assets—specifically, printing machine fingerprint conditions—and able to control them daily?

During undersigned visits to various flexographic printing providers, it was observed that data management is frequently outsourced to third-party reproduction houses. Historically, reproduction house services were convenient for supplying flexographic printing plates; however, with the digitalisation of printing processes, in-house expertise has become essential for monitoring and adjusting printing variables daily.

With the digitalisation of printing processes and the advent of high-tech flexographic common impression cylinder (CI) presses (or modular presses), in-house expertise is essential to monitor and adjust printing variables daily. Therefore, having skilled printing technology engineers on-site is becoming a critical asset for any significant print service provider. These professionals must possess comprehensive knowledge of colour management and the entire value chain, as well as the ability to analyse data and implement corrective measures to eliminate issues and maintain or improve quality. Use of the Simplex method to optimize CMYK input values so that, after printing, the measured TVI matches a target TVI curve (such as ISO 12647-2 and 12647-6 standards). The Simplex Search is based on Nelder-Mead

Simplex Method, is a direct search method used to find the minimum (or maximum) of a function in a multi-parameter (n-dimensional) space.

Notably, parallel to the analytical needs of the print service provider sector, many flexo machine manufacturers now operate their own repro and plate-making departments—a further indication of the growing importance of pan-industry Big Data control.

Factors to consider before adopting ECG in flexographic printing

In the early 2000s undersigned participated a project at a world-leading flexo print service provider pioneered the Extended Colour Gamut (ECG) printing process using the Opaltone system. This company successfully implemented ECG across all group operations by controlling their entire value chain's Big Data. This innovation significantly reduced costs, mainly by minimising the need for spot colour inks, and supported sustainability by reducing leftovers of waste inks. Due to the implementation of ECG technology in flexo technology and in cooperation with creative agencies, the aforementioned printing service provider did not have to deal with mixing spot colours and could leave ECG printing inks in the machine. As a result, machine downtime due to wash time for colour changes was reduced and production throughput increased.

Implementing ECG in flexographically printed packaging has become a significant trend, yet many companies lack in-house expertise and turn to third-party advisors. There are many consulting companies, but the standardization process and continuous quality improvement require daily presence.

Before adopting ECG, factors to consider include the availability of comprehensive Big Data, in-house production of flexographic plates, adherence to quality standards, and expertise in colour management.

Today, approximately 25 years later, the implementation of ECG in flexo-printed packaging has become a significant trend. Still, often the majority of companies feel compelled to give up the quest because of the lack of access to in-house competence. This has led to a growth in resorting to third-party advisors offering ECG implementation services. Despite specific expertise residing with such advisors, the essential connection between raw materials, machine design, parameters and reproducibility of graphic requirements is, by definition, lacking when the expertise is not physically in-house and on-board daily. Especially in the case of remote monitoring, the parameter input remains insufficient whilst the quantity becomes overwhelming.

Before implementing ECG (Extended Colour Gamut) printing, companies must carefully evaluate the following factors, grounded in logical reasoning and deductive analysis by Nelder-Mead Simplex Method.

Applying the first stage Nelder-Mead method into a 4-colour printing process:

a. Start with 5 CMYK combinations;
b. Simulate or measure the TVI response from each;
c. Compute the sum of squared errors to the target;
d. Iterate via reflection, expansion, contraction, or shrink;
e. Stop when ΔTVI is minimized.

1) The **availability** of comprehensive printing machine Big Data for four-colour process printing

a. A **critical challenge** in four-colour process printing is maintaining stability daily. The in-house quality department must monitor the following key variables:

b. **Pressure setting** based on the machine fingerprint data, which directly affects colour reproduction during printing

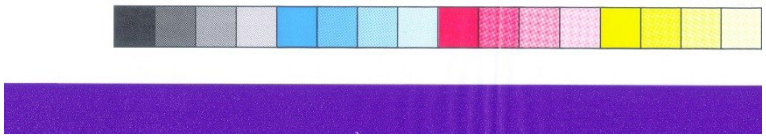

Figure 1. Four colour printing control patches. [1] [3]

c. **Achieving stable pressure values** to establish a correlation between the pressure settings during the fingerprinting process and the optimal colour shades on the substrate.

d. **Accuracy** in the secondary colours is required to monitor consistent print quality in four colour process printing.

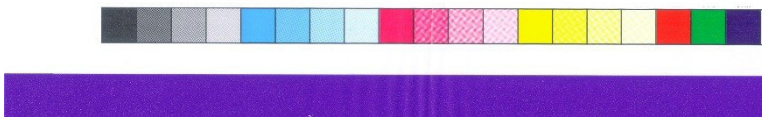

Figure 2. Four colour printing control patches with overprint control patches [1] [3]

2) Consistency in the in-house production of flexographic printing plates [2]

a. Producing flexo plates internally offers advantages such as increased speed, security for proprietary processes, and intellectual property protection.

b. In-house production allows for faster resolution of non-conformities, minimising interruptions to manufacturing processes.

3) Adhering to four-colour process printing quality standards (i.e. ISO 12647-6)

a. The correlation between ink pigmentation and printing ink viscosity. Defining the ink pigmentation percentages and their relationship to ink viscosity settings are essential for the standardisation of the print process.

b. The correlation between the chosen anilox rollers and press performance. Using the appropriate anilox roll specification (lines per cm or lines per inch) ensure optimal ink performance and consistent ΔE values.

Table 1. List of optimal ΔE values during the print process [3]

Substrate ΔE_{00}	All patches ΔE_{00}		Maximum ΔC_h
	Mean	95% quantile	composed grey
A.0	*B*.5	*C*.0	*D*.5

c. Monitoring critical variables Colorimetric Tone Value (CTV) needs to align with the pressure settings (1 b.) and stability measures (1 d.)

d. Ensuring compatibility between the smallest dot size and the chosen anilox roller results in effective print reproduction and avoids dot dunking.

4) In-house colour management expertise

a. Establishing in-house standards that align with international requirements (ISO 12647-6) ensures print uniformity.
b. Having the necessary tools available for daily quality assurance like spectrophotometers, dot size and dot shape evaluation devices, and ICC profiling tools ensure consistent print quality.
c. The quality control personnel should possess expertise in optical physics and colour theory so they can perform logical and deductive analysis of the daily manufacturing data.

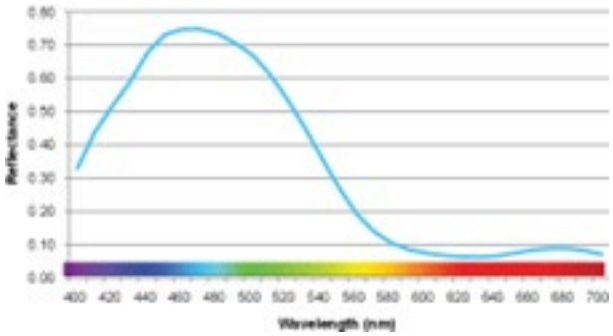

Figure 3. Example of spectral reflectance curve used during the quality control process [8]

5) Control of key variables

a. Clear decision-making rules for material procurement and quality control need to be established.
b. Changes in materials such as inks or adhesives require thoroughly evaluating variables, including supplier data on ink pigmentation levels.
c. Decisions should not only be cost driven. Reduced ink costs must be evaluated against pigmentation percentages (changes in ΔE towards the standard ink profile) and print mileage per kilogram.

6) Stability across shifts and over time

a. All shifts must maintain uniformity in process management, especially in multinational enterprises.
b. Key parameters must be recorded and documented during shift handovers to ensure continuity.
c. Quality control teams and management staff should track and analyse logged data inputs effectively.
d. The printing company's engineer's must be able to continuously improve the printing machine printing and speed setting curves, in daily routine.

7) Current percentage of non-conformities

a. Recorded non-conformities should undergo a systematic case-by-case analysis using logical and deductive methodologies to determine the root cause of the problem.
b. Findings must be communicated to the shop floor personnel and documented by key quality management stakeholders.
c. Critical technological and quality risks should be clearly defined and methodically assessed.

8) Additional operational risk considerations

a. The process of onboarding and offboarding employees must be well organised to ensure the continuity of in-house quality requirements.

b. Training and mentoring processes should be thoroughly recorded and updated regularly.
c. Ongoing training programs, both in-house and from third-party providers, are essential for theoretical and practical advancements.

By employing inductive reasoning, which derives conclusions from observed data, and deductive analysis, which validates these conclusions against logical frameworks, companies can make informed decisions about adopting ECG in their printing operations while guiding customers on best practices to optimise material usage in manufacturing.

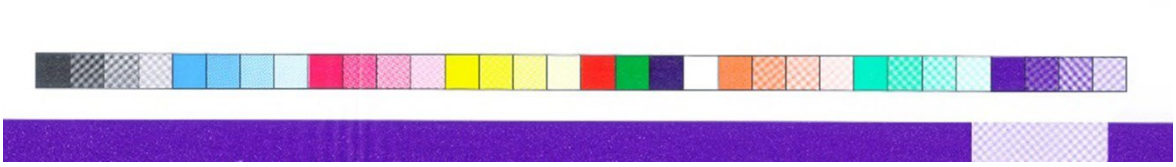

Figure 4. Colour control bar used in expanded gamut (ECG) printing

Conclusions

Companies can use inductive reasoning and deductive analysis Nelder-Mead Simplex Method to make informed decisions about adopting ECG in their printing processes while advising customers on best practices to optimise material usage. Implementing ECG should not be difficult if companies adhere to clearly defined printing standards and develop in-house expertise.

If these requirements are met, implementing ECG should not be overly challenging. The key factors are installing or adhering to existing, well-defined printing standards and building in-house expertise with technology engineers' support, adopting best practices throughout. With consistent efforts, customers and brand owners will appreciate knowing that their trademarks are safely and reliably printed using flexographic technology worldwide.

The next time you consider standardising flexographic printing processes, don't hesitate to say, **"Yes!"** Standardisation becomes a valuable investment. By controlling your big data and monitoring all printing variables daily, you can ensure your company's long-term success and competitiveness.

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Transforming Offset Printing with Digital Twins and AI: insights from research initiatives

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Abstract

The manufacturing industry has a long tradition in the European Union, being one of the key employers providing jobs for highly skilled and qualified staff. Despite this, the sector is currently facing challenges related to global competition and rising costs, leading to declining profit margins. Additionally, companies are required to meet new environmental initiatives, demanding an ambitious voluntary commitment effort from their side, which has been proven to be difficult to implement. At the same time, manufacturing companies generate vast amounts of unstructured data daily yet struggle to leverage this data for supply chain optimization. This problem is especially noticeable in situations when there are many semi-structured data sources, like the ones found in offset printing operations (images, sensor data, etc.), typically leading to the creation of data silos storage and inefficiencies. Thus, a systematic approach is needed to optimize the process of receiving, combining, and analyzing data, which can, in turn, promote the creation of innovative business models based on manufacturing data. Similarly, the usage of a digital twin in production offers several advantages, primarily enhancing productivity, quality and cost efficiency. This paper presents two use cases illustrating how Digital Twin technologies and the CyclOps platform can be applied to offset printing operations, digitalizing factory processes and enabling AI-driven models, towards achieving Zero-Defect Manufacturing (ZDM), fostering improved efficiency and innovation in the manufacturing process.

Keywords: Offset printing, digital twin, artificial intelligence, CyclOps

1. Introduction

The printing business is among the major manufacturing sectors globally, producing items such as packaging, flyers, books, magazines, and newspapers. The industry is essential to the European economy, producing an annual turnover of over €88 billion in EU GDP and employing over 770,000 individuals. Nonetheless, the industry is also confronting environmental and economic issues that might adversely affect demand and, consequently, the sector's economy. The production of high-quality printing items is intricate and significantly influences the environment because to the substantial consumption of raw resources (such as water, paper, ink, and aluminum) and chemicals that contribute to environmental deterioration (Kalafatelis et al., 2023B).

Contemporary manufacturing environments utilize IoT devices to comprehensively monitor the production chain, generating substantial volumes of data. These data may be employed to enhance the efficiency of printing operations using Artificial Intelligence (AI) and Machine Learning (ML) approaches, hence advancing the industry. Moreover, the use of AI/ML methodologies in manufacturing settings has demonstrated a significant capacity to optimize processes related to automation, waste reduction/prediction, and product quality, advancing towards Zero-Defect Manufacturing (ZDM).

This article presents two separate use cases in Offset Printing designed to improve production processes, utilizing a Digital Twin and the CyclOps platform. This document is organized as follows. Section 2 delineates the use case pertaining to the application of digital twin technology in printing processes. In Section 3, we describe the CyclOps platform and demonstrate its application on the Offset Printing domain. Finally, Section 4 encapsulates and deliberates the use cases.

2. DIGITAL TWIN FOR OFFSET PRINTING

Digital Twin solutions in the manufacturing sector represent a transformative approach to optimizing production, enhancing efficiency, and driving innovation. A digital twin is a virtual replica of physical assets, systems, or processes, enabling real-time monitoring, simulation, and analysis. By leveraging data from sensors and IoT devices, manufacturers can create detailed models that mirror real-world operations. This allows for predictive maintenance, improved product design, and streamlined supply chain management. Digital twins help manufacturers anticipate issues before they occur, reduce downtime, and increase productivity, ultimately leading to more agile and cost-effective operations in an increasingly competitive market.

2.1 Application of Digital Twin in Offset Printing Manufacturing Use Case

Living in a digital era, a modern and competitive printing company understands that digitalization is key for moving towards the new age of business and commerce. The digitalization process is of paramount importance for an organization to improve its production line. One of the most successful paradigms of digitalization, to be adopted by the printing company, is the Digital Twin. The Digital Twin scheme offers the possibility of creating a digital copy of the physical resources and production line. The process comes with several advantages like being able to simulate facilities in a protected environment, with minimal risks and costs.

In this use case, the company's target is to transform its printing process, which is the main pillar of operations. The printing process lacks real-time decision-making, prevents standardization, and has a significant environmental impact. Monitoring, process optimization, and proactive maintenance will be possible thanks to the transformation of the forenamed process through the Digital Twin experiment. More specifically, the Digital Twin is intended to assist human operators in the difficult machine (line) selection process, which is to send orders to the best available printing line.

Selecting the most suitable machine line to print an order (also referred to as a job) is one of the most important decisions in the production process. In the use case, there are three (3) different lines of printing: one (1) 5-colour printing line, one (1) 8-colour printing line, and one (1) 4-colour printing line. One of the most important decisions of the production process is to select the most suitable machine line for each unique print job (order).

To better understand the process in the use case, the figure above presents the machine line selection activity in a more detailed way. First, the order arrives. Then the production schedule is checked to see

which jobs are in priority and if any jobs are currently being printed. The suitable machine line is selected based on the order features that we will present in the following subsection. Finally, the order features and selected machine lines are stored in the company's database, to be used by other departments for other tasks. Figure 1 presents an abstractive illustration of the machine selection process.

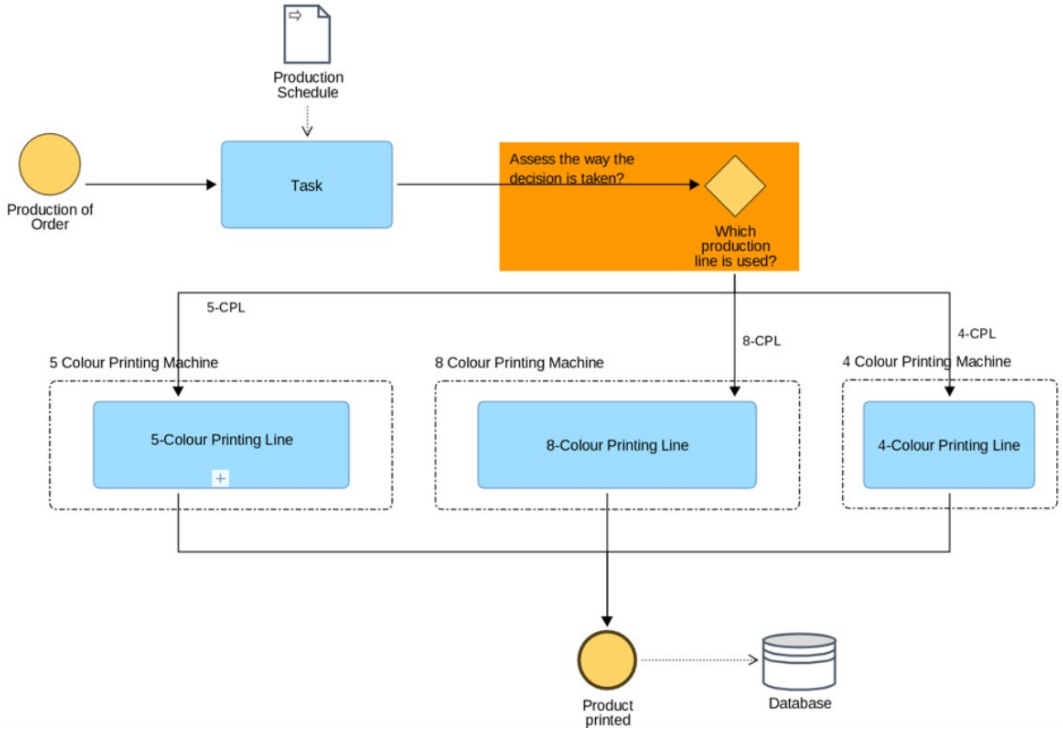

Figure 1: The machine selection process

The following parts have been taking into consideration into design specifications:

i) mapping the digital process landscape, showing all the processes of the physical unit
ii) user stories
iii) design of the experiment
iv) the specific task of machine allocation which will be optimized

The beginning is the modeling of the Digital Process Landscape. This task is of paramount importance, as it discloses all processes that can be digitized. It should be noted that the Digital Twin experiment is essentially a digitalization step, created to optimize one or more tasks.

Modeling the Digital Process Landscape comes with several steps and advantages:

i) Instantiation and adaptation of process landscape for Customer needs. Each customer may come with different needs, which the enterprise should listen to and follow strictly. As the physical process is adapted to customer needs, so is the digital process.
ii) Specification of Digitalization Goals. The enterprise should identify the goals of the digitalization process. In the current experiment, several measurable KPIs have already been specified.
iii) Identification of Digitized Processes. In an industrial unit, not all processes can be digitized and further optimized. Furthermore, some processes are much more important for the enterprise, and when optimized, a significantly larger gain is obtained. Finally, there exist processes that are easier to digitize and optimize. All these factors are taken into consideration.

iv) Definition of Data and Information Flow of Digitized Processes. The generated data to be used plays a critical role in the optimization task. All the necessary inputs and outputs of all processes in terms of data are required to be defined.

v) Specification of selected Digitalization Processes. Several of the processes will be selected as the digitalization processes to be optimized.

The following Figure 2 presents the complete Digital Process Landscape. This Landscape reveals the most important processes that play a significant role in the printing production line.

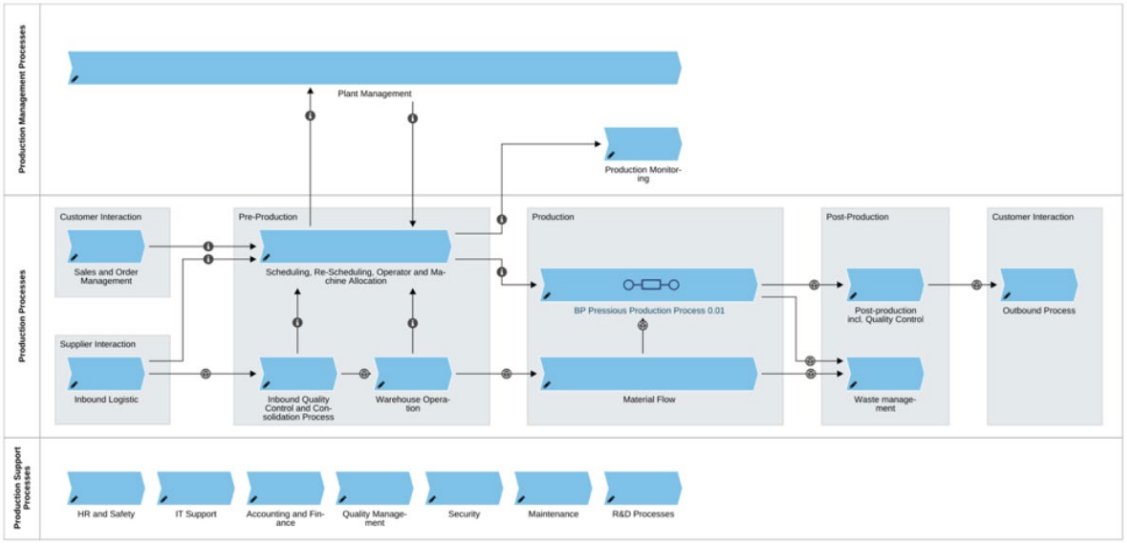

Figure 2: the Digital Process Landscape.

The operators would like to simulate a part of the production process, more specifically the machine line selection.

The economics department would like to know the cost of printing each unique order.

Given a specific order, the operators would like to know which is the optimal printing machine line.

The department that handles scheduling would like to know if an order can be printed on an alternative machine line.

The following Figure 3 is an abstractive high-level illustration of the Digital Twin architecture. On the left side, an abstract illustration of the physical production flow is shown. A customer arrives, giving a specific order. Then the order is passed to the Sales department. Given an order, the Sales department proceeds with the order analysis and outputs the paper type, quantity, size, and format. The total cost is computed by the Finance department and then the order is given to the Production department. Via the sensors, the extraction of important features like accuracy ratio, ink consumption, and color accuracy is possible. On the right side, the Digital Twin is presented. Older and simulated orders are given for cost computation. Then the ML models can be trained to learn optimal configuration for machine selection. Newly arrived orders can be given to the trained ML models and via the Digital Twin we have access to the optimal configuration (best machine) for the specific order.

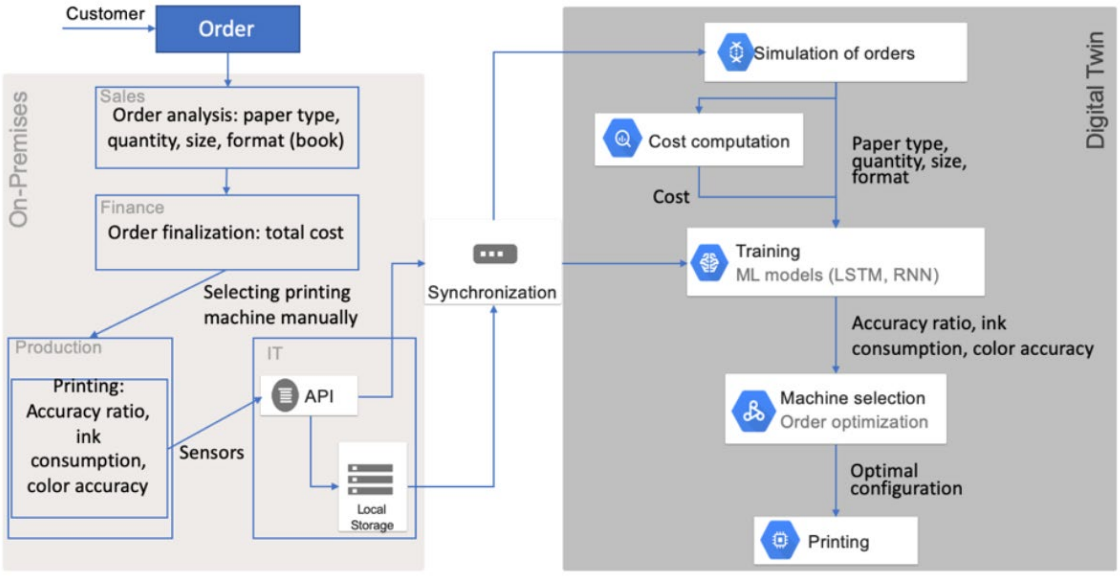

Figure 3: the Digital Twin design

The implementation of business process modeling (BPM) is done with ADONIS, a full-featured business transformation suite created specifically for process management by B.O.C company. The three most important components that we want to model: a) order features that help the operator allocate jobs to machine lines, b) the cost computation of each machine line, and finally, c) the actual decisions that the operators use to select the suitable printing line.

Each order when given by a customer is characterized by several features. Afterwards, the order is enriched with some additional information coming from the customer. The ones that we exploit for the Digital Twin are presented in the following table.

	Description
ID	auto-increment integer identifier of a printing order
Delivery time (days)	the number of days that the order shall be printed and delivered to the customer
Ink Varnish	the ink varnish selection is considered as a boolean attribute with True or False possible values
Colour (4 or >4	This categorical variable denotes the color requirements of the particular printing assignment. In offset printing, the most requested color requirement is the 4-colour printing (class 1), followed by 4+1 colour printing (class 2 that involves the use of special / pantone colors, for example gold and/or silver) and grayscale printing (class 3 entailing only black and white colors)
Quantity	the number of paper pieces requested in this specific order. Quantity takes integer values extending to up to large numbers, depending on the type of printing assignment (e.g. newspaper, poster, etc.). **Type**: Each specific printing order has an associated discrete type of category, also denoting required specifications related to the post-press procedure
Quality	The quality of the paper is associated with the specific printing order. The *Quality* parameter takes string values depending on the properties of the requested paper. The most used ones are 'Velvet' (the most frequently used), 'Uncoated', and 'Illustration/Gloss' paper quality
Job name	each job comes with a small description, mostly including the customer's name, and requested type
Sides	a job may be required to be 1-side or 2-side
Weight (gr)	the weight of the paper to be used in the printing process, measured in grams
Press sheets	it is a larger than-requested sheet that fits multiple smaller printed sheets. For example, a press sheet may include multiple pages of a book, which are then cut to create single pages. Its maximum size may be 70x100 cm
Dimension	the dimensions of a printing order come in the following format: 350x280 mm - 500x280 mm
Cost 4-col	the cost of 4-col line to print the order
Cost 5-col	the cost of 5-col line to print the order
Cost 8-col	the cost of 8-col line to print the order
Machine ID	the machine line to print the order

Table 1: Dataset for the digital twin

The next step towards the Digital Twin is to create a digital representation of the decision process, via an interactive diagram. The diagram reflects how the printing company selects a specific printing-machine line for a given order:

i) First, the delivery time is checked. If the delivery date is less than 2 days, the simpler digital printers are selected.

ii) The next step is looking at the ink varnish, given by the job order. If the ink varnish selection is True, the order is printed on the 5-colour line. If the ink varnish is false, the algorithm proceeds to the next step.

iii) Next, the job color feature is checked. If the job color is larger than 4 colors, the 5-colour line is selected. If the job color is equal to or less than 4 colors, we move to step 4.

iv) The next features to be used are Quantity and Printing sheet. If the quantity of printing sheets is less than 500, the 4-colour line is selected to print the order. If the value is equal to or higher than 500, the algorithm proceeds to next step.

v) Next, the paper's weight is checked. Books, journals, newspapers, and magazines fall under the category of weight equal to or less than 170 grams. On the other hand, posters, leaflets, business cards, and folders have a weight higher than 170 grams. If the weight is higher than 170g, the job is to be printed on the 4-color or 5-color lines, depending on the cost. The cost calculation is done by the pre-quotation department. If the weight is less than 170g, we move to step 6.

vi) Dimension is the next feature to be taken into consideration. Here, the dimension is transformed to "True 4-col" or "False 4-col". This means that either the job can be printed on the 4-colour line or not. If the value is "True 4-col", a cost comparison between all the lines is performed. In the other case of the dimension being "False 4-col", a cost comparison between the 5-colour and the 8-colour lines is done. The line with the lowest cost gets to print the job.

Before reaching the final step of printing, a comparison with previous jobs on similar lines is made. If no exception arises, the printing process begins. If an exception arises, the job is reallocated to a new machine. In the case of exceptional circumstances, a job can be outsourced to another site.

The following Figure 4 presents the physical process in full detail: features, inputs, outputs, and decision rules. Rectangles represent actions or processes; diamonds represent conditions and lines represent the flow.

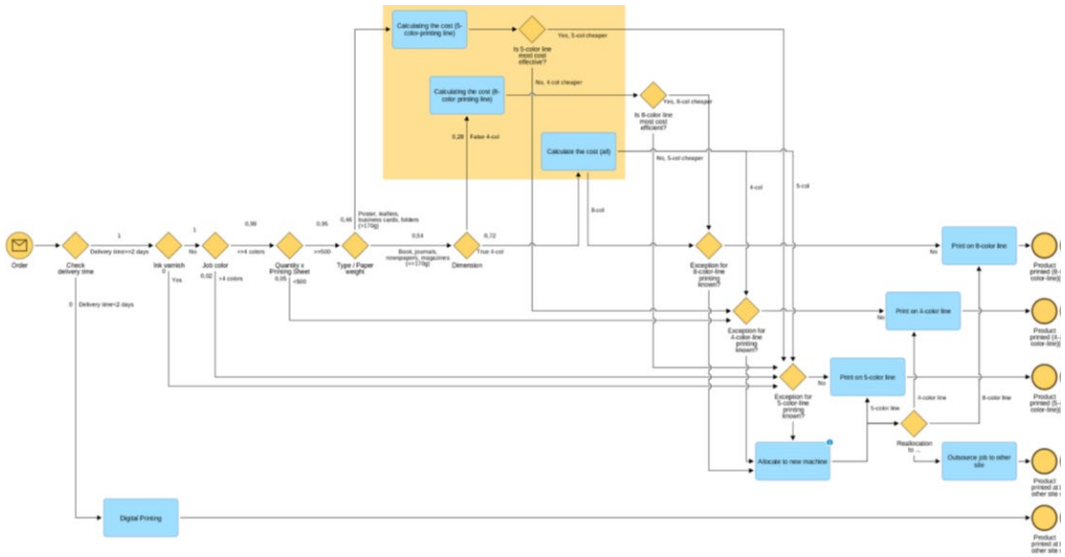

Figure 4: the machine allocation decision diagram, created with ADONIS

3. END-TO-END DATA LIFE CYCLE MANAGEMENT

The ability to cross-reference and integrate heterogeneous data sources is becoming increasingly essential for companies, helping them to gain a competitive advantage. Utilizing these sources, AI-driven applications are transforming vital sectors such as healthcare, manufacturing, and transportation, among others. Within this shift, Data Spaces have evolved as a fundamental framework for facilitating data sharing and exchange, particularly within the context of the European Strategy for Data (European Commission, 2020). This EST seeks to establish a unified data market, augmenting Europe's global competitiveness and data sovereignty (European Commission, 2023).

Despite this progress, the governance of the data life cycle, has not kept pace with technological advances. This gap is especially evident when dealing with semi-structured data from numerous evolving sources, where manual governance leads to fragmented data silos, making clear the need for a systematic and standardized approach to data ingestion, integration, and analysis to support new data-driven business models and data spaces. Additionally, while current research and development (R&D) efforts focus on specific aspects of the data life cycle (e.g., scalable data management or AI explainability), governance remains largely overlooked. Most organizations still develop their own data architectures, a re-

source-intensive process that only large tech firms can efficiently manage. Examples include Amundsen (Amundsen, 2019) and Databook (Uber, 2018). Although cloud providers offer layered solutions, data flow design remains ad-hoc, leaving smaller organizations at a significant disadvantage.

To address this challenge, a comprehensive framework is needed to govern the full data life cycle, enabling secure, interoperable, and scalable AI-driven applications for organizations of all sizes. This framework must support large-scale data from diverse, distributed sources to foster efficient data sharing and exchange.

3.1 CyclOps Concept – Introduction

CyclOps (CyclOps, 2024) aims to redefine the end-to-end data life cycle, enabling organizations to adopt a data-driven culture and utilize data spaces. The European Union's digital strategy emphasizes the creation of sector-specific data spaces to unlock the economic and societal value of data. Within this vision, **CyclOps** (GA No. 101135513) is a Horizon Europe research and innovation project that aims to build a trustworthy, human-centric, and AI-driven platform for **automated orchestration of data pipelines in data spaces**. By focusing on interoperability, security, explainability, and ease of use, CyclOps provides an environment where organizations can **ingest, curate, process, and share data** while maintaining sovereignty and compliance with European regulations.

CyclOps addresses four strategic use cases—tourism, the green deal, public procurement, and manufacturing—chosen for their potential to demonstrate replicable, cross-domain value. Among these, the **manufacturing use case in the domain of offset printing** is of particular relevance to the graphic arts community. This paper first provides an overview of the CyclOps platform and then details the manufacturing case study, highlighting its implications for sustainability, efficiency, and competitiveness in graphic production chains.

3.2 Vision and objectives

This process is guided by user input and requirements through a Human-in-the-Loop approach, prioritizing a user-centric approach, towards allowing organizations to conduct contextualized analyses, without requiring data management expertise. CyclOps operationalizes the data life cycle through a layered, bottom-up framework composed of five key components, as showcased in Figure 5:

I. **DataOps:** automated ingestion, curation, and quality control of structured and unstructured data.
II. **AIOps:** advanced AI/ML operations for feature engineering, model training, validation, and deployment.
III. **Data and Execution Abstraction (DEA):** distributed processing kernels and execution engines that support scalability.
IV. **Intent-based Human Interface (IHI):** a natural language and interactive interface that translates user requirements into executable workflows, ensuring human-in-the-loop control.
V. **Data Governance and Trust (DGT):** compliance with privacy, cybersecurity, and interoperability standards across federated data ecosystems

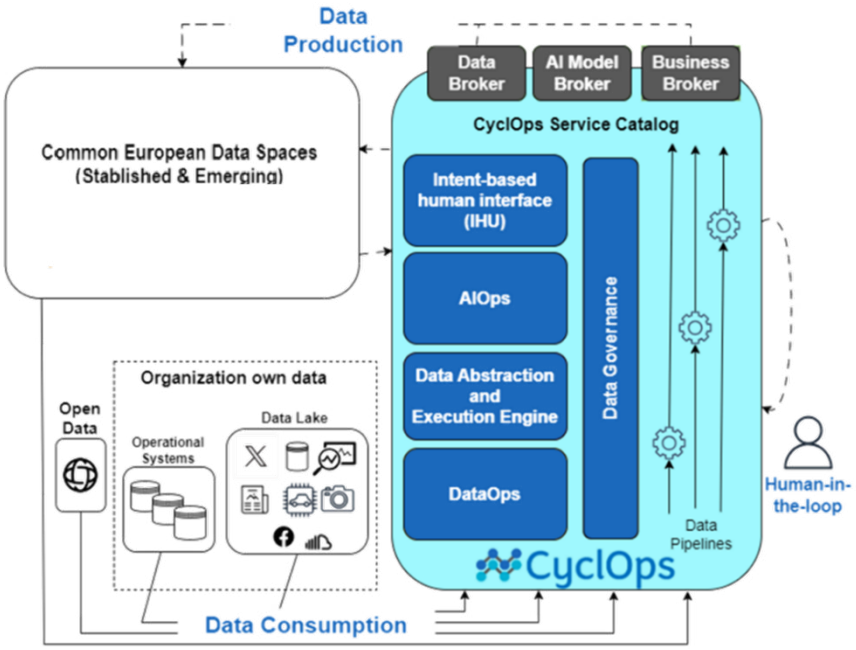

Figure 5: CyclOps conceptual view

3.3 Methodology

CyclOps adopts an iterative, user-centered methodology. Weekly consortium workshops combine technical partners (responsible for AI, semantics, data management) and use case owners (sectoral companies and institutions), ensuring co-design. Requirements are continuously refined in terms of data, AI, trust, and usability. The platform is being validated across the four pilot use cases, with the manufacturing case representing the graphic arts sector.

3.4 Manufacturing Data Space Use Case: Offset Printing

3.4.1 Context and motivation

The European manufacturing sector faces acute challenges from global competition, volatile energy and raw material costs, and increasingly strict environmental regulations. Offset printing—still central to packaging, publishing, and commercial graphics—suffers from high raw material consumption (paper, inks, aluminium plates) and product defects that inflate costs and environmental impact

Companies such as Pressious (PRES) and Color Print (CP) in Greece serve as industrial pilots. Despite strict quality control systems, they report frequent product deficiencies, high waste rates, and energy-intensive workflows. A new digital paradigm is needed to improve process efficiency and sustainability.

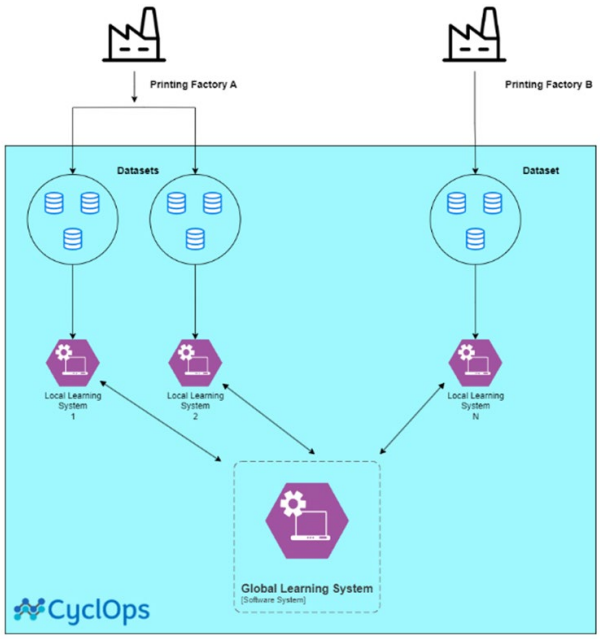

Figure 6: A high-level view of the Federated Learning scheme deployment across two printing companies

3.4.2 Use Case Definition

The CyclOps Manufacturing Use Case (UC4) aims to create a Manufacturing Data Space (MDS) for offset printing, enabling secure, standardized, and value-driven use of production data.

Data flows include:

- Pre-press and press parameters (order number, aluminium usage, ink, paper, machine settings, color specifications).
- Machine logs and failures for predictive maintenance.
- Environmental conditions (temperature, humidity) affecting print quality.
- Warehouse and supply chain data for optimization

These heterogeneous datasets are currently fragmented and underexploited, preventing real-time decision-making and cross-company benchmarking. CyclOps enables a shared infrastructure that respects data sovereignty while fostering collaborative intelligence.

3.4.3 Technical approach

The use case leverages cutting-edge AI techniques within the CyclOps platform:

- **Federated Learning (FL):** PRES and CP retain their sensitive operational data locally while collaboratively training ML models. This ensures compliance with intellectual property and privacy constraints while improving predictive power across sites
- **Transfer Learning (TL):** Models trained on one factory's Heidelberg printers are adapted to another's, minimizing retraining efforts and ensuring robustness across heterogeneous production environments.
- **Zero-Defect Manufacturing (ZDM):** AI models perform **anomaly detection, predictive maintenance**, and **consumable refilling forecasts** to reduce flaws and downtime

- **Circular economy integration:** Immutable tracking mechanisms for paper, ink, aluminium, and water usage help minimize waste and align with EU waste management directives

The **FIWARE Data Space Connector** is adopted to link factory-level systems with the Manufacturing Data Space, ensuring trust, interoperability, and scalability

3.4.4 Expected Outcomes

The specific use case is expected to deliver:

- A **fully operational MDS for offset printing**, contributing to the European federated data ecosystem.
- **Reduced defect rates** by shifting from post-hoc quality control to proactive anomaly detection.
- **Optimized resource consumption**, lowering paper, ink, and aluminium waste.
- **Improved sustainability metrics**, including lower carbon footprint and alignment with EU Green Deal targets.
- **Enhanced competitiveness** for European printing firms, enabling them to reduce costs and expand in global markets.

3.4.5 Relevance to Graphic Arts

For the graphic arts industry, this use case demonstrates a **paradigm shift from reactive to proactive production management**. By embedding AI and data-driven intelligence at every stage of the printing workflow, CyclOps aligns with **Industry 5.0 principles**, emphasizing **human-centricity, resilience, and sustainability**. It sets a precedent for how **printing companies can integrate into European data spaces**, gaining efficiency while contributing to circular economy goals.

4. CONCLUSIONS

Printing environments exhibit significant unpredictability, making errors an inevitable and prevalent occurrence. These faults can significantly affect several dimensions, from direct economic loss to the environmental consequences of squandered resources. Towards this direction, this study presents two distinct use cases in Offset Printing aimed at enhancing production processes.

The analysis and digitalization process of the printing production line brings many advantages. First, modeling the machine selection process, has enabled the documentation and visualization of real-world decision-making. This process can now be easily simulated in a safe and cost-efficient digital environment, facilitated by a Digital Twin. For new print orders, he simulation accurately predicts the most suitable machine line, allowing operators to input multiple orders and receive optimized recommendations for each. Additionally, past orders can also be checked and validated. The digital model also revealed that some jobs could be processed by multiple machine lines, allowing greater flexibility. Furthermore, the simulation environment provides a platform for parameterizing datasets and fine-tuning configurations related to machine selection. Using ADONIS, different setups can be efficiently tested, enabling informed decision-making with minimal cost. As a result, the integration of new machines into the production line becomes faster and more efficient.

Another important benefit of the Digital Twin is the potential to reduce printing costs. Analyzing a dataset of thousands of orders revealed that, for many, more cost-effective machine lines could have been

selected. A comparison between the simulated and actual machine lines demonstrated a cost reduction of approximately 5%, highlighting opportunities for further optimization. Although scheduling conflicts and existing machine utilization may account for some of the inefficiencies, this finding underscores the need for improvements in resource scheduling. In light of this, printing companies are encouraged to explore new ways to optimize efficiency and reduce costs, including partnerships and innovative projects that could address broader challenges within the production line. For instance, digital tools could be employed to automate scheduling and dynamically allocate resources, optimizing both operational costs and human resource management.

Furthermore, the implementation of CyclOps brings transformative benefits to the printing industry by automating tasks such as quality control using ML models, which reduces machine downtime and enhances production efficiency. The CyclOps project represents a landmark effort in operationalizing **European Data Spaces** through AI-orchestrated data pipelines. In the context of offset printing, CyclOps demonstrates how federated and transfer learning models can transform manufacturing into a **zero-defect, low-waste, and sustainable ecosystem**. By combining technological innovation with environmental responsibility, CyclOps not only enhances the competitiveness of European printing companies but also contributes to the broader EU ambition of a resilient and data-driven economy.

The **manufacturing use case** thus serves as a blueprint for data-space-enabled transformation in graphic arts and beyond, paving the way for new business models, optimized resource management, and sustainable industrial growth.

5. ACKNOWLEDGMENTS

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Sustainable Packaging using the Design Thinking Process

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Abstract

Sustainability is very important to most university students. In fact, Generation Z students are generally very committed to sustainability, and it is with this in mind that a project was created to examine and design sustainable packaging in developing countries. Students are tasked with first doing some research and determining what they define as a developing country. They then need to come up with a sustainable packaging solution that fits the needs of the country. Several concepts are created by the students, and one final package is selected to complete the project. Students complete this project using the design thinking process that forces them to work with their peers and get feedback from their peers at multiple times throughout the project timeline.

Graphic communication students are very familiar with designing packages but are not that familiar with designing sustainable packages meant to help a developing country. The majority of students working on this project were not very familiar with the design thinking process and after being exposed to the process, found substantial benefits in using the process when it comes to creating worthwhile project solutions. The design thinking process is a solution-based process that used in various industries and by companies like Google and Apple, but not often used as part of a classroom project. It is traditionally a non-linear process that focuses on creating multiple solutions and on creating the best solution possible through peer feedback and better understanding of the problem being solved.

This paper will examine the design thinking process and how it is used for a sustainability packaging assignment. and provide examples of how the process is utilized in the classroom. Student examples of sustainable packages will also be shared to better illustrate the concept behind using design thinking to create a sustainable package for a developing country.

Keywords: Design Thinking, Sustainability, Packaging, Peer Review

Visual Communication for a Theatrical performance: What can Digital Printing do?

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Abstract

Every science and professional activity can be a driver or enabler for the development, of another science and activity. In this context, the present research, investigates the degree of use and application of Graphic Arts and Printing Technologies, especially by the application of Digital Printing processes for a theatrical performance.
The application of printing technologies for a theatrical performance are often called "theatrical visual communication" and they include a variety of different printed matters, such as posters, flyers, banners, and performance programs. Therefore, the objective of the present study investigates the characteristics of these printed matters and the degree and suitability of digital printing for these.
The result of this research is that digital printing is quite suitable for almost all categories of printed matters for every application in the design and production of theatrical visual communication. This is based on the flexibility, the variety of digital printing application and substrates printed with digital printing.

Keywords: Theatrical visual communication, Printed matters, Graphic arts technologies, Digital printing.

1. Introduction

Theatrical Visual Communication, as defined in this research, concerns the promotion, presentation, and advertising of a theatrical performance. It also involves informing theatergoers and, more generally, those who will attend the performance, with information about the performances that are scheduled to take place, including the venue and time, the contributors, the actors, and, more generally, all the details and data that the audience should know about the performance.

This communication is carried out both in print and, nowadays, through digital media. It is a fact that the development and evolution of digital media has changed the landscape of theatrical visual communication, so it is natural that the presentation and promotion of a theatrical performance may include radio announcements, television presentations, video messages on television, and posts on online platforms.

However, the promotion and presentation of a theatrical performance in digital media, radio, television, etc., is not the subject of this research, which is oriented on printed matters required for the promotion of a in theatrical performance.

As such, a theatrical performance requires various types of printed materials, which are classified below:

- theatrical performance catalogues and programs,
- promotional printed matter for the theater (inside and outside the theater),
- posters,

- banners,
- leaflets,
- invitations,
- promotional material - advertisements printed and digital

The characteristics of the above categorized printed matters for a theatrical performance are analyzed, followed by the presentation of selected samples.

2. Graphic arts technologies and digital printing

The graphic arts printing sector is a particularly creative field of human activity, distinguished both for the breadth of its applications and uses, and for its timeless and uninterrupted provision of products and services that benefit society as a whole. In addition, it is equally distinguished for its ability to transform, mutate, and reorganize itself when technological developments require it or make it necessary for various reasons and in various ways.

2.1 The printing sector and industry

Traditionally, the central stage for a printed document is still printing, i.e. the conversion of processed originals into multiple copies through printing. The stages of graphic arts production are linked together in a complex workflow where each stage contains its own elements. Based on printing, the main stages of print production are defined as shown in Figure 2, as follows (Kipphan, 2001):

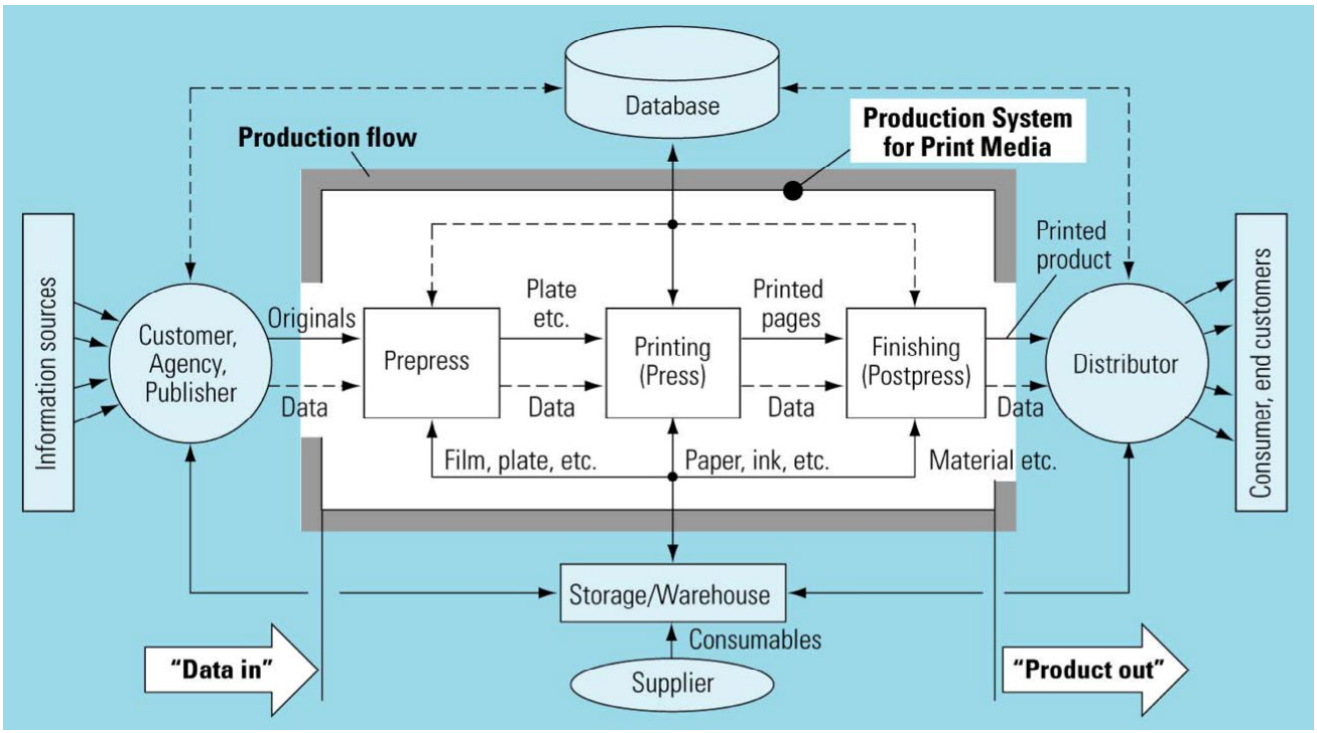


Figure 2. Production flow of a graphic arts industry (from the customer to the distribution of the finished product)
Source: Kipphan, 2001, p. 14

Furthermore, the printing workflow is broken down based on the input, processing, and output of data from the originals and digital files, to the printing plates/cylinders printing and bookbinding/finishing, as shown in Figure 3:

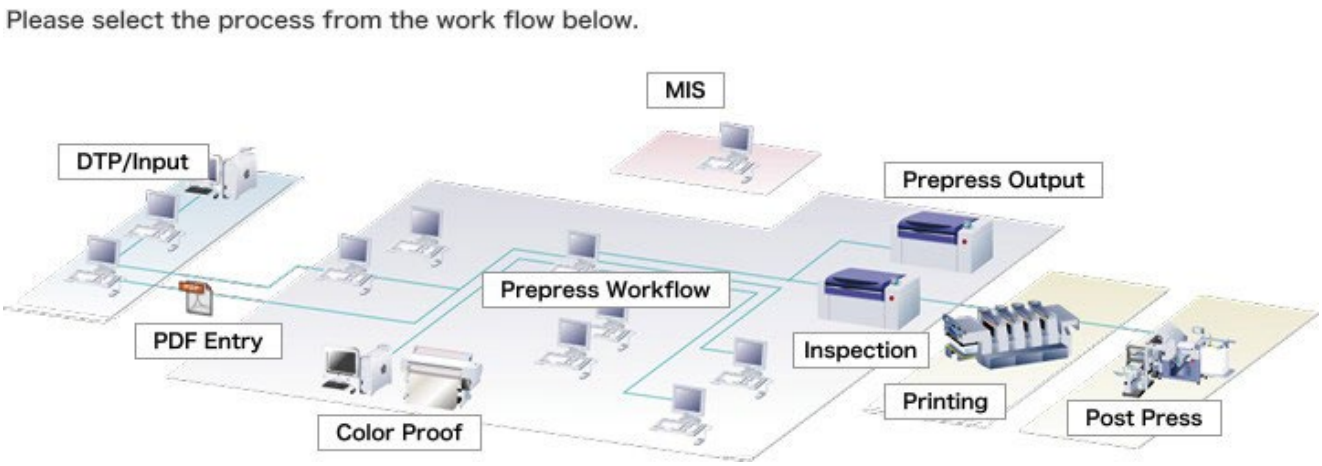


Figure 3. Workflow diagram based on the three stages of pre-press, printing, and finishing
Source: "GTP 60 Graphic Arts Technology" Dr. Anastasios Politis, Dr. Elizabeth Georgiadou, Dr. Marios Tsigonias, Presentation at the Hellenic Open University Graphic Arts Technology, 2023

The pre-press sector includes all the processes that take place before printing, which can be summarized as typographic design and editing of the publication, processing of text, images, and pages, output of data to film, printing plate or cylinder (phototransfer and manufacture of printing plates or cylinders with image setters) and output of the final digital files in the case of digital printing (Politis, 2019).

Figures 4 and 5 present workstations in the pre-printing and data output section with the imagesetter recording the printing plates for the offset method.

Figures 4. and 5.: Prepress
Source: "GTP 60 Graphic Arts Technology"
Dr. Anastasios Politis, Dr. Elizabeth Georgiadou, Dr. Marios Tsigonias

Next, the originals that have been transferred—recorded on the printing plates or cylinders— are printed using machines on the printing substrate with one of the following main printing processes which are, in summary, offset, gravure, flexography, screen printing, tampon printing, and digital printing (Politis, 2019), (Georgiadou et al. 2023).

Figure 6. shows a modern sheetfed offset printing machine.

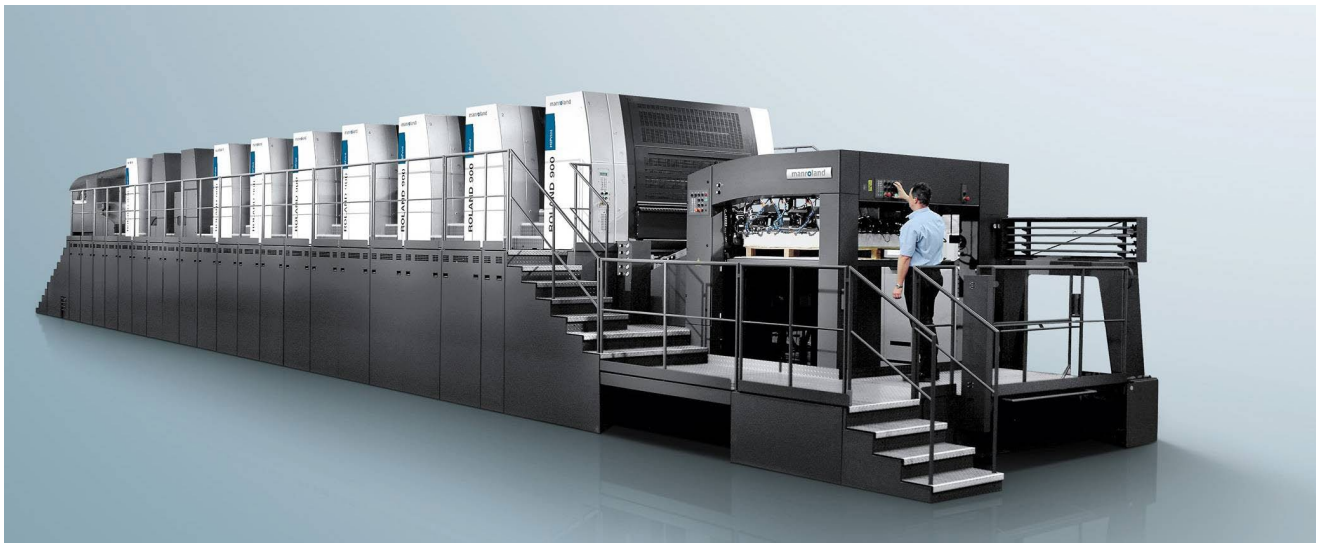


Figure 6.: Sheet-fed offset printing press
Source: "GTP 60 Graphic Arts Technology" Dr. Anastasios Politis, Dr. Elizabeth Georgiadou, Dr. Marios Tsigonias, Presentation at the Hellenic Open University GTP 60 Graphic Arts Technology, 2023

Finally, in the post-printing stage – the finishing stage – the printed sheets or rolls are converted into finished, complete printed products of all kinds. Post-printing processes include, in summary, bookbinding (industrial - artistic), box making, label design and production, paper/cardboard and other printing and non-printing substrate processing, and special graphic arts finishing work (Georgiadou et al. 2023).

2.2 Digital printing, as a main technological development in graphic arts

Digital printing is one of the most dynamically evolving printing technologies, offering great flexibility, especially for small print runs and personalized printed materials. The absence of the traditional process of manufacturing printing plates or cylinders, as is the case with classic printing methods, allows for the application of new technological capabilities, such as variable data printing and on-demand printing, with the ability to print very small numbers of copies. Digital printing can be applied to a wide range of substrates, including flexible materials such as paper, as well as rigid materials such as cardboard, marble, wood, leather, glass, fabrics, etc.

As the research showed, the main features of digital printing are:

- the printing of personalized and variable data that serve on-demand publications (publication - print on demand) by combining fixed content with personalized elements (e.g., names, addresses), or fully personalized printing that uses text, designs, and images from databases and adapts them to the recipient of the print (e.g., advertising brochures of a multinational company that treats each country differently).
- short-run printing for small jobs, but also large jobs to reduce storage costs,
- ability to support Web-to-Print technology, which involves ordering and collecting data for printing via the Internet.

3. Printed matters in theatrical visual communication

Once the performances have been determined, the framework for promoting and advertising the performance is defined using the necessary printed material. These include in particular advertising leaflets, posters, stickers, the main sign at the theater, functional printed materials such as admission tickets, catalogues, books and programs, to be distributed to the audience, invitations to the premiere or press releases.

The characteristics of theatrical visual communication and the printed materials required are determined by factors such the budget, which determines the extent of advertising and promotion, the number of copies of the program, and the type of the main sign outside the theater, where the performance takes place. Also, the length of the performance decides how many tickets to print, while the space available determines the type, size, and number of posters, banners, and other visual media to use.

In general, for all theatrical performances, a particularly small number of copies is required, so this parameter determines both the design and the printing method. Therefore, based on all of the above, it is possible to determine the specific characteristics of the printed materials used in a theatrical performance, analyzed below:

3.1 Tickets

It is a fact that today tickets are distributed electronically and printed by the viewer before the performance, or they can also be electronic and displayed and certified at the entrance by the use of a mobile phone. Hence, they are designed and printed like other types of tickets. However, there is a significant number of theatrical performances where the traditional method of attending the performance with a physical ticket is still used, mainly where no prior online booking or purchase of an electronic ticket is needed. In figure 7, a traditional ticket for a theatrical performance is illustrated:

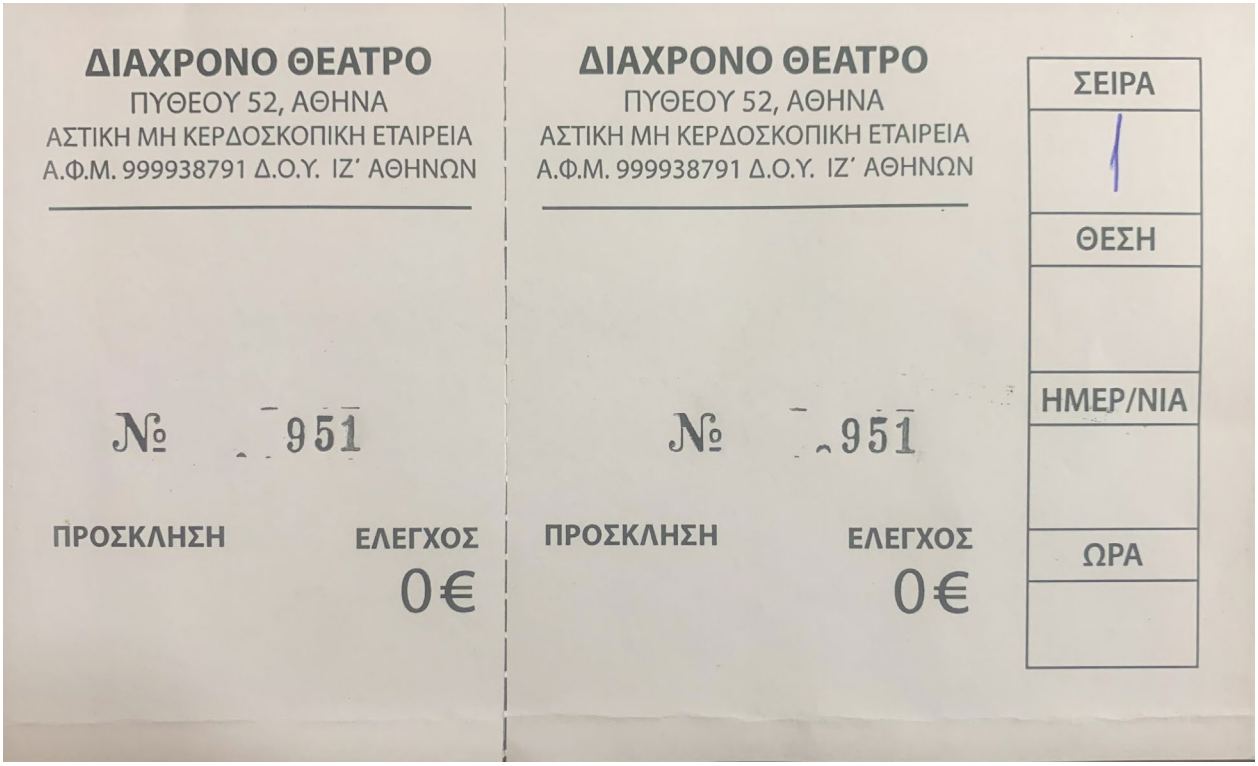


Figure 7.: Ticket to a theater performance

3.2 Promotional printed matters – Brochures

Brochures are traditional printed materials with no special requirements when compared to other types of commercial printing. Traditionally, they are printed using the offset method, but they have the special feature that they must be printed in small numbers of copies. In this case, digital printing methods are used, due to the technological possibility of printing very small numbers of copies and, in fact, minimizing delivery time. Quite useful is the technological capability of digital printing "Print on Demand - PoD" is applied in practice (Georgiadou & Politis 2012).

Figure 8.: A program of a theater performance

3.3 Promotional posters in the theater

Promotional **posters** for the theatrical performance in the theater (entrance, foyer, corridors, etc.) are a key element in promoting the performance. They are printed according to the dimensions of the specific areas where they will be placed. In the past, offset printing was used, but for small print runs, it was a quite costly process. In this field, digital printing offers the possibility of printing of just one (1) copy, exactly at the desired dimensions, considerably minimizing costs. Here, too, print on demand (PoD) is applied (Georgiadou & Politis 2012).

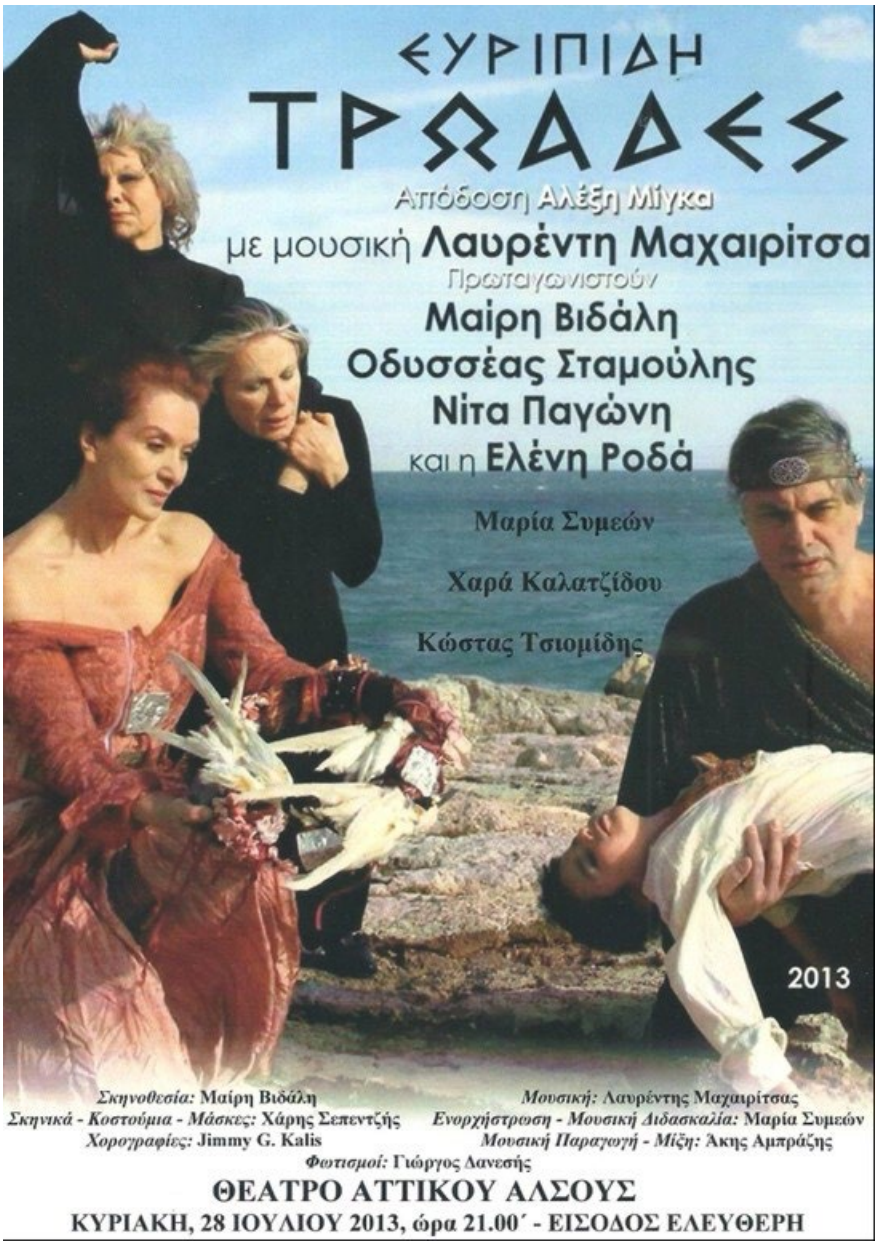


Figure 9. ***Poster*** *from theatrical performance has been printed using the offset printing method, on coated paper weighing 120gr/m2, measuring 50x70 cm, and in 800 copies.*

An additional category of promotion for a theatrical performance is **banners**, or roll-ups, which are digitally printed and then incorporated into special mechanisms that make them particularly easy to transport, folding, and hanging at the performance location (Copy express, 2024).

Figure 10: ***Banner****, on* ***canvas****, dimensions 2.00 x 1.20 meters, one copy (2017)*

3.4 Theatrical performance program (booklet, book, catalogue)

Based on the author's thorough research and experience (Sepentzis, 2025), it appears that the program is a particularly important medium in theatrical visual communication. It presents the contributors to the theatrical performance, the content, the plot, the parts, and any other information that the viewer needs

to know. Programs are handed out to the audience as they enter the performance, so that they have the necessary information about the performance.

The characteristics that determine the program of a theatrical performance relate to the type of performance, the budget, the duration, and the capacity of the theater. Therefore, depending on the performance, programs are designed, printed, and bound. Programs can range from a simple four-page leaflet to a book, in cases where they also contain the text of the play.

In general, programs are printed in small numbers, as are all printed materials related to theatrical visual communication (Sepentzis, 2025).

Books - Theater performance programs

Accompanying books and programs from various theater performances are presented. All have been printed using the offset printing method, on coated paper weighing 120gr/m2, with a final size of 17 x 24 cm and in 300 copies each. The number of pages varies from 16 to 48 pages. They can be separated or combined into a single publication.

Theater performance books (with the text of the play)

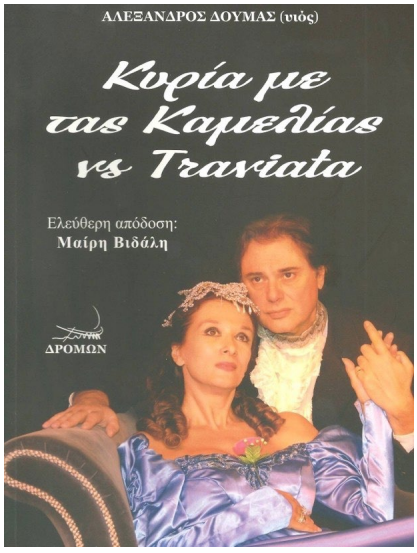


Figure 11.

Figure 12. The above program was designed with special pagination including content for two projects, with two covers on both sides, with a final page size of 17 x 12 cm and wire-bound on the spine, with a print run of 500 copies.

Promotional and advertising materials for theatrical performances (flyers)

Promotional and advertising materials for theatrical performances are common printed materials. They are usually single sheets printed on one or both sides. They are mainly produced using the offset printing method in small numbers of copies, while digital printing is also used to save time and money.

Below is an example of these forms:

Figure 13.: Offset printing on coated paper weighing 120 g/m2, measuring 19.5 x 9.5 cm, with a print run of 2,000 copies.

Leaflets

Figure 14.

Figure 15.

Figures 14 and 15: Double-sided printing of a leaflet for the performance "Four Seasons" at the BRODWAY theater using the offset method, on coated paper weighing 120 g/m², measuring 21.0 x 29.7 cm, with a print run of 500 copies.

3.5 Central sign outside the theater

The central sign is one of the most important promotional elements of a theatrical performance. In every theater, there is a designated space on the facade or roof where the sign is placed with the basic details of the performance, such as the title of the play, the author, the director, the producers, and the actors. The main sign is usually large and requires full installation with lighting. Traditionally, the central sign has been done by hand painting, while in the past it could also be produced in the form of a very large poster by printing smaller pieces that make up the total content using the offset method (Sepentzis, 2025).

However, here too, the number of copies required are just one or two, which makes prohibitive to produce it with a traditional printing method such as offset. In any case, a key feature is the durability of the printing substrate and the print in weather conditions. For the central sign, digital printing is ideal, using large-format printing with special outdoor-resistant inks (UV) and printing on a waterproof substrate, such as canvas (Copy express, 2024).

Central signs

The following Figure (19) show the main title of theatrical performance at the Florida theater.

Figure 16.: FLORIDA Theater: Central inscription for Jean de Letraz's theatrical performance: "Moumo" - French Farce Comedy (1995), directed by Yannis Mortzos and Set Design - Costumes by Haris Sepentzis.

Illuminated central signs

Sticker affixed to transparent Plexiglass, with neon backlighting.

Figure 17.: Illuminated sign measuring 2.60 x 1.00 meters,

Theatrical performance "KAMBARE Hellas, to cry or to laugh," Toula Boutou - Manolis Destounis: Revue, BROADWAY THEATER - Main Stage (2014), directed by Vasilis Platakis and set design by Haris Sepentzi.

3.6 Invitations

Invitations are a handy and common way to share information about theater. They are mainly dedicated for press releases, avant premieres (before the premiere), and the premiere itself, where a selected audience is invited to see the theatrical performance.

Invitations are also printed in small quantities, so here too, printing on demand (PoD) is an option. What is more and given that the invitation is usually addressed to specific people, it can be enhanced by printing each person's name, creating a personalized printed matter and essentially adding value to the event for the selected guest. This feature is only available with digital printing, using Variable Data Printing (VDP) technology and, in this case, with the guest's name and title.

Invitations

Examples of invitations to theatrical performances are provided, with the characteristic requirement of recording the details of specific guests. As already documented, with digital printing and special design, it is entirely possible to print personalized details (for each individual-name, organization, etc.) using Variable Data Printing (VDP) technology.

Μαρίας Συμεών

«Ο Αστραπόλαγος και η κυρα-Αργώ»

Μουσική Παιδική Κωμωδία

Βασισμένη στον γνωστό Μύθο του Αισώπου « **Ο Λαγός και η Χελώνα** »

«**Ο Αστραπόλαγος και η κυρα-Αργώ**», ένα δροσερό, ζωντανό, διδακτικό, παραμύθι γεμάτο πουκιλία, χρώματα, γέλιο, μηνύματα... Απαραίτητο; ... Η συμμετοχή των παιδιών... !!! **Ο Ατραπόλαγος είναι ο λαγός αστραπή!** Κανείς δεν μπορεί να τον προσπεράσει στο τρέξιμο! Αυτή η θαυμαστή ικανότητα των ποδιών του τον έχει κάνει να καμαρώνει τόσο πολύ γι' αυτό και να θαυμάζει επικίνδυνα, ο ίδιος τον εαυτό του! **Πολύ επικίνδυνο στ' αλήθεια!** Γιατί επαναπαύεται στις ικανότητές του, αφήνεται, και αρχίζει να κοροϊδεύει, ό,τι γύρω του δεν κινείται τόσο γρήγορα –που σ' αυτό το παραμύθι, δεν είναι άλλο από τη **γλυκιά και ήσυχη χελωνίτσα, κυρα-Αργώ**. Την προκαλεί, λοιπόν, παράζοντας και κοροϊδεύοντάς την, σ' έναν άνισο αγώνα μεταξύ τους.

Η κυρα-Αργώ δεν του αρνιέται, γιατί ξέρει πως στη ζωή του κανείς, πρέπει ν' αγωνίζεται αληθινά... με την ψυχή του..., να είναι περήφανος και να μη το βάζει κάτω! Καταλαβαίνει πως ο λαγός... θα τη νικήσει...!!! **Όμως, θέλει ν' αγωνιστεί.. να προσπαθήσει.. όπως πρέπει να προσπαθούμε πάντα στη ζωή μας.. να βάζουμε στόχους και ν' αγωνιζόμαστε γι' αυτούς!...**

... Και να που η δικαιοσύνη δεν ζήτησε μόνο τα γρήγορα πόδια του λαγού, αλλά και την αλαζονεία του χαρακτήρα του κι έτσι η τύχη θέλησε να σταθεί στο πλευρό της χελωνίτσας κυρα-Αργώς.

Για να δούμε όμως... **πως ο καυχησιάρης Αστραπόλαγος τιμωρήθηκε για την αλαζονική συμπεριφορά του; Και πως η χελωνίτσα κυρα-Αργώ, κατάφερε να φτάσει στον προορισμό της;!!!**

Μαρία Συμεών

Η Θεατρική παράσταση παίζεται για Σχολεία, 10.00΄-11.10΄ το πρωί, κατόπιν συνεννόησης, ανάλογα με τον αριθμό των μαθητών, είτε στο **Χώρο Τεχνών «Αλεκτον»**, *χωρητικότητας 130 ατόμων, είτε στο* **Θέατρο «Μπροντγουαίη»**, *χωρητικότητας 700 ατόμων, ή και στο ίδιο το Σχολείο, εφόσον υπάρχει κατάλληλος χώρος, ή, τέλος, στο Δημοτικό Θέατρο της Περιοχής του Σχολείου, εφόσον διατίθεται αυτό από το Δήμο, οπότε μπορούν να συνυπάρξουν και άλλα Σχολεία του Δήμου.-*

Συντελεστές της Παράστασης:

Συγγραφή - Σκηνοθεσία: **Μαρία Συμεών**
Μουσική (Σύνθεση-Ενορχήστρωση): **Μαρία Συμεών**
Σκηνικά - Κοστούμια - Μάσκες: **Χάρης Ν. Σεπεντζής**
και Χορογραφίες: **ο Δημήτρης Ιβάνωφ**
στο Σχεδιασμό Φωτισμών: **ο Βασίλης Πλατάκης**
Ειδικές Κατασκευές: **Χάρης-Νίκος Σεπεντζής**
Ηχοληψία - Μείξη Ήχου: **Βασίλης Κίτσος**

Στους ρόλους οι ηθοποιοί:

(Με σειρά Εμφάνισης)
Αφηγητής (Αίσωπος): **Στέφανος Αθανασόπουλος**
Αστραπόλαγος (λαγός): **Απόλλωνας Μπόλλας**
κυρα-Αργώ (χελώνα): **Βανέσσα Αραπάκη**
Καραμελίνα (αλεπού): **Μαρία Συμεών**

ΔΙΑΡΚΕΙΑ: 70΄ΛΕΠΤΑ

Ειδική Προσφορά για ΣΧΟΛΕΙΑ: 5 ΕΥΡΩ/Μαθητή
(ΔΩΡΕΑΝ ΕΙΣΟΔΟΣ σε 5 ΑΠΟΡΟΥΣ Μαθητές/Σχολείο!!)

Τηλέφωνα Επικοινωνίας : 210 28.29.777 - 210 28.11.211 - 6944 34 33 11
Υπεύθυνος Παραστάσεων: κ. Χάρης Σεπεντζής **e-mail:** x.sepentzis@windowslive.com

ΠΑΡΑΚΑΛΕΣΗ, ΟΙ κ. Δ/ΝΤΕΣ ΝΑ ΑΠΟΚΟΨΟΥΝ, ΝΑ ΥΠΟΓΡΑΨΟΥΝ ΚΑΙ ΝΑ ΣΦΡΑΓΙΣΟΥΝ ΤΗΝ ΠΡΟΣΚΛΗΣΗ, ΓΙΑ ΤΗΝ ΧΡΗΣΗ ΤΩΝ ΕΚΠ/ΚΩΝ

.....

Θέατρο Μπροντγουαίη

Αγ. Μελετίου 61 & Πατησίων (Στοά)
Στάση Κεφαλληνίας, Κυψέλη, Τηλ.: 210.86.20.231

Π Ρ Ο Σ Κ Α Λ Η Σ Η

(Άτομα 3 – Ελεύθερα)

ΣΕΙΡΑ
.....
ΚΑΘΙΣΜΑ
.....

Την Κυριακή, 22 Μαΐου 2011 και ώρα 5:15΄ το απόγευμα, το Θέατρο Μπροντγουαίη θα παρουσιάσει σε Επίσημη Πρεμιέρα τη Μουσική Παιδική Κωμωδία της Μαρίας Συμεών

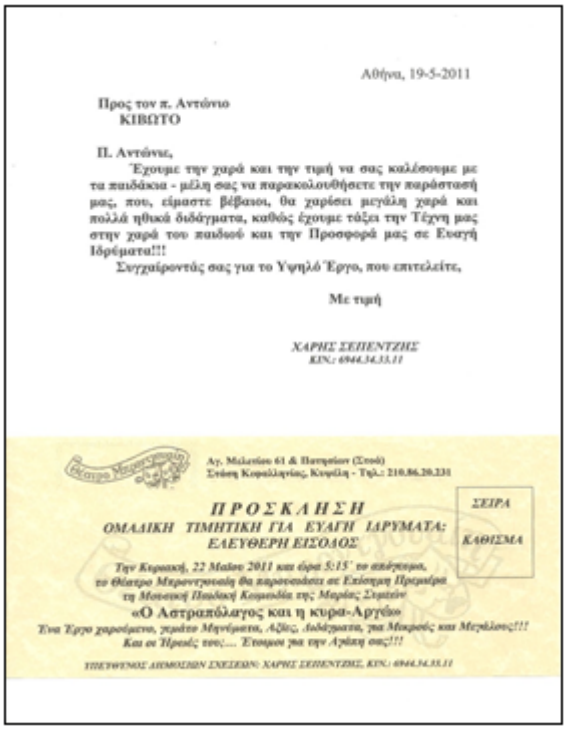
«Ο Αστραπόλαγος και η κυρα-Αργώ»

Ένα Έργο χαρούμενο, γεμάτο Μηνύματα, Αξίες, Διδάγματα, για Μικρούς και Μεγάλους!!!
Και οι Ήρωές του;... Έτοιμοι για την Αγάπη σας!!!

ΥΠΕΥΘΥΝΟΣ ΔΗΜΟΣΙΩΝ ΣΧΕΣΕΩΝ: ΧΑΡΗΣ Ν. ΣΕΠΕΝΤΖΗΣ, ΚΙΝ.: 6944.34.33.11

ΣΧΟΛΕΙΟ: ..... Ο Δ/ΝΤΗΣ ΤΟΠΟΣ ΣΦΡΑΓΙΔΑΣ ΣΧΟΛΕΙΟΥ
ΤΗΛ.: ..... FAX: .....

Figure 18.: Traditionally printed invitation with the requirement to fill in personal details


Αθήνα, 19-5-2011

Προς τον π. Αντώνιο
ΚΙΒΩΤΟ

Π. Αντώνε,
Έχουμε την χαρά και την τιμή να σας καλέσουμε με τα παιδάκια - μέλη σας να παρακολουθήσετε την παράστασή μας, που, είμαστε βέβαιοι, θα χαρίσει μεγάλη χαρά και πολλά ηθικά διδάγματα, καθώς έχουμε τάξει την Τέχνη μας στην χαρά του παιδιού και την Προσφορά μας σε Ευαγή Ιδρύματα!!!
Συγχαίροντάς σας για το Υψηλό Έργο, που επιτελείτε,

Με τιμή

ΧΑΡΗΣ ΣΕΠΕΝΤΖΗΣ
ΚΙΝ.: 6944.34.33.11

Αγ. Μιλτιάδου 61 & Πατησίων (Στοά)
Στάση Κυψέλη - Τηλ.: 210.86.20.231

ΣΕΙΡΑ
ΚΑΘΙΣΜΑ

ΠΡΟΣΚΛΗΣΗ
ΟΜΑΔΙΚΗ ΤΙΜΗΤΙΚΗ ΓΙΑ ΕΥΑΓΗ ΙΔΡΥΜΑΤΑ:
ΕΛΕΥΘΕΡΗ ΕΙΣΟΔΟΣ

Την Κυριακή, 22 Μαΐου 2011 και ώρα 5:15΄ το απόγευμα,
το Θέατρο Μαριονέτας θα παρουσιάσει σε Επίσημη Πρεμιέρα
τη Μουσική Παιδική Κωμωδία της Μαρίας Σταύρου
«Ο Αστραπόλαγος και η κυρα-Αργώ»
Ένα Έργο χαρούμενο, γεμάτο Μηνύματα, Αξίες, Διδάγματα, για Μικρούς και Μεγάλους!!!
Και οι Ήρωές τους;... Έτοιμοι για την Αρένα σας!!!

ΥΠΕΥΘΥΝΟΣ ΔΙΟΜΟΛΟΓΩΝ ΣΧΕΣΕΩΝ: ΧΑΡΗΣ ΣΕΠΕΝΤΖΗΣ, ΚΙΝ.: 6944.34.33.11


Αθήνα, 19-5-2011

Προς τον Πρόεδρο
του Συλλόγου «Το Χαμόγελο του Παιδιού»
κ. Γ. Γιαννόπουλο

Κύριε Πρόεδρε,
Έχουμε την χαρά και την τιμή να σας καλέσουμε με τα παιδάκια - μέλη σας να παρακολουθήσετε την παράστασή μας, που, είμαστε βέβαιοι, θα χαρίσει μεγάλη χαρά και πολλά ηθικά διδάγματα, καθώς έχουμε τάξει την Τέχνη μας στην χαρά του παιδιού και την Προσφορά μας σε Ευαγή Ιδρύματα!!!
Συγχαίροντάς σας για το Υψηλό Έργο, που επιτελείτε,

Με τιμή

ΧΑΡΗΣ ΣΕΠΕΝΤΖΗΣ
ΚΙΝ.: 6944.34.33.11

Αγ. Μιλτιάδου 61 & Πατησίων (Στοά)
Στάση Κυψέλη - Τηλ.: 210.86.20.231

ΣΕΙΡΑ
ΚΑΘΙΣΜΑ

ΠΡΟΣΚΛΗΣΗ
ΟΜΑΔΙΚΗ ΤΙΜΗΤΙΚΗ ΓΙΑ ΕΥΑΓΗ ΙΔΡΥΜΑΤΑ:
ΕΛΕΥΘΕΡΗ ΕΙΣΟΔΟΣ

Την Κυριακή, 22 Μαΐου 2011 και ώρα 5:15΄ το απόγευμα,
το Θέατρο Μαριονέτας θα παρουσιάσει σε Επίσημη Πρεμιέρα
τη Μουσική Παιδική Κωμωδία της Μαρίας Σταύρου
«Ο Αστραπόλαγος και η κυρα-Αργώ»
Ένα Έργο χαρούμενο, γεμάτο Μηνύματα, Αξίες, Διδάγματα, για Μικρούς και Μεγάλους!!!
Και οι Ήρωές τους;... Έτοιμοι για την Αρένα σας!!!

ΥΠΕΥΘΥΝΟΣ ΔΙΟΜΟΛΟΓΩΝ ΣΧΕΣΕΩΝ: ΧΑΡΗΣ ΣΕΠΕΝΤΖΗΣ, ΚΙΝ.: 6944.34.33.11

Figure 19 *Figure 20*

Identical invitations with different details in the name and organization, which can be implemented with Variable Data Printing (VDP) technology.

3.7 Stickers

Stickers are used in specific cases, either to add information to one of the above categories or to change information, e.g. the place and time of a performance (on a tour, another location or another theater, etc.), without having to reprint all the theater visual communication forms. This makes it possible to make use of existing materials, especially if there is a large stock of them, or if a stock has been planned for special performances.

Stickers can also be used to differentiate only a part of a scene, e.g. to add a waterfall, a river, or a lake, or even a bird or animal in a forest, without having to reprint the entire forest. In addition, a sticker in large format digital printing could be placed on a transport truck.

Stickers are printed beautifully using digital printing technologies and applications, in the desired dimensions and in the desired (usually minimal) number of copies, just like other theatrical visual communication - printed materials.

4. Examples of traditional and digitally printed theatrical visual communication matters – a comparison

4.1 Floor Set TETRACTYS - ANCIENT ORCHESIS

4.1.1 Description of the project

The set is for the play "TETRACTYS," which was performed in 2019 at the UNIVERSITY OF ATHENS - EKPA / FSPA (Sepentzis, 2024).

It is a floor-mounted geometric set for ARCHAIA ORCHESIS, directed by Anna Lazou and choreographed by Fifika Nikolopoulou. Construction, design, and painting of the set by set designer Haris Sepentzis. The set is floor-mounted, measuring 3.00 x 3.00 meters, with the purpose of guiding the steps of the dancers of ARCHAIA ORCHESIS. Figure 21 shows a model of the set, while Figure 22, shows a photograph of the set.

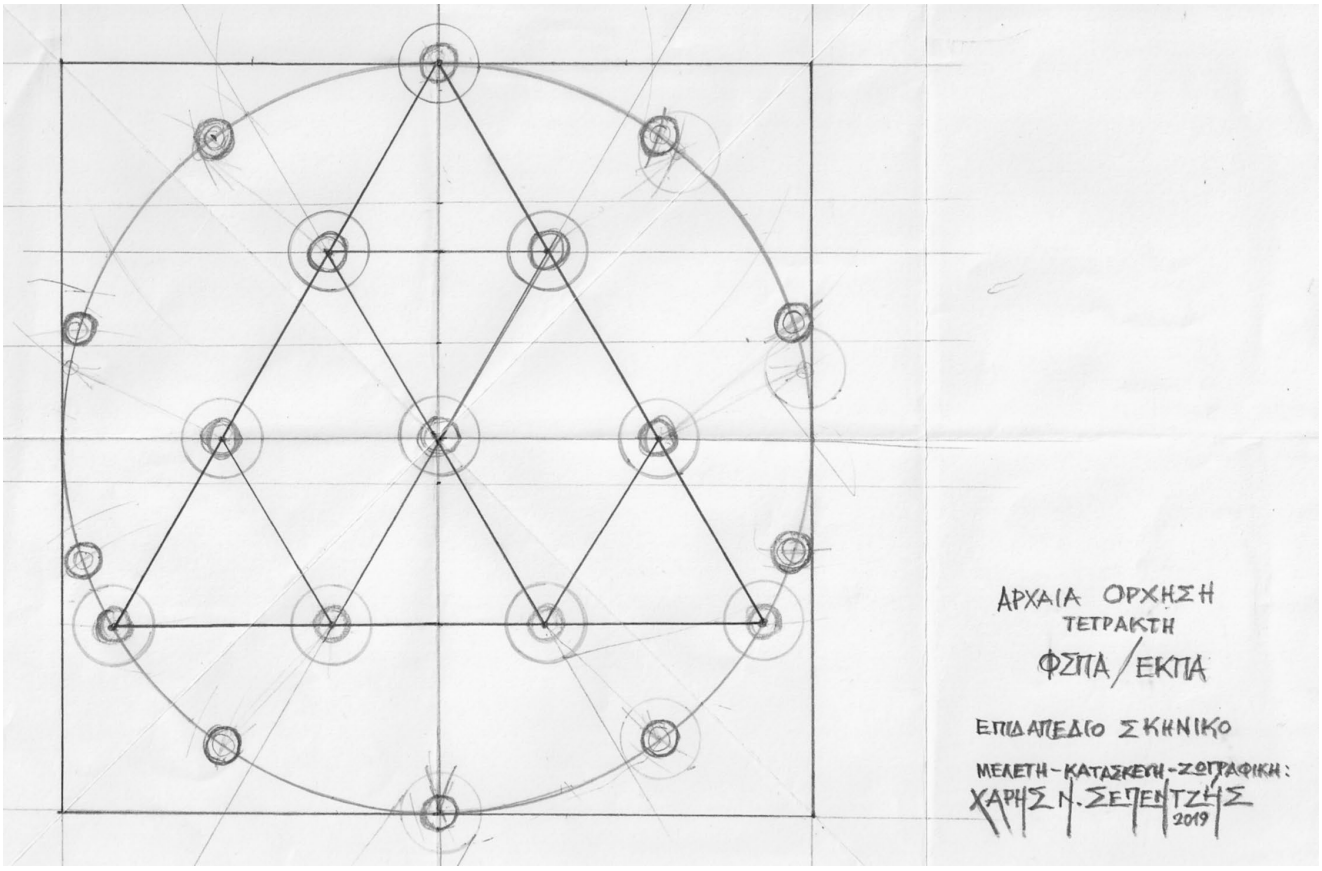


Figure 21: Model of the floor-mounted set
Source: Researcher's personal archive

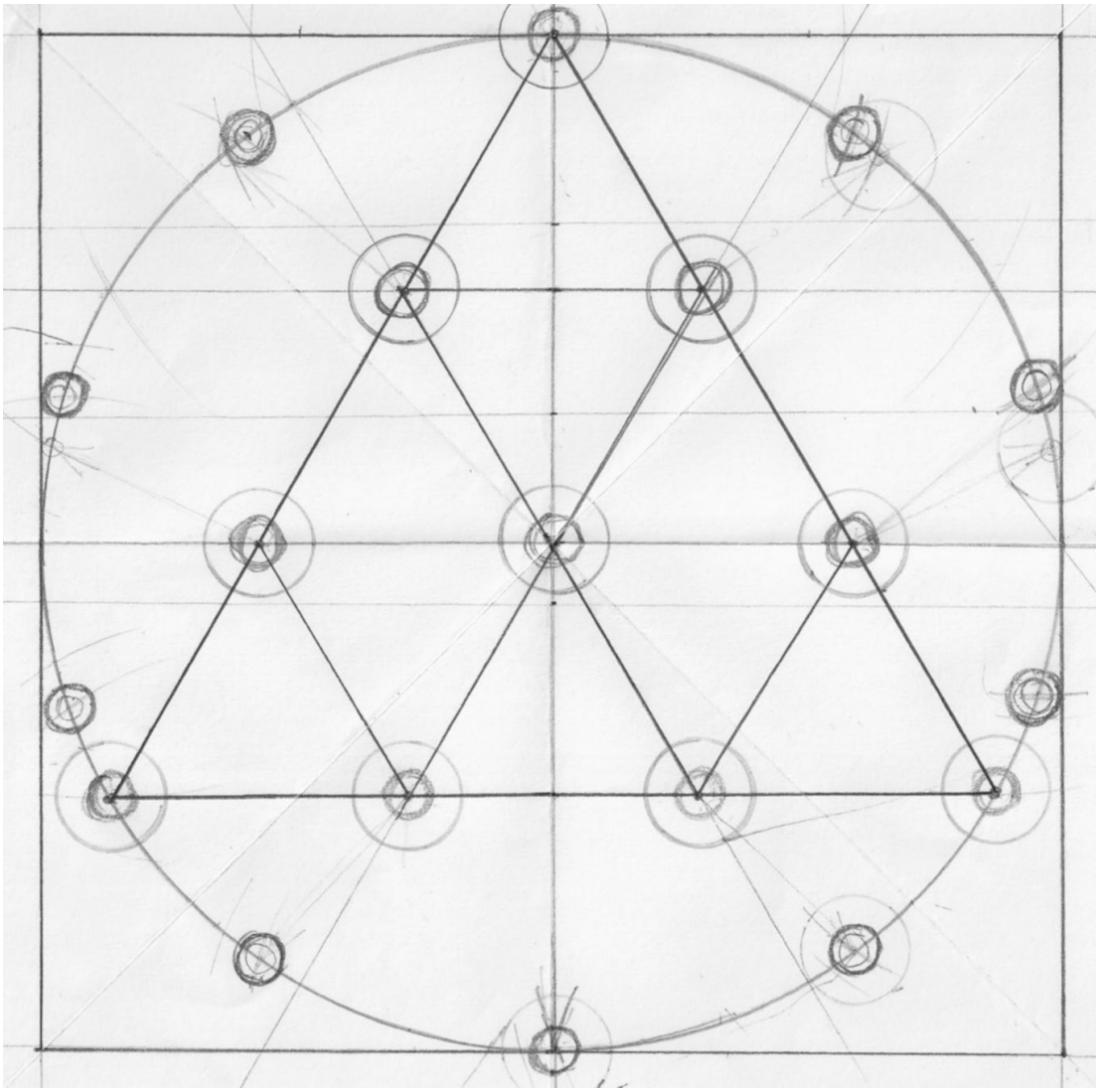


Figure 22 The set is depicted in a photograph
Source: Researcher's personal archive

4.1.2 Analysis of construction – printing

The floor scene was created by painting on a special canvas that is a suitably treated thick fabric - cotton canvas, with a parallel coating of special varnish with suitable hardeners to protect the painting and prevent it from deteriorating. This process is necessary because it protects the backdrop from stress when stepped on by the dancers during the performance of the choreography.

The traditional painting process cost €3,000 and took five days to complete. The digital printing process, which also included the application of varnish to protect the painting from wear and tear when stepped on during the performance of the choreography, had a total cost of €500 and was completed in one day.

4.1.3 Comparison

Printing and varnishing using the digital process cost 1/6 of the traditional painting method and took 1/5 of the production time.

4.2 "Mimi... drags a boat" Theatrical visual communication project - central poster

4.2.1 Description of the project

This concerns the central inscription - giant poster for Dinos Spyropoulos' revue entitled "Mimi... drags a boat." The giant poster covered the entire exterior facade of the Bournelis Theater. It measured 27.60 x 5.00 meters and had a surface area of 138 square meters. It was mounted on a wooden frame with 23 panels, each measuring 5 meters high and 1.20 meters wide. Figure 9.9.1 shows the design in the digital file of the central inscription - the giant poster that was delivered to the graphic arts company for printing.

Figure 23 The digital file of the central inscription – the giant poster
Source: Researcher's personal archive

Figure 24 The central inscription – giant poster of the review, printed and placed on the facade of the Bournelis Theater. Source: Researcher's personal archive

4.2.2 Comparative analysis of construction – printing

The giant poster was created using digital printing on canvas in a single piece with UV inks. The cost was €3,000 and it took approximately two days to print (total production process). A traditional construction with painting would have cost around €12,000 and would have required at least 20 days of work.

4.2.3 Comparison

Production using digital printing costs 1/4 of the cost and takes 1/10 of the time of the traditional method using painting. The difference is very significant, and digital printing was clearly chosen for the creation of the central inscription of the inspection.

5. Conclusions from the comparison of the characteristics of theatrical visual communication and the possibilities offered by graphic arts technologies, particularly digital printing

The main outcome result of this research is that in every application in the design and production - construction of Theatrical Visual Communication, Graphic Arts Technologies, especially Digital Printing are one of the most dominant - if not the most determining factor - of the visualization of the necessary theatrical infrastructure and the required depictions of the fields that must be presented in each Visual Communication project and creation for a theatrical play.

Based on all of the above, it can be concluded that the specific characteristics of theatrical visual communication prints are the very short or small number of copies and large or very large format print sizes. In particular, for center signs or posters the requirements for theatrical visual communication prints are even smaller, limited to just 1 or 2 copies.

Given the capabilities of digital printing technologies, it becomes evident that the all categories of a theatrical performance, can be produced quite efficiently with digital printing technologies and applications, while traditional printing methods are not suitable, or are available at a high and often prohibitive cost.

5.1 Conclusions from the comparative analysis

The main conclusion that emerged from the comparative study is that digital printing is ideal for all applications for sets, costumes, dresses, and fabrics in the context of designing and implementing a set design for a theatrical performance.

In particular, it appears that digital printing significantly reduces both the cost and time of constructing a set. It also allows for the use of cheaper materials for the construction of set supports and hangers, while at the same time allowing the use of sets with the exact designs and dimensions specified in the set design study, accurately reflecting the artistic vision of the director and the creation of the required set. Furthermore, the application of other technologies, such as varnish coating, ensures the durability of sets, such as a floor set for choreography, without damaging the floor.

A very important feature is that digital printing makes it possible to produce a single copy of each item in set design, costume design, and theatrical visual communication. This feature is particularly useful in set design and costume design, where in most cases only one copy of a set or costume is required.

Furthermore, graphic arts technologies and creative design allow for the digital design of set designs and costumes, making it possible to print any theme that serves the set design without restrictions on dimensions, designs, or colors, expanding the set designer's horizons and enhancing their artistic expression.

Finally, digital printing and graphic arts technologies in general, offer the possibility for efficient and less costly illustration of the performance's visual communication, with significant advantages over traditional painting and/or traditional processes.

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Automatic Colorization of Grayscale Images Using Convolutional Neural Networks: A Small-Scale Study

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Abstract

This paper presents a small-scale study on the implementation of convolutional neural networks (CNNs) for grayscale image colorization. Motivated by the challenge of restoring missing color information in grayscale photographs, the approach uses semantic and structural cues learned from large-scale image datasets. A CNN trained on approximately 1.3 million ImageNet images was tested on a subset of the COCO dataset, comprising 20 categories with 20 images each. The grayscale lightness (L) channel was used as input, and the model predicted the chrominance ab channels, which were combined to reconstruct RGB images. Colorization performance of the model was quantitatively assessed with three complementary metrics: Structural Similarity Index (SSIM) for lightness-structure fidelity, CIEDE2000 (ΔE) for pixel-wise color accuracy, and Learned Perceptual Image Patch Similarity (LPIPS) for perceptual realism. Results show consistently high SSIM values (≥ 0.95), indicating robust structural preservation; generally low LPIPS values (< 0.21 for 74% of images), suggesting convincing perceptual realism; and a wider spread of CIEDE2000 differences (1 – 8 for 99% of cases), capturing category-dependent color fidelity. A more detailed category-specific analysis revealed that even small chromatic shifts in certain objects (e.g. traffic lights) can be perceptually disturbing despite low CIEDE2000, while neutral textures (e.g. zebra stripes) may look plausible to humans but are characterized by larger CIEDE2000 values. The study emphasizes the importance of combining the three metrics for a balanced evaluation of image colorization. Also discussed are some limitations of the study (dataset size, absence of human observers) as well as its possible applications in historical photo restoration, animation, video editing and remote sensing.

Keywords: image colorization, convolutional neural networks, SSIM, CIEDE2000, LPIPS

Introduction

The colorization of grayscale images has long been a challenge in computer vision. While grayscale images contain only one-third of the information of their color versions, semantic context and texture cues enable plausible reconstruction of missing chromatic content. Earlier attempts at colorization often required manual intervention or relied on hand-crafted features. With the rise of deep learning, particularly convolutional neural networks (CNNs), automatic approaches have become feasible. Zhang et al. [1] demonstrated that CNNs can hallucinate perceptually realistic colors, even if the ground truth chromatic information is not fully recovered. The purpose of this study is to investigate the performance of a CNN-based colorization model on a small-scale test set and to assess its effectiveness using three evaluation metrics that capture structural, chromatic, and perceptual qualities of the output.

Materials and Methods

CNN was trained on the ImageNet [2], a large publicly available dataset of approximately 1.3 million color images, ensuring a wide variety of content and color distributions. Images were first converted from RGB to the Lab color space, where the luminance (L) channel served as input and the network was trained to predict the chrominance (ab) channels. The predicted ab values were then combined with the original L channel to reconstruct RGB images. The network architecture (Fig. 1) consisted of eight convolutional stages, each containing multiple convolution + ReLU + BatchNorm layers. Feature maps grow from 64 to 512 channels. While lower CNN layers learn simple features – edges, corners, colors – higher ones combine these into complex structures, such as objects or scenes. Resolution changes were achieved via strided and dilated convolutions, avoiding the use of pooling layers to preserve spatial detail. For testing, a subset of the COCO dataset (val2014) [3] was used, consisting of 20 categories with 20 images each, for a total of 400 test images.

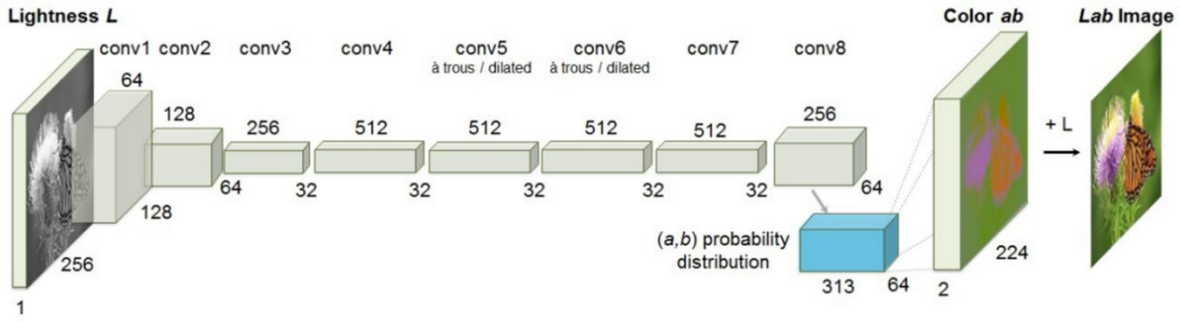

Figure 1. CNN architecture implemented in our study for grayscale image colorization [1].

To assess the model perfomance, i.e. the colorization appropriateness, three metrics were employed: (i) Structural Similarity Index (SSIM) [4], which assesses structural fidelity; (ii) CIEDE2000 (ΔE) [5], which quantifies pixel-wise color differences in the Lab space; and (iii) Learned Perceptual Image Patch Similarity (LPIPS) [6], which uses pretrained CNN features to measure perceptual realism. Metrics were based on the comparison of actual color (= ground truth) images with their colorized versions. All computations were done in Python with accompanying image processing and machine learning libraries.

Results

Fig. 2 shows category-wise model performance on 400 test images in terms of CIEDE2000 and LPIPS metrics. Since SSIM values for all images were between 0.95 and 0.999, this parameter provides very little discrimination between images/categories and was not included in metrics comparison. CIEDE2000 values ranged from 1.2 to 15.9 while LPIPS scores were between 0.04 and 0.57.

Some examples of best- (in terms of LPIPS) and worst colorizations are displayed in Figs. 3 and 4, respectively. Fig. 5 shows an example of Zebra and Traffic light image pairs with a low LPIPS/high CIEDE2000 and vice versa.

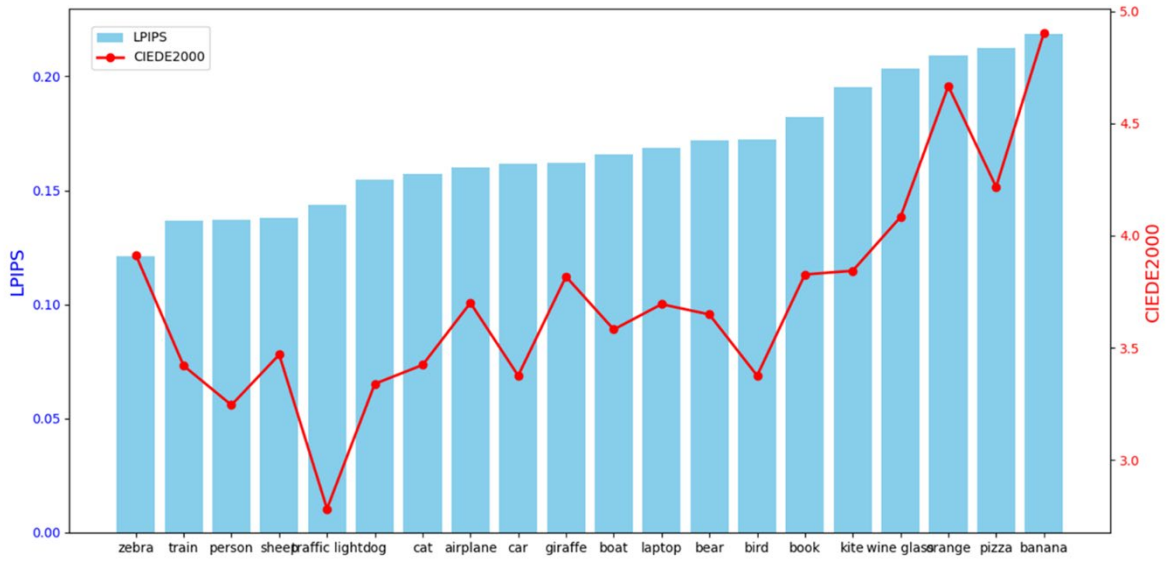

Figure 2. LPIPS and CIEDE2000 scores comparison for 400 test images divided into 20 categories.

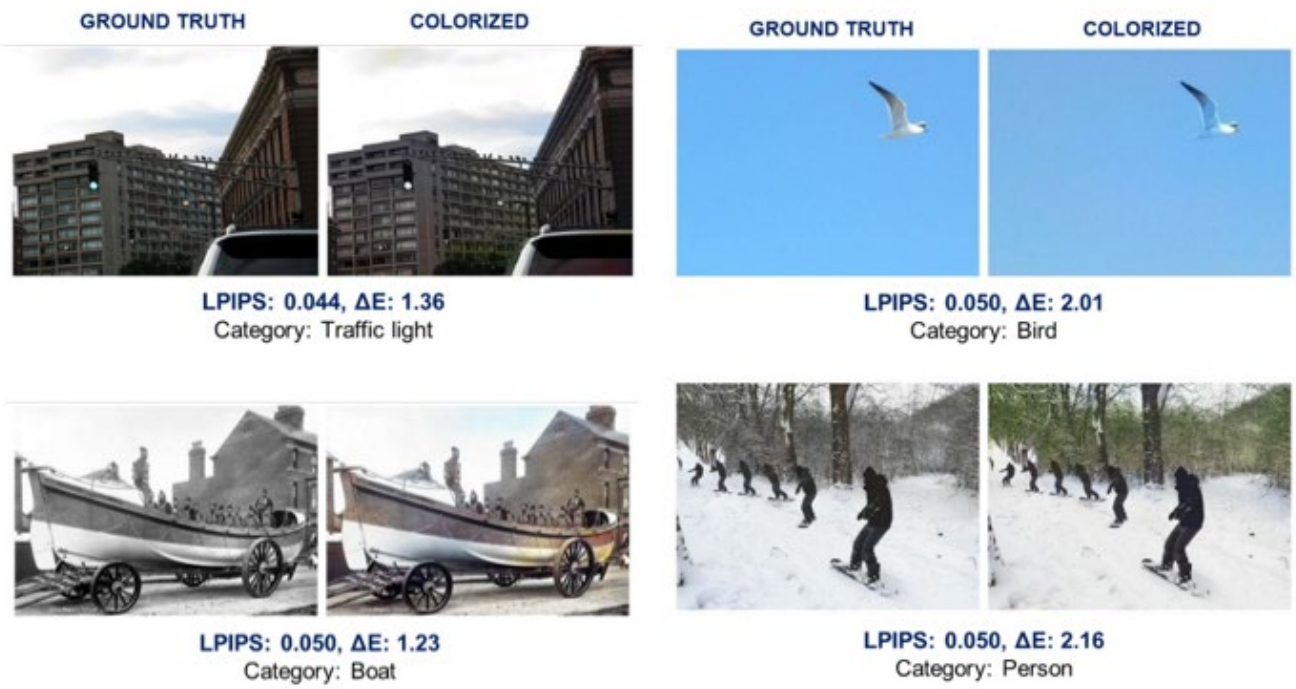

Figure 3. Examples illustrating very good colorization quality – very low LPIPS.

Figure 4. Examples illustrating poor colorization quality – very high LPIPS.

Figure 5. Colorizations characterized by low LPIPS and high CIEDE2000 (left) and vice versa (right).

Discussion

In colorized images the structure was preserved very well across all categories since the corresponding SSIM scores were all found to be above 0.95. LPIPS scores (see Fig. 2) were predominantly low – below 0.21 for 74% of images – indicating good perceptual realism. CIEDE2000 metric exhibited larger variability: most cases – 95% of images – fell within 1 < CIEDE2000 < 8, spanning imperceptible through clearly noticeable color differences. In general, categories where model performance was the best (low LPIPS and CIEDE2000) include Zebra, Train, Person, Sheep, Traffic lights while colorization results were the poorest with several food-related categories such as Wine glass, Orange, Pizza and Banana.

When examining some of the ground truth-colorized image pairs with the best and worst performance (Figs. 3 and 4), several interesting observations can be made. Colorized versions of both the Traffic light and Bird examples (Fig. 3, top left- and right) match almost perfectly their ground truth originals in terms of color fidelity and perceptual similarity leading to very low CIEDE2000 and LPIPS scores.

Situation is similar with the Boat and Person colorized images (Fig. 3, bottom left- and right); with the latter example, a bit higher CIEDE2000 value (2.16) is due to a greenish shade of the background tree branches that are neutral gray in the ground truth version; this difference, however, does not deteriorate perceptual realism. On the other hand, cases where the model performance was the poorest often include food – see Fig. 4 top- (Wine glass) and bottom-right (Banana) images – and/or unusual scene lighting, such as with the Bird, Wine glass and Boat category ground truth images. Here the model was not able to colorize images properly and also perceptually they look rather unrealistic.

Although LPIPS and CIEDE2000 metrics in general correlate reasonably well, with Pearson correlation coefficient being 0.72 for 400 images, several images in categories such as Zebra and Traffic lights do not follow this trend (see also Fig. 2). In the case of zebra image pair (Fig. 5, left) the stripes in the colorized image look perceptually fine resulting in extremely low LPIPS, but even small deviations in neutral/black tones lead to more pronounced color differences in LAB color space and therefore to larger CIEDE2000 score. In contrast, when looking more closely to the traffic lights image pair (Fig. 5, right) one can notice a color shift in the sky region as well as in the top traffic light towards somewhat unnatural orange and yellow hues, respectively. So although colorization result is similar to the ground truth image in terms of color accuracy (low CIEDE2000), it looks less natural to a human observer, leading to somewhat higher LPIPS score.

The study demonstrates the importance of combining the three metrics for a balanced evaluation of image colorization. In our future work we plan to include testing on a larger-scale image database, comparison with alternative colorization models as well as human observers-based evaluation of perceptual quality of colorized images.

Conclusion

CNN-based colorization can produce structurally accurate and perceptually convincing results across diverse categories, while exact chromatic fidelity remains challenging for particular images featuring nonstandard lighting or ambiguous regions. A combination of metrics used in the study (SSIM, CIEDE2000, LPIPS) offers a balanced evaluation scheme and can guide model design for applications in digital restoration, animation, video editing, and remote sensing.

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Biography

Aleš Hladnik is a Full Professor at the University of Ljubljana, Slovenia. He obtained his PhD in 2003 from the University of Graz, Austria. After working 11 years for the Pulp and Paper Institute in Ljubljana, he joined the Faculty of Natural Sciences and Engineering, Chair of Information and Graphic Technology, in 2006. His research focuses on applied statistics, color science, digital image processing, machine learning, and artificial neural networks, with a broader interest in information technologies.

Mihael Lazar is an assistant professor and lecturer at the University of Ljubljana, Slovenia. After nine years of engineering project work in the fields of automation and information technology in the private sector, he joined the Faculty of Natural Sciences and Engineering, specifically the Chair of Information and Graphics Technology, where he obtained his doctorate. His research in the field of graphics and information technology focuses on digital image processing, color science, machine learning and artificial neural networks.

Thermally conductive composites for FFF 3D printing with hybrid filler – the influence of individual fillers and the amount of filler

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Abstract

The article is focused on researching composite materials with high TC (Thermal Conductivity) along printing for printing 3D structures using AM (Additive Manufacturing), more precisely, the FFF (Fused Filament fabrication) technique, in which the polymer fiber, i.e., filament, is melted to a temperature related to the flow temperature of the given material. It is then extruded through a nozzle onto the printing bed. The hybrid filling method with micron-sized fillers of randomly distributed thermally conductive fillers in a polymer was used because of its favorable synergistic conditions of various shapes and sizes of fillers, as follows from the literature. Exponential growth with the addition of fillers was observed as expected. The composites were made up of a PC (Polycarbonate) as a matrix and a hybrid filler, specifically, h-BN (Hexagonal Boron Nitride), EG (Expanded Graphite), PCFs (Pitch-based Carbon Fibers), and Al (Aluminum Particles). Composites with 10, 20, and 30 wt% were prepared. Due to the apparent exponential behaviour of the increase in TC with increasing volume fraction of fillers, a composite with 40 wt% fillers was also prepared; however, its printability is significantly deteriorated. The article further comments on the influence of individual fillers on the thermal properties of the final composite. The influence of individual fillers was evaluated by removing one filler component from the system. Composites with three hybrid components instead of four have been created, and such filaments and changes in TC were evaluated and discussed. The printed samples were analyzed using laser flash analysis to determine thermal diffusivity and thermal capacity, from which thermal conductivity was calculated. From the article, it is clear that some fillers work better than others, and some may even have a negative effect due to various reasons, such as wetting the filler with polymer, the formation of voids in the printed sample, etc. Either way, the effect of fillers on the processability of the resulting composite is also important.

Keywords: Thermal conductivity, additive manufacturing, FFF 3D printing, composites, hybrid fillers

Prototyping of plates with Braille Dots for the visually impaired with 3D printing technology

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Abstract

This study aims to explore the potential of additive manufacturing (AM), namely fused deposition modelling (FDM) and stereolithography (SLA), in producing tactile Braille signage for the visually impaired and blind. The objective was to determine the feasibility of using AM processes in making accessible, low-cost, and customizable Braille blocks with dimensional and ergonomic uniformity. Several versions of the design were designed and prototyped using both FDM and SLA technologies, based on the same CAD design. The results showed that although placement and spatial distribution of Braille dots were adequate, the geometric accuracy – i.e., shape, curvature, and dot size – fell short of usual Braille tolerances, particularly for FDM. Visual examination revealed that the dots produced by FDM exhibited flat tops and planar edges, with evident layer shifting and surface imperfections such as stringing. SLA yielded higher fidelity and surface smoothness, producing more readable and ergonomically superior dots. Four final block designs were compared for readability and tactile comfort in a pilot study involving five volunteers. All participants were able to correctly identify most characters, and a subjective ranking indicated clear preferences, with one design emerging as the most user-friendly. While SLA produced better results, FDM remains a more inexpensive and safer choice for mass or home production. The findings affirm that with proper optimization, for example, font and small design adjustments, AM can be a viable process for Braille signage production, each technology presenting inherent strengths depending on the application context.

Keywords: Braille, additive manufacturing, 3D printing, visual impairment, accessibility

Introduction

The number of people with vision impairment or blindness is reaching 2.2 billion people worldwide [1]. Braille is a universally recognized tactile writing system designed for individuals who are blind or visually impaired. It employs a three-dimensional, dot-based structure that enables reading through touch rather than vision. Unlike traditional print, Braille characters are embossed and are interpreted by running the fingertips over the raised patterns. Each Braille character consists of up to six raised dots arranged in two vertical columns and three horizontal rows [2]. By varying the number and position of these dots, 64 unique combinations can be created to represent letters, numerals, punctuation marks, mathematical symbols, and other characters [3].

Additive manufacturing (AM) has experienced significant advancements in recent years [4]. It is worth noting that the term "3D printing" is more commonly used when referring to processes utilizing polymer-based materials, whereas "additive manufacturing" is typically associated with technologies involv-

ing metals or ceramics [5]. Regardless of terminology, AM techniques are based on the layer-by-layer deposition of material guided by three-dimensional digital models created in CAD environments [6], [7], enabling the fabrication of spatially complex objects.

Initially, due to limitations in precision, 3D printing was regarded primarily as a method for producing low-resolution prototypes or moulds intended for further manufacturing steps. However, recent developments have broadened its applicability. 3D printing has proven particularly beneficial in supporting individuals who are blind or visually impaired by enabling the creation of customized tactile tools and aids, such as 3D-printed tactile maps [8]–[10], representations of cultural heritage artifacts [11]–[13], tablets incorporating Braille patterns [14]–[16] or portable medicine containers [17].

Herein, we apply 3D printing technologies (FDM and SLA) for Braille printing for the blind to help with everyday functional use. 3D desktop printers are easily available and cheap; therefore, they can be used in offices or homes. We show the process from concept, creating a 3D model, and then prototyping by FDM and SLA printing. Finally, the quality of the plates with Braille dots was assessed.

Materials and methods

Design of 3d printing model

The plate model was designed using Autodesk Fusion 360 (San Francisco, CA, United States). Fig. 1 shows a CAD plate model with the Braille and Latin numbers. The Braille dots were designed according to Marburg Medium, which is recommended for pharmaceutical packaging and labelling [18]. The model was designed with the specifications for Braille dots as follows:

- Dot height: 0.5 mm;
- Dot down diameter: 1.3–1.6 mm;
- Dot spacing from dot center to dot center horizontally or vertically: 2.5 mm;
- Character spacing from dot center to dot center: 6 mm;
- Line spacing: 10 mm.

Figure 1. The CAD plate model with the Braille and Latin numbers.

Printing

For printing the plates using FDM technology, an Original Prusa i3 (Prusa Research, Prague, Czech Republic) printer was used together with its dedicated slicer, PrusaSlicer, and PLA material (Polylactide,

Filament PM, Chudobín, Czech Republic). For comparison, for SLA technology, an SLA Creality Halot Mage Pro 8k (Creality, Shenzhen, China) was used with its system slicer, Creality Print, and standard resin. The plates were designed and printed in 6 different designs by FDM and one version by SLA.

2.3. Methods

Braille dot quality assessment

Printed Braille dot samples were evaluated with a Braille Dot Checker (BOBST, Mex, Switzerland). Measurements of dot diameter, height, and spacing were performed according to the DIN EN 15823 standard [19].

Pilot studies

To practically compare the four versions of the projects, pilot studies were conducted in which a group of five volunteers was asked to read and assess the Braille signs on the plates. A short survey was conducted to collect feedback on the impressions of using the plates (see Table 1 for questions and possible answers). Firstly, the volunteers were asked to read the Braille dots on the plates. Then the volunteers were asked to arrange the blocks in order from best to worst. Finally, the volunteers were asked to comment on their impressions and what they felt through the touch. The objects were given in random order.

Table 1: Survey questions

Entry	Question	Answer
1	Was the inscription read correctly?	Yes/No
2	Placing the blocks in order from best to worst	1 to 5
3	Volunteers' comments on the project	—

Results and discussion

Printing the Braille alphabet did not pose major difficulties, although multiple attempts were required to achieve the final overprinted models. Among six project, four were selected for further evaluation. Ensuring that the Braille dots met the required standards for height, diameter, and spacing was essential. Finally, four versions were selected for quality assessment and pilot testing. The final versions of the plates are shown in Fig. 2.

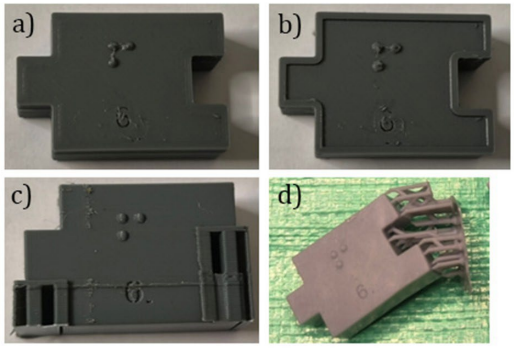

Figure 2. Final models of plates before sanding. Design 1–3 plates printed by FDM, design 4 – plate printed with SLA.

Dot Braille quality assessment

A visual analysis of the Braille dots revealed deviations from the intended design, with the overprinted dots exhibiting flattened tops and sharp edges, resembling truncated cones. This might be related to the shrinkage of the material, which was also observed by us in our previous work [16].

Fig. 3 shows Braille dot images obtained with the Braille Dot Checker, a non-contact optical system designed for the assessment of dot placement, dimension, and structural deformation. A visual analysis of the Braille dots revealed inaccuracies in replicating the intended dot geometry. The overprinted dots exhibited flattened tops and sharp edges, resembling truncated cones (Fig. 3a). A visual analysis of the Braille dots revealed inaccuracies in replicating the intended dot geometry, as the overprinted structures exhibited flattened tops and sharp edges, resembling truncated cones (Fig. 3a). The print layers, particularly at the tops of the dots, were not perfectly aligned with the underlying layers, leading to slight shifts in material placement and distortion of the desired rounded shape. In addition, individual dots showed the presence of surface contamination and unwanted protrusions of material, commonly referred to as stringing, caused by filament leakage or dragging from the nozzle during transitions between spatially separated printing points (Fig. 3a). Optimization of the design and printing parameters of the plate enabled the complete elimination of this issue (Fig. 3c–3d).

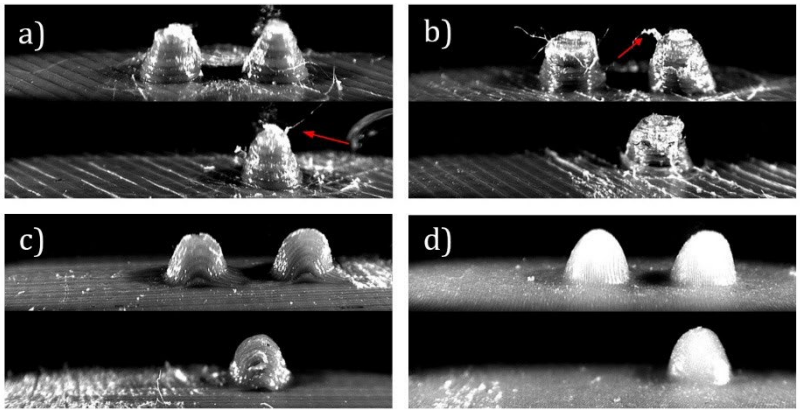

Figure 3. Reproduction of Braille dots a) design 1, b) design 2, c) design 3, d) design 4 (SLA).

The quantitative analysis of dot height and diameter is presented in Table 2. The overprinted samples failed to achieve the target specifications for dot height. The measured dot heights ranged from 0.60±0.02 to 0.67±0.04 mm. The diameters varied between 0.39±0.01 and 1.44±0.02 mm. These values fall in accordance with an ISO standard. However, a significant deviation from the intended dot height is observed.

Table 2. Measured values of dot height and diameter, together with estimated values according to ISO 24503:2011 standard.

Design	Dot height in mm	Diameter in mm
Estimated value	0.5	1.4
1	0.67±0.04	1.39±0.01
2	0.66±0.03	1.43±0.04
3	0.60±0.02	1.41±0.04
4	0.63±0.02	1.44±0.02

Pilot studies

To enable a practical comparison of the four redesigned plate samples, empirical tests were conducted involving five volunteers who were asked to identify the letter presented on each plate. In addition, a user feedback survey was carried out to gather qualitative insights regarding the overall usability of the blocks, as well as preferences and impressions related to each specific version. Based on the legibility results, it can be concluded that all blocks were readable, with only one participant misreading the inscription in the case of design 1. Subsequently, the volunteers were asked to rank the blocks from most to least preferred. The results are presented in Table 3, where the number 1 corresponds to the highest rank and 5 to the lowest. The final ranking was determined by summing these positions as points. Accordingly, the design with the lowest total score was considered the best, followed by the remaining designs in ascending order of their total scores. Based on this ranking, it can be concluded that, according to the participants' subjective assessment, design 2 was the most convenient to use, followed by design 1, while design 4 was rated as the least favourable.

Table 3:.Survey results: Placing the blocks in order from the best to the worst

Design	Volunteer				
	A	B	C	D	E
1	4	3	1	4	2
2	2	4	2	3	4
3	3	2	3	2	3
4	5	1	4	1	1

Finally, the feedback from volunteers was collected. The results are summarized in Table 4. The results indicate that the smoothness of the Braille dots is a key factor determining legibility even when the dimensions fall within the Marburg Medium standard ranges. Design 4, fabricated by SLA technology, was rated the most user-friendly, while design 1, despite high dimensional accuracy, ranked lower due to the perceived sharpness of its dots. As shown in Table 3 and Figure 3a, smoother dots correspond to higher tactile readability.

However, as noted in comment 3 (Table 4), this may be related to deformations resulting from support placement or dimensional deviations. Additionally, testing of multiple design 4 specimens revealed fitment issues, indicating a need to modify the diameter of the connecting hole to ensure proper plate assembly.

Table 4. Comments collected during the survey

No.	Feedback	Number of people with the same feedback
1	Designs 1 and 2 are less readable and pleasant to use due to the sharpness of the touch points.	4
2	The plates could be smaller if their height is maintained, and they are still comfortable to use.	2
3	Design 4 is difficult to connect with other plates.	5

Conclusions

In summary, the study led to the development of usable designs with Braille dots by FDM and SLA technologies. The decision to switch the font to Marburg Medium, which is recommended for labelling, successfully resolved the issues encountered in earlier projects. It was not possible, however, to definitively evaluate which technology, FDM or SLA, performs better.

From a financial perspective, the FDM technology appears more advantageous due to its lower costs and greater availability. At the same time, FDM offers greater safety, as the uncured resin used in SLA printing is toxic to humans and requires careful handling as well as a separate, well-ventilated printing area. Nevertheless, as demonstrated in the pilot tests, SLA offers superior outcomes in terms of product usability and the legibility of printed dots.

To sum up, the overprinted tablets with Braille dots are readable with acceptable quality. Nevertheless, the reproduction accuracy in terms of shape, curvature, and dimensions did not meet the required tolerances for Braille dots. Despite these geometric imperfections, 3D printing technologies offer a low-cost solution for producing Braille plates—particularly for short-run, on-demand, or customized applications—which can significantly support the everyday functioning of individuals with visual impairments.

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Alginate Blends as a Bio-Based Adhesive for Bookbinding Application

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Abstract

The bookbinding industry is a significant producer of adhesive waste. The synthetic adhesives are not biodegradable and contribute to microplastic pollution in the environment. In this study, alginate-based adhesives with microcellulose fibres (MCF) with different additives (short-chain Alginate, lignin, dextrin) were investigated in their rheology and their adhesion strength for the paper edge bonding. It has been demonstrated through rheological analysis that an increase in the concentration of MCF results in an increase in viscosity. Pull-out tests demonstrated that the incorporation of MCF enhances the adhesion strength of alginates, with 1 wt% of MCF achieving the highest pull-out force. The combination of alginate, MCF and short-chain alginate (Alg-S) has been demonstrated to enhance the adhesion strength by a further 4 N/cm. Nevertheless, a low adhesion strength has been demonstrated by alginate-based adhesives when compared to conventional PVAc adhesives. The findings suggest that alginate-based adhesives have considerable promise as an adhesive in bookbinding, where optimisation is essential.

Keywords: Adhesives, Alginate, Bookbinding, Post Press, Sustainable materials

1. Introduction

The bookbinding industry is a significant producer of waste. This includes the discarding of large quantities of paper, which also contains adhesive residues. In 2021, the production of adhesives was 967,000 tons. Of this total, 3.2% were used in the graphical industry, which equates to 31,000 tons of adhesive (Industrieverband Klebstoffe e.V., 2023). As a consequence of their petrochemical provenance, commercial adhesives are not biodegradable, resulting in the presence of micro plastic in the environment (Habenicht, 2009, l763-764; Göttsching, 1999; Onusseit, 2006; Zhang, Gao, Kang, Shi, Mai, Allen & Allen, 2022).

The utilisation of bio-based adhesives in the field of bookbinding has a long historical precedent, with a significant period of usage extending over several centuries. The adhesives in question are derived from glutin, a substance derived from slaughterhouse by-products. When combined with thread-sewn structures, a favourable lay flat property and durable bond can be achieved. Nevertheless, the complexity of these techniques resulted in the replacement of bio-based adhesives by simpler and more economical petrochemical alternatives. Recently, there has been a resurgence of interest in bio-based adhesives, driven by an increasing awareness of sustainability and environmental responsibility (Arias, González-Rodríguez, Vetroni Barros, Salvador, Francisco, Moro Piekarski & Moreira, 2021).

One potential solution is alginate, a biopolymer derived from brown algae. It is estimated that the global production of alginate amounts to 26 million tons per year, with a wide range of applications including use as a packaging material, in cosmetics and in pharmaceuticals (Olatunji, 2024; Ching, Bansal & Bhandari, 2017).

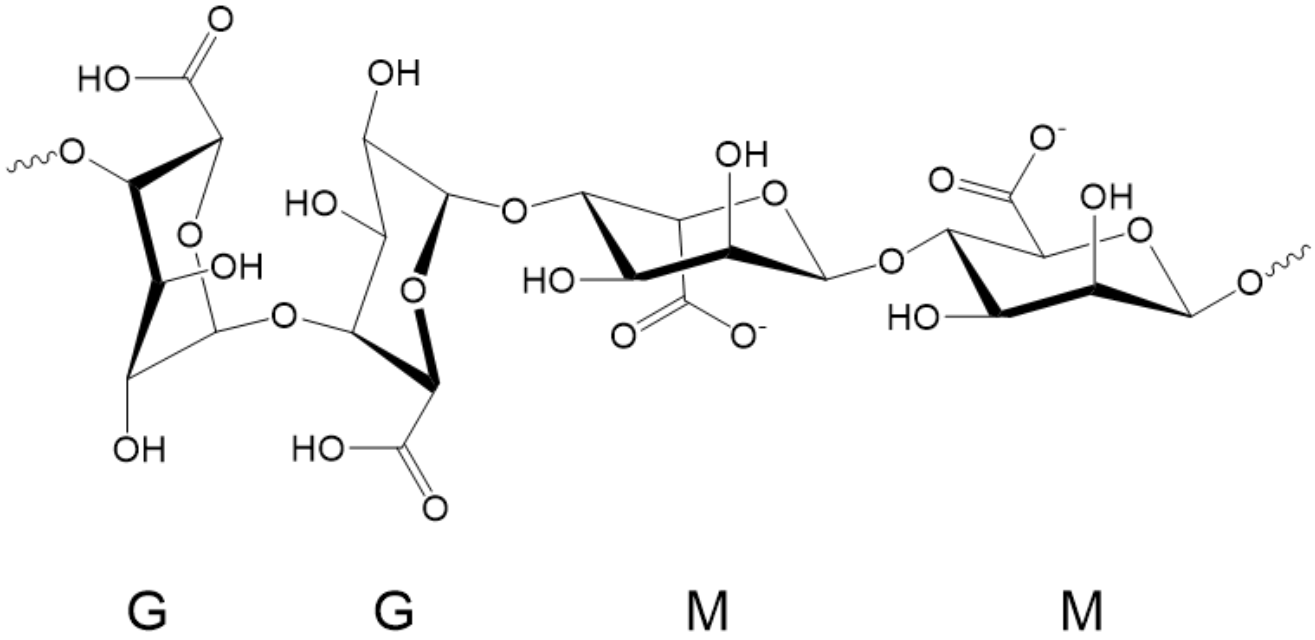

Figure 1: Chemical structure of the alginate blocks

Alginate is composed of α -1,4,guluronic acid (G) and β-D-mannuronic acid (M) units, arranged either randomly, in blocks, or alternately (Figure 1).

One of the key properties of alginate is its capacity to crosslink with divalent ions, such as Ca^{2+}, thereby forming a stable and irreversible film through ionic interactions. This process is often referred to as the "egg-box model" (Cao, Lu, Mata, Nishinari & Fang, 2020). This ionic crosslinking process has been shown to impart strong cohesion; however, it simultaneously reduces the availability of polar groups required for adhesion, resulting in decreased adhesive strength.

As an alternative option, micro cellulose fibres (MCF) have been introduced to enhance the cohesion properties without compromising adhesion.

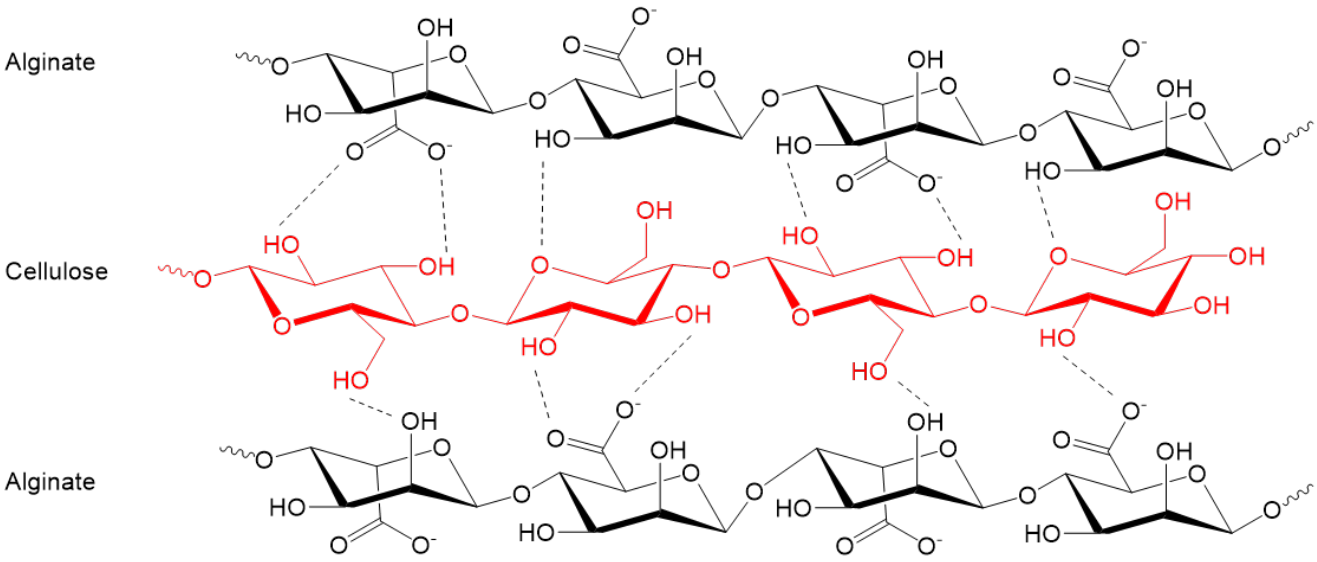

Figure 2: Interaction of alginate (black) with cellulose (red) via hydrogen bonds (dotted line)

It has been hypothesised that the alginate and the MCF chains interact via hydrogen bonds, thereby improving cohesion and adhesion. Furthermore, the microcrystalline structure of MCF may facilitate mechanical interlocking at the paper edge, thereby enhancing adhesive performance(Sirviö, Kolehmainen, Liimatainen, Niinimäki & Hormi, 2014).

In this study, alginate/MCF adhesives were combined with short-chain Alginate (Alg-s), lignin and dextrin in various concentrations to investigate the effect on rheological behaviours and pull out strength. The aim was to assess their suitability for sheet-edge bonding applications in bookbinding.

2. Materials and methods

Sodium alginate (10000 – 600000 g/mol) and short chain Alginate (20 – 50mPas) were purchased from *AppliChem*. Glycerol, Micro Cellulose (20 µm), were purchased from *SIGMA Aldrich*. Dextrin, Soda Lignin (>90 %) where purchased from Carl Roth GmbH.

2.1 Preparation of the adhesives

2.1.1 Preparation of the sodium alginate/MCF based adhesive

Sodium alginate (2 wt%) was mixed with Glycerol (25 wt%) at 1000 rpm at room temperature to form an alginate solution. After that, varying concentrations of MCF (0, 0.1, 0.5, 1, 2, ,3 wt%) were added to the alginate solution and were stirred at 5000 rpm. After one hour of stirring, a homogenous adhesive was obtained in a form of a white, viscous liquid.

2.1.2 Preparation of the alginate/MCF/Lignin based adhesive

Sodium alginate (2 wt%) was mixed with Glycerol (25 wt%) at 1000 rpm at room temperature to form an alginate solution. After that, MCF (1 wt%) were added to the alginate solution and were stirred at 5000 rpm until it forms a homogenous suspension. Varying concentrations of soda lignin (0, 0.2, 0.5, 1, 2 wt%) were added to the suspension. After one hour of stirring, a homogenous adhesive was obtained in a form of a brown, viscous liquid.

2.1.3 Preparation of the alginate/MCF/Alg-s based adhesive

Sodium alginate (2 wt%) was mixed with Glycerol (25 wt%) at 1000 rpm at room temperature to form an alginate solution. After that, MCF (1 wt%) were added to the alginate solution and were stirred at 5000 rpm until it forms a homogenous suspension. Varying concentrations of short-chain alginate (0, 0.5, 1, 2 wt%) were added to the suspension. After one hour of stirring, a homogenous adhesive was obtained in a form of a white, viscous liquid.

2.1.4 Preparation of alginate/MCF/Dextrin based adhesive

Sodium alginate (2 wt%) was mixed with Glycerol (25 wt%) at 1000 rpm at room temperature to form an alginate solution. After that, MCF (1 wt%) were added to the alginate solution and were stirred at 5000 rpm until it forms a homogenous suspension. Varying concentrations of soda lignin (0, 0.5, 1, 2, 3 wt%) were added to the suspension. After one hour of stirring, a homogenous adhesive was obtained in a form of a white, viscous liquid.

2.2 Preparation of the test samples

The Ribler Gecko 75 adhesive binder were used to produce A6 format test sample books which comprises 40 pages. The adhesive was applied with a wet thickness of 1 mm.

Amber Graphics 90 g/m^2 were utlisied as test papers, provided by *Inapa Deutschland*.

2.3 Rheology

All viscosity measurements were performed using a Physica MCR-300 rheometer, equipped with a 24.955 mm cone-plate. The dynamic viscosity was measured within a shear rate range of 10-1000 1/s at 293.15 K. Each sample was measured three times, and the mean value and standard deviation were calculated. The entirety of the rheological analysis was conducted utilising the Python programming language.

2.4 Pull test

All pull test measurements were performed using a QLIBRO PPT Newton 451. Page 3, 8, 13, 18, 23, 28, 33, 38 were pull out from the produced test samples. For each test sample, the mean value and the standard deviation were calculated and were analysed using Python programming language.

2.5 3d Microscopy

The Alginate/MCF images were captured using a Keyence 3d Microscope VK-X-3000.

3. Results and discussion

3.1 Alginate/MCF adhesive

3.1.1 Rheology

The dynamic viscosity of the samples with different MCF concentrations are shown in figure 3:

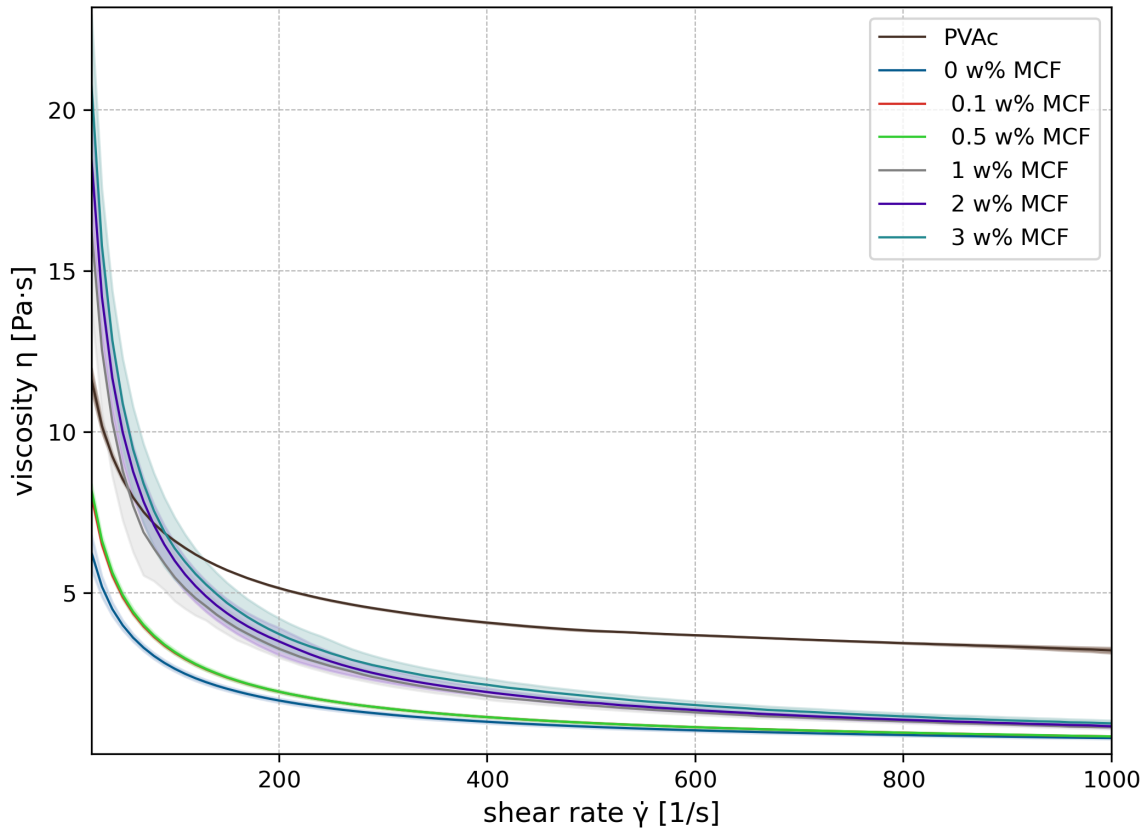

Figure 3: Mean dynamic viscosity curve of alginate/MCF adhesives with varying MCF concentrations, alongside their standart deviation (lighted out) and PVAc as reference

The incorporation of MCF into the alginate dispersion exerts a pronounced significant influence on the rheological behaviours, particularly at low shear rates. It was established that, at a shear rate of 100 s^{-1}, the sample without MCF exhibited a mean viscosity of approximately 2.644 Pa·s. The sample containing 0.5 wt% MCF demonstrates a viscosity of approximately 3.163 Pa·s and exhibits an increasing viscosity behaviour. The sample with 3 wt% MCF demonstrates the highest significant viscosity, exhibiting approximately 6.579 Pa·s. This results in a trend of increasing viscosity with the addition of MCF to the alginate dispersion.

However, as the shear rate increases, all samples approach a common plateau value, which can be attributed to shear-induced degradation of the microstructural cross-linking (aggregates/entanglements and particle alignment).

Polyvinyl acetate (PVAc), used as a reference material, demonstrates a higher viscosity than the 0, 0.1, and 0.5 wt% MCF samples at low shear rates. However, compared to formulations with higher MCF concentrations (1, 2, and 3 wt%), PVAc shows a relatively lower viscosity in this range. At high shear rates, PVAc maintains a higher mean viscosity than all MCF-containing samples, further supporting the shear-thinning behavior introduced by MCF.

3.1.2 Pull test

In order to investigate the effect of varrying the MCF concentration on adhesion strength, different pages of the test book samples were pull out using the pull tester. The obtained results are shown in the following figure.

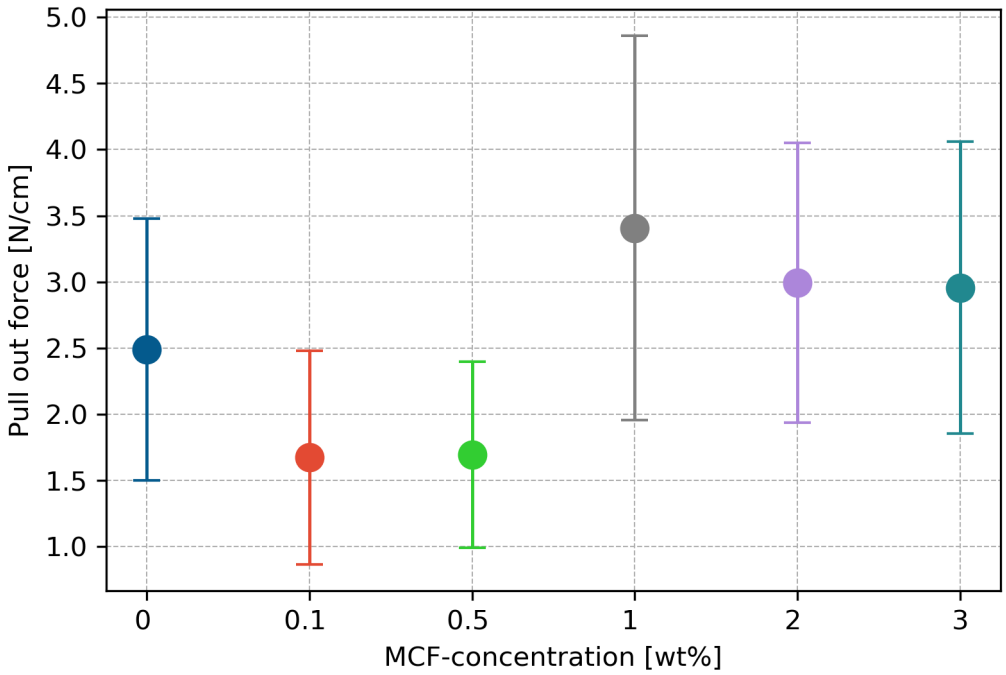

Figure 4: Mean pull-out force of alginate/MCF adhesives with varying MCF concentrations, along with their standart deviation

The pull out measurements (Fig. 4) shows a non-monotone behaviour in the adhesion with increasing MCF concentration. The findings of the study demonstrate that a decrease in MCF concentration (0.1, 0.5 wt%) results in a reduction in the average pull-out force. Conversely, an increase in MCF concentration (1, 2, 3 wt%) leads to an enhancement in the average pull-out force. The highest pull-out force was achieved with 1 wt% of MCF concentration, with a value of 3.4 N/cm.

It has been demonstrated that low levels of MCF can result in inhomogeneity distribution within the alginate matrix. It is hypothesised that agglomerations may occur in the matrix, resulting in an amorphous structure. This phenomenon, which is referred to in the extant literature as the "anti-plastification effect", has been shown to result in a significant reduction in adhesion strength (Eslami, Elkoun, Robert & Adjallé, 2023).

Should the concentration be increased further, it is expected that the cellulose will distribute more homogeneously in the matrix until a saturation effect occurs. It is assumed that this is reached at 1 wt%, as the adhesion strength does not increase further after this point.

Whilst the mean pull-out values demonstrate elevated standard deviations, ANOVA ($\alpha = 0.05$) with a Tukey post-hoc test is employed to elucidate the statistical significance of the measurements. This finding suggests that the samples at 0.1 and 0.5 wt% ($p > 0.05$) and the samples at 1 and 2 wt% ($p > 0.05$) demonstrate no statistical significance when compared to each other. The remaining samples demonstrate statistical significance.

3.2 Alginate/MCF/Alg-s based adhesive

3.2.1 Rheology

The dynamic viscosity of the samples with different Alg-s concentrations are shown in figure 5:

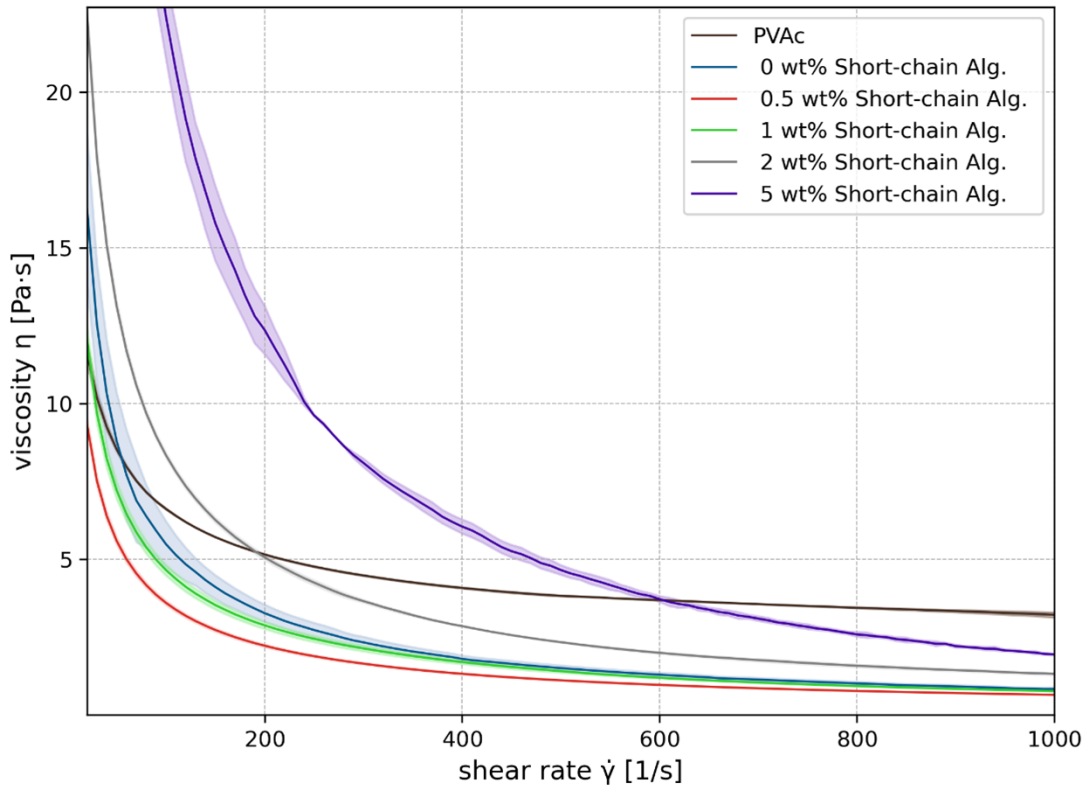

Figure 5: Mean dynamic viscosity curve of alginate/MCF/Alg-s adhesives with varying MCF concentrations, alongside their standart deviation (lighted out) and PVAc as reference

The incorporation of Alg-s into the alginate/MCF dispersion exerts a pronounced significant influence on the rheological behaviours, particularly at low shear rates. It was established that at a shear rate of 100 s^{-1}, the samples of 0.5 wt% exhibited an average viscosity of 3.598 Pa·s, whilst those of 1 wt% demonstrated an average viscosity of 4.651 Pa·s. The viscosity of the two samples is significantly lower than that of the sample without Alg-S, which has an average value of 5.484 Pa·s. It is hypothesised that the "anti-plastification effect" exerts a substantial influence on viscosity, with agglomeration and heterogeneity having a direct impact on the observed viscosity. As the concentration of Alg-s is increased, the viscosity of the dispersions increases in accordance with the findings presented in Section 3.1.1.

However, as the shear rate increases, all samples approach a common plateau value, which can be attributed to shear-induced degradation of the microstructural cross-linking (aggregates/entanglements and particle alignment).

Samples with a weight percentage exceeding 2 wt% exhibited a higher viscosity than the reference adhesive PVAc. This finding led to the establishment of a viscosity limit at a mean value of 8.339 Pa·s, as the nozzle of the Gecko Binder 75 has been found to be incapable of accommodating higher viscosities.

3.2.2 Pull test

In order to investigate the effect of varrying the Alg-s concentration on adhesion strength, different pages of the test book samples were pull out using the pull tester. The obtained results are shown in the following figure.

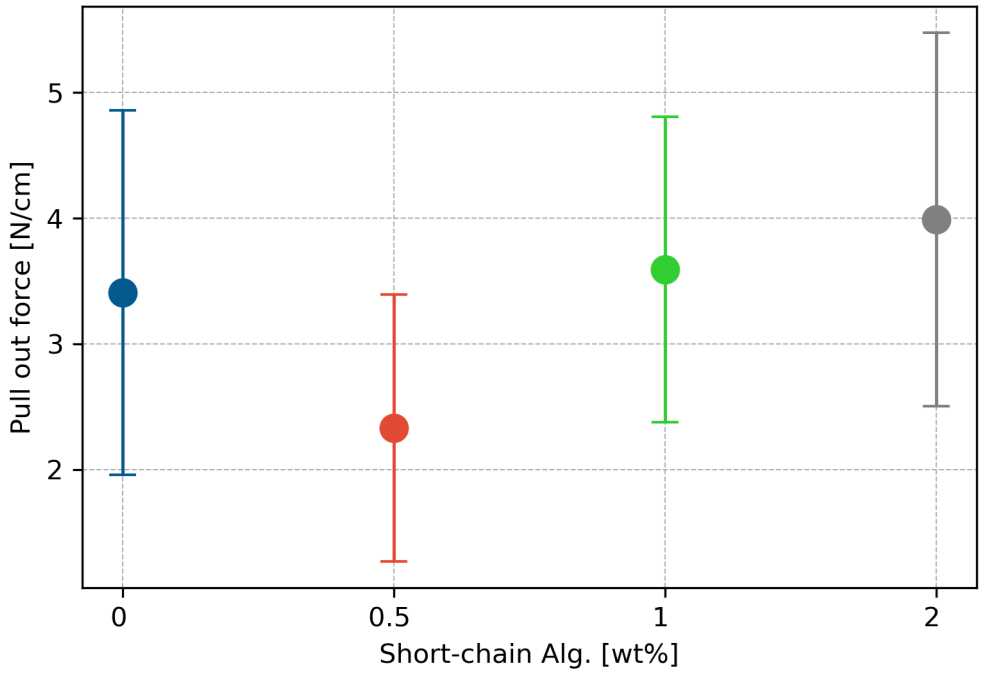

Figure 6: Mean pull-out force of alginate/MCF/Alg-s adhesives with varying MCF concentrations, along with their standart deviation

The pull-out measurements exhibit a non-monotone behaviour in the adhesion with increasing Alg-s concentration. The findings of the study demonstrate that a decrease in Alg-s concentration (0.5 wt%) results in a reduction in the average pull-out force. At 1 wt%, a pull-out value of 3.6 N/cm is observed, which is almost identical to the Alg/MCF adhesive value of 3.4 N/cm. The highest pull-out force was achieved with 2 wt% of Alg-s concentration, with a value of 4 N/cm.

It is assumed that the “anti-plastification effect” plays a significant role in the decrease of the pull-out force at small concentrations, where an inhomogeneous distribution leads to an amorphous structure in the matrix.

It is hypothesised that the pull-out force could be increased even further by increasing the Alg-S concentration beyond 2 wt%, although this would be limited by the viscosity.

Whilst the mean pull-out values demonstrate elevated standard deviations, ANOVA ($\alpha = 0.05$) with a Tukey post-hoc test is employed to elucidate the statistical significance of the measurements. This finding suggests that the samples at 0 and 1 wt% ($p > 0.05$) and the samples at 1 and 2 wt% ($p > 0.05$) demonstrate no statistical significance when compared to each other. The remaining samples demonstrate statistical significance.

3.3 Alginate/MCF/Lignin based adhesive

3.3.1 Rheology

The dynamic viscosity of the samples with different lignin concentrations are shown in figure 7:

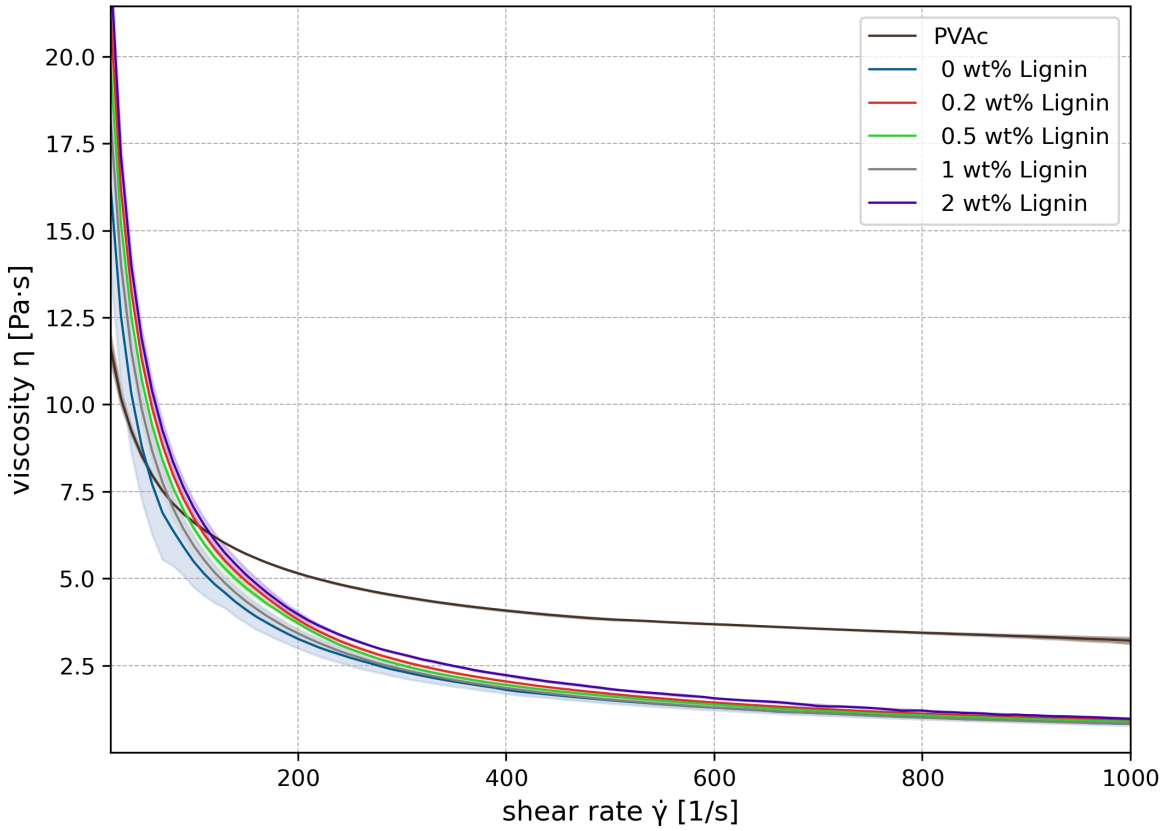

Figure 7: Mean dynamic viscosity curve of alginate/MCF/lignin adhesives with varying MCF concentrations, alongside their standart deviation (lighted out) and PVAc as reference

The incorporation of lignin into the alginate/MCF dispersion demonstrates a substantial impact on the rheological behaviour. It is evident that, at high shear rates, all samples exhibit a shear-thinning effect, as observed in the previous sections. However, at low shear rates, there is an absence of a clear trend in the observed data, which has led to the assumption that measurement failures have occurred.

3.3.2 Pull test

In order to investigate the effect of varrying the lignin concentration on adhesion strength, different pages of the test book samples were pull out using the pull tester. The obtained results are shown in the following figure.

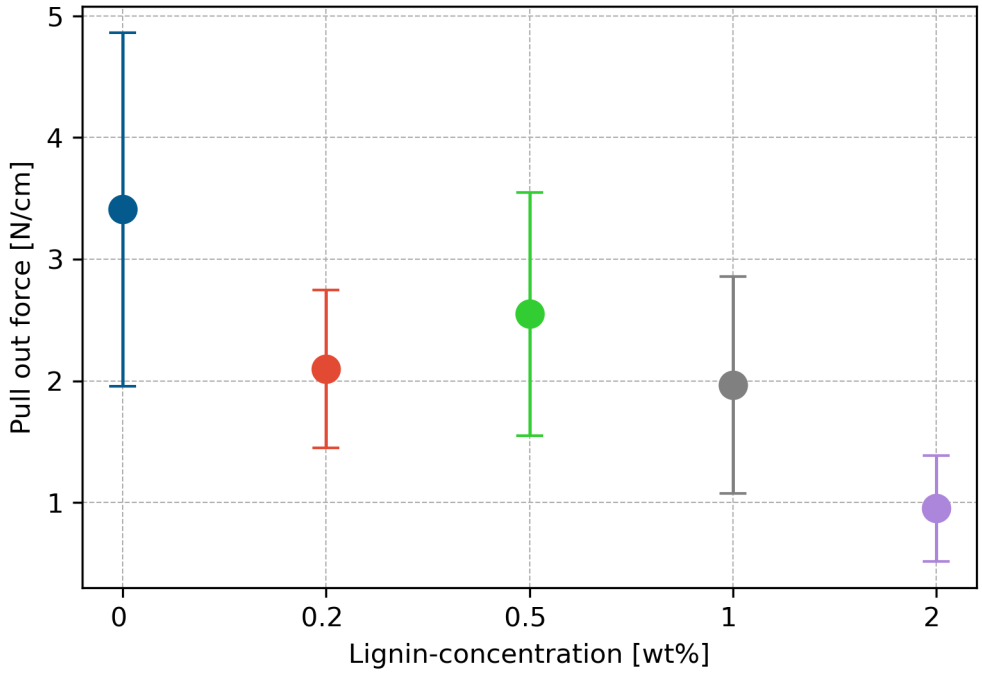

Figure 8: Mean pull-out force of alginate/MCF/lignin adhesives with varying MCF concentrations, along with their standart deviation

As demonstrated in the preceding sections, the pull-out measurements demonstrate a non-monotone behaviour in the adhesion with increasing lignin concentration. The findings demonstrate that no improvement could be achieved due to the fact that the highest value recorded was 0.5 wt% lignin at 2.55 N/cm.

It is hypothesised that the "anti-plastification effect" can also be observed in this instance, given that at 0.2 wt%, a lower pull-out force is exhibited in comparison to 0.5 wt%.

The study's findings indicate a decline in the mean pull-out force in conjunction with an augmentation in lignin concentration.

3.5 Alginate/MCF/Dextrin based adhesive

3.5.1 Rheology

The dynamic viscosity of the samples with different dextrin concentrations are shown in figure 9:

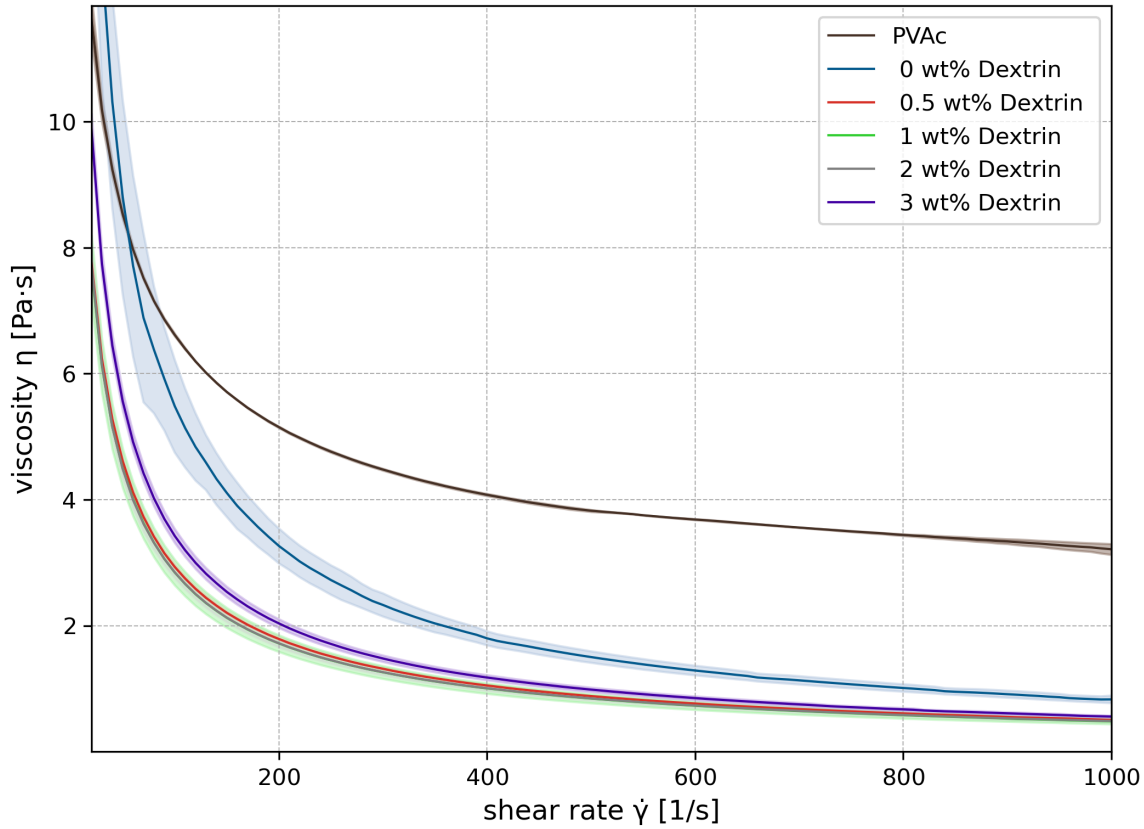

Figure 9: Mean dynamic viscosity curve of alginate/MCF/dextrin adhesives with varying MCF concentrations, alongside their standart deviation (lighted out) and PVAc as reference

The incorporation of Alg-s into the alginate/MCF dispersion exerts a pronounced significant influence on the rheological behaviours, particularly at low shear rates. It was established that at a shear rate of 100s^{-1}, samples of 0.5 wt% to 3 wt% dextrin exhibited similar viscosity. The range of this measurement is from 2.933 Pa·s to 3.424 Pa·s. It was observed that the samples exhibited a lower viscosity in comparison to the sample not containing dextrin.

The decrease in viscosity is probably the result of one or more effects: altered hydration of the alginate network, plasticizing effects on polymer interactions, and/or adsorption on MFC surfaces, resulting in improved dispersion (less flocculation).

However, as the shear rate increases, all samples approach a common plateau value, which can be attributed to shear-induced degradation of the microstructural cross-linking (aggregates/entanglements and particle alignment).

3.5.2 Pull test

In order to investigate the effect of varrying the dextrin concentration on adhesion strength, different pages of the test book samples were pull out using the pull tester. The obtained results are shown in the following figure.

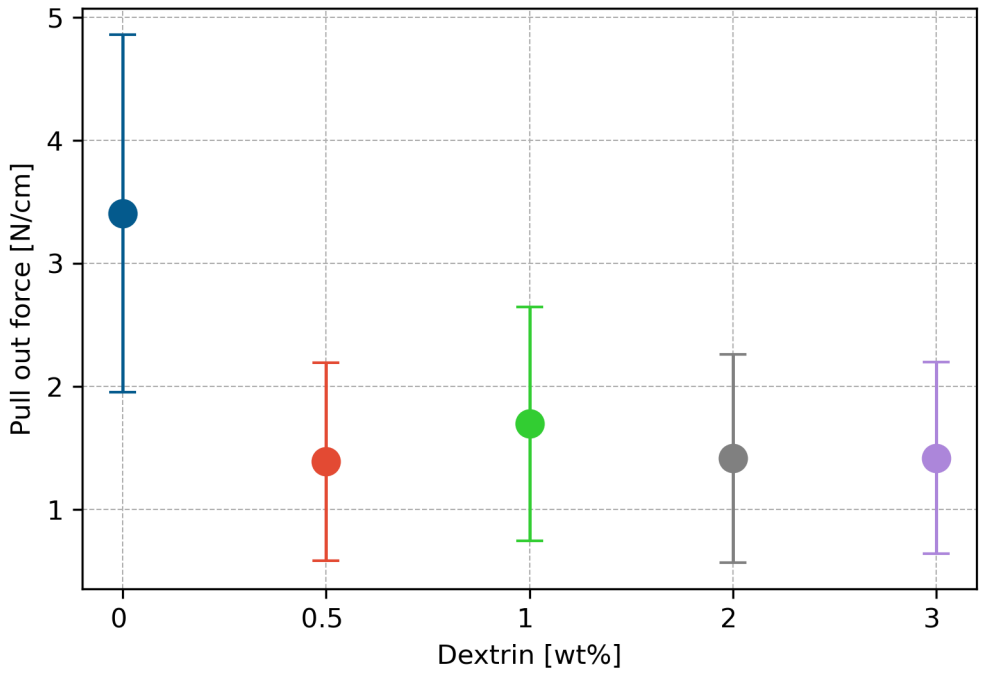

Figure 10: Mean pull-out force of alginate/MCF/dextrin adhesives with varying MCF concentrations, along with their standart deviation

As demonstrated in the preceding sections, the pull-out measurements demonstrate a non-monotone behaviour in the adhesion with increasing dextrin concentration. The findings demonstrate that no improvement could be achieved due to the fact that the highest value recorded was 1 wt% dextrin at 1.70 N/cm.

The study's findings indicate a decline in the mean pull-out force in conjunction with an augmentation in dextrin concentration.

3.6 Comparison pull test

In order to investigate the adhesion strength of the bio-based adhesive formulation in comparison to a conventional synthetic adhesive, the best results from the previous pull-out test and a PVAc adhesive as a reference were compared with each other. The ensuing figure presents the results obtained from the pull test.as

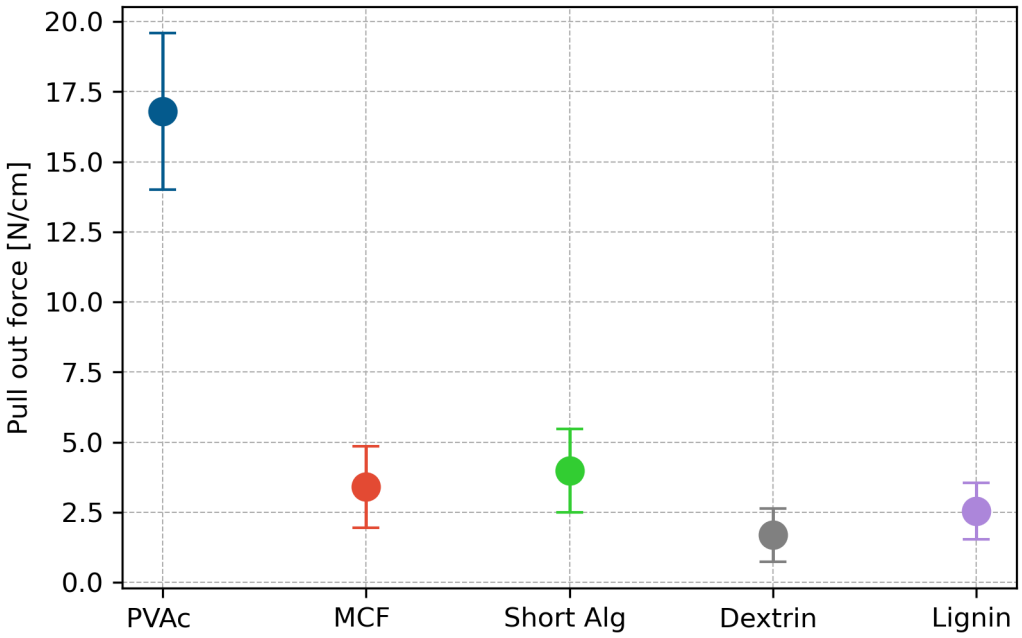

Figure 11: Comparison of the different mean pull-out force of the different bio adhesives with PVAc, along with their standart deviation

The graph demonstrates that the reference PVAc has an average pull-out value of 16.78 N/cm, thereby exhibiting a significantly higher adhesive strength in comparison to the alginate-based adhesives, which range from 1.7 N/cm to 4 N/cm (Alg/MCF = 3.4 N/cm, Alg/MCF/Alg-s = 4 N/cm, Alg/MCF/Dextrin = 1.7 N/cm, Alg/MCF/Lignin = 2.55 N/cm). The values demonstrate a high standard deviation, with PVAc exhibiting the most significant deviation.

PVAc formulations have been demonstrated to exhibit significantly higher adhesive strength than alginate-based formulations. This enhanced strength can be attributed to superior film and cohesion formation, as well as higher interfacial adhesion. The polymer's non-ring-like structure enables it to generate significantly more Van der Waals forces and, in addition, polar forces due to its acetate group. Conversely, alginate-based systems exhibit a more complex design and consequently generate significantly less Van der Waals forces. The following interpretations can be proposed for the effects of each: MCF has been shown to increase overall cohesion via hydrogen bonds, and to penetrate the paper edge, thereby anchoring it mechanically and creating an adhesive force. In combination with Alg-s, this penetration is likely to be further improved. Conversely, dextrin is hypothesised to reduce the general cohesion of the network (see section 3.5.1). This assumption is also postulated to be applicable to the lignin formulation.

Whilst the mean pull-out values demonstrate elevated standard deviations, ANOVA ($\alpha = 0.05$) with a Tukey post-hoc test is employed to elucidate the statistical significance of the measurements. The findings indicate a statistical significance for all samples.

4. Conclusion

In this study, the biopolymer alginate was combined with varying concentrations of micro cellulose fibres (MCF) to investigate its potential as a bio-based adhesive. Rheological characterisation confirmed that increasing MCF concentrations resulted in higher viscosities. Pull-out tests demonstrated that the addition of MCF improved the adhesive performance of alginate, with 1 wt% MCF yielding the highest pull-out force. The alginate/MCF adhesive was then combined with short-chain alginate (Alg-s), lignin and dextrin in order to investigate whether the adhesion strength could be further enhanced. Rheological characterisation revealed a decrease in viscosity with the addition of small quantities of Alg-S. It is evident that an increase in concentration results in a corresponding increase in viscosity. The 2 wt% threshold is widely accepted as the upper limit for bookbinders. The addition of dextrin has been demonstrated to reduce the overall viscosity of the adhesive. It is not possible to make any statements about the lignin formulation due to measurement errors. Pull-out tests revealed that Alginate/MCF/Alg-S exhibited the highest adhesive performance of the alginate formulations, with 2 wt% Alg-s achieving an average pull-out force of 4 N/cm

Nevertheless, in direct comparison to a conventional petrochemical PVAc adhesive, the alginate-MCF formulations exhibited substantially lower adhesion strengths. These findings suggest that while alginate-MCF adhesives currently do not match the performance of synthetic benchmarks, they offer a promising foundation for the development of renewable and biodegradable adhesive systems. Further research focusing on formulation optimization, dispersion strategies, and processing techniques is recommended to enhance their mechanical properties and broaden their potential application range, particularly in fields such as sustainable bookbinding.

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Comparative Analysis of the Quality of Accurate Printing Using Digital Printing Systems

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Abstract

Presently, the printing industry produces a large number of products with micro-marks, fine graphic details, micro-lines or micro-text. These micro-images are often, for specific reasons, printed on a variety of materials using different inks and printing techniques. The accuracy of the reproduction of the micro-images is important in order to obtain specific micro-images of precise dimensions on printed products. Also, accurate reproduction of screen micro-dots determines the quality of colour reproduction and the colour accuracy of image halftones.

Traditional and digital printing technologies (e.g. offset printing, flexography, electrophotography, inkjet, etc.) are well known to exhibit different abilities to reproduce fine image detail. For example, offset printing processes have long been standardised to ensure quality requirements and accurate reproduction of colours and micro-images. Meanwhile, standardisation of digital printing processes, including electrophotography and inkjet printing, is complicated for several reasons. Firstly, due to the wide variety of processes: each equipment manufacturer uses alternative digital presses and its own unique patented technologies. This, together with the use of alternative printing materials, different ink compositions and physical-chemical characteristics, imaging and image transfer properties, ink curing specifics, and data preparation, etc., lead to different results in terms of micro-image reproduction, its geometric dimensions and edge uniformity, etc.

This study presents a comparative analysis of micro-images printed using the two main digital printing technologies such as electrophotography and inkjet printing. A unique wedge was used in this study to control and pre-model the reproduction quality of digitally printed linear micro-images. The wedge contains single and grouped vertical, horizontal and 45° micro-lines ranging from 0.01 to 0.15 mm in width. The samples were printed on 4 different printing materials using 5 different printing presses, including the presses from top manufacturers such as Xerox, Indigo and Canon. Each different combination of printing press, paper and ink was evaluated as a separate "press-paper-ink" system.

In order to assess the accuracy of the image reproduction, measurements of the change in the geometric dimensions of the monochrome 0.04-0.15 mm micro-lines were made using digital microscopy and the ΔE of the halftones was determined by spectrophotometry. The surface roughness (Ra) was determined for all paper types in order to assess its influence on the quality of the micro-image reproduction in each case.

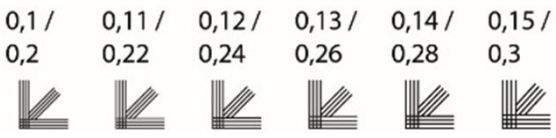

Fig.1. The fragment of the control wedge for 0,1-0,15 mm width 3-direction micro-lines micro-lines aligned individually with double-width spacing

In order to compare the quality and assess the accuracy of printing in the different digital printing systems "press-paper-ink", critical integral quality indicators were identified: 1) the minimum reproducible sizes of the graphic micro-images; 2) the minimum change in the size of the micro-image during the printing; and 3) the accuracy of the printed graphic micro-images in general (Fig. 2).

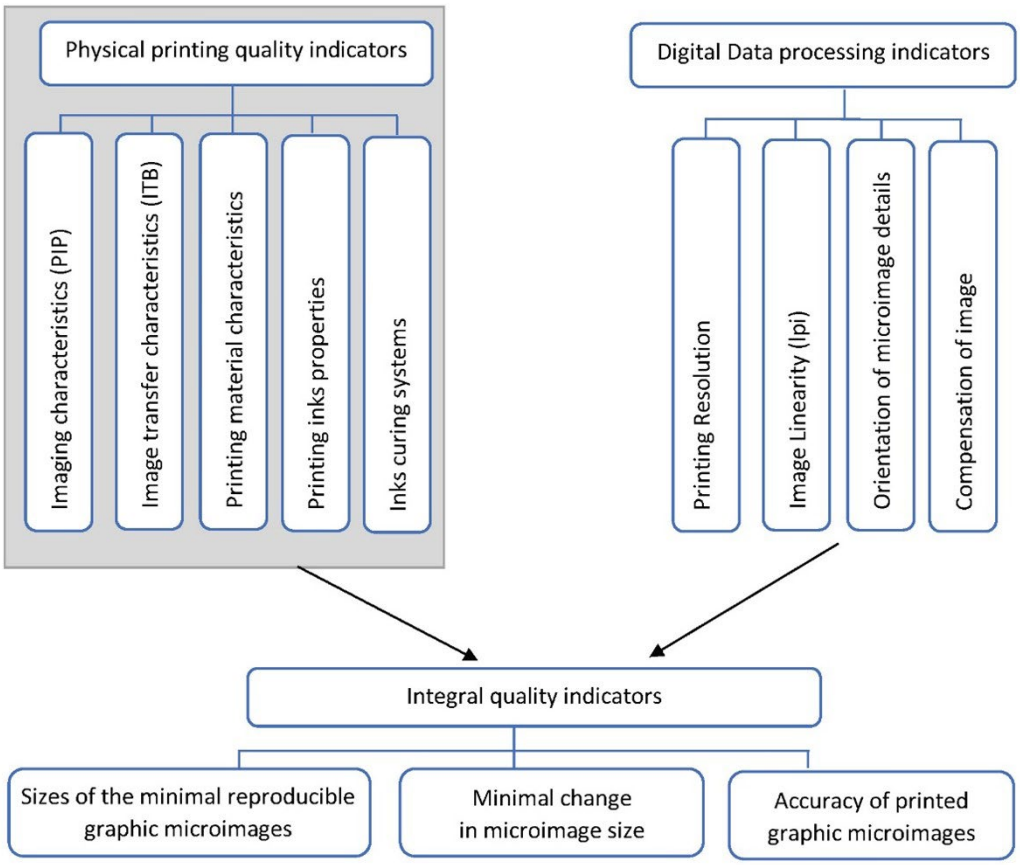

Fig. 2. Conceptual model for determining the integral quality indicators of the accuracy of micro-images on digital electro-photographic prints

The results of the study showed that the accuracy of micro-line reproduction varies from one digital printing system to another, depending on physical parameters such as imaging and image transfer characteristics, printing material properties, ink characteristics and curing mode in the case of electrophotography. In addition to these characteristics, it is also necessary to emphasize digital processing characteristics such as printing resolution, screening parameters, spatial positioning of micro-lines and image compensation. The results confirm that the accuracy of the reproduction of thin micro-lines depends on the parameters of the printing press (dpi), lpi, paper characteristics and ink type. Furthermore, it is evident that the quality of the micro-image reproduction depends on the orientation of the micro-lines on the print. In all cases, the reproduction of micro-lines up to a width of 0.05 mm on electro-photographic and inkjet prints can be considered unstable.
The obtained results allow applying mathematical methods to compare the capability of digital printing systems to reproduce linear micro-images on printed products of any size and geometric orientation. Moreover, the results presuppose selecting optimal systems for printing specific products with micro-images and modelling the layout by assessing the orientation of the micro-images on print.

Keywords: electrophotography, inkjet, digital printing, accurate printing, micro-image

Environmental Accounting and Business Ecosystems as the Key Parameters for the Implementation of Sustainability Strategies in the Printing & Packaging Industry

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Abstract

The global packaging market size is estimated to grow from USD 1.20 trillion in 2022 to reach an estimated USD 1.58 trillion by 2032, growing at a 3.16% CAGR between 2023 and 2032 (Singh, 2024). However, packaging contributes significantly to environmental issues, as it is a major source of plastic waste, fuels climate change through the extraction of fossil fuels for production and greenhouse gas emissions from landfills, and pollutes the oceans with plastic debris and micro plastics that harm marine ecosystems. Packaging production also consumes natural resources and contributes to air and water pollution, leading to landfill overload, while the limited efficiency of recycling exacerbates the problem.

From the other hand, Packaging has a quite significant role in preventing the loss of goods and products, with its main functions of keeping goods and products safe after production (or harvesting) securing the transportation, distribution and sales. Therefore, it appears as a necessity a balance between sustainability and the use of packaging.

Sustainability is attempted to be applied in the Printing and Packaging Industries, by forming a new viewpoint, based on the new structures and concepts such as Environmental Management Accounting and Circular Economy. This means that the long-applied linear approach based on the"take-make-use-dispose" on packaging, is (or should be) replaced by sustainable approaches, such as reducing packaging and managing its waste, through separation, collection, recovery and recycling, as well as reuse, in the context of the circular economy. As such, the successful implementation of such models, depends on their applicability across the entire value chain.

The present study proposes, a supportive solution, based on the integration of a reliable Environmental Accounting and Environmental Management Accounting system in companies, in combination with the creation of a business ecosystem mechanism. It is expected that this will add the economic and financial dimension to sustainability applications at the company level, and overall as an industry, and it is hoped that it will enable a more comprehensive transition for sustainability in the printing and packaging sectors.

By developing and implementing an Environmental Accounting and Environmental Management Accounting (EMA)system, leadership and management will be able to obtain important, reliable and comparable data regarding the life cycle costs associated with the packaging production. Furthermore, it is expected that the application of such a system will provide the opportunity to support decision-making processes for new business models and investments and to implement action plans and policies with a high degree of transparency, regarding a company's overall financial and environmental performance.

Keywords: Sustainability, Printing and Packaging Industry, Circular Economy, Environmental Accounting, Environmental Management Accounting - EMA, Business Ecosystems

1. Introduction

1. The usefulness and necessity of packaging is multifaceted, as it encompasses protection, communication, and convenience. It physically protects products from damage, contamination, and environmental factors such as moisture and light during transport and storage. Packaging also serves as an important marketing tool, conveying information, promoting brand identity, and creating a positive first impression on the customer. In addition, it provides ease of handling, storage, and use and may include features such as tamper-evident seals for consumer safety. [1]

The "usefulness" of packaging goes beyond product protection, i.e., it is also a factor in perception and choice. Hence, packaging has short life but long-lasting environmental impacts. On a global scale, the concern for climate change and environmental destruction has triggered a series of sustainable practices and actions aimed at sustainability.

Globally, the production of plastic products (not just packaging) in 2015 was ~ 407 million tones; of this ~ 146 million tones (≈ 36 %) was for packaging. [2] According to OECD, In 2019, approximately 353 million tones of plastic waste were produced globally. Furthermore, worldwide, 141 million tones of plastic packaging are produced annually, contributing to approximately 1.8 billion tons of carbon emissions each year. Concerns are heightened by the fact that only 14% of plastic packaging is collected for recycling, while 40% of it is used only once before being discarded. [3]

Sustainable packaging has emerged as a critical intersection between environmental protection and operational efficiency, as organizations strive to meet consumer demand for environmentally friendly products while maintaining profitability. In this context, the importance of sustainable packaging operations lies not only in reducing environmental impact but also in responding to evolving consumer expectations, regulatory requirements, and the need for innovation in materials and design. [4]

Consumers are increasingly interested in the environmental impact of packaging, with a majority willing to pay more for sustainable options. They value attributes like reusability, recycled materials, and recyclability, and this trend is driven by growing environmental awareness and health concerns about harmful chemicals in some packaging. However, a gap exists between positive attitudes and actual behavior due to a lack of knowledge about recycling and the complexity of sustainable choices notes. Consumers often do not know how to recycle properly and may confuse different terms such as bio waste, biodegradable, etc. In addition, they may not even be familiar with the various symbols, cleaning procedures, and waste sorting.[5]

2. Sustainable Packaging and its Importance

2.1 Definition and Principles of Sustainable Packaging

The term sustainable packaging is a general term that encompasses different stages of the packaging value chain and has to do with the raw materials used, the optimization of material use, production methods, the energy sources used, waste management, recyclability and reusability, etc.

According to the definition of "Sustainable Packaging" by SPC (Sustainable Packaging Coalition), sustainable packaging is that which:

- Is beneficial, safe and healthy for individuals and communities throughout the packaging's life cycle
- Suitable for markets in performance and cost

- Is sourced, produced, transported and recycled using renewable energy
- Optimizes the use of renewable or recycled raw materials
- Is produced using "clean" production technologies and best practices
- Is designed to minimize materials and energy and
- Is designed to be effectively recovered at the end of its life-cycle and integrated into biological or industrial closed-loop processes. [6]

Ellen MacArthur Foundation – New Plastics Economy, considers sustainable packaging through the circular economy. As such, design should prevent waste and pollution, packaging should be systematically used or recycled and materials remain in the lifecycle as long as possible. [7]

Furthermore, according to the UNEP guidelines (2013), sustainable packaging should focus on reducing plastic pollution through a three-pronged approach:

- eliminating unnecessary plastics
- shifting to reuse and recycling, and
- promoting a circular economy for packaging

This approach includes designing products for circularity (non-toxic, reusable, recyclable, and compostable) and increasing reuse models, such as refill systems and return-coating systems. The guidelines also emphasize design for recyclability, increased use of recycled materials and improvements on waste management through initiatives such as the Extended Producer Responsibility (EPR). [8]

2.2 Background and Rationale

Sustainable packaging is also a prerequisite for sustainable development and a necessary complement to the sustainable management of the natural and social environment. In this manner, it includes the responsible use of natural and social resources, the shared responsibility of all stakeholders, governance, and the close cooperation between all stakeholders throughout the value chain.

2.2.1 Sustainable Packaging Practices Model (SPPM)

Research conducted by Lekesiztürk & Oflaç (2022), sustainable packaging practices used in packaging supply chains, concluded to a proposal of the so called "Sustainable Packaging Practices Model (SPPM)" with nine key practices: [9]

(1) awareness,
(2) innovation in sustainable raw materials and processes,
(3) reduction of packaging materials and carbon footprint,
(4) waste sorting and recycling,
(5) collection and reuse,
(6) energy saving and use of renewable energy sources,
(7) reduction of water consumption and water recycling,
(8) certification, and
(9) co-creation. [9]

2.2.2 Consumers and Sustainable Packaging

At the same time, consumers have certain key interests and motivations that contribute to the adoption of sustainable packaging, such as:

Environmental concerns: Many consumers are concerned about issues such as plastic pollution and resource depletion and want to minimize their own environmental footprint.

Health and safety: There is growing concern about harmful chemicals in certain packaging materials, particularly in food and beverages, making sustainable packaging appear safer.

Brand values: Consumers are attracted to brands that demonstrate a commitment to sustainability, which strengthens brand loyalty and aligns with their personal values.

Willingness to pay: The vast majority of consumers, especially younger age groups, are willing to pay more for products with sustainable packaging.

Simultaneously, many consumers look for specific sustainable packaging features such as: Reduced packaging, recyclable and recycled materials, biodegradable and reusable options, Environmentally friendly production.

2.2.3 Product manufacturers and Sustainable Packaging

Product manufacturers are showing growing and substantial interest in sustainable packaging, driven by a combination of factors such as legislation, consumer demand, and business benefits.

In a study conducted in 2025 study, Duarte et. al, aimed to understand how companies address and integrate sustainability challenges into packaging design, as well as the motivations and processes that influence managers' decisions when adopting sustainable practices. This research divided the factors found to influence manufacturers into external and internal.

The external factors include:

- consumer and competitor perceptions,
- legislative framework,
- company views on developments and ease of access to innovative technologies nd
- sustainable packaging materials.
- The internal factors found to influence companies' decisions regarding:
- sustainable packaging,
- sustainable packaging strategies of companies, and
- the impact of sustainable packaging on business models and operations [10]

2.2.4 The role of Authorities in Sustainable Packaging

Another key challenge is the role of the authorities primarily responsible for waste collection and management, i.e., municipalities and similar authorities. Regulatory authorities play an important role in shaping, promoting and implementing policies that lead to more environmentally friendly packaging systems. Their contribution can be summarized in seven main areas:

(1) Establishing legislation and standards

Authorities establish legally binding frameworks that specify:

- which materials are allowed or restricted (e.g. banning certain plastics),
- packaging for reduced weight/volume,
- mandatory recycling rates,
- eco-design criteria.

Example: The European Packaging and Packaging Waste Directive (94/62/EC) requires Member States to reduce the environmental impact of packaging through specific recycling and recovery targets. [11, 12]

(2) Setting quality and environmental compliance standards

International organizations such as ISO create technical standards that define how packaging should be designed, produced, and managed to minimize environmental impact. An example is the ISO 18601–18606 (2013), regarding standards for recycling, reuse, energy recovery, etc.

This ISO family consists of the following standards:

ISO 18601: Packaging and the environment — General requirements. [13]
ISO 18602: Packaging and the environment — Optimization of the packaging system. [14]
ISO 18604: Packaging and the environment — Material recycling. [15]
ISO 18606: Packaging and the environment — Organic recycling. [16]

"Improving Plastics Management: Policy Responses" (2018). ISO 14021: Environmental labels and declarations (Self-declared environmental claims. [17]

(3) Supervision and enforcement

Authorities check whether companies comply with regulations, through:

- inspections of production facilities,
- checks on packaging on the market,
- imposition of sanctions in cases of violation,
- establishment of a system of recording and reporting of recycling data, etc.

These ensures that companies are not limited to "green washing" but are adopting real sustainability practices. [13]

(4) Promoting the circular economy

- Regulators encourage or mandate the adoption of circular economy models that include:
- deposit return systems,
- Extended Producer Responsibility (EPR),
- creation of markets for recycled materials (such as mandatory recycled plastic content in new packaging).

(5) Informing, guiding and supporting businesses

The authorities provide:

- guidelines for eco-design of packaging,
- technical support and training programs,

- funding for research and innovation in new packaging technologies,
- encouraging the implementation of sustainable practices through tax incentives.

(6) Consumer protection and transparency

- Regulators enforce rules for:
- correct recycling labeling,
- information about the composition of packaging,
- avoiding misleading "green" claims,
- protecting public health through the control of substances in contact with food.

(7) Harmonization and international cooperation

As packaging production is globalized, authorities are cooperating:

- on common strategies to reduce plastic waste,
- on international agreements (e.g. UN Framework for Plastics),
- on harmonized standards to facilitate trade and recirculation of materials. [18, 19, 20]

3. Sustainable Packaging and Environmental Management Accounting and Green Business Ecosystems

3.1 Sustainable Packaging and EMA

Integrating reforms to address climate change and implement action plans for the green agenda are vital for fostering sustainability and demonstrating commitment to environmental sustainability and economic resilience in alignment with European and international standards.

EU-level initiatives and activities facilitate the sharing of experiences, partnerships, and peer learning. The successful implementation of the SDGs critically depends on the active involvement of regional, local, and civil society stakeholders, which is essential for the efficient achievement of the 2030 Agenda for Sustainable Development. As such, the strategic goal for sustainable packaging is linked to the recognition and management of the costs and benefits of achieving it. [21]

The increased environmental impacts and the environmental costs they entail, as well as the inability of traditional costing systems to provide the information required to manage these impacts and the associated costs, necessitate the adoption of EMA. EMA practices were developed to address the limitation(s) in traditional Management Accounting, which does not provide sufficient information on environmental management. As a result, it has been pointed out that traditional management accounting cannot reveal hidden costs for unsustainable environmental activities. EMA helps businesses measure their environmental activities and allocate the related costs and revenues achieved from environmental activities. [22]

3.2 Green Business Ecosystems in Sustainable Packaging

3.2.1 Business Ecosystems

The business ecosystems are a metaphor for the way natural organisms coexist in nature.

Business strategist James Moore adopted this biological concept in his 1993 Harvard Business Review article "Predators and Prey: A New Ecology of Competition," in which he drew a parallel between companies operating in the increasingly interconnected world of commerce and a community of organizations that adapt and evolve to survive. Moore suggested that a company should not be viewed as a single company in an industry, but as a member of a business ecosystem with participants spanning multiple industries.

A business ecosystem is a network of organizations—including suppliers, distributors, customers, competitors, government agencies, and so on—involved in providing a particular product or service through both competition and cooperation. The idea is that each entity in the ecosystem influences and is influenced by the others, creating a constantly evolving relationship in which each entity must be flexible and adaptive to survive, much like in a biological ecosystem. [22]

3.2.2 Green business ecosystems

Green business ecosystems are self-organized business entities that have developed and continue to develop flexible business models around economically viable issues. The emphasis is on delivering customer value and superior environmental performance through optimal environmental risk management in synergy with other environmental objectives both at global and regional levels. To thrive, these organizations compete and cooperate with each other for available resources, evolve, and adapt to external disturbances.

Key features of green business ecosystems include: the application of production management requirements, in terms of environmental protection and conservation, at all stages of value creation, from product design to end-of-life, and the integration of knowledge and technological achievements for environmental performance into the organizational structures of companies, allowing the application of tools such as Environmental Management Accounting (EMA). [22]

4. Green Packaging Business Ecosystem

A green packaging business ecosystem goes beyond simply using recyclable materials. It requires a circular economy where the value of materials is maintained for as long as possible. Here are the key elements that would make up such an ecosystem, structured around the principles of reduce, reuse and recycle:

- Eco-design

Sustainability starts in the design studio.

Lightweighting: Minimizing the amount of material used, without compromising the safety or functionality of the product.

Mono-materials: Designing packaging from a single type of plastic (e.g. only PET or only PP) instead of composite multilayer materials. This makes recycling easier and more economically viable.

Avoidance of Toxic/Hazardous Substances: Use of inks and additives with a low environmental footprint.

- Opening to Reusable Systems

Instead of throwing away packaging after a single use, the ecosystem encourages the consumer to return it.

Deposit Return Schemes (DRS): A standardized, nationwide system where consumers pay a small deposit for the packaging and get it back when they return it to special machines.

Standardized Packaging: Use of common, durable packaging (e.g. glass bottles of a common shape) that can be washed and reused by different companies.

- Industrial Symbiosis & Collaborations

Collaboration between competitors and different industries is the key to an "open" system.

Open Innovation: Companies share best practices and recycling technologies (e.g. chemical recycling) instead of keeping them secret.

Collaboration with Waste Managers: Closely connecting packaging producers with sorting centers (KDAY) to ensure that the materials they produce can actually be recycled in existing infrastructure.

- Digital Technologies & Transparency

Technology helps track the flow of materials.

Digital Product Passports: Use QR codes or RFID tags that inform the consumer what the packaging is made of, where it should be recycled and how many times it has already been recycled or reused.

Transparency in Origin: Consumers can see whether recycled content comes from industrial waste (post-industrial) or household waste (post-consumer), building trust.

- Consumer Education and Activation

The ecosystem only works if the end user participates.

Clear Labeling: Easily understandable recycling icons (e.g. the arrow symbol with the number) that explain what goes in the blue bin and what is returned.

Economic Incentives: In addition to the money-back guarantee, discounts on products can be offered if the consumer returns the packaging.

In summary, a sustainable packaging ecosystem is a closed system (circular) that remains "open" to collaboration, innovation and transparency between all parties involved: producers, retailers, consumers, and waste management companies.

5. The proposed Open Green Packaging Business Ecosystem (OGPBE)

An open green business ecosystem for sustainable packaging should be a collaborative network in which various participating entities - manufacturers, material producers, retailers, consumer organizations, waste management organizations and organizations, educational institutions, relevant government agencies, etc., would collaborate with the aim of promoting the circular economy and reducing environmental impacts. A necessary condition is the monitoring of the production, distribution, consumption, reuse, recycling and disposal cycle with common environmental accounting terms.

As an example, a large consumer products company could collaborate with a startup that produces packaging based on corn or other plants, the transportation is done with a logistics company that uses electric

vehicles for distribution. At the same time, the containers would be returned to the startup that produces the packaging, with a container return system that would include a reward, equal to: the cost of supplying the raw material, minus the cost of recycling. The entire process would be visible to interested parties, through an application, which would monitor the entire circuit, according to the principles of environmental accounting and environmental management accounting.

5.1. Principles of an open green business ecosystem, incorporating Environmental Accounting

The principles of an open green business ecosystem, incorporating Environmental Accounting, requires the transition from traditional linear models (production-consumption-disposal) to an integrated system that measures, manages and values environmental impacts alongside financial performance.

These principles are based on:

5.1.1 Transparency and Common Data Infrastructure (The "Open" Part)

The ecosystem must allow for the seamless flow of information between all participants (suppliers, manufacturers, distributors, recyclers, regulators).

Blockchain/DLT technologies: Use of immutable databases to record the origin of materials, environmental certifications and carbon emissions at every stage of the supply chain.

APIs: Standardized protocols for data exchange, allowing different accounting systems (e.g. a supplier's SAP and a manufacturer's Oracle) to "talk" to each other.

Digital Product Passports: Implementation of the new EU regulation, where each product/packaging carries a QR code with all environmental information, accessible to everyone.

5.1.2 Integrating Environmental Accounting

Environmental accounting is the measurement mechanism that guides decisions. It includes two main approaches:

Management Accounting:

Pollution Cost Recording: Identifying hidden costs, such as fines for waste, energy costs for inefficient production lines, and waste treatment costs.

Life Cycle Costing (LCC): Calculating the total cost of a product from birth (extraction of raw materials) to death (recycling/disposal), not just the production cost.

Non-Monetary Measurement: Monitoring the use of natural resources (m^3 of water, kWh of energy, tons of CO2) and converting them into monetary values.

Financial Accounting:

Reporting: Incorporating environmental performance into official balance sheets and annual reports (according to standards such as CSRD, GRI, SASB).

Risk Assessment: Identifying assets at risk from the transition to a green economy (stranded assets) and forecasting future liabilities (e.g. site cleaning costs).

5.1.3 Circular Operating Models (The "Green" Side)

The structure must support business models that align with green goals measured by accounting.

Service-as-a-Service Systems: Moving from selling packaging to providing a "packaging service." The company retains ownership of the packaging and is responsible for its maintenance, cleaning, and refilling.

Industrial Symbiosis: Using one company's waste (production by-products) as a raw material by another company within the ecosystem. Environmental accounting makes this transaction visible and measurable.

5.1.4 Governance and Incentives

Without good governance, the open ecosystem cannot function.

Regulatory Framework: Clear government laws (e.g. the EU PPWR) that impose minimum standards of sustainability and accounting transparency.

Economic Incentives: Tax breaks or subsidies for companies that adopt environmental accounting and demonstrate measurable reduction in environmental footprint.

Trust & Commitment: A central (albeit digital/decentralized) governance body that oversees compliance with rules and standards, fostering trust in the "openness" of data.

In this structure, environmental accounting provides the language and the data, while the open structure allows the diffusion of this information, transforming sustainability from a simple compliance to a central driver of value and innovation for the entire ecosystem.

5.2 The structure of an Open Green Packaging Business Ecosystem

Transition of the packaging industry to a circular, low-emission and resource-efficient production model, with transparent measurement of environmental footprint, requires a clear view / vision, which then should be transformed to a strategic framework. This framework consists of the following principles:

- Core Principles

Open and collaborative innovation
Data transparency and traceability
Common environmental standards
Externalities embedded in costs
Circular material flows (reuse–repair–recycle)

- Pillars of Structure

Governance & Coordination Includes:
Central Coordination Body (cluster management)
Stakeholder Council (industry, SMEs, suppliers, municipalities, National Recycling Coordination Center (NRCC), research centers)
Environmental Accounting Committee Innovation & Circular Economy Committee.

The above bodies will define in a transparent manner the procedures for the following issues:

Definition of common metrics and standards
Monitoring of environmental performance
Development of common tools (e.g. LCA platform)
Management of financing / green incentives

- Production & Supply Flows Pillar

This pillar includes the main nodes of the ecosystem which are:

Packaging material producers (paper, bioplastics, metal, glass)
Packaging processors & industries
Logistics / distribution companies
Retail & points of consumption
Recyclers, recovery & treatment units
Collective recycling system operators

Between the nodes:

Material flows with full traceability
Common environmental data exchange protocol
Circular use agreements (e.g. returnable packaging, reuse pools)

- Digital Infrastructure & Data Pillar:

This pillar mainly concerns a central environmental accounting platform that includes:

LCA Hub (Life Cycle Assessment)
Calculation of CO_2 footprint, energy consumption, water, resources, etc. throughout the life cycle.
Material Flow Cost Accounting (MFCA)

Material Flow Cost Accounting (MFCA) is a tool for environmental cost accounting that evaluates the cost of the entire production process by allocating costs according to the concept of waste and environmental impact. This methodology can be applied to every stage of production. Environmental

- Environmental Cost Accounting (ECA)

Integration of environmental externalities into costs

- ESG Dashboard with KPIs

ESG KPIs and reporting are an integral part of every business, providing information, transparency and trust to stakeholders. By measuring and reporting these KPIs, businesses can gain valuable insight into where to expand, refine or phase out ESG initiatives. [23]

- Blockchain / DLT for material traceability

In a world increasingly concerned with environmental stewardship, the quest for sustainability has led many industries to reevaluate their supply chains, with a particular focus on material sourcing.

- Open API for institutions, universities and startups

Educational institutions are increasingly sharing educational data: with their students via applications, between different systems within an institution, and with other institutions, businesses, and organizations.

The underlying data, however, is stored in various systems (i.e. databases) both inside and outside the educational institutions. And to be able to communicate with these systems, a set of definitions known as an API (Application Programming Interface) is required.

- Innovation, R&D and Entrepreneurship Pillar:

This pillar includes:

Green Packaging Innovation Lab
Materials cycle pilots (e.g. closed-loop PET, reusable packaging)
Green start-up accelerator (biomaterials, eco-design, logistics optimization)
Open library of eco-design standards
New material testing protocols with environmental accounting criteria

- Policies, Incentives and Regulatory Compliance Pillar:

This pillar covers the integration of EU Regulations (PPWR – Packaging & Packaging Waste Regulation, CSRD, EPR) the Environmental taxation or incentives, the ISO standards (ISO 14040 for LCA, ISO 14051 for Material Flow Cost Accounting), the Transparency rules for ESG reporting, the Green rate of return for companies with a lower footprint and finally the Incentives for reuse (e.g. reduced fees for reuse systems). [23]

- Proposed Organizational Architecture

The Supreme Ecosystem Council, proposed a supreme organizational architecture which is presented in the diagram below:

Diagram 1: A supreme organizational architecture
Source: Supreme Ecosystem Council

Furthermore, in the diagram 2, the structure of the proposed Open Green Packaging Business Ecosystem (OGPBE) is illustrated:

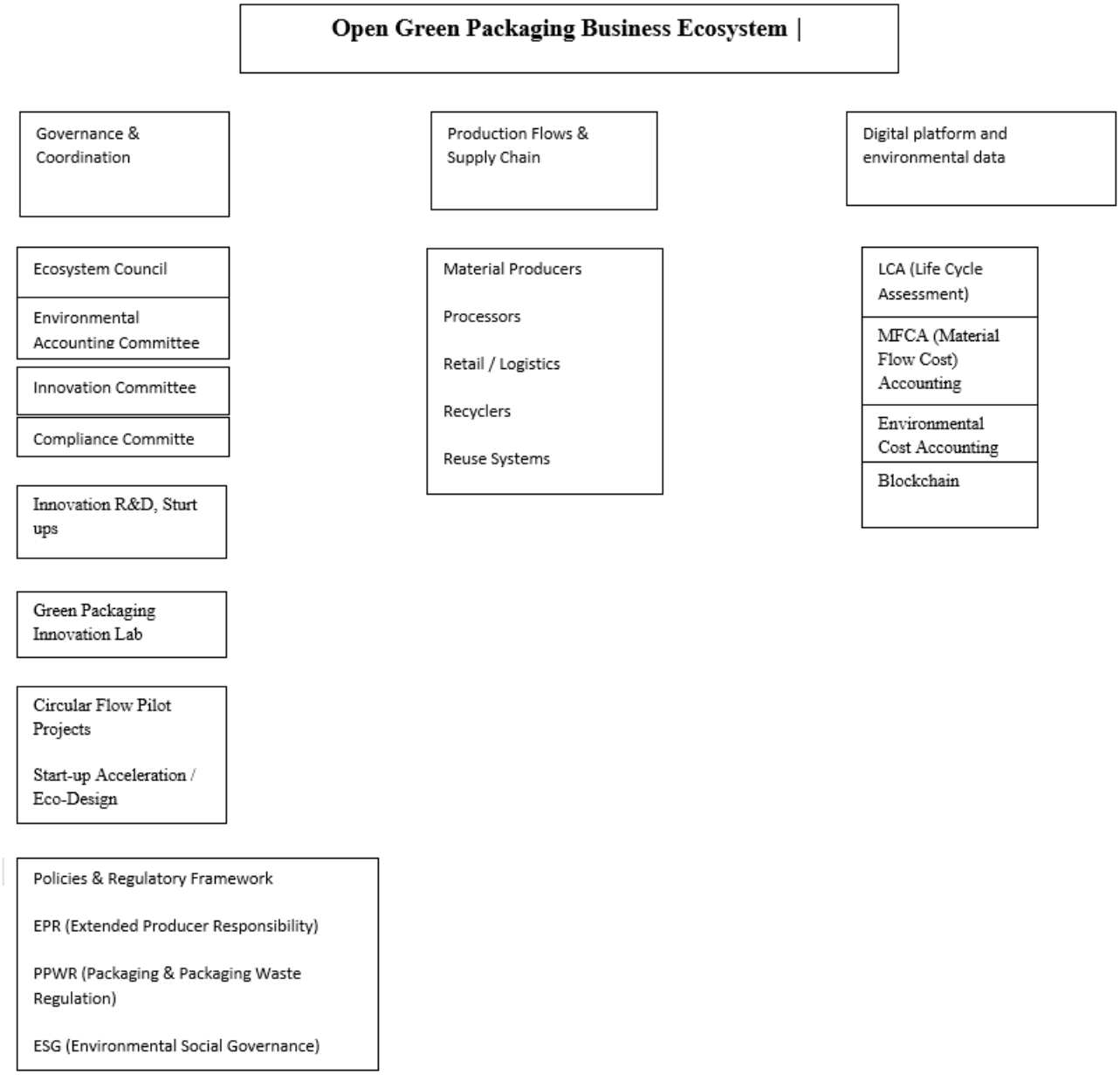

Diagram 2: The structure of the proposed Open Green Packaging Business Ecosystem (OGPBE)
Source: Supreme Ecosystem Council

5.3 The expected results from the creation of the proposed Open Green Packaging Business Ecosystem (OGPBE)

Some of the expected results from the creation of the proposed OGPBE are the reduction of packaging waste, the transparent calculation of environmental costs, a more efficient return on ESG investments, the rapid compliance with European requirements and finally a stronger competitiveness of businesses in the sector.

6. Conclusions

The application of Environmental Accounting and Environmental Management Accounting systems in the packaging industry is complementing sustainability and circular economy procedures. Packaging contributes significantly to environmental issues, mainly consuming natural resources and contributes to air and water pollution, leading to landfill overload, while the limited efficiency of recycling exacerbates the problem. However, packaging has a quite significant role in preventing the loss of goods and products, with its main functions of keeping goods and products safe after production (or harvesting) securing the transportation, distribution and sales. As a result, it is a necessity to find a balance between sustainability and the use of packaging.

Sustainability is a big issue nowadays, both in general, and in particular regarding packaging processes, design and production. Research conducted revealed that there is a vast amount of efforts for the efficient application of sustainability procedures. However, there is a lack of precise financial management when sustainability procedures are applied.

Therefore, it is evident that innovative financial management procedures should be applied. One of the most efficient structure and concept is the Environmental Management Accounting - EMA. EMA, appears as a quite supportive solution, based on the integration of the Environmental Accounting and Environmental Management Accounting system.

When applied in connection with a business ecosystem mechanism the maximum of efficiency is achieved. As such, the proper application of an EMA system, completes successfully the sustainability procedures, by adding the economic and financial aspects, at company level. and overall as an industry, and it is hoped that it will enable a more comprehensive transition for sustainability in the printing and packaging sectors.

The implementation of an Environmental Accounting and Environmental Management Accounting (EMA) system, leadership and management of packaging companies will be able to obtain important, reliable and comparable data regarding the lifecycle costs associated with the packaging production. In addition, the application of such systems will provide the opportunity to support decision-making processes for new business models and investments and to implement action plans and policies with a high degree of transparency, regarding a company's overall financial and environmental performance.

6.1 Future Research

The application of Environmental Accounting and Environmental Management Accounting systems need to be further tested at company level, in particular in the packaging sector, where various procedures, processes, materials and management are integrated.

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