J. Print Media Technol. Res. – Vol. 11 No. 1 (2022)
March 2022

1-2022

ISSN 2414-6250 (Online)
UDC 665

Journal of Print and Media Technology Research

Scientific contributions

ISSN 2414-6250

Editor-in-Chief
Gorazd Golob (Ljubljana)

Published by iarigai
www.iarigai.org

The International Association of Research Organizations for the Information, Media and Graphic Arts Industries

J. Print Media Technol. Res. – Vol. 11 No. 1 (2022)
March 2022
ISSN 2414-6250 (Online)
A print version is available on-demand
ISSN 2223-8905 (Print)

Journal of Print and Media Technology Research

A PEER-REVIEWED QUARTERLY

PUBLISHED BY

The International Association of Research Organizations
for the Information, Media and Graphic Arts Industries
Magdalenenstrasse 2, D-64288 Darmstadt, Germany
http://www.iarigai.org
journal@iarigai.org

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To meet the need for a high quality scientific publishing platform in its field, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries is publishing a quarterly peer-reviewed research journal.

The journal is fostering multidisciplinary research and scholarly discussion on scientific and technical issues in the field of graphic arts and media communication, thereby advancing scientific research, knowledge creation, and industry development. Its aim is to be the leading international scientific journal in the field, offering publishing opportunities and serving as a forum for knowledge exchange between all those interested in contributing to or learning from research in this field.

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- Environmental issues and sustainability
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- Social trends and their impact on media

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Submissions are invited at any time and, if meeting the criteria for publication, will be rapidly submitted to peer-review and carefully evaluated, selected and edited. Once accepted and edited, the papers will be published as soon as possible.

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Journal of Print and Media Technology Research

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March 2022

J. Print Media Technol. Res. – Vol. 11 No. 1 (2022), 1–78

Journal of Print and Media Technology Research is listed in:

Emerging Sources Citation Index

Scopus

DOAJ – Directory of Open Access Journals

Index Copernicus International

NSD – Norwegian Register for Scientific Journals, Series and Publishers

Printed in Slovenia

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A letter from the Editor

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Four papers are published in the first issue of the Journal in 2022. The first research paper deals with packaging visual design, and the second investigates microbial purity of recycled fibres retrieved from printed paper and coated paperboard. The third one is a review paper on printing methods used for producing metallic embellishments, with a main focus on metal effect pigments. The last one in the current issue is a research paper from the media field, presenting the comprehensive study of immersive journalism based on the Samsung VR platform available between 2015 and 2020. Again, the interdisciplinary character of the Journal is confirmed by the papers from different fields, which are all within the scope and of interest to our readers.

In the Topicalities, edited by Markéta Držková (marketa.drzkova@jpmtr.org) an overview of recent patents in multi-material 3D printing is available as the main topic, complemented with some news on the 2022 Flexographic Technical Association awards, new fire-resistant paper-based materials, and updated Interoperability Conformance Specifications for colour management.

In the Bookshelf an overview of books is presented, covering additive manufacturing / 3D printing technologies, printed electronics / functional printing, typography, graphic communication, and some more general fields like guidebooks on planning and executing experiments, computer graphics, and machine learning.

Among academic dissertations, three doctoral theses are presented. Andrej Iskra defended his thesis on the method for analysis of facial images using an eye-tracking system at the University of Ljubljana. The second thesis is on Perovskite solar cells with printed functional layers, defended by Matej Hvojnik at the Slovak University of Technology in Bratislava. Timo Hartus defended his thesis on thermal studies of ink solvent and toner behaviour on coated paper, at Aalto University.

In the Events section, an overview of conferences, congresses and symposia in the near future is presented. A number of events will be available again for in-person attendance because the situation affected by Covid-19 pandemia is better, however, the list is still shorter than in the previous period.

With the present issue, some changes in the editorial team are introduced. Since 2012 when the Journal was launched, only some minor alterations were done. The decision for current changes was discussed for some time by the Board of iarigai, the publisher, and by the members of the Editorial Board of the Journal, however, the present decision was challenging and we are convinced it is not a final one. As it is well known, the changes are the only constant in our life, and without changes, there is no progress.

On this occasion, on behalf of the publisher and the Editorial Board, I would like to thank all those who have so far contributed to the successful editing and regular publication of the Journal with their work, contributions, influence, advice, and encouragement. Among them are Renke Wilken, Darko Agić, Wolfgang Faigle, Ulrike Herzau Gerhardt, Marie Kaplanová, John Kettle, Patrice Mangin, Anu Seisto, Johan Stenberg and Philipp Urban. The newly appointed members of the Editorial Board and the Scientific Advisory Board have also proven their professionalism and active cooperation with the editorial team in the past years, so we are convinced they will contribute to the successful development of the Journal in the future.

Ljubljana, March 2022

JPMTR-2117
DOI 10.14622/JPMTR-2117
UDC 366.1:621.798|72.012

Research paper | 156
Received: 2021-12-17
Accepted: 2022-02-14

The influence of packaging visual design on consumer food product choices

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Abstract

Previous research reported on the significant role that packaging visual elements play in food context. Still, little is known about how typeface design can influence consumer expectations and stimulate their food choices in the case of spices. Thus, the present study aimed to investigate the influence of packaging typeface on the consumers' selection of spice and their expectations of its quality. The first part of the study was an online experiment in which participants were presented with packaging that differed in visual elements, namely typeface (sans-serif, handwritten) and ingredient depiction (photo, illustration, without depiction). The second part of the study was conducted in a laboratory setting where participants viewed packaging that varied in typeface and flavor (red pepper, dried basil), and explained their reasons for selecting a particular packaging. The results showed that typeface influenced the participants' choices and their expectations. The first experiment revealed that the effect of the typeface occurs only in the presence of ingredient depiction (either photo or illustration), while the second experiment indicated that the participants' expectations of spice quality were based on the perceived typeface legibility. This implies that a legible typeface on food packaging can be a useful tool for attracting consumers' attention and stimulating their choices of food products.

Keywords: packaging, typography, consumer behavior, legibility, graphic design

1. Introduction

Food packaging has a great potential to serve as a medium for food-related information. All the information, both pictorial and textual, attracts the attention of a consumer and can arouse the desire to buy the food product (Wyrwa and Barska, 2017). When making a buying decision, consumers mostly rely on the packaging visual design and their expectations about the product quality. Finding out how appropriate particular visual elements are on food packaging, is key for successful packaging design in terms of the consumers' food buying choice. So far, previous research into food packaging explored this to some extent.

Hamlin (2016) found that graphic design had an impact on food product choices. Silayoi and Speece (2004) reported that positive influence of visual elements on food choice is more evident in low-involvement situations. Abrams, Evans and Duff (2015) found that visual design was especially important when making quick buying decisions. The influence of graphic elements was also confirmed by Liao, et al. (2015) who compared different types of emotional responses to packaging visual elements. Later, Lidón, et al. (2018) revealed that the visual appearance of a particular element (i.e. product depiction) had an impact on product liking and willingness to buy. The influence of an isolated visual element was recently investigated by Vila-López, Kuster-Boluda and Alacreu-Crespo (2021). They found that variations in design, such as in the color of the label, affected participants' food selection. This was in line with the findings of Van der Laan, et al. (2012) who reported on the attractiveness of the packaging visual design as a strong predictor of food choice. In the study by Peters-Texeira and Badrie (2005) the majority of participants (85.4 %) reported that the packaging attractiveness influenced their choice of food product in the same product category. Taken together, all these findings confirm Cardello's (1994) suggestion that the

visual appearance of the food itself has a powerful impact on its acceptability, but that the visual appearance of its packaging is equally important.

Besides the investigation of consumers' food choices, previous researches were also focused on the consumers' perception of food quality under the influence of packaging characteristics. In a study (Konstantoglou, Folinas and Fotiadis, 2020) that investigated consumers' attitudes toward food packaging, the results indicated that consumers recognize the importance of packaging's role in food protection and that quality of food is associated with the quality of its packaging. The perceived quality of a food product was measured for different product types, such as snacks (Wang, 2013), chocolate (De Kerpel, Kobuszewski Volles and Van Kerckhove, 2020), yogurt (Becker, et al., 2011), mousse, pasta (Simmonds, Woods and Spence, 2018), cheese (Bou-Mitri, et al., 2021), carrots (Nørgaard Olesen and Giacalone, 2018) and drinks (Gislason, et al., 2020; Włodarska, et al., 2019). However, there are some food product categories that have been neglected by the packaging researchers. When it comes to perceived food quality, spices are one of the categories, which are worth investigation and have not been studied yet.

Most of the above-mentioned studies used either product choice or perceived quality as dependent variables, while independent variables resulted from variations in the packaging visual elements. For example, Gislason, et al. (2020) varied color and label design elements, such as shape and complexity, to investigate the consumers' expected quality of beer. In a study, which investigated the influence of packaging design on yogurt evaluation (Becker, et al., 2011), the packaging designs varied in shape and color saturation. Some of the researchers varied the position of special visual elements such as transparent windows, and investigated its influence on the expected quality (Simmonds, Woods and Spence, 2018). De Kerpel, Kobuszewski Volles and Van Kerckhove (2020) examined the effect of variations in packaging surface (glossy versus matte) on the perception of chocolate quality. In a study of packaged tea, Kovačević, Brozović and Itrić Ivanda (2019) used variations in eco-mark design and its position on the front side of the packaging. Similarly, Magnier, Schoormans and Mugge (2016) used the AB ("agriculture biologique") logo on coffee packaging to examine its effect on consumers' perceived quality of the product. Nørgaard Olesen and Giacalone (2018) focused on fresh food. They used a systematic variation of label color and packaging type to explore their influence on participants' perception of quality of fresh carrots.

Despite the number of visual variables included in previous research, only a few food packaging studies considered typeface as an independent variable. In a study that examined the effects of two different typefaces weights (Karnal, et al., 2016), the results suggested that typeface associations can influence the perception of product healthiness. Liao, et al. (2015) used two different typefaces (simple versus ornate) to examine whether the typeface can affect people's emotional responses towards chocolate packaging. The packaged chocolate was also investigated by Kovač, et al. (2019) who included the typeface as one of the independent variables in their study of consumer preferences.

Other studies were mainly focused on the participants' expectations about the taste based on the typeface visual characteristics (for example, Otterbring, et al., 2022). Velasco, et al. (2014) combined different typefaces with other packaging attributes and found that a rounded typeface can communicate sweet tastes better than angular typeface. Furthermore, it was found that visual properties of a typeface can be associated with basic taste attributes (sweet, bitter, and sour) and have an impact on the actual taste ratings (Velasco, Hyndman and Spence, 2018). These studies presented relevant findings on the role of typeface in transmitting messages regarding food taste. However, the influence of typeface on the consumers' expectations of the food quality is still insufficiently examined.

In the context of food packaging, visual characteristics of a typeface not only influence associations created in the consumers' minds, but also the correct identification of letters. In order to have any effect on the consumer, a typeface has to be legible. The legibility is a desirable aspect of any textual information, and food products are not an exception. This was confirmed in the previous study of SMEs food products (Saad and Idris, 2014). Our study went further in the examination of the effects of typeface and included the perceived legibility of typeface as a potential moderator in generating positive impressions about food quality.

The scope of this paper is even broader. The main purpose of our study was to fill the research gaps in the area of visual design and food packaging. The aim was to investigate the influence of the packaging typeface on the consumers' food product choices and their expectations about the product quality by conducting two experiments. The first experiment was conducted online. Its goal was to collect basic data about the consumers' spice buying habits and their gravitation to particular visual elements on the spice packaging design. The second experiment was conducted in the laboratory setting and its goal was twofold; (1) to examine whether the influence of typeface remained the same when the experimental procedure changed and (2) to get a wider picture regarding the consumers' attitudes toward the spice packaging by collecting qualitative data.

2. Experiment I

For the first experiment, an online questionnaire was used. The online questionnaire was used in a number of recent packaging-oriented studies (Hall, et al., 2021; Poslon, Kovačević and Brozović, 2021; Taillie, et al., 2020; Kovač, Brozović and Itrić Ivanda, 2019) and it was appropriate for our first experiment to get a quick collection of responses. The study was conducted during May 2021 using Google Forms. A web link to the questionnaire was sent via e-mail using the authors' personal databases. The respondents were adult consumers (n = 154) residing in Croatia, who agreed to participate in the study. They were fully informed about the nature of the study and that anonymity was assured. Their age ranged from 19 to 57 years (M = 24.04, SD = 6.65); 76.62 % were women. In most households in Croatia, females are responsible for food purchases, so the sample was appropriate for the investigation of the food selection in our experiment.

2.1 Design of the packaging samples

Given that the main independent variables were based on visual stimuli, special care was given to the visual appearance of the packaging variants in the experiment. The design of the packaging samples and the selection of visual elements were driven by literature review. As suggested by Kovačević, Brozović and Banić (2020), all packaging samples had a symmetrically balanced composition, a high contrast between the text and the background and a clear visual hierarchy of information. The font size was in accordance with European Parliament and Council Regulation (EC) 1169/2011 (2011) which specifies that x-height of the letters shall be 1.2 mm or greater. Two typefaces were used for the manipulation of the typeface variable; Arial as the sans-serif typeface, and Brush Script MT as the handwritten typeface. These two typefaces were chosen because they significantly differ in their visual appearance. They were used across many studies of people's responses to textual stimuli. For example, in order to manipulate text legibility in learning materials, Eitel and Kühl (2016) used Arial for a legible (fluent) version of text and Brush Script MT for a less legible (disfluent) version. Based on the pretest for the main experiment, which examined printed questions, Song and Schwarz (2008) also used Arial for easy-to-read conditions and Brush Script MT for difficult-to-read conditions. In the same manner, these typefaces were used in the study of the book review by Chen and Sakamoto (2016) and Mantonakis, et al. (2013) who investigated the effect of fluency on product judgment.

Photos and illustrations were used for the different styles of spice depiction. Both types of depiction were commonly used in similar packaging studies to present the ingredients (Hall, et al., 2021; Abrams, Evans and Duff, 2015; Lidón, et al., 2018; Timmerman and Piqueras-Fiszman, 2019; Kovač, et al., 2019). According to the European Parliament and Council Regulation (EC) 1169/2011 (2011), food depiction is not mandatory for spices. If used as voluntary food information, pictorial information shall not be displayed in such a way that detriments the presentation of mandatory information (i.e. the name of the food). This guideline was taken into account in the process of designing the packaging samples.

The design (Figure 1) was created by a professional graphic designer (one of the authors) who used the most common packaging design for spices in Croatia as a reference for the design of the packaging samples

Figure 1: Packaging samples used in Experiment I: (a) without depiction, sans-serif; (b) photo, sans-serif; (c) illustration, sans-serif; (d) without depiction, handwritten; (e) photo, handwritten; (f) illustration, handwritten

(i.e. pictures of stand-up pouches) in this study. Stand-up pouches are considered to be suitable for red pepper and for ground spice powders (King, 2006). If laminated, the pouches can be especially useful for the protection of the spice phenol content which is associated with spice antioxidant activity (Asimovic, et al., 2014).

2.2 Procedure

The questionnaire consisted of three sections. Besides the basic socio-demographic variables, the first section inquired about the respondents' spice buying habits by asking the closed-ended question "How often do you buy spices?" in which the respondents selected one option among a predefined list. The options were: "Never", "Once a year", "Several times a year", "Once a month".

The second section inquired about the respondents' preferences for different packaging samples. In total, there were six packaging samples (Figure 1). They were grouped in three pairs based on spice depiction; a pair without depiction, a pair with a photo, and a pair with an illustration. Each pair consisted of a packaging with the sans-serif and handwritten typefaces. The order of presenting the packaging samples was randomized for each respondent. The respondents were asked to choose one packaging in each pair that they expected to have a better quality of spice.

In the third section a general selection task was used in order to investigate the respondents' preferences for a particular depiction style. All six packaging samples were presented to the respondents and they were asked to select the one that they expected to have the highest spice quality.

2.3 Results and discussion on Experiment I

2.3.1 The influence of typeface

For each packaging pair presented to the participants in the selection task, the McNemar's test was performed to investigate the influence of typeface on the participants' choices (Table 1). The McNemar's test was used since the purpose of the analysis was to compare paired samples using nominal dichotomous data and to determine significant differences in the frequency of selection for a particular item (Kovačević, Brozović and Banić, 2020; Kovačević, Brozović and Itrić Ivanda, 2019; McCrum-Gardner, 2008). The results showed a significant difference in the participants' selection of the packaging with the photo ($p < 0.001$), indicating that spice in the packaging with a combination of the photo and sans-serif typeface was perceived to have better quality (66.9 %) than the spice in the packaging with the combination of the photo and handwritten typeface (33.1 %). The results for the packaging samples with the combination of illustration and the two different typefaces also showed the participants' inclination toward the sans-serif typeface. Significantly more participants (70.1 %) expected that the spice in the packaging with the combination of the illustration and sans-serif typeface had better quality than the spice in the packaging with the combination of the illustration and handwritten typeface (29.9 %), $p < 0.001$. This finding was surprising, because the style of the typeface is considered to be more harmonious with the style of the illustration. For the pair of packaging without any spice depiction, the results showed no significant effect of the typeface on the participants' choices ($p = 0.171$).

Table 1: The participants' selection of spice packaging across conditions (p is based on McNemar's test)

Packaging spice depiction	Packaging typeface	*n*	%	*p*
None	Sans-serif	86	55.8	0.171
None	Handwritten	68	44.2	
Total		154	100.0	
Photo	Sans-serif	103	66.9	0.000
Photo	Handwritten	51	33.1	
Total		154	100.0	
Illustration	Sans-serif	108	70.1	0.000
Illustration	Handwritten	46	29.9	
Total		154	100.0	

Additionally, we wanted to investigate whether the preferences for different packaging samples differed across the participants with different buying habits (i.e. self-reported frequency of buying spices in their everyday life). The results were split in four categories: "Never", "Once a year", "Several times a year" and "Once

Table 2: Results of the McNemar's tests for sans-serif vs. handwritten split by participants buying habits (asterisks indicate statistically significant differences between the groups)

Frequency of buying spices	*n*	Packaging without spice depiction	Packaging with illustration	Packaging with photo
Never	15	$p = 0.118$	$p = 0.055$	$p = 0.118$
Once a year	44	$p = 0.651$	$p = 0.291$	$p = 0.024$*
Several times a year	59	$p = 0.193$	$p = 0.037$*	$p = 0.009$*
Once a month	36	$p = 0.617$	$p = 0.005$*	$p = 0.005$*

a month". The McNemar's test showed no significant differences in choices between sans-serif and handwritten typeface for packaging samples without spice depiction across all categories (Table 2). However, for the packaging that contained the illustration of the ingredient, significant differences were found in the categories "Several times a year" ($p < 0.05$) and "Once a month" ($p < 0.05$), indicating that the participants who buy spices often, perceived the packaging with the sans-serif typeface to have a better quality of spice. For the packaging that contained a photo of the ingredient, significant differences were found in three categories: "Once a year", "Several times a year" and "Once a month" (all values $p < 0.05$), indicating that the participants who buy spices at least once a year expected that the spice in the packaging with the sans-serif typeface had a better quality. Any further interpretation of the results for the buying frequency categories should be taken with caution due to the small sample.

2.3.2 Preferences for product depiction style

In the general selection-task, the participants selected one packaging among all the packaging samples used in this experiment. The frequencies of selection for each packaging sample are shown in Table 3.

Table 3: The frequencies of selection of each packaging sample in general selection-task

Packaging spice depiction	Packaging typeface	*n*	%
None	Sans-serif	27	17.5
None	Handwritten	8	5.2
Photo	Sans-serif	46	29.9
Photo	Handwritten	27	17.5
Illustration	Sans-serif	32	20.8
Illustration	Handwritten	14	9.1
Total		154	100.0

In order to investigate whether the participants differed in their preferences for a particular depiction style (i.e. illustration or photo), a McNemar's test was performed only on the results of the participants who chose the packaging with the spice depiction ($n = 119$). The results showed that the participants chose the packaging with the photo more frequently (61.34 %) than the packaging with the illustration (38.66 %), $p < 0.05$, suggesting that the participants prefer realistic presentations of the ingredient in presenting the quality of spice. This is in line with earlier studies which demonstrated the consumers' inclination towards photographic representations of the product. For example, in a study by Kobayashi and Benassi (2015) who investigated the impact of coffee packaging characteristics on consumers' purchase decisions, participants preferred an enriched photo of the coffee drink rather than a drawing. Similar conclusions were reached by Kovač, et al. (2019) who examined the effects of different visual elements on strawberry chocolate packaging and reported that participants preferred a photo of the strawberry over an illustration. Their results suggest that a photo presents the ingredient more realistically than the illustration, which gives consumers a feeling of reliability. According to advertising research, unrealistic images should be avoided if marketers strive to maximize the perceived benefits of a product (Kim, Choi and Wakslak, 2019).

We used the results of the first experiment as the basis for the design of the second experiment. Firstly, the effect of the typeface was noticeable only in the groups of participants who buy spices at least once a year. According to this finding, the recruitment criterion for participants in the second experiment was that they buy spices frequently. Secondly, the effect of the typeface was significant only in the presence of spice depiction. Thirdly, when comparing the two types of spice depiction, the participants preferred the photo over the illustration. In line with these results, the stimuli used in the second experiment were packaging with a photographic image of the spices.

3. Experiment II

A face-to-face interview, including the participants' subjective ratings of the packaging samples, was used for the second experiment. It took place in an experimental room at the University of Zagreb, Faculty of Graphic Arts. In comparison to the online collection of data for the Experiment I, this method provided better control over the viewing conditions for each participant and enabled us to get additional qualitative data. The participants were adult Croatian consumers ($n = 60$), who claimed that they buy spices several times a year. All the participants signed their written consent prior to taking part in the study. Their age ranged from 24 to 80 years ($M = 43.07$, $SD = 13.73$); 68.3 % were women. The experimental procedure received approval from the Ethics Committee of the Faculty of Graphic Arts, University of Zagreb (approval reference number 641-01/21-01/1).

3.1 Design of the packaging samples

The design of the packaging samples was based on the same principles as in Experiment I. In Experiment II only packaging samples with a photo depiction were used. Packaging for a new spice flavor (i.e., dried basil) was added. In order to control the variables, the design of the basil packaging was consistent with the packaging for the red pepper. Only the product-related information was changed (i.e., the spice name,

the background color and the photo of the spice). Two packaging variables were manipulated: typeface (sans-serif versus handwritten) and flavor (red pepper versus dried basil), which resulted in four different packaging samples (Figure 2).

3.2 Procedure

The participants took part in the experiment one by one. They were seated in front of a computer screen (Lenovo computer display LEN L1900pA, with a resolution of 1280 × 1024 pixels) at the approximate distance of 70 cm. Pictures of packaging samples (Figure 2) were presented on screen.

In the first section of questions, the participants were instructed to view the packaging samples individually and rate the expected spice quality for each of them. A 7-point scale was used, ranging from "unacceptable quality" (1) to "high quality" (7). There was no time limitation in completing the task.

In the second section of questions, they were asked to rate the legibility of the product's name for each packaging. A 7-point scale was used again, ranging from "unacceptable legibility" (1) to "high legibility" (7). The order of presenting the packaging samples was counterbalanced for participants.

In the third section, we used selection tasks similar to those in Experiment I. In Experiment II, the purpose of the selection tasks was twofold. Firstly, we wanted to investigate whether the influence of the typeface remains the same if a new spice type (i.e., dried basil) is taken into consideration. Secondly, participants were asked to justify their choices and explain their reasons for particular choice decisions during the selection tasks. For the selection task, the packaging samples were grouped in two pairs; a pair of packaging for the red pepper and a pair of packaging for dried basil. Each pair consisted of packaging with the sans-serif and handwritten typefaces. The participants were asked to select one packaging in each pair that they expected to have a better quality of spice. Their comments were recorded by an interviewer.

At the end of the interview, the participants were asked "When buying spices, which visual information on the packaging do you pay more attention to: textual or pictorial?". The purpose of this extra question was to investigate if the text-oriented and the picture-oriented participants differ when associating spice quality with typeface legibility, since it is known that the way in which consumers process information can affect the impact of visual design cues on food choices (Vermeir and Roose, 2020).

3.3 Results and discussion on Experiment II

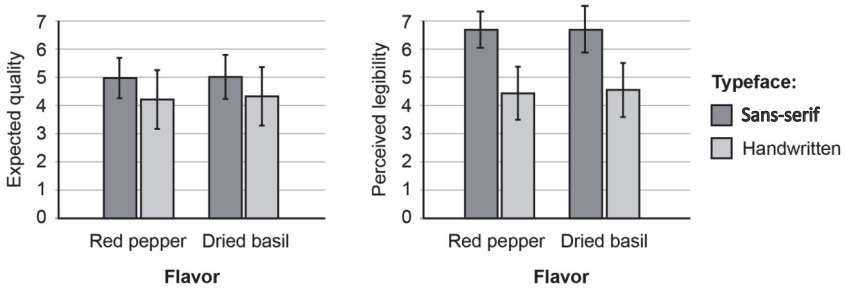
3.3.1 The influence of typeface and flavor on expected quality

A repeated measures analysis of variance (ANOVA) was used to examine the influence of typeface (sans-serif versus handwritten) and flavor (red pepper versus dried basil) on the expected quality of spice. There was a significant effect of typeface on the expected quality, $F(1, 59) = 31.96$, $p < 0.001$, indicating that the spice in the packaging with the sans-serif typeface was expected to have better quality ($M = 5.00$, $SD = 0.76$) than the spice in the packaging with the handwritten typeface ($M = 4.28$, $SD = 1.03$). Figure 3 shows the results. This was in accordance with the results of the first experiment. There was no significant effect of flavor on the expected quality ($p > 0.05$) and no (typeface vs. flavor) interaction effect ($p > 0.05$). This suggests that changing the product type in our second experiment did not affect the participants' responses regarding the perceived quality of the spice.

3.3.2 The influence of typeface and flavor on legibility

To investigate the influence of typeface (sans-serif versus handwritten) and flavor (red pepper versus dried basil) on the perceived legibility, a repeated measures ANOVA was used. As expected, there was a significant effect of typeface on the legibility ratings, $F(1, 59) = 406.98$, $p < 0.001$, indicating that the sans-serif typeface was evaluated as more legible ($M = 6.65$, $SD = 0.72$) than the handwritten typeface ($M = 4.48$, $SD = 0.94$). No significant effect of flavor on the legi-

Figure 2: Packaging samples used in Experiment II: (a) red pepper, sans-serif; (b) dried basil, sans-serif; (c) red pepper, handwritten; (d) dried basil, handwritten



a) *b)*

Figure 3: The results for the expected quality (a) of spice and perceived legibility (b) of typeface

bility was found ($p > 0.05$), indicating that participants' evaluation of the legibility of spice name was not influenced by variations in background color and lettering. However, there was a significant (typeface vs. flavor) interaction, $F(1, 59) = 4.87$, $p < 0.05$, suggesting that the handwritten typeface was perceived as more legible on the packaging for dried basil ($M = 4.53$, $SD = 0.97$) than on the packaging for the red pepper ($M = 4.43$, $SD = 0.91$). This may be influenced by the specific characteristics of the letters used in the product name. The Croatian word "Sušeni" which refers to dried basil contains very distinctive letters in this particular typeface. The letter "š" especially stands out. On the other hand, the Croatian word "Crvena" which refers to red pepper contains a very decorative letter "C" which can be confused with "O", and the rounded letter "v" which can be easily confused with "u".

3.3.3 Correlation between legibility and expected quality

The Spearman correlation analysis was performed to evaluate the association between legibility and the expected quality of spice. The Spearman correlation coefficient r_s was 0.458, indicating that better legibility ratings were associated with better quality, and this relationship was significant ($p<0.001$). When data were split by participants' categorization into text-oriented ($n = 35$) and picture-oriented ($n = 25$) groups, the results revealed that this correlation was higher for the text-oriented participants ($r_s = 0.582$, $p<0.005$) than for the picture-oriented participants ($r_s = 0.304$, $p<0.005$).

3.3.4 The influence of typeface and flavor in selection tasks

For each packaging pair presented to the participants in the selection task, the McNemar's test was performed. The results showed a significant difference in the participants' selection of packaging for red pepper ($p < 0.005$), indicating that the red pepper in the packaging with the sans-serif typeface (70 %) was perceived to have a better quality than the red pepper in the packaging with the handwritten typeface (30 %). Additionally, there was a significant difference in the participants' selection of packaging for dried basil ($p < 0.001$), indicating that dried basil in the packaging with the sans-serif typeface (75 %) was perceived to have a better quality than the dried basil in the packaging with the handwritten typeface (25 %). The obtained results are in contrast with the findings reported by Otterbring, et al. (2022) which suggested that the typeface did not have a direct impact on the participants' food choices. However, given that their findings are based on different typefaces and presentation context, the conclusions regarding the discrepancy with our results should therefore be treated with caution. There was no significant difference in the participants' choices when data were grouped by flavor ($p > 0.05$).

3.3.5 Participants' comments

Qualitative coding was done by an inductive approach and the category codes were derived from the overview of all participants' answers. All the reasons that were reported by the participants while justifying their selection of the spice packaging were grouped into three categories: "Excellent legibility of the product name", "Professional visual design of the packaging" and "Association between the typeface and the product type" (Table 4).

For example, if a participant explained the reasons for his/her choice by saying "The font seems to be appropriate for a natural product for cooking" that answer was categorized as "Association between the typeface and the product type". If a participant commented "This packaging looks very modern" that answer was categorized as "Professional visual design of the packaging". If a participant commented "I can easily read the information on the packaging, which gives me an impression of a good product" that answer was categorized as "Excellent legibility of the product name". The most frequently mentioned reasons for selecting the spice in the packaging with the sans-serif typeface fell into the category "Excellent legibility of the product name" ($n = 63$), followed by "Professional visual design of the packaging" ($n = 24$).

Table 4: Participants' reasons for their choices of packaging (n presents the number of mentions)

	Excellent legibility of the product name	**Professional visual design of the packaging**	**Association between the typeface and the product type**
Selection of packaging with sans-serif typeface			
Red pepper	$n = 31$	$n = 11$	$n = 0$
Dried basil	$n = 32$	$n = 13$	$n = 0$
Selection of packaging with handwritten typeface			
Red pepper	$n = 0$	$n = 7$	$n = 11$
Dried basil	$n = 0$	$n = 8$	$n = 7$

For the packaging with the handwritten typeface, the most frequently mentioned explanations for selection were: "Association between the typeface and the product type" ($n = 18$), followed by "Professional visual design of the packaging" ($n = 15$). This suggests that people do pay attention to the typeface on the packaging and that the typeface connotative aspect is appreciated, but good legibility is sometimes more relevant for the product choice. The high number of comments referring to excellent legibility of the sans-serif typeface is in accordance with the results of our correlation analysis which showed a high connection between the legibility of the spice name and the expected quality of the spice.

4. General discussion

The results of both experiments showed that the typeface influenced the participants' choices and their expectations of product quality. Experiment I revealed that the effect of the typeface depends on the presence of the ingredient depiction on the packaging, while Experiment II demonstrated that the majority of the participants based their quality expectations on the legibility of the product name.

In the first experiment we employed an online questionnaire which provided a sufficient number of responses and relevant data based on which Experiment II was designed. The main finding of the first experiment was that the typeface affected the participants' choices only when the packaging presented an image of the ingredient. As confirmed in previous research (Timmerman and Piqueras-Fiszman, 2019; Lidón, et al., 2018), ingredient depiction can play a significant role in consumers' impressions. Our results indicate that its effect can stimulate a positive perception of the sanserif typeface when forming expectations regarding spice quality. However, the results cannot be generalized because typefaces used in our experiment did not influence the choices for the participants who never buy spices. Although the percentage of that group was quite small (9.7 %), the result suggests that the participants' buying behaviour should be taken into consideration when investigating the effects of typeface in food packaging design.

Another important finding was the result of the general selection task. Among all the packaging variants used in the experiment, most of the participants selected the packaging with the photo depiction of spice. It is known that product imagery presented on the package can help consumers get information on the product (Simmonds, Woods and Spence, 2018; Purnhagen, van Herpen and van Kleef, 2016) and some of them use it to predict what the product would taste like (Simmonds and Spence, 2017). Thus, it is not surprising that realistic imagery can be especially beneficial for them. The power of realistic depiction was demonstrated in previous work by Abrams, Evans and Duff (2015) who reported that visual realism on food packaging was associated with healthier food. Earlier study by Ampuero and Vila (2006) revealed that people associated photographs with upper class products, while illustrations were a signal of accessible products. Still, in some circumstances the illustrations can be more effective than photographs (Septianto, Kemper and Paramita, 2019), at least when a designer wants to promote an organic food product.

The results of our second experiment excluded the effect of flavor on the participants' responses, confirmed the findings from the first experiment and revealed more data explaining the participants' preferences for the sanserif typeface. According to the participants' subjective ratings, spice in the packaging with the sanserif typeface was expected to be better in quality than the spice in the packaging with the handwritten typeface. The same was found of the perceived legibility of the product name on the packaging, indicating that the sanserif typeface (i.e., Arial) was perceived as more legible than the handwritten one (i.e., Brush Script MT).

These results are consistent with previous research that measured legibility of the Arial typeface more directly than our study. For example, Možina, et al. (2020) measured reading time for Arial and Times on different types of paper and found that text in Arial was read faster and with higher accuracy. The better legibility for Arial was also reported by Ko (2017) who measured legibility scores for Arial and Times New Roman on-screen.

Our further correlation analysis showed that better legibility ratings were associated with better quality of spice, especially for the text-oriented participants. This shows how important the typeface functionality is to consumers when examining packaging visual cues in the spice evaluation process.

Previous research also confirms the positive effect of easy-to-read typefaces in other contexts, such as increasing the attractiveness of a tour (Huang, Wu and Shi, 2018) or indicating the credibility of an online costumer review (Huang, et al., 2018). Our results indicate that the relationship between ease of reading and positive customer evaluation can also be manifested in food marketing, at least in the case of specific food products such as spice.

When it comes to the qualitative part of our study, we noticed a high congruence between the participants' verbal responses and their evaluation ratings. The comments given by the participants during the selection tasks supported these conclusions in regards to the connection between good legibility and positive impressions of spice quality.

The most frequently mentioned reasons for choosing the spice in the packaging with the sans-serif typeface referred to the excellent legibility of the spice name. On the other hand, for the packaging with the handwritten typeface, the participants mostly mentioned the typeface connotations as an explanation for their selection. For example, one participant said that the handwritten style of text insinuates a homemade meal and the taste of traditional quality food. This result is in line with previous studies which reported on the influence of specific visual properties of stimuli on consumer associations (Marques da Rosa, Spence and Miletto Tonetto, 2019) and sensory expectations (Gil-Pérez, et al., 2019). Still, the remarkably greater number of participants in our study based their spice selection on legibility (n = 63) rather than on the product–typeface association (n = 18). This implies that the consumers' personal mental association should definitely be taken into consideration when developing graphic design for food packaging, but understanding the effects of the parameters which make food names legible could also be used as an aid for a successful marketing strategy.

5. Conclusion

Our study showed that a legible typeface can be a useful tool for encouraging food product selection and conveying the message of product quality. When asked to choose the spice with a better perceived quality, based only on the packaging visual design, the participants preferred the one with the sans-serif typeface. Even changes in the experimental procedure or spice flavor did not weaken this effect. The findings contribute to the relevant evidence-based literature that offers practical guidelines for graphic designers, packaging producers and food marketers. However, our study has limitations. Firstly, the packaging samples were presented on-screen. This presentation mode has its benefits (such as low cost, simplicity and the ease of controlling the viewing conditions), but the disadvantage is the lack of physical contact with the product which would bring the experimental procedure closer to a realistic context. Another limitation was a small number of typeface variants used in the experiments. Although special effort was put into the appropriate selection of the two typefaces for the investigation, and their usage was well-established in past research, inclusion of a larger number of typefaces could offer a deeper knowledge about the associations between typography and consumer perception of food products.

Despite the limitations, our study demonstrated the powerful role of typeface in food packaging. Future studies could contribute to better understanding of its impact by investigating its interaction with other visual elements omitted in this study, such as transparent windows, graphic symbols and patterns. Following the recommendations provided by the legislation relevant to nutrition and foods regarding information clarity, as well as the significance of the effects of the typeface legibility suggested by our results, future studies should also examine typeface effects on other product related information, which can be voluntary printed on packaging for spices, such as alternative product description, storage recommendations and instructions for use. Regarding the hedonic aspect of food products, it would also be valuable to measure to which extent typeface aesthetics and functional properties may affect consumers' sensory expectations or, perhaps even more important, their real taste experience.

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JPMTR-2115
DOI 10.14622/JPMTR-2115
UDC 579.2|676.2-027.33

Research paper | 157
Received: 2021-12-01
Accepted: 2022-01-26

Microbial purity of recycled fibers made from printed offset paper and nanomodified polycaprolactone coated paperboard

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Abstract

In order to increase the sustainability of paper or board production, it is desirable to use recycled fibers as much as possible. Microorganisms are in a smaller or higher amount present on the surface of paper or paperboard, so they are also present in the paper pulp or on the cellulose fibers. The purity of the mentioned fibers is important for obtaining a quality raw material that is health conforming. The aim of this study is to determine the microbiological quality of recycled fibers obtained by recycling of paper and paperboard intended for the manufacture of packaging products. Samples were in an average microbiological environment without food exposure. Quality of recycled fibers was studied through the total number of bacteria and determined for different recycled samples. The total number of microorganisms was estimated by both the disintegration and smear method. Results showed that only the disintegration method was suitable for the evaluation since the smear method did not produce any results. Moreover, the disintegration method was suitable only for the determination of bacteria alone, since no growth of molds or yeast occurred. In addition, the influence of paper composition, paperboard coatings and recycling methods on bacterial growth is demonstrated. The number of bacteria obtained on recycled fibers is affected by the presence of nanoparticles in coatings (Zn, Si and Al), as well as by the presence of different components in the base paper.

Keywords: sustainability, paper, offset prints, microorganism, bacteria

1. Introduction

Paper as one of the materials with the highest recycling rate is a sustainable material source for the cyclical manufacture of paper- and board-based packaging. The most important process in the production of recycled paper is deinking. Deinking is dependent upon the quality of the used paper for recycling, the type and properties of the printing inks and printing process, the age of the printed product and climatic conditions during its life cycle (Vukoje and Rožić, 2018). In order to achieve desirable optical and mechanical properties of recycled pulp, improved deinkability of printed paper products is an essential factor, and therefore different deinking processes can be used for the production of recycled fibers (Vukoje and Rožić, 2018). Due to the growing demand and increasing use of printed packaging materials such as cardboard, packaging grades classification regarding deinkability is also of great importance (Blanco, Miranda and Monte, 2013). Moreover, due to increased paper recycling rates, the quality of the waste paper used for recycling decreases since different paper fractions for recycling are being collected resulting in increased content of harmful substances (Pivnenko, Eriksson and Astrup, 2015). Thus, the evaluation of the quality of recycled paper should be considered. Pivnenko, Eriksson and Astrup (2015) showed a list of 10 000 chemicals potentially present in paper products, of which 157 were classified as hazardous. Some of these substances are associated with the printing industry or they originate from contamination of the paper during the use phase or during collection and handling in the waste management phase. Some of the present chemicals very likely remain in the solid matrix during paper recycling, and thus they may end up in new recycled products.

Paperboard packaging materials are finding increasing potential in packaging applications compared to classic polymer packaging materials, not only because of their environmental friendliness but also because of the fact that correctly stored paperboard materials when used in packaging reduce the potential of cross-contamination of food due to a quicker viability loss by spoilage

and pathogenic microorganisms, except for molds, compared to the polymer packaging according to Siroli, et al. (2017).

Due to increasing demand for environmentally friendly packaging materials, producers are obliged to use recycled fibers in their packaging manufacture, as well as other biodegradable materials. Different authors have been pointing to the problem of using recycled materials for food packaging applications, especially in the case of paper packaging, due to their chemical, microbiological and toxicological impurity and potential for migration of contaminants into the foodstuff and possible risk to consumers (Sipiläinen-Malm, et al., 1997; Escabasse and Ottenio, 2002; Pivnenko, Eriksson and Astrup, 2015).

Sipiläinen-Malm, et al. (1997) isolated aerobic spore-forming bacteria from recycled fiber pulp, some of which were considered pathogenic. Johansson, et al. (2001) showed that recycled papers are the source of microbial contamination that in the end may affect the purity of the paper. Moreover, the total amount of bacterial and fungal spores present in the paper is correlated with the amount of used recovered material as well as the season of production. Hladíková, et al. (2015) showed that by the increase of the recycled fibers content, the number of bacteria in the paper samples increased, while the molds were isolated only in a few paper samples. Additionally, it was concluded that microbial contamination of paper-based packaging containing recycled fibers may potentially cause a health safety risk (Hladíková, et al., 2015). Likewise, Namjoshi, et al. (2010) showed a positive correlation between recycle content and bacterial populations. Additionally, they found that bacteria persist in paperboard over long periods and may reenter the recycling process. According to Johansson, et al. (2001), the possibility of microorganisms and their metabolites migrating from the paper into food is dependent on humidity, pH, temperature and amount of fat or salt. Such migration can be overcome by the use of functional barriers between recycled packaging paper and food (Johansson, et al., 2001). Flemming, Meier and Schild (2013) and Zumsteg, Urwyler and Glaubitz (2017) showed the presence of microbial contamination in paper production, which may lead to economic losses, deterioration of raw materials and lowering product quality.

Even though the re-use of paper increases the microbial charge in the industrial process, the industrial process decreases the number of food-borne pathogens in the paper effectively. Thus, *Escherichia coli* (*E. coli*), *Salmonella*, *Shigella* or confirmed coliform bacteria (Namjoshi, et al., 2010) and *Enterococcus* (Johansson, et al., 2001) were not found in any recycled paperboard product. Despite that, a possible negative impact caused by the remaining microbes on the human health could not be fully excluded (Johansson, et al., 2001). Additionally, Johansson, et al. (2001) reported the presence of endotoxins in recycled material, which was correlated with the amount of recycled material as well, indicating that endotoxins released during paper production and recycling might pose an environmental health problem.

Most microorganisms are harmless, various of them are used in biotechnology for the production of metabolites, enzymes and diseases protection inoculum. Microorganisms are used for bioremediation or fermentation in food processes. Some microorganisms or their enzymes have been used also in pulp and paper industry, such as cellulases and xylanases, which are economically and environmentally friendly. Pathogenic microorganisms like bacteria, viruses, fungi, protozoa, and multicellular parasites can cause diseases for humans and animals, as well economic and environmental consequences.

Considering the fact that the use of recovered paper increases the presence of microorganisms in the industrial process, which in the end has a negative impact on product purity and quality (Johansson, et al., 2001), the focus of this research was on the effects in industry related to a way that ensures product and consumer safety, to present the microbiological purity of recycled fibers derived from different samples, i.e. showing how different printing substrates, inks, nanomodified coatings, and recycling methods, influence the microbial growth on recycled fibers.

2. Experimental

2.1 Materials and preparation of the samples

Microbial purity of recycled paper samples obtained from recycling of different print samples and by different recycling methods was estimated in this study (Table 1).

For the preparation of cyan offset prints, white woodfree uncoated paper made from virgin fibers was used. Cyan offset prints were prepared using the Prüfbau Multipurpose Printability Tester simulating dry offset process. Test strips were printed in the full tone. Although this method introduces ink, and the impact on microbial growth is studied, it lacks the practical presence of fountain solution, which in reality can be a major source of contamination. Printed test strips were mixed with the unprinted paper samples, i.e. when the samples were recycled the total area of print in the recycling mixture was 37 % when com-

pared to the total area of used paper. Prepared cyan offset prints were recycled by means of INGEDE 11 method (INGEDE e. V., 2012) in combination with ultrasound (Badelin Sonoplus HD 3100 with a frequency of 20 kHz) pre-treatment for a duration of 10 minutes and amplitude 70 %. Additionally, enzymatic treatment was applied (BLX 14168, 1-4-endoglucanase, Buckman) instead of chemicals but adopting the same experimental procedure described in the INGEDE 11 method. The enzymatic recycling was performed at 45 °C, pH 7 with 0.125 % enzyme dosage calculated on the basis of oven-dry samples weight (Verma, Bhardwaj and Singh, 2017).

For the examination of microbiological contamination of recycled fibers made from the recycling of paperboard coated with polycaprolactone (PCL) coating and PCL nanomodified coating, the paperboard made from recycled fibers (230 g/m^2, GD2 grade, Umka color) was used. The middle layer of the used paperboard consists of mixed wastepaper and the top layer from sorted white wastepaper. The board is triple coated on the top side and single coated on the back side. The paperboard samples were printed by the offset printing process and coated with PCL coating and PCL nanomodified coating prepared for the improvement of packaging applications, as presented in research by Bota, et al. (2017) (Table 1). The coating was prepared from PCL biopolymer (Aldrich), dissolved in ethyl acetate while heated at 40 °C and stirring about 30 min to obtain 10 % homogeneous solution, using a magnetic stirrer. The PCL nanocomposite coatings were further prepared by dispersing nanoparticles with disperser (IKA T25 digital TURRAX) for 8 min at 15 000 rpm. The nanoparticle amount was calculated on the basis of PCL mass fraction: ZnO and Al_2O_3 were added in a portion of 1 % (samples GC2/PCL/1 % Zn and GC2/PCL/1 % Al) while SiO_2 was added in a portion of 2 % (sample GC2/PCL/2 % Si). The coating was applied using K202 Control Coater in controlled conditions defined by the ISO 187:1990 standard (International Organization for Standardization, 1990). Paperboard samples used in the recycling process were 100 % printed and coated, when compared to the total area of used paper. Prepared paperboard samples were recycled by means of INGEDE 11 method.

During recycling process of printed samples, all the chemicals and their dosages were in accordance to defined procedure described in INGEDE 11 method, except in case of enzymatic treatment. From the prepared pulp suspension, recycled laboratory paper handsheets were prepared on sheet former Rapid-Köthen Sheet Machine (PTI), according to standard method ISO 5269-2: 2004 (International Organization for Standardization, 2004). For each recycling process tap water was used, since the flotation process requires at least 12 L of pulp suspension, while during the handsheet preparation at least 8 L of water is required for just one laboratory paper handsheet production. Thus, the sheet former is connected to tap water supply system. During production of laboratory paper handsheets, the drying process was used, in which the wet pulp, placed between carrier board and cover sheet, was subjected to heating and vacuum drying at 92 °C for 5–7 min.

After each recycling, all the equipment used in the process was adequately cleaned and washed using washing chemicals and large amounts of hot tap water, previously chlorinated. Standard sterilization of the equipment requires sterilization at high temperatures and pressures, which in this case, was not possible due to the size of the devices, while the sterilization with strong chemicals could adversely affect the effective-

Table 1: Samples and recycling methods used for the production of recycled paper

Samples abbreviation	Samples used for production of recycled paper samples	Recycling method
OFFSET-ENZYME	Cyan offset prints (120 g/m^2)	Modified INGEDE 11 + enzyme
OFFSET-INGEDE 11	Cyan offset prints (120 g/m^2)	INGEDE 11
OFFSET-INGEDE 11 + ULS	Cyan offset prints (120 g/m^2)	Modified INGEDE 11 + ultrasound
GC2	GC2 uncoated paperboard (230 g/m^2)	INGEDE 11
GC2/PCL	GC2 PCL coated paperboard (230 g/m^2)	INGEDE 11
GC2/PCL/1 % Zn	GC2 paperboard with PCL coating modified with 1 % Zn nanoparticles (230 g/m^2)	INGEDE 11
GC2/PCL/2 % Si	GC2 paperboard with PCL coating modified with 2 % SiO_2 (230 g/m^2)	INGEDE 11
GC2/PCL/1 % Al	GC2 paperboard with PCL coating with 1 % Al_2O_3 (230 g/m^2)	INGEDE 11

ness of the devices. Thus, the step of devices sterilization is the limiting factor of this research. Additionally, the limitation of the study is microbiological check of recycling devices since this step was not conducted as well.

2.2 Methods for microbiological testing

When planning a microbiological test experiment, firstly the suitable test methods should be chosen. In this study, two methods were used, the smear method and the disintegration method. It is important to emphasize that sterile technique for determination of microbiological growth was used (sterile test tubes, sterile rods, sterile pipettes, sterile Ringer solutions, sterile knife for cutting the paper).

The microbiological testing of the recycled paper laboratory samples was not done immediately after the recycling process was conducted. The samples were tested after some time. But before research was conducted, all samples were preconditioned in the same laboratory conditions for 48 h (23 ± 2 °C, 45 ± 3 % RH) on air. The samples used were not tested for microbiological purity prior to recycling.

2.2.1 Examination by the smear method

Sterile test tubes with sterile Ringer's solution were used for the preparation of different dilutions (10^{-1} to 10^{-10}). A horizontal method of sampling from the surface by using contact was used for the estimation of total number of bacteria and molds in recycled papers, by means of a sterile swab wetted in Ringer solution. As a swab material a commercially available sterile swab placed in sterile polypropylene tube was used. For each test, new sterile swab was used. It means, the swab is free from bacteria or other living microorganisms before sampling the studied samples, and free from any chemicals, bleaching agents, etc. The swab material was not treated with any chemicals or any other sterile technique before or during sampling. After sampling of samples surface, a swab was taken and placed in the sterile test tube, mixed for 30 s and separated by 1 mL of sterile pipette and transferred to another sterile 10^{-1} dilution tube. This procedure is repeated until 10^{-10} dilutions are made. Then, 1 mL of each dilution was placed on nutrient agar Petri dishes with Plate Count Agar (PCA) for bacteria examination and Sabourad Dextrose Agar (SDA) for examination of molds (both commercially available from Komed, Sveta Nedelja, Croatia). The growth media used are non-selective and commonly used to assess or to monitor the "total" number of microorganisms. Petri dishes were incubated at 37 ± 1 °C for 48 ± 3 h for bacteria and 30 ± 1 °C for 5 days for molds under aerobic conditions. After incubation, the total number of colony-forming units (CFU) was estimated.

2.2.2 Examination by the disintegration method

The second microbial purity test was performed using the disintegration method, where 0.1 g of the test paper was disintegrated in a sterile Ringer's solution to obtain a fiber suspension. Recycled laboratory paper samples were disintegrated in the sterile test tube, with presterilized rod. Test tubes with sterile Ringer's solution were prepared and used for the preparation of different fiber suspension dilutions, which were afterwards plated on nutrient agar on Petri dishes with PCA for bacteria examination and SDA for examination of molds. In particular, 1 mL of each dilution was placed onto the Petri dishes and incubated at 37 ± 1 °C for 48 ± 3 h for bacteria and 30 ± 1 °C for 5 days for molds under aerobic conditions. After incubation, the total number of CFU was estimated and the concentrations of bacteria and molds per 1 g of paper were calculated. The experiments were carried out in triplicate. The average values are presented in this study.

3. Results and discussion

Only the total number of bacteria estimated by the disintegration method is shown since the smear method did not produce satisfactory results, i.e. no growth of microorganisms occurred. The similar result was obtained by Guzińska, Owczarek and Dymel (2012) who studied different methods of identifying microbiological contamination of paper and paperboard evaluation (defibering and smear). Despite the fact that smear method is standard procedure in microbiology, from this research and study by Guzińska, Owczarek and Dymel (2012) it can be assumed that this method has some limitations when used in sampling of recycled paper. The problems related to that may have been caused by the presence of the bacteria in the deeper layers or the absence of smooth surface, making the smearing sampling difficult. However, the smear method showed good results when materials containing a water impermeable aluminum foil or plastic coats were examined for microbiological contamination (Guzińska, Owczarek and Dymel, 2012).

During production of laboratory handsheets, the drying process was used, in which the whole laboratory handsheet was subjected to heat not only the surface. Additionally, the surface was not in direct contact with the machine since the pulp was placed between carrier board and cover sheet. Since the whole handsheets were subjected to heat, it could kill the microbes not only on the surface, but inside as well. In addition, the heating process is not expected to kill all the microbes since the complete sterilization process occurs at the temperatures above 120 °C for a minimum duration of 20 min. Despite drying process, moisture is always

present until the sample is fully dry, and so moisture can be present on warming conditions, ideal for microbial growth internally in the paper, which is the last part to become heated. Moreover, the microbiological tests were not performed right after the production of laboratory handsheets. Before the handsheets were tested for microbiological properties, they were placed in the laboratory for 48 h, at the same conditions, on air. During that period the laboratory handsheets were exposed to other external influences (microbes from the air) since they were not stored in sterile conditions.

Within this research, disintegration method showed good results and it was used for identification of microbiological contamination of recycled paper samples. Additionally, no molds or yeasts growth was observed within this experiment, only bacteria. In this study, the microbial growth on different recycled paper samples was studied, as well as the influence of different printing substrates (offset paper and paperboard), different recycling methods (INGEDE 11, INGEDE 11 in combination with ultrasound pretreatment and enzymatic recycling) and the presence of PCL nanomodified paperboard coating on bacterial growth.

Figure 1 shows the influence of cyan offset prints recycling method on microbial purity of recycled fibers. By comparing the obtained results, it can be seen that recycling method affects the number of microorganisms present in the samples. The largest number of microorganisms was isolated in the sample obtained by recycling with the INGEDE 11 method and ultrasound, which may indicate that the recycled fibers contain fewer toxic components that can inhibit the growth of microorganisms. Since in this part of the study, the same sample (cyan offset prints) were used for the recycling, it can be concluded that chemicals and pretreatment methods may affect the microbial purity of recycled fibers. It can be noticed that enzymes in paper recycling process contribute to the reduction of the number of microorganisms and the mentioned method of recycling is the most favorable in the terms of microbial purity (Figure 1). In addition, during the enzymatic treatment, recycling takes place under mild conditions (neutral pH, lower temperature) but during chemical deinking and ultrasonic pretreatment, some extreme conditions occur due to appearance of cavitation. Ultrasonic pretreatment thus more likely causes the stronger damage of cellulose fibers probably resulting in cellulose crystallinity decrease. In addition, the use of alkaline condition in ultrasonic treatment and conventional INGEDE 11 method, causes the higher rate of cellulose crystallinity decrease (increase of amorphous cellulose) compared to enzymatic treatment (Pathak, Bhardwaj and Singh, 2011; Sumari, Roesyadi and Sumarno, 2013; Kumar and Dutt, 2021). Moreover, it is known that amorphous parts of the cellulose are more susceptible to bacteria growth than crystalline regions, thus the lower number of bacteria for samples made using enzymatic recycling process can be found in comparison to samples made from conventional chemical and ultrasonic recycling (van Wyk and Mohulatsi, 2003). Moreover, it is important to emphasize that for the evaluation of microbial abundance in the tested samples in this study, dilution experiments were used. Each sample was tested three times, and for every tested sample, the series of dilutions were made. For this reason, the results uncertainty and somewhat higher statistical errors probably occur from the used methodology and nonrandom spatial distribution of the bacteria in dilutions.

The growth of bacteria on cellulose fibers after recycling of offset prints can be seen in Figure 2.

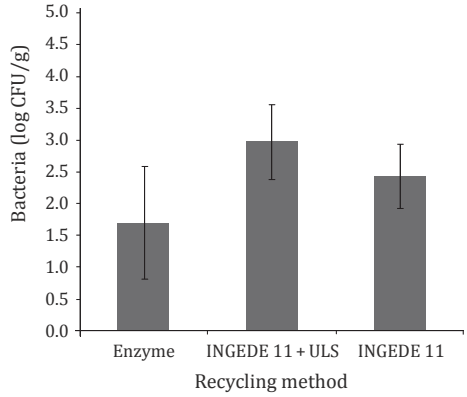

Figure 1: Influence of the offset prints recycling method on the total number of bacteria

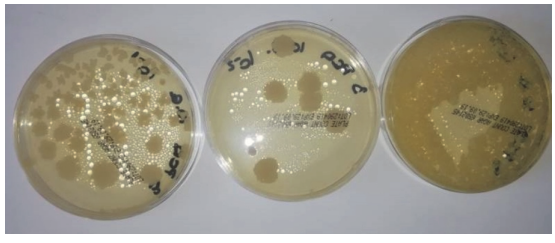

Figure 2: Example of bacterial growth on coated paperboard in different dilutions

Even though the best microbiological properties of the recycling procedures are obtained by the enzymatic deinking (Figure 1), for the evaluation of microbial purity of recycled paper obtained from recycling of paperboards, INGEDE 11 method was used for their recycling due to its frequent use in the paper industry. The use of INGEDE 11 method indicates how printed products will perform in an industrial deinking operation and is widely used by the paper industry and by many stakeholders in the paper value chain. This is the reason why it was used as a model

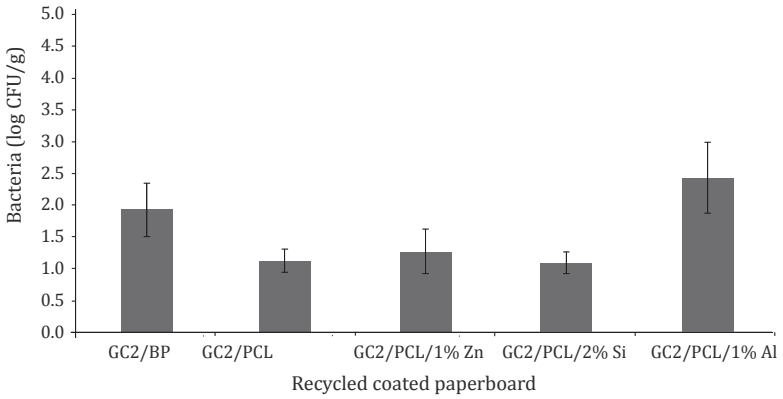

Figure 3: Influence of the coating formulation on paperboard surface on the total number of bacteria

for development of standardized procedure to simulate the principle process steps for ink detachment and ink removal under standardized alkaline conditions at a laboratory scale, namely in ISO 21993:2020 (International Organization for Standardization, 2020).

The results show that the presence of PCL coating and PCL coating modified with nanoparticles in wastepaper can affect the microbial purity of recycled fibers (Figure 3). Smaller number of bacteria was observed for the samples containing PCL coating and PCL coating modified with Zn and Si nanoparticles, which means that they show antibacterial properties. Al nanoparticles do not show significant antibacterial properties, unlike Si and Zn nanoparticles, probably due to the different properties of nanoparticles and their interaction with bacteria.

According to Zhang, et al. (2014) aluminum has no antibacterial function. Additionally, there is a possibility that nanoparticles were washed out into the wastewater stream during paper recycling resulting in lower degree of antibacterial properties.

The study of PLA coated paper containing ZnO nanoparticles recycling (Zhang, et al., 2016) showed that 86–91 % ZnO nanoparticles ends up in the rejected material stream, mostly embedded within the polymer coating, while 7–16 % nanoparticles end up in the accepted fiber material stream. The lack here is that their presence in the process water cannot be completely ruled out since their concentration was not directly measured. The authors are of the opinion that nanoparticles may accumulate in the white water system during paper recycling process due to coating fragmentation and migration to water streams.

The antibacterial properties of nanoparticles are due to their small size, i.e. nanoparticles can behave as molecules when interacting with a cell, which allows them to easily penetrate the cell membrane and interfere in vital molecular pathways if the chemistry is possible (Nastulyavichus, et al., 2019). ZnO nanoparticles exhibit strong antibacterial property over a broad range of microorganisms, i.e. ZnO shows more pronounced effect on Gram-positive (*Staphylococcus aureus*) than Gram-negative (*E. coli* and *Pseudomonas aeruginosa*) bacteria, and the bactericidal efficacy was found to increase by decreasing the particle size (Yemmireddy and Hung, 2017). According to Jia, et al. (2019) antibacterial and antifungal activity of ZnO nanoparticles is related to the release of Zn^{2+} ions, and mainly caused by the attachment of ZnO nanoparticles to the bacterial cell wall.

The antibacterial effect of the Si-nanoparticles can be assigned to their attachment on the bacterial outer wall resulting in the mechanical damage of the bacterial membrane related to the oxidative effects of the amorphous Si nanoparticles generated singlet oxygen and reactive oxygen species or due to photodynamic inactivation by the singlet oxygen, that is usually generated on the surface of Si nanoparticles during their production in water and alcohol, which leads to significant oxidative damage of the biological object and DNA damage (Smirnov, et al., 2018). Due to silanol groups interaction with bacterial wall's functional groups by hydrogen bonds, destabilization of the peptidoglycan (bacterial wall) occurs (Mustafa, 2018).

Components present in paper (fillers, chelating agents, etc.) and printing inks and their constituents (i.e. heavy metals) may affect the development of microorganisms, i.e. they may show antimicrobial properties (Muñoz-Bonilla and Fernández-García, 2012; Lemire, Harrison and Turner, 2013). The results show that a higher number of bacteria developed on recycled paper samples made from offset prints compared to recycled samples made of nanomodified coated paperboard (Figure 4). This behavior is likely to arise from two possible scenarios. First, the paper used for cyan offset prints, itself is cleaner than the paperboard

used for printing and coating with PCL nanomodified coating. Therefore, there is a smaller number of toxic components as well. Second, the recycling of cyan offset prints was made in such a way that the total print coverage was 37 % of the total weight of the recycling paper (the rest was unprinted paper). When recycling nano modified coated paperboard, 100 % of the prints were recycled (paper was not mixed with unprinted paper). This would mean that a small amount of the printing ink present in the prints has a negative effect on the development of the bacteria, i.e. the constituent components of the printing ink are likely to be toxic to bacteria.

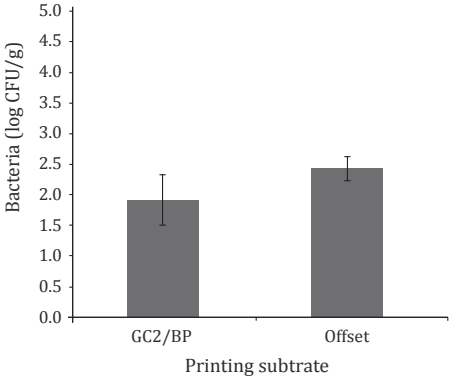

Figure 4: Influence of printing substrate on the bacterial growth (GC2/BP – uncoated paperboard, offset – offset paper) recycled by means of INGEDE 11 method

When talking about microbial purity of recycled fibers, it is generally necessary that the total counts of yeasts, molds and bacteria must be as low as possible without presence of pathogenic bacteria, including *E. coli* and other enterobacteria (Suihko and Skyttä, 1997). It should be noted as well that some of the pathogenic microorganisms in the recycled and virgin paper pulp can be destroyed in the process of paper bleaching by the action of oxidizing agents or due to high temperatures present for example in the repulping process and paper drying.

4. Conclusions

The results of this study show that disintegration method is suitable for the isolation of bacteria from recycled paper, unlike smear method. The possible explanation of the obtained results probably lies in the fact that inner parts of the paper (deeper layer of paper) due to higher moisture content contain higher number of bacteria. Moreover, it is possible that the smear method has limitation when used in paper sampling due to rougher surface. Additionally, the disintegration method used was only valid for isolation of bacteria because no molds or yeasts were found. Obtained results indicate that paper components can influence the bacterial growth. Paperboard, which is made of recycled fibers and therefore contains a certain number of toxic components acting against bacterial growth, will give a smaller number of bacteria than offset paper. Additionally, a greater amount of printing ink in the samples may have an antibacterial effect as well. The recycling method itself will also affect the growth of bacteria, i.e. cleaner fibers will provide more bacteria. With nanomodified PCL coatings, the nanoparticles themselves can also act antibacterial. Pathogenic microorganisms in the recycled and virgin paper pulp can be destroyed in the process of paper bleaching by the action of oxidizing agents or due to high temperatures present in repulping process and paper drying. Moreover, the process of paper drying can have some influence on the microbiological growth. In the future, research should be conducted on different nutrient media to determine whether their composition has an impact on bacterial growth. Additionally, it is important to emphasize that the paper samples used were not tested for microbiological purity prior to recycling, and thus it can be assumed that microbial presence after a period of time following recycling could have originated from a range of contamination sources. Thus, all the future research should involve the study of incoming paper samples prior to recycling in order to get a better insight into the bacterial contamination of recycled paper samples and the influence of paper components on microbial growth.

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JPMTR-2118
DOI 10.14622/JPMTR-2118
UDC 655-028.25:686.4

Review paper | 158
Received: 2021-12-17
Accepted: 2022-02-15

Printing methods used in the label and package printing industry for the production of metallic embellishments with a focus on metal effect pigments

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Abstract

In the label and package printing industry, many methods are used for the application of a metallization on a substrate for graphical purposes. By applying metals like aluminum and copper-zinc on a substrate, outstanding visual effects can be achieved. It is shortly discussed why metallic surfaces appear different compared to non-metallic surfaces and what kind of terms can be used to describe a metallic appearance. Further, different printing methods for metallization are categorized according to the form of the initial metallic material used for the given printing method. It is distinguished between methods using metallic pigments with and without printing ink and metallic foils. Special attention is paid to the printing methods using aluminum pigments in printing ink. The appearance influencing properties of aluminum pigments are listed and different methods of their production are described. The influence of the different ink systems on aluminum pigments and printing methods using these inks are outlined. Furthermore, printing methods using metal effect pigments not incorporated in an ink such as bronzing and the EcoLeaf technology are shortly explained as well as different metallization methods using foil directly involved in the printing process like foil fusing, foil transfer and foil stamping methods.

Keywords: metallic pigments, metallization, metallic effects, print

1. Introduction

Over the past 30 years, the use of metallic pigments on printed products has increased, and today printed products on which at least partial metallic effects can be found are everywhere. For instance, they can be found on chocolate boxes, high quality greeting cards, perfume wrappings, gift wrap papers and labels of cosmetic products or alcoholic beverages, on the packaging of tobacco products or book covers (Freeman, Chapman and Rimmer, 2008; Kehren, 2013; Pfaff, et al., 2021). By applying special effects such as metallic effects on printed products, the noteworthiness and aesthetic value can be greatly improved, compared to reference samples without special effects (Bertholdt and Müller, 2014; Laine, Leppänen and Nurmi, 2009). Hence, by applying metallic effects on packaging, a product can stand out from the mass of the offer and can influence a customer at the point of sale (Silvennoinen, Peiponen, and Myller, 2008; Wißling, 2013). Research has shown that purchase decisions are strongly influenced by the attractiveness of a product and by how much it stands out. The more the packaging of products draws the attention of a customer, the more likely it is purchased (Clement, 2007; Hartmann and Haupt, 2019).

Already thousands of years ago, the attracting effect that is caused by metallic effects on products was realized. Early civilizations, for instance the Egyptians, worked gold into thin sheets and applied it on wood, bones or other materials (Wheeler, 1999; Pfaff, 2017). One religion that early used special effects for books extensively, among others also the application of gold, was the Manichaeism, which spread widely starting in the 3rd century AD not mainly because of its ideas but mostly because of the attractive visual appearance of its books (Monro, 2014). According to MAN Roland Druckmaschinen (2002), in Germany, the first ones who used metallic embellishments in no relation to religious usages were brewers and winemakers in the

19th century who produced bottle labels with golden, silver, and bronze effects. In the label and package printing industry real gold is not applied due to its high cost. Today, the material used to create metallic effects in all kinds of colors is mainly aluminum while copper-zinc pigments are only used to some extent (Wicks, et al., 2007; Pfaff, et al. 2021). Aluminum can relatively easy be processed to foils or pigments and its application can result in a metallic effect (Wheeler, 1999). According to Krietsch (2021), in the label and package printing industry, the proportion of aluminum pigments to copper-zinc pigments is about 70 % to 30 %. Copper-zinc pigments provide for a shiny gold effect. Aluminum pigments provide for a metallic appearance without hue and can be overprinted with any color to obtain a colorful metallic effect.

1.1 Classification of printing methods for producing metallic embellishments

In a general sense, printing is the replication of originals. In 2D graphic printing, the focus is on the correct reproduction of color information as well as textual and pictorial information on a substrate (Meyer, 1999; Hupp, 2008, p. 3). In a wider sense, graphical printing does not only regard the reproduction of color information but moreover, the reproduction of appearance information, which besides color also includes texture, translucency and gloss. In this review, not only printing methods using conventional printing processes i.e. printing processes with a printing plate such as offset, flexo, gravure and screen printing but also inkjet printing, electrophotography, bronzing and the EcoLeaf technology are reviewed as well as those involving foil in the printing process. In this paper, the word "film" is used to describe thin polymer films. The word "foil" is used to describe a thin metal surface that is applied on film and can be removed from it or transferred to a substrate.

The methods used for the metallization of a substrate in the label and package printing industry can be divided into two general categories. First, those methods that use metal effect pigments which are either dispersed in printing ink or not dispersed in printing ink. Second, methods that use some sort of foil, which is directly involved in the printing process. A schematic for the classification of the different methods can be seen in Figure 1. Which method is best suited for a specific product is dependent on the subject to be printed, the number of copies, substrate, available machines and material and further processing steps (Morlok and Beckmann, 2009).

Depending on the printing method, parameters within the process and the material used, the appearance of the metallization can differ greatly. Figure 2 shows this on the basis of eight samples. They have been metalized by foil fusing, cold foil stamping, gravure printing, flexo printing and offset printing.

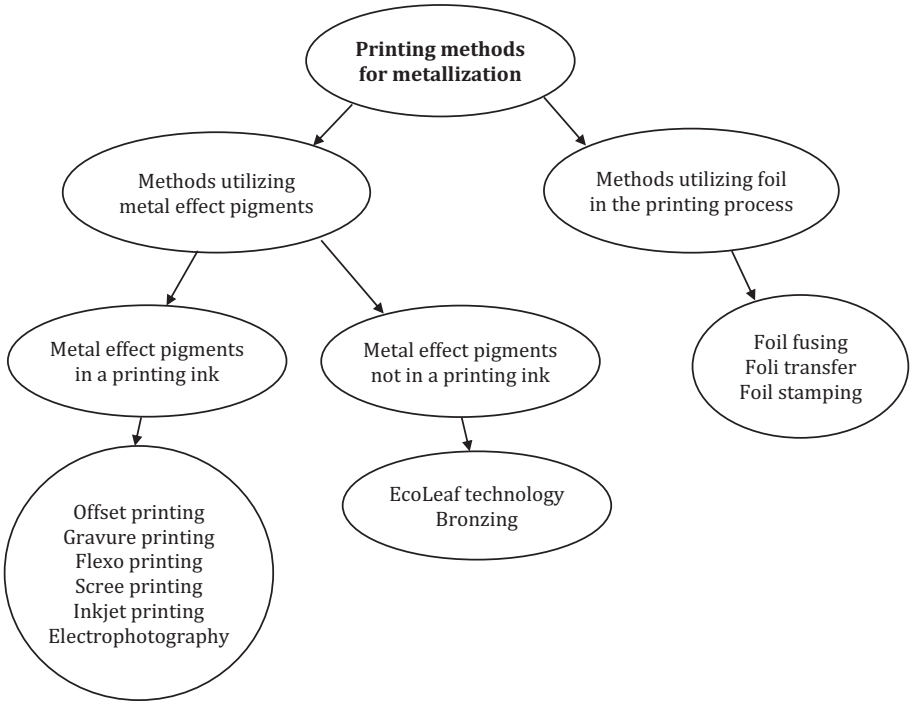

Figure 1: Classification of methods used for the production of metallic embellishments in the label and package printing industry

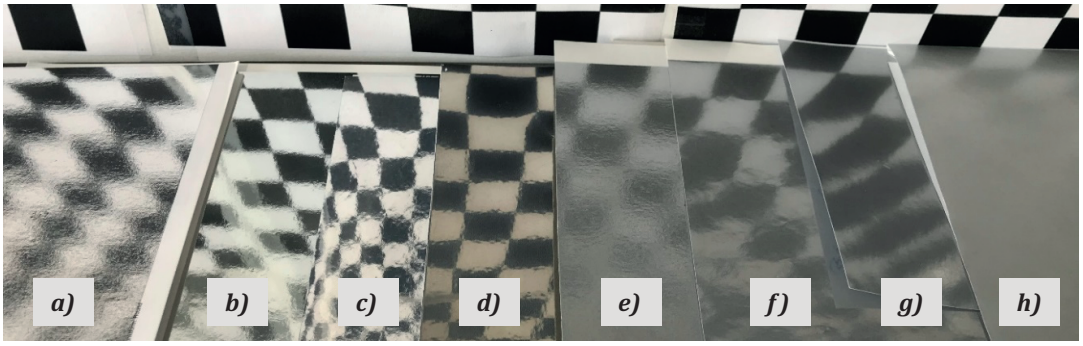

Figure 2: Printed metallic gloss samples made by foil fusing (a), cold foil stamping (b, c), gravure printing (d), flexo printing (e to g) and offset printing (h); the samples were photographed in front of a checkerboard pattern (Weber, Spiehl and Dörsam, 2021a)

2. Appearance of metallic surfaces

Metallic surfaces look different from e.g. paper or plastic surfaces due to the specific peculiarities of metal on the atomic level. Commonly used terms to describe the metallic appearance are briefly explained.

2.1 Peculiarities of metal on the atomic level with effects on the appearance

According to Nassau (2001), the metallic effect that is perceived due to the high reflectivity of a metallic surface has its origin in the interactions between the metallic atoms in the material. The root of the shiny metallic appearance with its high reflectivity is the delocalized nature of the valence electrons with their ability to move freely through a piece of metal. When dealing with an insulating material, the percent reflectivity R for a beam of light falling onto the material at normal incidence is given by Equation [1] as stated by Nassau (2001, p. 165).

$$R = 100\,\% \frac{(n-1)^2}{(n+1)^2} \qquad [1]$$

The refractive index of the material is n which is defined as the ratio of the phase velocity of light in vacuum to the phase velocity of light in the goven material (Hass and Hadley, 1972). Typical glass has a refractive index of about n = 1.5, which results in a reflectivity of about R = 4 %. Hence, most of the light is transmitted into the glass and absorbed and only a small part is reflected (Nassau, 2001, p. 165). As mentioned by Nassau (2001, pp. 162–166), metal behaves different to that. If light falls on a metallic surface it is so intensely absorbed that it can only penetrate it into a depth of a few hundred atoms, typically less than a single wavelength. The absorbed light, which is an electromagnetic wave, induces alternating electrical currents on the metal surface. These currents cause the immediate remittance of light out of the metal, which leads to a strong reflection. For the refractive index for metals, N, a complex component is added which results in Equation [2] as stated by Nassau (2001, p. 165).

$$N = n + ik \qquad [2]$$

where k is the coefficient of the absorption that is related to the exponential decay of an electromagnetic wave as it passes through the regarding material (Hass and Hadley, 1972). According to Nassau (2001, p. 165), the percent reflectivity with k now becomes

$$R = 100\,\% \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \qquad [3]$$

For an aluminum sample, under sodium illuminant (sodium D lines, which denotes light at a wavelength at around 589 nm), the values n = 1.2 and k = 7.1 result in a reflectivity of R = 91 %.

2.2 Terms to describe the appearance of a metallization

The optical impression one gets from metallic surfaces is due to a combination of directional reflection and scattering of light (Wißling, 2013). Terms that can be used to communicate a “metallic” appearance are introduced in the following.

Gloss: Metallized surfaces are often described to appear glossier than non-metallic surfaces. Beneath color, texture and translucency, gloss is a visual perception attribute that describes the perceived appearance of an object. It can be subdivided into various different aspects such as specular gloss, haze or distinctness of image. Weber, Spiehl and Dörsam (2021b) describes aspects of gloss that can be measured with commercial gloss meters in greater depth. Contrast gloss is described by Hunter and Harold (1987) as the contrast

between specularly reflecting areas and non-specularly reflecting area of one material. Leloup, Audenaert and Hanselaer (2019) introduce a gloss meter that enables for the measurement of contrast gloss.

Luster: Pfaff, et al. (2021) points out that "the term 'luster pigments' is also often used for effect pigments because almost all effect pigments provide lustrous effects in their applications". Often, metallic surfaces are described to have "a rich luster." However, it is not well defined how luster differs from flop or contrast gloss of metallic surfaces and which surfaces can be described with the term. According to Hunter and Harold (1987, p. 79), luster is usually used in the textile industry to describe the contrast between areas of one material that are in the specular angle of light reflection and areas that are not in the specular angle and thus only reflect diffuse light to an observer. According to McCamy (1996), the term luster is also appropriate for metals due to the similarity of metallic paint on a cylinder compared to satin wrapped around a cylinder. In ASTM E284 – 17 (American Society for Testing and Materials, 2017) it is noted that the term luster is not used for surfaces that are as glossy as to form clear mirror images.

Lightness: Lightness is an attribute of color perception by which the color of a non-self-luminous body is judged equivalent to a series of neutral ranging from black to white in terms of reflected light (American Society for Testing and Materials, 2017; Berns, 2019). It is communicated using the L^* value of the CIELAB system.

Brilliance: The term brilliance is used in some publications on metallization, such as Wißling (2013), to describe a metallic appearance. However, according to Kirchner, et al. (2007), the term brilliance is not well defined and it is unclear how it is different to other phenomena such as gloss or sparkle.

Flop: The change of appearance of e.g. gloss or color with the viewing angle of a metallic surface is called flop (Wheeler, 1999; American Society for Testing and Materials, 2017; Nanetti, 2016). McCamy (1996) describes the measurement and calculation of flop in detail. In some scientific publications flop is used to characterize the appearance of a coating containing metal effect pigments. However, Bertholdt and Müller (2014) and Rich, et al. (2017) state that flop does not track the visual assessments of printed metallic ink well.

Visual texture: Kirchner, et al. (2007) defined two texture parameters that describe the visual texture under two different illumination conditions, which are directional lighting and diffuse lighting. Those two parameters are glint impression and diffuse coarseness. Visual texture refers to the perceived small-scale non-uniformity of an effect coating when viewed from a distance of a meter or less.

Glint impression: According to Kirchner, et al. (2007), glint impression is the impression of tiny light spots (glints) that are much brighter than the surrounding. These glints turn on and off as the observation or illumination geometry using unidirectional light is changed.

Diffuse coarseness: According to Kirchner, et al. (2007), diffuse coarseness describes the perceived contrast in the irregular light/dark pattern that can be exhibited by metallic effect coatings under diffuse illumination conditions.

Sparkle: The appearance of small bright points that appear to be much brighter than their surrounding and that is especially apparent if the observer, specimen or the light source are moved is called sparkle (American Society for Testing and Materials, 2017). While sparkle refers to small highlights widely separated from each other, the term glitter that is also used in some publications described a "grainy finish" (Kirchner, et al., 2007). Ferrero and Bayón (2015) and Ferrero, et al. (2021) describe the measurement of sparkle in detail.

Opacity/hiding power: The covering capacity of an ink is described as hiding power and opacity. It is "the property of an ink film that enables it to prevent the passage of light and thereby to hide the substrate on which it has been applied" (Schaeffer, 2012). According to Wißling (2013), this term is especially important for inks containing metallic pigments as the opacity of those depends on the pigment size distribution. The more fine-grained the pigments the better the hiding power.

2.3 Remarks on the communication of metallic appearance in the printing industry

Although a lot of research has been conducted in the field of the characterization of metallic appearance (Rich, et al., 2017; Rosenberg, 2000; Bertholdt and Müller, 2014; American Society for Testing and Materials, 1968) there are still no standardized methods widely applied in the printing industry to communicate the appearance of metallic embellishments. Most print shops rely on the subjective appraisal of experienced staff or the measurement of specular gloss in the 60° angle to judge and compare metallic embellishments. However, these two methods of judgement can lead to problems. The subjective appraisal can fluctuate from day to day, and depends on a specific person. Furthermore, it is still hard to communicate a

subjective appraisal. Also, for metallized samples the measurement of the specular gloss fails to capture the perceived gloss precisely and cannot be used well for the comparison of samples that have been metallized using different printing methods. A further problem that arises when using gloss meters for the measurement of metallized print products is the lack of defined fields for measurement on the print control strip. This can make the measurement of gloss of the metallized parts of the print product impossible, as these are often smaller than the measuring field of the instrument.

3. Metal effect pigments

Reasons why methods using pigments could be chosen for metallization instead of using foils is their high flexibility that allows spot-wise application and could prove as cost saving in the case of spot-wise application compared to using foils. The application of inks containing metal effect pigments could also be chosen, if no foil application module is available in the machines used by the printer.

3.1 Categorizing metal effect pigments

As stated by Buxbaum and Pfaff (2005), the historic meaning of the word "pigment" which has its origin in the Latin language (pigmentum) is "color". The modern meaning of the word originates from the 20th century.

According to DIN 55943-1993-11, which got withdrawn due to reasons unknown to the authors (Deutsches Institut für Normung, 1993; 2019), a pigment is a substance consisting of particles that are insoluble in the application medium and that are used as a colorant, for its corrosion-inhibiting or magnetic properties. Pigments can be divided into organic and inorganic pigments. Metal effect pigments belong to the inorganic effect pigments (Brock, Groteklaes and Mischke, 2000; Deutsches Institut für Normung, 2011; Kipphan, 2000; Pfaff, 2017). Their optical effect is based on the directional reflection from predominantly flat and aligned metallic pigment particles.

The main differences between metal pigments and organic pigments are particle size, specific gravity and particle geometry (Wheeler, 1999). While conventional light-absorbing pigments are spherical particles with diameters below 1 µm, metal effect pigments are 100 to 1000 times larger and are shaped like thin flakes with diameters of up to 200 µm (Benzing, et al., 1992; Wheeler, 1999; Brock, Groteklaes and Mischke, 2000; Maile, Pfaff and Reynders, 2005; Pfaff, et al., 2007). The shape factor of the metallic pigments that describes the ratio of thickness to diameter is between 1 : 50 and 1 : 500 (Brock, Groteklaes and Mischke, 2000).

3.2 Appearance influencing properties of metal effect pigments in a printed layer

The key characteristics that directly affect the optical properties of a printed metallization using metal effect pigments are the size, shape, surface roughness, spatial orientation, concentration and size distribution of the flakes as well as their distribution after printing (Eckart, n.d.; Sung, et al., 2002; Wißling, 2013). These properties can influence all the appearance characteristics mentioned in section 2.2. The different properties influence the appearance as follows.

Pigment size: The larger the size of the pigments used, the greater the reflective share of every pigment which leads to an increased lightness and flop. Additionally, for the reason that the edges of the pigments contribute highly to the scattering of light (edge effect), the reflection is clearer if the ratio of the surface area to the amount of edges of the pigments becomes greater (Sung, et al., 2002; Wißling, 2013). Furthermore, the smaller the pigment size the more opaque the ink layer (Kipfmüller, 2013). If the d_{50} size of the pigments is below 1 µm, they are too small to act as a mirror and light is scattered (Prölß, Trummer and Kröll, 2007). As described by Wißling (2013), d_{XX} is a measure for the average particle size distribution. Therefore, d_{10} means that 10 % of all particles are smaller than the value specified and 90 % are bigger. The d_{50} means that 50 % of the measured particles are bigger and 50 % are smaller than the given value.

Pigment shape: As described by Wißling (2013), the shape of the pigments also influences the ratio of the surface area to the amount of edges. In case of coarse pigments, there is a higher amount of edges and the light gets more scattered. In the case of round pigments, the edge amount of every pigment is at its minimum and the light gets scattered less. Additionally, the thickness is an important shape factor. The thinner the pigments the better their parallel orientation. However, the thicker the pigments the greater their hiding power (Brock, Groteklaes and Mischke, 2000).

Pigment surface roughness: The greater the roughness of the pigment surface, the more light is scattered and the lower the gloss and clarity of the reflection (Wißling, 2013).

Pigment size distribution: As described by Wißling (2013) and Wheeler (1999), a tight size distribution of the pigments leads to a brighter visual effect than a wide span value with pigments of the same median size. This is because there are less larger flakes that disrupt the smooth orientation and fewer small particles that lead to a darker appearance though they are contributing to the hiding power. McCamy (1998) states

that a high concentration of small pigments leads to a more uniform look and to no noticeable sparkle even if the illumination is highly directional. Pigments with a large surface area lead to sparkle.

Orientation of the pigments: According to Sung, et al. (2002) and Wißling (1999), the orientation of the metal effect pigments is a very important aspect. The better the flat orientation of metal effect pigments after their application on a substrate, the higher the measured gloss values of a surface. Bertholdt and Müller (2014) state that platelet shaped metallic pigments can experience a tilt in the printing direction. In this case, the visual impression of the metallic effect is different in the printing direction from against the printing direction.

Leafing und non-leafing properties of metal effect pigments: As described by Becker, et al. (2018), Rich, et al. (2017) and Wißling (2013), pigments used in printing inks can have leafing and non-leafing properties. As described by Pfaff, et al. (2021) this is linked to the wetting behavior of the pigments. Leafing pigments float up to the surface of an ink layer while there is still a thin layer of polymeric coating on top of the pigments. Thus, they are not exposed to air. Non-leafing pigments with favorable wetting behaviors are equally distributed in the ink film. Inks with non-leafing pigments can more easily be overprinted with color inks. While leafing pigments tend to lead to a brighter and higher gloss, the non-leafing pigments are more scratch resistant. The wetting behavior of the pigments is determined by the additives used in the production process and by the additives used to prevent chemical reactions of the pigments in the ink. The distribution of leafing and non-leafing pigments in an ink layer is shown in Figure 3.

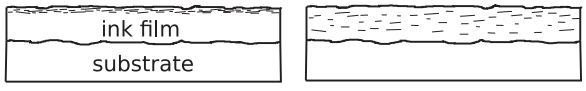

Figure 3: Distribution of leafing (a) and non-leafing (b) aluminum pigments in ink

Pigment dispersion: As reported by Eckart (n.d.) and Pfaff (2017), the dispersion of the pigments in an ink and the even distribution of these is a further influencing factor. If the pigments are not well dispersed, they tend to aggregate in the ink, which finally results in lower gloss of the printed product as well as in a "salt and pepper effect". The pigment aggregation also leads to an increased need of ink to obtain the desired hiding power. Hence, proper dispersion equipment is needed prior to the printing process while considering the flaky shape of the pigments that does not allow for high shear forces. Krietsch (2021) and Wyss (1989) recommend cone shaped stirrers for the preparation of an ink prior to printing as shown in Figure 4. By using these sorts of stirrers it is possible to achieve homogenous stirring without strong turbulences and shear forces and hence not damaging sensitive substances like the thin metallic pigments.

Figure 4: Cone shaped stirrer

Protective layer on pigments: Wißling (2013) explains that in many applications metal effect pigments have to be protected from corrosion or other chemical reactions between the pigments their surrounding have to be inhibited. For the reason that light is scattered on the protective layer, the visual appearance is influenced as the gloss decreases with the application of a protective layer. As described by Wißling (2013) and Schlenk (2008) the pigments can be stabilized by treating them using organic phosphorus compounds or by coating them with silica. Organic phosphorus compounds are more in use in the printing industry because the scattering of light is relatively small. Silica layers are mainly used in the car industry because they can make pigments weather-resistant.

3.3 Production methods and different types of aluminum pigments

According to Smalley (1924, cited in Edwards, 1927, p. 9), the inventor Sir Henry Bessemer was the first to invent an industrial process in the 19th century for the production of bronze powder in order to obtain a gold-colorant. If the pigments are mainly made of aluminum, high purity aluminum (min. 99.5 %) is used because the purer the aluminum the more stable it becomes in its chemical form (Kokot and Kleeberg, 2013; Wheeler, 1999; Wißling, 2013).

Today, there are two common methods for producing different types of aluminum pigments with different properties. One of the methods is the wet milling process. In this process ball mills are used to produce "cornflake" and "silverdollar" pigments. Using the physical vapor deposition process, vacuum metallized pigments (VMPs) can be produced.

3.3.1 Conventional production method by wet milling

The conventional production method of aluminum flakes is the wet milling process. Wheeler (1999) and Wißling (2013) describe it. Here, first aluminum granulate is produced by atomizing melted aluminum. Afterwards, the aluminum cools down immediately. This aluminum grit is given to the ball mill, which is partly filled with steel grinding media. Then a lubricant, in this case a long chain fatty acid, typically oleic acid or stearic acid or white spirit, is added to prevent cold fusion and to achieve the desired leafing or non-leafing properties. When adding stearic acid, leafing flakes are produced while the adding of oleic acid leads to the production of non-leafing flakes. Additionally, a high boiling aliphatic hydrocarbon blend is added to form a mobile slurry. During milling, the particles become so thin that they begin to break up. The median particle size of the thin metallic flakes produced is typically thinner than 1 µm (Maile, Pfaff and Reynders, 2005; Wheeler, 1999; Wißling, 2013). Brock, Groteklaes and Mischke (2000) states that the grinding time and the type and quantity of grinding aids already adjust the pigments for their subsequent properties and area of application. According to Wheeler (1999) and Wißling (2013), the flakes produced through the wet milling process are called cornflake pigments due to their irregular shape and their resemblance to breakfast cereals. By using special, very fine aluminum grit and a gentler, time-consuming milling process that involves smaller, more expensive grinding media, silverdollar pigments can be produced. Due to their extremely narrow particle size distribution their application leads to better optical effects, compared to cornflake pigments. They are the brightest and most brilliant metal effect pigments that can be produced by a milling process but their covering power is only moderately. Due to the strong mechanical forces on the cornflake and silverdollar pigments during production their surface is rougher than compared to pigments produced in the physical vapor deposition process (Pfaff, et al., 2021).

3.3.2 Physical vapor deposition process

Vacuum metallized pigments (VMPs) achieve the highest gloss of all metal effect pigments. According to Eckart (n.d.), using the right print application it is possible to obtain similar gloss effects compared to using foil printing methods. Levine, et al. (1982), Wheeler (1999) and Krietsch (2021) describe that for the production of VMPs, first a thin polymer film is coated with a release layer by gravure printing. Afterwards, a layer of 40–60 nm of aluminum from the gas phase is applied onto the release layer. This process of metallization takes place under very high vacuum while several layers of release layer and aluminum can be applied on one film to obtain a higher yield. Hereafter, the aluminum layers are released from the film in a solvent bath under ambient pressure. In a further process, the released aluminum is reduced to small flakes until they reach the desired size distribution. The process of reducing and treating of the VMPs can take several days.

As stated by Wißling (2013) and Wheeler (1999), the aluminum layer applied on the film has nearly the same smoothness as the film itself and therefore, the surface of the resulting pigments also has a very smooth surface, which reduces the scattering of light. Additionally, due to their small thickness, the pigments do not hinder each other so much in their alignment to the coating surface after printing when comparing them to the thicker cornflake and silverdollar pigments. Hence, in terms of gloss and mirror-like appearance, VMPs are far superior over cornflake and silverdollar pigments. The costs of the VMPs are very high compared to cornflake and silverdollar pigments due to the very high vacuum provided for the process, the vaporizing of aluminum and the long time needed for the treatment of the pigments.

If VMPs are used in UV-curable inks, they necessarily become leafing pigments due to the treatment with organic phosphorus compounds that makes them float. In solvent-based inks (e.g. ethyl acetate ink systems) the same pigments can be used as non-leafing pigments because they do not need a protective layer in this case (Krietsch, 2021).

4. Printing methods for application of metal effect pigments in printing ink

Substrates can be metallized using metal pigments incorporated in printing ink. The printing methods mentioned in this section can be used to apply these inks onto the substrate.

4.1 Composition of printing inks and the influence on the appearance

According to Kipphan (2000) and Teschner (2017), printing inks are made up of colorants (pigments or dyes), binders, additives, and solvents. The ink transfer mechanism and the type of drying/fixing of the ink on the substrate determine the structure and the components of a printing ink and hence influence the metal effect pigments used. The commonly used drying and curing systems to produce metallic embellishments by applying ink with metal effect pigments to a substrate are solvent-based inks, water-based inks, UV-curable inks and oil-based inks. The system used influences the resulting appearance. As stated in Eckart (n.d.), when comparing solvent-based, UV-curable and water-based systems, solvent-based systems lead to the highest

gloss and brightness, followed by the UV-curable inks, while water-based systems represent the greatest challenge. Oil-based inks normally also do not lead to results with a high gloss.

4.1.1 Solvent-based inks

Solvent-based inks contain a large amount of solvent that evaporates after printing, leading to a shrink of the ink layer of up to 70 %. Additives and one or more binders are also part of the ink. Small amounts of binder in solvent-based inks result in high brilliance and hiding power (Eckart, n.d.).

As described by Karlsson, et al. (2008) and Wißling (2013), out of the ink systems used for printing inks, the stability of the aluminum pigments is best in solvent-based inks. This also means that there is not necessarily a need for protecting the pigments with a protective layer against corrosion, which would reduce their optical properties. Additionally, pigments in solvent-based systems align very well to the substrate surface because they are pressed against it as the solvent vaporizes and the wet film shrinks. The lower the viscosity of the coating film, i.e. generally the higher the proportion of solvent in the coating, the better the alignment. Hence, metallic gloss is easier to achieve with low concentrated inks than with high concentrated ones. For environmental and legal requirements, solvent-based inks are less and less used while it is desirable to develop water-based inks.

4.1.2 Water-based inks

In general, the mechanism for orientation of the pigments is the same as for solvent-based inks: the water-based media evaporates and due to the shrinking of the film, the pigments are aligned along the substrate surface. However, as described by Eckart (n.d.), water-based inks are microscopically inhomogeneous due to organic binder suspended in water. During drying, the film does not shrink as much as compared to solvent-based systems. The change of viscosity during drying does not favor the pigment orientation and the dried ink layer is thicker than that of solvent-based systems. The binder particles do not always flow into each other to create an optimal film, which creates light scattering points, which leads to less gloss.

Additionally, water-based media present great challenges for the application of aluminum, as well as gold bronze pigments because they are prone to react with water what can result in a grey, non-glossy appearance of the final print product. According to Wißling (2013), the reaction of "gassing" that takes place with unprotected aluminum pigments in water is as shown in Equation [4].

$$2\,Al + 6\,H_2O \rightarrow 2\,Al(OH)_3 + 3\,H_2 \qquad [4]$$

Additionally, to the out-greying of the pigments, the hydrogen can cause pressure in the ink containers that can even cause punching of the container and explosions (Eckart, n.d.; Karlsson, et al., 2008; Li, et al., 2008; Wheeler, 1999; Wißling, 2013). Hence, a highly requested demand for aluminum pigments is a good resistance against "gassing" in water-based media (Wißling, 1999). This protection is achieved by treating the pigments with a layer of organic phosphorus compounds or by coating the surface with silica.

4.1.3 UV-curable inks

According to Eckart (n.d.) and Kipfmüller (2013), UV-curable inks are also called 100 % systems, which means that the full layer is cured and nearly no evaporation takes place. Metallic UV-curable inks need to have a higher reactivity than conventional pigmented UV-curable inks because the metallic platelets act as small mirrors that prevent the UV-rays from penetrating deep into the ink layer. Hence, the amount of pigments, binder and photo initiators has to be matching, otherwise the ink is not cured optimally.

In UV-curable inks, silicate and polymer-coated aluminum and bronze pigments are used. Uncoated aluminum and bronze pigments catalytically induce polymerization of the binder components (Eckart n.d.; Wißling, 2013). This in return means that residual chamber material from the printing machine is not recommended to be mixed with fresh ink because the damage on the stabilization of the flakes that can occur during the printing process leads to a chain reaction and therefore to pre-polymerization of the ink (Eckart, n.d.). The coating of the pigments can result in a lower gloss of the print result but it is not regarded as significant as for the coating of metallic pigments in water-based systems. As mentioned by Bertholdt and Müller (2014) and Eckart (n.d.), when using UV-curable inks it is recommended to place the curing unit well behind the printing unit to optimize the metallic effect. The reason for this is that the ink needs time to flatten and leafing pigments need enough time to float up. To further optimize the result, heat can be induced into the ink layer to reduce its viscosity, which leads to a faster and better-aligned orientation of the pigments (Kurreck, 2021). However, when printing on film, due to the effect of heat on the printing material, register deviations may occur (Kokot, 2007, p. 239).

4.1.4 Oil-based inks

There are also oil-based printing inks with metal effect pigments as described in Wißling (2013) and by Becker, et al. (2018). They are commonly used for offset print-

ing machines. According to Krietsch (2021), the orientation of pigments is somewhat different in offset oil-based inks compared to UV-curable inks, however, to the authors' knowledge, these differences have not been characterized yet.

4.2 Classic printing methods and their peculiarities

The method used for printing metallic embellishments decides about the size of pigments that can be used, the thickness of the printed layer, the ink system used, as well as the viscosity of the ink used in the print process. While for offset printing ink containing platelet shaped pigments the viscosity is typically in the range of 20–80 Pa·s, which is highly viscous (Becker, et al., 2018), the viscosity of typical flexo printing inks and of gravure printing inks is at about 0.05–0.5 Pa·s (Kipphan, 2000, p. 139). The inkjet printing inks typically have a low viscosity in the region of just a few mPa·s, which is highly watery (Becker, et al., 2018).

4.2.1 Offset printing

As explained by Kipphan (2000) and Teschner (2017), offset printing technology is an indirect printing technology. The printing and non-printing elements of the printing plate are in one plane while the printing elements are hydrophobic and the non-printing elements are hydrophilic. The ink adheres to the hydrophobic areas but does not adhere to the hydrophilic ones, which are wetted by a fountain solution. From the printing plate, the ink is further transferred to a rubber blanket that transfers it to the substrate. The task of the inking unit is to supply the printing plate continuously, streak-free and evenly with ink. For roller inking units, the ink is transferred from an ink metering system via rollers to the printing plate. These roller-type inking units consist of 10 to 15 alternating stiff and flexible rollers. For the most inking systems the stiff rollers (hard surface) generally perform an oscillatory movement in a transverse direction (they are also referred to as "distributor rollers") to smoothen the ink profile on the roller surface and the scores/lines in the ink which appear in the travel direction of the sheets.

As pointed out by Krietsch (2021), due to the reciprocating movements of the distribution rollers, high shear forces are applied on the metallic pigments and they can be destroyed in printing process. Thinner pigments are better suited for being transferred through the inking units because more ink is around these pigments, resulting in a better protection of these pigments in the printing process. With a decreasing size of the features to be printed and a subsequently small ink reception of the substrate, the printing ink also remains longer in the ink distribution system of the printing machine. This can affect the pigments as well as the viscosity of the printing ink due to the fountain solution that can accumulate in the ink.

For the reason that offset printing machines use these kind of roller-type inking units, the metallic pigments used in offset printing must be comparatively smaller to be carried from one roller to the other. Hence, the d_{50} size of gold bronze pigments commonly used for offset printing is only 2–4.5 µm and the d_{50} size of aluminum pigments is 4–9 µm (Wißling, 2013). Inks containing metal effect pigments used in offset printing are commonly either oil-based inks or UV-curable inks.

4.2.2 Gravure printing

As described by Kipphan (2000) and Teschner (2017), the distinctive feature of gravure printing is that the printing elements are engraved into the printing cylinder in the form of cells, while the non-printing areas are at a constant original level. During the process, the entire printing cylinder is flooded with ink in an ink fountain and the surplus ink is removed from the non-printing areas by a doctor blade. The remaining ink in the image elements (the cells) is directly transferred to the substrate from the gravure cylinder. The simplicity of the printing principle contrasts with a more complex and expensive production of the engraved printing cylinder and the relatively long delivery times of the printing cylinders. For this reason, as well as for the high printing speeds of about 15 m/s that are achievable and the wear resistance of the printing cylinder, gravure printing is mostly used for large print-runs. However, by laser engraving of the cylinders, the printing method becomes more economically efficient.

In case of using metal effect pigments the size of the pigments and the dimension of the cells of the printing elements have to fit to each other what allows the pigments to be transferred without problems. Different sources make differing statements about the size of platelet shaped pigments that can be used in gravure printing. Wißling (2013) states that commonly bronze pigments in gravure printing have a maximum size of 10 µm while the maximum size for aluminum pigments is 18 µm. Wheeler (1999, p. 132) mentions that "in gravure […] particles with any dimension larger than about 25 µm will block the cells of the print cylinder […]." However, according to statements of Krietsch (2021) and Kurreck (2021), pigments with a size of up to 200 µm can be used in gravure printing. In this case, the cells of the cylinder have a depth of about 150 µm and the cylinder has 20 lines engraved per centimeter. Literature states that the brilliance that can be reached using gravure printing is superior in compar-

ison to offset and flexo printing because the used ink systems and flake sizes allow an optimal orientation of the pigments (Wißling, 2013).

For the inks used in gravure printing, the highly volatile solvents with fast drying properties are fundamental for their successful performance. However, also UV-curable inks and water-based inks find their use in gravure printing (Leach and Pierce, 1993; Wißling, 2013; Kurreck, 2021).

4.2.3 Flexo printing

In flexo printing, the images stand up in a relief, which serves a direct transfer of the ink to the substrate. Mostly, an anilox roller that takes up a specific amount of ink from an ink fountain doses the ink. A doctor blade, that can be chambered, removes surplus ink that is not in the cells of the anilox roller. From the anilox roller the ink is given further to the printing cylinder that transfers it to the substrate (Kipphan, 2000; Leach and Pierce, 1993). In contrast to gravure printing, flexo printing requires additional ink splitting and pigment transfer, which places increased demands on the mobility and transfer properties of the pigments. According to Wißling (2013), for this reason, flexo printing usually uses finer-particle pigments than gravure printing. However, according to Krietsch (2021), it is also possible to use pigments up until a size of 200 µm in flexo printing if a high sparkle effect is desired.

Using flexo printing, the achieveable gloss is higher than that of offset printing. However, compared to gravure printing, flexo printing comes in second place in terms of gloss that can be reached.

4.2.4 Screen printing

Screen printing is a process in which ink is forced through open stencils of a screen onto the substrate. The screen consists of a fabric that serves as mechanical support and the stencil material for the image generation (Kipphan, 2000). Wheeler (1999) and Wißling (2013) state that the screen printing process has the smallest demands upon the metallic pigments and pigment sizes of 50–100 µm can be used given an appropriate choice of screen mesh size what leads to a very intense sparkling result. In screen printing solvent and water-based as well as UV-curable inks can be used.

4.2.5 Inkjet printing

Inkjet printing belongs to the non-impact printing technologies and does not require an intermediate carrier for the image information and the ink can be transferred directly to the substrate (Kipphan, 2000). This offers the advantage that the printed subject can be personalized and that print jobs with short runs can be printed economically. The aluminum pigments used in inkjet printing are stated to have a small size with an average size distribution curve from 1 µm to 15 µm. If the pigments are greater than 15 µm they might not pass through the printing system such as tubes, channels, filters, and nozzles (Prölß, Trummer and Kröll, 2007).

4.2.6 Electrophotography

Different methods for the application of metal effect pigments on a substrate by electrophotography are offered by several companies as for instance Xerox providing dry toner with integrated metal effect pigments that are applied by dry electrophotography (DEP), also called xerography, or HP Indigo that provides so called ElectroInk Silver that is applied by liquid electrophotography (LEP).

The process of DEP can be divided into five steps, which are explained by Kipphan (2000). First, the print image is imaged on the photoconductive surface of a roller by initially homogenously charging and then discharging the non-imaging parts of the surface of the roller. Second, special ink particles with a size of about 8 µm, which is powder toner and contains the pigments, is transferred to the roller. The toner particles are charged so that they stick to the imaging areas of the roller. Third, the actual printing takes place and the toner, containing the pigments is transferred onto the paper by generating electrostatic forces between the roller and the substrate. In this case there is no contact between the roller and the substrate. Fourth, the toner is melted and fixed on the substrate by applying heat and pressure onto the toner particles on the substrate. Last, residual toner particles on the drum are cleaned up to prepare the drum for the next turn. The LEP technology is described by HP Indigo (2020). Essentially, at the beginning the process of LEP is similar to DEP. The surface of an imaging cylinder is charged on the areas where the inking is performed. After inking, the ink is not directly transferred onto the substrate but transferred to an offset cylinder where heating takes place to melt the ink particles together. Last, the ink film is transferred from the offset cylinder to the substrate while there is direct contact between the offset cylinder and the substrate.

Both DEP and LEP require different solutions to integrate metal effect pigments into the ink. As described by Jan (2017), for DEP the toner components, which are latex or wax particles are partially coated with aluminum using a sputter coater or electron-beam vapor deposition to form a hybrid metallic component that consists of a chargeable part needed for the application in DEP and the aluminum pigment to achieve the desired metallic effect. The solution for

LEP is described by Chun (2016) and by HP Indigo (2020). Here, aluminum pigments are encapsulated in a special resin and hence form chargeable particles. These are dispersed in the carrier liquid that is used in the printing process.

4.3 Influence of shear forces during the printing process

According to Eckart (n.d.), Pfaff (2017) and Wißling (2013), before the printing process starts, the metallic ink has to be stirred using a special low-shear stirrer at low rotation speed in order to obtain a good pigment dispersion, which is important as explained in section 4.2. One should be cautious when stirring the ink, otherwise, pigments could be damaged. The highest shear forces emerge from the doctor blade if a printing process is chosen that uses one. The printing speed, the angle of the doctor blade, the pressure between doctor blade and cylinder as well as the lubrication of the cylinder and blade that should always be sufficient, all influence the shear forces on the pigments.

However, there are also common features in conventional printing processes. In all of these printing processes, doctor blades are used to meter the ink. In offset printing, this is on the ink fountain roller, in gravure printing on the printing plate, and in flexographic printing in the chambered doctor blade. Due to the doctor blade the ink is strongly sheared in the printing process. The doctoring process itself is a complex process and is not yet fully understood scientifically (Bitsch, 2021). Therefore, it is also not clear what influence the doctoring processes have on the metallic effect in the various printing processes.

4.4 Influence of the substrate

According to Eckart (n.d.), Wißling (2013) and Stahl and Dörsam (2013), choosing the right substrate and preparing it before the application of metallic ink is as crucial as choosing the right ink and printing process to obtain the desired appearance. Since the applied ink follows the surface structure of the substrate, only smooth substrates with a low level of roughness lead to results of high gloss. Applying primer on the base paper helps smoothing the surface and enhancing the substrate. Coated paper and calendered paper sorts are best suited to achieve high gloss and bright effects. It is also important to check the pH-value of the used paper. Acidic paper and board can affect the metal effect pigments in a negative way (Wißling, 2013).

As stated by Kurreck (2021), when applying primer to smoothen the surface it should be considered that water-based primer intrudes more easily into the base paper and hence, does not have a smoothing effect as high as UV primer has. Furthermore, the right amount of primer for the specific substrate used has to be chosen. If a quite rough base paper is used, more primer has to be applied to smoothen the surface. If the base paper is already smooth, less primer should be applied. Otherwise, the excess primer can lead to an orange peel effect. Eckart (n.d.) adds that the benefit of applying primer is also the reduced water absorptivity of the base paper. A high absorptivity leads to a separation of binder and pigments of the metallic ink. Due to the changed binder to pigment ratio, a poor rub resistance, poor adhesion and a limited over-printability can be the result.

5. Other printing processes for the production of metallic embellishments

In the following section, technologies are presented that also can be used for producing metallic embellishments. First, the bronzing technology is presented, which is a relatively old technology that is nowadays only used by a few print shops. With the bronzing technology, mostly bottle labels of e.g. wines are embellished. The EcoLeaf technology on the other hand is a very new technology that until today only finds its application at pilot customers. Next, embellishment methods are presented that utilize foils in the printing process.

5.1 Printing methods for application of metal effect pigments without ink

5.1.1 Bronzing

In the printing industry, the term “bronzing” refers to two different meanings. The first is the printing method for the metallization of print products. The second meaning refers to an effect that is responsible for the colored metal-like shine that sometimes appears at the surface of ink layers in the specular direction, that is also called gloss differential (Hébert, et al., 2015). Here, bronzing refers to the method for the production of metallic embellishments. Usually, bronzing is used for the application of gold effects on elaborate labels for beverages (Rosenberg, 2000). Because of the great size of the flakes that are usually made out of copper and zinc, a particularly eye-catching sparkle effect can be reached. As stated by Kirwan (2013) and Rosenberg (2000), in the process of applying the metallic flakes, an adhesive base is printed on the substrate on the areas to be bronzed. Hereafter, in the bronzing application system, special dusting devices apply the bronzing powder all over the sheet but the flakes only adhere to the areas with adhesive. Afterwards, the sheet is cleaned to remove the excess powder. Mainly for the reason that the bronzing process is relatively slow and expensive it is not commonly used.

5.1.2 EcoLeaf technology

The EcoLeaf technology is intended to provide an alternative for foil-based processes for metallization. The technology is quite new and first companies have just finished test programs (Labels & Labeling, 2021). As stated by Lohmann (2020) the technology was presented to the public for the first time in 2016. It is presented to be more economic- and environment-friendly than foil-based processes. Web presses and further processing machines can be retrofitted with this technology.

As described by Landa, et al. (2016a; 2016b; 2016c; 2016d), and Lohmann (2020), the EcoLeaf technology uses aluminum pigments that are applied as a monolayer on a substrate, which means that the height of the metallization is only the thickness of one pigment. In order to apply the pigments on the substrate, first a "trigger image" is printed onto a substrate that makes the metallic pigments stick on the surface. Print processes used for the trigger image can be screen, flexo, and inkjet printing. Using screen printing, haptic metal effects can be created. Using flexo printing, fine metallization with a high resolution can be achieved and inkjet printing enables a metallization that is variable within the running process. Afterwards, the metallization is applied onto the trigger image inside a metallization unit. Inside the metallization unit, aluminum pigments suspended in a fluid are applied onto a donor roller. The pigments adhere to the surface regions of the donor roller that are not preoccupied with pigments. Surplus pigments as well as the fluid are extracted. In the next step, which is the metallization of the substrate, the surface regions of the donor roller that has just been completely covered with pigments that lay planar on the surface of the donor roll come into contact with the substrate. If there is contact between the donor roller and a part of the substrate that has been primed with the sticky trigger image, the pigments adhere on the trigger image because the adhesion between trigger image and pigments is stronger than the adhesion between donor roll and pigments. In the next step, a new monolayer of pigments is applied on the parts of the donor roller that released pigments to the trigger image.

5.2 Printing methods using foil in the printing process

Generally, it can be said that using foils it is much easier to obtain high gloss than compared to aluminum pigments because they provide for a closed layer of thin metal without interruption of pigment edges. Compared to pigments in printing ink there is also no additional ink layer that scatters light and reduces the gloss. In Figure 5, samples metallized by four different foil technologies can be seen.

Figure 5: Samples metallized by foil fusing, cold foil transfer, hot foil stamping and digital hot foil stamping (sample from Konica Minolta) from left to right and up to down

5.2.1 Foil fusing

For foil fusing, a substrate which is mostly paper or board is joined with a metallized film. For the reason that the film stays on the printed matter, it becomes tear resistant.

The lamination is only possible over the entire surface of a sheet (Morlok and Beckmann, 2009). Erdmann (2018a) explains that parts of the surface that should not exhibit the metallic gloss of the foil have to be overprinted with opaque white, which makes the method uneconomical if only spot effect of individual highlights should be achieved. According to HTWK Leipzig (2020) and Morlok and Beckmann (2009), the lamination film has a thickness of 12–30 µm and is made of polypropylene, polyester, acetate, or polyamides. It can be applied by wet-lamination or thermo-lamination. While for wet-lamination a wet glue is applied on the sheet before lamination, for thermo-lamination a dry glue is applied that is activated by heat. Thermo-lamination has the benefit that the glue is not soaked up by paper with a high water absorptivity.

5.2.2 Cold foil transfer

When metallizing a substrate using cold foil transfer from a metallized film, the thin aluminum layer is transferred onto the substrate, but not the film. For instance, using metallized films from the company Leonard Kurz, Germany, only a layer with a thickness of 0.2 µm of aluminum is transferred onto the substrate. The polyester film for the transfer has a thickness of 12 µm (Niemela, 2020). According to Heidelberger Druckmaschinen (n.d.) and Castleton (2000), one

unique characteristic of cold foil transfer compared to film lamination and hot foil stamping is that the process of metallization can happen in-line in an offset printing machine at full printing speed of 16 000 sheets per hour, while the speed of the transfer has little effect on the quality of the finished product. Normally, an adhesive pattern is applied in the first offset unit of a printing machine using an offset plate with register accuracy, which results in the fact that very fine lines of 0.05 mm (0.002 inches) can be reproduced. In the foil transfer unit, which comes next, the foil is pressed against the substrate between two cylinders, while the adhesive is activated (e.g. by exposure to UV light). Hence, the metallization adheres to the areas where the adhesive pattern is printed but not anywhere else. The film from which the metallization is transferred can then be spooled up. For the reason that the pressure cylinders only exert minimal pressure, the film can be removed from the substrate easily while a distortion of the substrate is prevented. In the following, at least four offset printing units are needed to overprint the substrate together with the metallized parts with CMYK colors and to obtain a colorful metallization. For the application of cold foil, generally smooth surfaces are required that do not completely absorb the adhesive and the thinner the foil the better the metallization because that enables the foil to adhere better on the substrate.

5.2.3 Hot foil stamping

Different to foil fusing and cold foil transfer, hot foil stamping, as the name of this method implies, needs an extra heat supply and an extra die that has to be made (Erdmann 2018b). According to Morlok and Beckmann (2009), the foil consists of the film with a layer that enables a transfer layer to detach easily when heated and the transfer layer that consists of an adhesive, the metallization, a color pigmented layer if a colored metallization is to be directly applied, and a protective layer. As described by Castleton (2000), the application of hot foil on a substrate is normally done offline after color printing. In the process of foil application a shaped and heated die presses the foil on the substrate, which activates the adhesive on the transfer layer of the foil. Hence, the part of the metallization corresponding to the shape of the die stays on the substrate. According to Heidelberger Druckmaschinen (n.d.), in contrast to cold foil transfer, motifs and text in hot foil are only possible from a line thickness of approximately 1 mm (0.039 inches). For the reason that the foil transfer is limited by the time taken for the heat to transfer through the foil, only throughputs of 6 000 to 8 000 sheets an hour can be reached. Additionally, there is a greater outlay in time and costs for manufacturing embossing dies compared to offset plates. However, using hot foils it is possible to produce metallizations with a high artistic value that is not flat and also can create a 3D effect due to the deformation of the paper that cannot be produced in line with cold foil. Furthermore, also rough substrates can be metallized because of the ironing effect of the die. Metallizations with hot foil are overprintable, however, another process step in a different machine is needed for overprinting. Hence, often foils that already have the right color are used.

As stated by Bühler, Schlaich and Sinner (2018, p. 52) there are also digital hot foil stamping methods, although these are no real stamping methods because no embossing takes place. One example is the digital hot foil by Konica Minolta, described by Yamamuro (2020). This invention solves the issue that foils applied on adhesive printed with digital printing methods do not resemble the visual effects of hot foil stamped methods because of the missing 3D effect. Using this method, visual effects normally known from hot foil stamping can be created without the use of a specially made die and without heat what speeds up the progress. In this method, toner or ink layers are printed on a substrate to form areas with large and small thickness. Then a foil with a high adhesiveness to the ink is pressed against the thickened layer on which the metallization is peeled from the film and is transferred to the substrate with the texture of the foundation layers.

6. Conclusion

This review paper provides an explanation of different printing methods used in the label and package printing industry to produce metallic embellishments and summarizes the most relevant literature on the topic. One major outcome is the classification of the printing methods according to the input material used for the metallization process of a substrate. Furthermore, important terms used for the communication of metallic appearance are listed and explained. Further developments in the area of printing methods for the metallization will aim for three different goals. The first is the enhancement of the print quality and gloss achievable with the respective methods. For instance, manufacturers of pigments and inks will search for solutions to achieve gloss results with their products that are comparable with methods employing foil. Manufacturers of foils will find solutions to produce thinner and thinner foils to gain better qualities and reduce consumption of resources. Second, manufacturers will strive to reduce the costs of their products, especially providers of digital printing methods such as electrophotography, and inkjet printing as the inks used for these methods are very expensive and as more and more customers favor digital printing and require solutions for short runs and individualized packaging

and labels. The third development regards environmental matters as an increasing number of governments enact laws to reduce greenhouse gas emissions and other environmental pollution and as more and more customers include the environmental impact of products into their purchase decisions. This will probably have impact on the production methods or the energy sources for the production of raw materials that are energy consuming but also on the respective printing processes. Further, in the field of printing inks, water-based inks will be further developed to achieve higher qualities comparable to UV-curable inks or solvent-based inks as the use of UV-curable inks induces problems in paper deinking and as it is to be prevented to use solvent-based inks releasing volatile organic compounds.

Acknowledgments

The authors would like to express their gratitude for the financial support by the Heidelberger Druckmaschinen AG as well as for the provision of metallized printing samples and the exchange of knowledge about various printing processes. Furthermore, we kindly acknowledge Schlenk AG, Roth (Germany), especially Mr. Burkhard Krietsch, for sharing information about metal effect pigments, and the application of metallic inks in printing processes. Besides, we kindly acknowledge H. C. Moog, Rüdesheim (Germany), for supplying gravure printed metallic samples and especially Mr. Achim Kurreck for providing information on ways of printing metallic embellishments. Eckart GmbH, Hartenstein (Germany) is to be thanked for sharing information about metal effect pigments and printing inks. We also thank Multi-Color Bingen Germany GmbH for discussions about bronzing and supplying samples.

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JPMTR-2108
DOI 10.14622/JPMTR-2108
UDC 070.1|(0.034.2)-028.23

Research paper | 159
Received: 2021-07-13
Accepted: 2022-01-17

Progress or regression in the practice of immersive journalism? Immersive storytelling in the productions of the *Samsung VR* platform between 2015 and 2020

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Abstract

Journalism has undergone countless changes in recent years, especially since the emergence of the network of networks. As digital technologies have gone from strength to strength, new ways of doing journalism have also gained traction, focusing on the potential offered by "going digital". This perspective goes hand in hand with another linked to virtual reality (VR) and 360-degree video, with additional technical characteristics. Since 2010, there has been talk of so-called "immersive journalism", which uses the above-mentioned technologies to narrate events, introducing a perspective into journalism that breaks with the classical concepts of working with information and making it available to the viewer, who now becomes an immersive user. This is the context of the present investigation, which focuses on the change of immersive journalism over the last five years. To this end, 1713 pieces available on the *Samsung VR* platform are analysed. The results reveal that there have been some changes in terms of production; however, in narrative terms, when it comes to reporting reality, the only evident change has been the way in which the functions of immersive storytelling elements have been updated.

Keywords: virtual reality, 360-degree video, immersion, journalistic practice

1. Introduction

The expansion of digitalisation has not only modernized our way of managing communication at the business level, but has also changed aspects pertaining to professional practices and routines within the various media, which are still being adapted to the Internet environment. Long gone are the days of a journalist rushing to write the last details of a news article on his typewriter to ensure that it would be ready for publication in the next day's paper. Today's communication professionals, whether they work for the press, radio or television, must be able to work from a hypermedia perspective on the information, which is published minute by minute on the Web, while consulting and updating the media's social networks, all the while receiving the latest news directly on their smartphones. In the 21st century, with the establishment of a multi-screen system (smartphone, tablet, PC), information consumers are increasingly active and have become prosumers (Toffler, 1981). This need for reinvention, imposed by digital convergence (Jenkins, 2008), has led the media to create new and innovative ways of representing reality. The latest innovation has been the use of virtual reality (VR) and 360-degree video as a means of narrating informative content, which has given rise to immersive journalism (de la Peña, et al., 2010) and, with it, new ways of doing and consuming journalism. These are the main novelties that immersive technologies have introduced into the world of journalism, and it is from here that the proposed investigation arises. Specifically, the possible changes that immersive journalism has undergone in the last five years will be analysed, with special emphasis on issues related to production and immersive storytelling.

2. Theoretical framework

2.1 Immersive technologies expansion and conceptualization

Devices related to immersive technologies are achieving great prominence in many different contexts of daily life, and this is perhaps the most significant aspect. It is

interesting to consider data in terms of their business penetration. The global market size of VR, augmented reality (AR) and extended reality (XR) is increasing year over year and could reach 297 billion dollars by 2024 (Statista, 2021a). Moreover, in relation to the total annual growth rate, the VR sector is expected to grow by 21.6 % each year between 2020 and 2027 (Grand View Research, 2021). Consumer demand of immersive devices is also increasing. More than 43.5 million AR and VR headsets are expected to be owned by private users by 2025 (Statista, 2021b). Some authors justify this rise in demand in the situation caused by the COVID-19 pandemic, which has imposed new ways of working (Baileson, 2019) and even learning (Cáceres-Piñaloza, 2020; Flores Cruz, Camarena Gallardo and Avalos Villarreal, 2014; Martínez-Garcés and Garcés-Fuenmayor, 2020).

Leisure and entertainment are fields where immersive content has developed the most, with a wide range of video games leading the way. By 2027, VR is expected to reach 92.31 billion dollars in the video game market. The demand will be driven by younger users, who are becoming very demanding in terms of entertainment and they are the potential consumers of these advanced technologies (Grand View Research, 2020; Martín-de-Santos, 2020). *Samsung Electronics, Google, Microsoft, HTC, Oculus, Apple,* and *Eon Reality* are the most prominent and leading companies offering immersive devices (Markets and Markets, 2020).

As another proof of the increasing relevance of the immersive context*, Facebook* has announced to include in its long-term business strategy the idea of *Metaverse*, which relates to the interaction with virtual worlds. In this context, immersive technologies will acquire an even greater importance from now on. *Facebook* has rebranded its name to *Meta* empowering with this decision its business goals (Casillas, 2021; Valladares, 2021; Vergne, 2021). As a result of the extensive development of immersive technologies, some concepts, such as VR or AR, have emerged. Also, the less widespread in the scientific literature, XR, which includes the two previous ones and has its origins in the reality-virtuality continuum provided by Milgram and Kishino (1994).

"Extended reality allows us to imagine scenarios to change the world, to simulate and represent situations or events, or to imagine ways of transmitting knowledge and discoveries and to find new relationships with information through interaction and immersion" (Rubio-Tamayo and Gertrudix, 2020, p. 106).

This terminological variety adds some complexity when it comes to defining the boundaries among them, especially when it is a field that is undergoing an unstoppable evolution (Rubio Tamayo, 2019).

2.2 Immersive journalism in the scientific literature

Focusing the attention on VR, which is addressed in this study, it is necessary to point out that from a theoretical point of view it has become a very recurrent subject in the scientific literature, since it has been applied to multiple other areas of knowledge, such as medicine (Joda, et al., 2019; Persky and Lewis, 2019; Riva, Wiederhold and Mantovani, 2019), psychology (Bouchard and Rizzo, 2019; Riches, et al., 2019; Yaremych and Persky, 2019), architecture (Nguyen, et al., 2016) and tourism (Juca Maldonado, Lalangui Ramirez and Bastidas Andrade, 2020; Taufer and Todeschini Ferreira, 2019), to give but a few examples. Moreover, it has, of course, also reached the media. The first journalistic content developed through VR emerged in the university environment in the 1990s, giving rise to several pioneering examples in this area which revealed the potential of VR to create immersive stories (Domínguez, 2013). In 2010, researcher Nonny de la Peña proposed the concept of "immersive journalism" to refer to "the production of news in a form in which people can gain first-person experiences of the events or situation(s) described in news stories" (de la Peña, et al., 2010, p. 291). From this moment onwards, while such media content has been being developed around the world, a bibliographical corpus has started to emerge, in which the academic concern for this object of study has been considered and presented from different perspectives: technological aspects (Gutiérrez-Caneda, Pérez-Seijo and López-García, 2020), ethics (Kang, et al., 2019; Sánchez Laes and Utne, 2019), production (Cantero de Julián, Calvo Rubio, and Benedicto Solsona, 2020), concepts of immersion and presence associated with consumption (Van Damme, et al., 2019; Nielsen and Sheets, 2019), the inclusion of VR in journalism studies (Sissons and Cochrane, 2019) and, of course, the topic of immersive storytelling (Caerols Mateo, Sidorenko Bautista and Garrido Pintado, 2020; Paíno Ambrosio and Rodríguez Fidalgo, 2019), are just some of the topics from a research perspective.

A key date that marks a turning point in the production of immersive content is 2015, when certain media started to make frequent use of VR and 360-degree video. Some would even go on to create teams and laboratories exclusively dedicated to this work. Moreover, the reduced cost of omnidirectional cameras, along with technological improvements in these devices, which can record in high definition, have led journalists to use them more and more. In fact, it is a much faster option in terms of production times than the pieces created digitally, as they spare the producer the task of designing and constructing a digital environment (Jiménez, et al., 2021). For this reason, it is important to highlight the difference between the var-

ious productions that are considered immersive: projects produced in computer-generated environments, based on a synthetic recreation of scenarios and situations, are one thing; but those that choose to use 360-degree video are another. The first group includes the works developed by de la Peña and Emblematic Group, such as *Hunger in L.A*. or *Project Syria*; and pieces like *Harvest of Change* developed in 2014 by *Des Moines Register*. In the second group, *MSNBC* stands out as the first media outlet to use 360-degree video, in this case, for a project on the effects of Hurricane Katrina. Since those first pieces, immersive production related to informative treatment has continued to open new doors to research, which has ultimately enhanced immersive journalistic practices.

3. Research approach

Next, we will examine the methodological aspects that support the study.

3.1 Hypotheses and objectives

Firstly, the two research hypotheses can be summarised as follows:

- Immersive journalism has gone through a first phase marked by a 'boom' in immersive productions, and is currently entering a second phase of adoption, which implies less production.
- In the last five years, the storytelling guidelines used by most producers/directors currently producing immersive information have begun to consolidate, sharing aspects with classic narration while showing innovation in other areas.

These hypotheses have given rise to the following general research objective:

- To determine the changes produced in immersive news content on the *Samsung VR* platform, both in terms of production and from a narrative point of view.

This general objective includes, in turn, the following specific objectives:

- To analyse the aspects that identify the immersive productions under investigation.
- To analyse the narrative elements and the function they fulfil in the productions examined.

3.2 Sample selection and justification

The selection of the sample has been limited to the content in VR and 360-degree video published on the *Samsung VR* platform (formerly available at <https://bit.ly/2wNMiea>). The reason for this is that this platform offered an extensive catalogue that users could access openly and free of charge until 2020 and it was possible to access content published since 2015. This is a significant date for this study, as it marks the moment when a great development in immersive journalism began to take place. Also, as indicated in the theoretical section, *Samsung* is one of the companies that made significant investments in immersive technologies.

There are other platforms that also host VR/360° content, such as *YouTube, Littlestar, Veer, Within, Oculus* or *Dark Corner*, among others – some of them more focused on leisure and entertainment content, and they have been the subject of study in some previous works; see for example Barbera Hernández (2020), Benítez de Gracia and Herrera Damas (2019), Gutiérrez-Caneda, Pérez-Seijo and López-García (2020), Ivars-Nicolás, Martínez-Cano and Cuadra-Martínez (2020); Rodríguez-Fidalgo and Paíno-Ambrosio (2020), Sirkkunen, et al. (2016), Pérez-Seijo (2021). Compared to them, *Samsung VR* established a categorisation of content. Among these categories, "news and documentaries" is the one used for this study because of its direct link to the journalistic field of the news genre.

The classification of themes is based on that provided in a previous research by Fernández Jara (2013) and which was applied to audiovisual journalistic documentaries. In order to carry out the proposed analysis, it has been modified and adapted to the proposed object of study.

Specifically, the themes are: 1 = Government, 2 = Armed and unarmed conflicts, 3 = Economy and employment, 4 = Activism, 5 = Terrorism, 6 = Migration, 7 = Prisons, 8 = Crimes and violent acts, 9 = Situation of women in the world, 10 = Gender violence and domestic violence, 11 = Gender identity and sexual orientation, 12 = Education models, 13 = Childhood, 14 = Poverty and inequality, 15 = Nature, 16 = Natural disasters, 17 = Pollution and natural disasters, and environmental awareness, 18 = Lifestyles, 19 = Personal profiles, 20 = Health, 21 = Science and technology, 22 = Culture, 23 = Production and consumption, 24 = Death, 25 = Religious practices, 26 = Media, 27 = Tourism and travel, 28 = Sports and motoring, 29 = Performing arts, 30 = Fiction, 31 = Experiences, 32 = Parades and military training, and 33 = Others. It should be specified that all of them were defined in the codebook for further categorisation.

This classification allows us to approach the object of study proposed here with greater depth and perspective, both in terms of time and content, and the result of this is the configuration of a significant and systematised sample from a scientific point of view, as it allowed access to a wide variety of productions. Specifically, the period of analysis runs from 15th December 2019 to

31st March 2020, which has allowed us to collect a sample of 1713 productions published between 2015 and 2020, that had the appropriate characteristics to be able to analyse the variables established for the analysis.

3.3 Methodology

As regards the methodological aspects followed when addressing the object of study, an analysis sheet and a codebook have been drawn up that include the variables that have been taken into account. In this regard, it must be said that there was no previous system of categories for analysing this type of platform (*Samsung VR*), which made it necessary to create a specific methodological tool to undertake the research. Specifically, the codebook used to approach the study has been divided into two blocks that clearly include all the relevant variables for the analysis, as shown in Table 1.

The variables that have been taken into account allow us, on the one hand, to identify the context in which the immersive production is classified and, on the other, to analyse narrative elements and the function that they serve. All of this was done with a view to analysing the changes produced in the use of VR and 360-degree video when relaying facts.

The data obtained has been processed with the SPSS statistical analysis program. To check the reliability of the analysis variables, a sample of 5.0 % of the proposed pieces was randomly selected, which meant a total of 86 pieces that were first analysed, identifying those variables that needed to be expanded or on which it was necessary to focus, and at the same time those that could be disregarded as they did not offer relevant data for the research. This pre-analysis made it possible to configure and readjust the variables in those cases where it was necessary to configure those that finally form part of the definitive file, as described above. The coding of the 1713 items was carried out by one researcher, giving rise to the same number of analysis files, following the previously established instructions. However, in order to check the reliability of the coding process of the sample, a second researcher was used to check the reliability of the coding process (Krippendorff, 1990). To perform the intercoder reliability calculation, 257 immersive news items were randomly selected, corresponding to 15.0 % of the sample. In this case, using SPSS software, Cohen's Kappa coefficient was calculated. The results show that all variables will have a value higher than 0.9, which indicates an almost perfect degree of agreement (Landis and Koch, 1977).

4. Analysis and results

The results obtained in the analysis of the productions published on the *Samsung VR* platform are listed below.

4.1 Identifying aspects of immersive journalistic content

When it comes to analysing immersive journalistic productions, it is first necessary to address four fundamental factors: the year of publication, the authorship, the geographical distribution and the language, as these data provide the context in which the projects under analysis originate and develop.

4.1.1 Year of publication

When considering the progress or regression of the immersive contents on the *Samsung VR* platform, it is essential to analyse the year of publication of each

Table 1: Analysis sheet

Variable	Indicator	Value
Identifying aspects of production	Year of publication on the platform	Specify: 2015, 2016, 2017, 2018, 2019 or 2020
	Author of the piece	Name
	Producer type	Specify: media, audiovisual producer, non-governmental organisation, non-media company or others
	Producer's nationality	Geographic region
		Country
Narrative elements of immersive productions	Duration	Specify
	Topic	Specify
	Image type	Specify: 360-degree video or recreation
	Audiovisual resources	Text
		Photography
		Video
		Sound
		Video effects
		Other resources

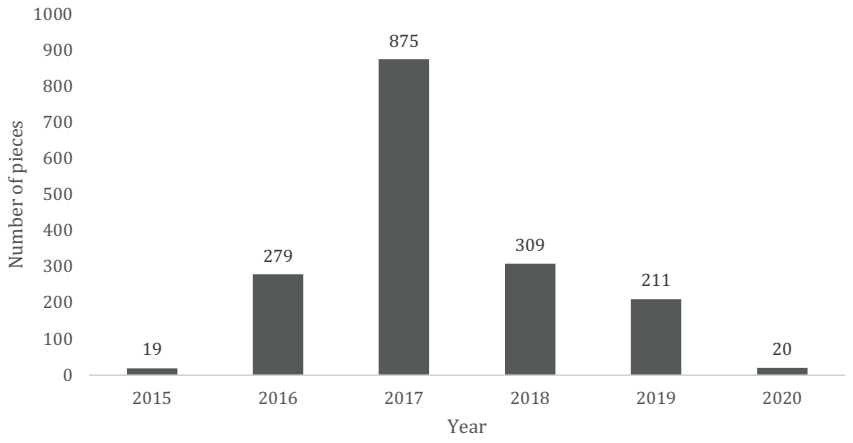


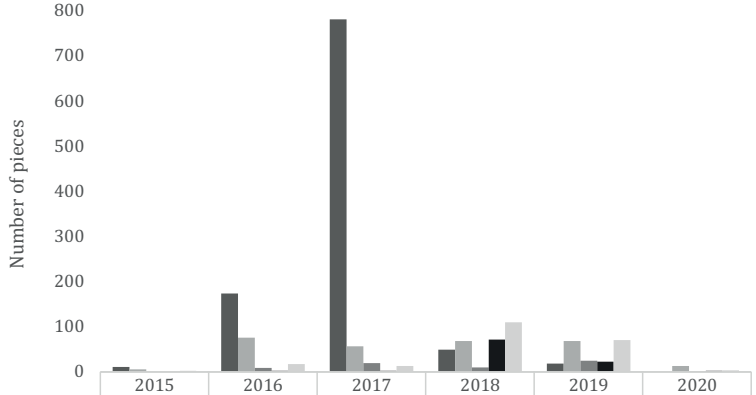
Figure 1: Distribution by year

piece (Figure 1). In this regard, the chronological distribution of the sample under investigation reflects a significant increase in production between 2015 and 2016, becoming even more pronounced in 2017. In total, 68.5 % of the sample was published in these first three years. However, a marked decrease is observed in 2018, when the number of productions decreases by almost two thirds compared to the previous year, a downward trend which also continues in 2019. Additionally, the data available from January to March 2020 seem to indicate that this decline is continuing.

4.1.2 Authors of the pieces and type of producers

Another aspect that contributes to a greater knowledge of immersive production is its authorship. In this case, the codebook included five variables: 1 = Media, 2 = Audiovisual producer, 3 = Non-governmental organisation (NGO), 4 = Non-media company, and 5 = Others. When coding the sample, the authorship indicated in the credits of the pieces was taken into account, as well as the metadata included in the *Samsung VR* platform. In this way, digital or printed newspapers, television channels, radio stations or news agencies were considered as "media". "Audiovisual producers" are those companies dedicated to the audiovisual sector that work independently and may, or may not be, linked to the media. Unlike the previous ones, the variable "company" includes those entities whose main activity is not directly linked to the media. Finally, the NGO is cstegory is clearly defined, and for those cases that could not be classified in any of the previous categories, the variable "others" was designed.

By breaking down the data relating to the year of publication of productions by the type of producer, the results are revealing (Figure 2). Between 2015 and 2017 the media accumulated the highest volume of productions, while in 2018 and 2019 the authorship appears more widely distributed.



	2015	2016	2017	2018	2019	2020
Media	11	174	782	49	18	0
Audiovisual producer	6	76	57	68	68	13
NGO	0	9	20	10	25	1
Non-media company	0	3	3	72	23	2
Others	2	17	13	110	71	4

Figure 2: Distribution by type of producer

When it comes to communication media, one must not only consider those which are exclusively public or private, but also those of a diverse nature (e.g. news agencies, newspapers or television stations). In total, up to 32 media have been identified, with different production volumes. This is the case with *CNN* (with 83 pieces), *Contrast VR – Al Jazeera* (25), *Die Welt* (1), *Discovery Communications* (7), *Euronews* (40), *RT – Russia Today* (15), *Sports Illustrated* (6), *The Associated Press* (10), *The New York Times* (429), *The Wall Street Journal* (8), *Time* (11), *Todo Noticias* (17), *USA Today* (24), *Yonhap News* (298) or *ZDF Enterprises* (2), among others.

It has also been possible to confirm the importance of audiovisual producers, some of which have specialized in creating content in VR and 360-degree. In this case, as can be seen in Figure 2, the volume of pieces from producers remained stable between 2015 and 2019. More specifically, 93 different producers have been counted, the most prolific being *RYOT* (with 49), *Whitestag* (39), *Targo* (11) and *Dreamo VR* (with 11 pieces).

Something similar occurs with non-profit organizations, whose production is widely distributed in the period analysed, except for 2015 and the first months of 2020, when this study was conducted, where no productions with this authorship were found. In total, up to 23 different organisations were identified, including *ChildFund International* (1), *Gates Notes* (22), *Greenpeace* (2), *Wisdom Teachers VR* (17) or *World Call to Action* (2), among others.

It is also interesting to highlight projects coming from companies not directly linked to the audiovisual sector, whose production increased rapidly between 2017 and 2018. Twenty-two companies were found, including *FLO* (28), *SamsungVR US* (10), *Red Bull* (4) or *Turistika.cz* (27).

Lastly, the volume of pieces from associations, educational centres, other organisations and institutions, and even individuals, is also significant, totalling 77.

Specifically, these are the main producers in 2018 and 2019. In this regard, authorships as diverse as the *Film Academy* (1), the *American Society of Landscape Architects* (1), the *Centre for Social Impact UWA* (1), *the Geographical Society* (1), *the USC Annenberg School for Communication and Journalism* (1) or the *Novosibirsk Planetarium* (1) can be mentioned.

4.1.3 Geographical distribution

Lastly, geographical identification data allows us to create a location map of the immersive projects that have been created globally over the last five years and which have been published on the *Samsung VR* platform. The data from the analysis show the presence of the pieces examined in eight major geographical regions: North America, Latin America and the Caribbean, Western, Central and South Asia, Eastern and Southeast Asia, Europe, and Oceania. The results obtained are shown in Figure 3.

One can observe a predominance of pieces made in North America compared to the other regions, constituting more than half of the sample examined, with 922 pieces. Europe, with 351 pieces, and East and Southeast Asia, with 305 pieces, follow second and third, respectively. The analysis by country has revealed that there are 37 different nationalities among the producers identified in the *Samsung VR* platform. Few countries accumulate the highest volume of pro-

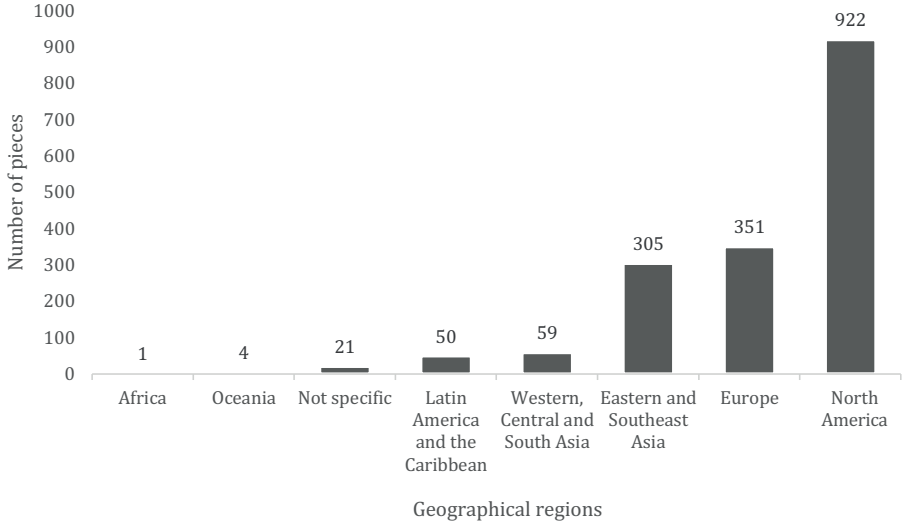


Figure 3: Distribution by geographical regions

duction, the United States being the main producer of this type of content, with 911 pieces; followed by South Korea, with 299; and Spain, with 101. In contrast, in the analysed category of "news and documentaries", countries such as the Philippines, Hungary, Italy, Japan, Kenya, Peru, Sweden, or Vietnam, only feature a single production on the platform.

When it comes to the distribution results by provenance, it should be noted that, while in some countries, such as the United States, there are many producers of VR and 360-degree content, in others, only one or two producers were identified. This means that countries with a similar number of producers also have a similar production volume. However, the case of South Korea is especially significant, where only the media *Yonhap News* accounts for 17.4 % of the total sample (with 298 pieces), while in the case of the United States, which was mentioned above, more than 114 account for only 53.2 % of the sample (with 911 pieces).

As the nationality of the productions also influences the language of production, English, used in 60.1 % of the sample (1029 pieces), stands out, followed by Korean, in 17.4 % (298). Much further behind are Spanish, at 3.0 % (52 pieces), German, 1.3 % (23 pieces) and Russian, 0.9 % (15 pieces).

4.2 Narrative elements of immersive journalism production

In addition to the identifying data described in the earlier paragraphs, which contextualise the immersive journalistic production, it is now necessary to provide a deeper analysis of the aspects of storytelling. Narrative elements in the projects under investigation and their function are analysed below. Specifically, the duration, subject matter, type of image and audiovisual resources have been examined.

4.2.1 Duration

The analysis of the 1713 pieces shows the great diversity of their duration, which ranges from 10 seconds for *Springtime in Massapequa* [by Dick Houghton, 2019] to 1 hour and 10 minutes for *Beto O'Rourke Townhall*, *Good Street Baptist Church* (*SamsungVR US*, 2018). However, the most interesting fact in this regard is the average duration of the pieces, which is 3 minutes and 7 seconds. Moreover, if we analyse the distribution of the duration by ranges, the data reveal that 53.5 % of the sample lasts less than 2 minutes; and only 11.7 % is longer than 6 minutes. This shows a clear preference for short-duration projects, as can be seen in Figure 4.

When entering into a more detailed analysis of the sample, another object of interest is the type of stories that are being narrated through the use of VR and 360-degree.

4.2.2 Theme

In this regard, it has been possible to identify pieces corresponding to 33 mutually exclusive general themes.

As can be seen from Figure 5, the tourism and travel is the most common subject [*The 360° Crossing of the Andes, All News,* 2017], followed by cultural topics [*Michelangelo and the Sistine Chapel at the Met, The New York Times*, 2017], and sports and motoring [*Ski with Ted Ligety, USA Today*, 2016]. The least common are those addressing issues of gender violence [*Don't Look Away, Movistar Plus*, 2018], death [*The Legend of the Black Angel, Meteor Station*, 2019], gender identity and sexual orientation [*Orlando vigil: Tears, chants, and hugs at NYC's Stonewall Inn, CNN*, 2016]. Nature projects are very frequent, although these are divided into three blocks: nature from a general perspective, such as flora and fauna [*Lazovsky reserve, Planetpics*, 2017]; pollution

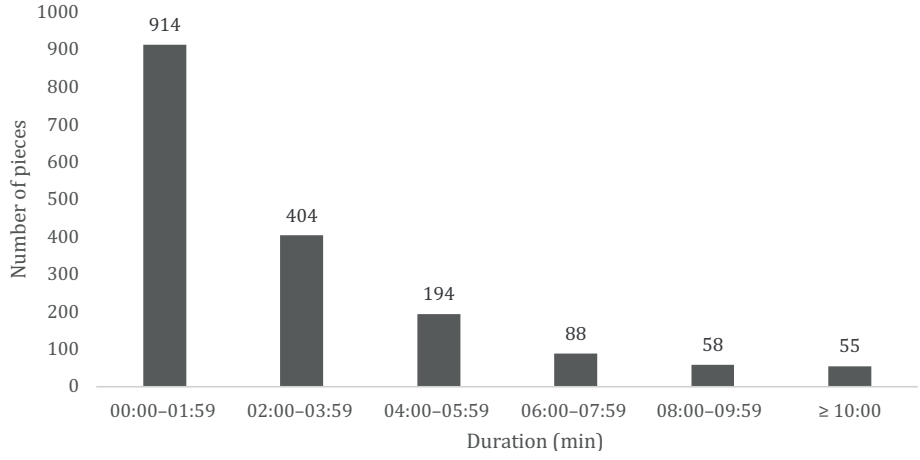


Figure 4: Distribution by duration

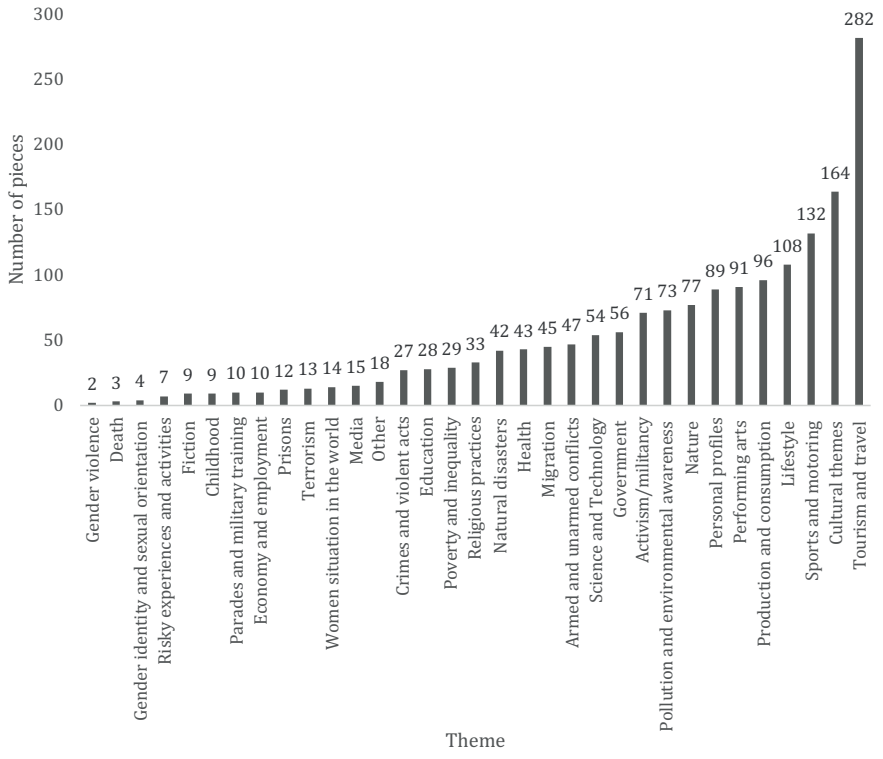


Figure 5: Distribution by theme

and environmental awareness, relating to the negative effects of human activity on the environment [*Global Warning: Arctic Melt, CNN*, 2017]; or natural disasters and their consequences for the population [*Living with a Hurricane's Devastation, The New York Times*, 2016].

On the other hand, when it comes to the journalistic perspective, it is necessary to enter into a more detailed analysis of media production topics. The data show that some media prioritise certain subjects over others. This is visible in those with the highest production volume, such as *The New York Times*, where, of the 429 productions analysed, the main topics are culture (60), tourism and travel (46), and production and consumption (33). Another example is that of *Yonhap News*, where, of the 298 pieces featured, the majority are linked to sports and motorsports (55), culture (55) or activism (25); or *CNN*, with 83 pieces which, in this case, embrace more evenly distributed themes, with tourism and travel (8), culture (8) and armed conflict (7) being slightly higher.

Lastly, it is necessary to cross-check the data related to the duration, firstly with the subject and secondly, with the type of author. As to the first cross-checking of variables, no type of relationship was identified that would lead us to believe that a direct relationship should exist. In other words, topics are neither more nor less prone to a longer or shorter duration. As to the second cross-checking of variables related to authorship, the data reflect that the producers do not have a fixed duration established when creating their pieces; that is, the same author can have projects of very different durations.

4.2.3 Image type

Another narrative element that defines immersive productions is the type of image used, since this introduces the most notable difference in relation to traditional journalistic productions. The analysis has allowed two methods to be established: 360-degree video and three-dimensional recreation (computer-created image). One can observe a clear predominance in the use of 360-degree video, with 1646 pieces using an omnidirectional camera; this is the case of *I Struggle Where You Vacation* [*RYOT*, 2016] or *Seeking Home* [*The Associated Press*, 2015], for example. Only 23 immersive pieces opt for three-dimensional recreations, which, unlike earlier ones, have been generated with specific software; an example of this is *How animals react to an eclipse* [*CNN*, 2017], *Michelangelo – Sistine Chapel* [*ILH Studio*, 2019] or *Volcanos – An Immersive Experience* [*ZDF Enterprises*, 2016].

What is striking in this analysis is that, in addition to the use of VR and 360-degree video, some pieces (specifically, 44) make use of a combination of both types of images. This method begins to be used from 2017, as shown in Figure 6.

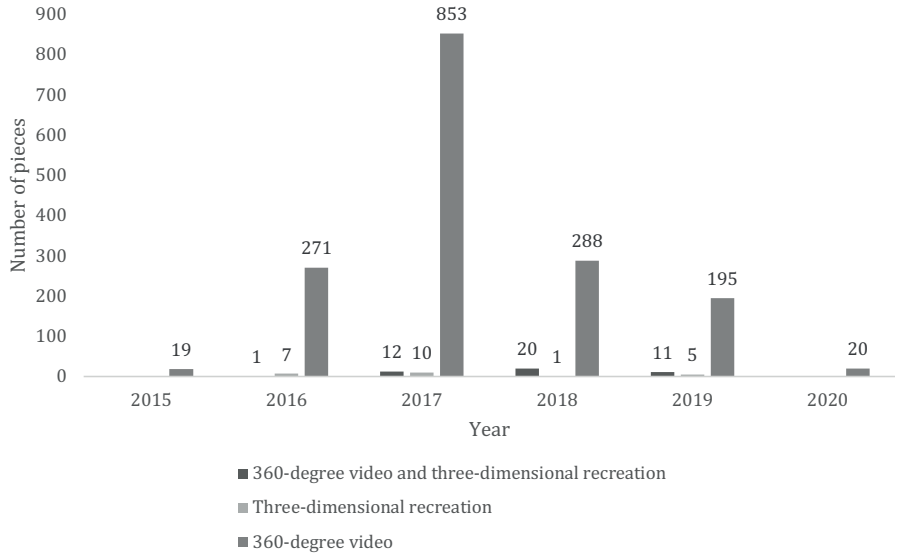


Figure 6: Distribution by image type and year

Certainly, although there are not many productions of this kind, it is significant that their number remains stable in the following years, until 2019, and even in 2018 they increase considerably, something which does not happen with pieces involving VR and in 360-degree videos. Generally, this option would occur in those productions where some type of simulation is performed. To show how a certain catastrophe has occurred, such as the spread of a fire, for example in *The Fire in Our Backyard* [*360 Labs*, 2018]; to reconstruct events, such as the dumping of polluting products [*Oil in Our Creeks, Contrast VR*, 2018]; to create artificial settings, such as a screening room [*Hitler's Secret Weapons, Targo*, 2019]; or to represent what some iconic places, that no longer exist today, would have looked like [*Guardian of Guge Kingdom, Creative autel*, 2018].

4.3 Audiovisual resources

When analysing narrative elements, audiovisual resources take on a special role. Their use is directly linked to the journalistic aspect of immersive production. In other words, traditional narrative elements (text, photography, video, sound, effects and other resources) are employed to determine their use and function when using virtual technologies in an informative context.

4.3.1 Use of text

As regards the presence of text, the results obtained show that 67.8 % (1162 pieces) of the analysed pieces introduced this resource at some point. In pieces where it has been identified, five varieties have been found, each depending on their required purpose: contextualization, location, identification, information and quotations. The differences between each of the identified functions are explained below.

- Contextualisation: these texts place the user in a situation, providing the historical context of the events that are going to be narrated or offering a short introduction to the topic addressed in the piece. These types of texts usually appear right at the beginning or in the first few seconds of the video, generally appearing on a black background or on a relatively still image, so as not to divert the user's attention. This contextualisation function appears in 281 projects (16.4 %), among which are pieces such as *Guardians of the Forest* [*Co.Reality*, 2020], *Nimrud's Riches*: *The Islamic State seeks to erase history* [*The Associated Press*, 2017] of *Skies of Terror* [*Contrast VR*, 2018].

- Location: this serves to let the user know where he/she is (where the piece takes place). It can be a country, a city or something more specific, like a street or a building. This type of text is found in 656 pieces (38.3 %). Sometimes, some more specific information may also appear, such as the proximity to a better-known city, the date, the temperature at that time, and even the geographic coordinates. Some of the pieces that include this type of localization text are *Bethphage* [*Discover Holy Places*, 2018], *Seeing the Internet in Real Life* [*The New York Times*, 2017] or *Visit an Austrian Village, Replicated in China* [*The New York Times*, 2017].

- Identification: this type of text appears in 584 productions (34.1 %). In most cases, it serves to identify the people who appear in the image or the voice-overs (a journalist or a source) so that

their name and, sometimes, a short description with their age or profession appear as 'televisual tags'. Additionally, they can be used to identify some objects, such as a certain car model in a car-themed piece, or an artwork in a gallery in a cultural-type piece. *Strong Coffee, Stronger Women* [*Gates Notes*, 2017], *When Pigeons Become Art* [*The Wall Street Journal*, 2016] or *The Circus: Donald Trump Rally in 360 VR* [*Showtime*, 2016], are some examples where the text has been used with an identification function.

- Information: this category includes brief informational data that cannot be shown in images or which complement the information; unlike the previous cases, this type of text does not serve a merely descriptive function, but also offers relevant data for the whole story. This method is also used in pieces where the journalist does not appear, either physically or in the form of a voice-over, so that all the information is provided in writing. This informative function is the most frequent in the sample under analysis, being present in 696 pieces (40.6 %). *In Caucasus Reserve* [*Planetpics*, 2017], for example, this resource is used repeatedly, when indicating the size and weight of the buffalo that appears in the image; while in *A Toxic Part of Texas* [*The New York Times*, 2017] this type of text is used throughout the piece, in the absence of a journalist or narrator.

- Quotes: on some occasions, a text is found that includes a famous or well-known quote, or which highlights a phrase that a source may have used during the piece. However, this type of text is not very frequent and has only been found in 15 pieces (0.9 %), examples being *Sumergite (sic) en el mundo del Combate Medieval en 360°* [*Todo Noticias*, 2017] or *Theirworld | Safe Schools: Nepal* [*Freelance Society*, 2018].

4.3.2 Presence of photographs

In the sample under analysis, only 5.2 % (90 pieces) include photographs at some point. Among the pieces where photographs are observed, three kinds have been identified, depending on the type of information they provide to the narration: archive, location or visual support. The differences between each of these functions are detailed below.

- Archive: photographs that refer to a past moment, prior to the one shown by the piece, as a flashback. They can show, for example, what a person looked like in the past, or how a city looked before or after a natural disaster. These types of photographs have been observed in 51 pieces that include this resource (3.0 % of the sample). One example of this is *Betty Reid Soskin* – "*White Towels and Imaginary Gateposts*" [*Wisdom Teachers*, 2019], where different family photographs of the main character are shown.

- Location: satellite or similar photographs indicate where a certain place is. These could also include other images that indicate a location mentioned in the piece but which is not the one where the story is taking place. However, location photographs are not widely used, being found in only 3 projects, such as *The Summer Palace trailer* [*VR China-Shambala*, 2018].

- Visual support: 39 projects include photographs used to this end. These are photographs that serve to complement the information provided in the piece, but which, for some reason, cannot be shown directly in the form of a video. A photograph can appear as an overlapping photograph in 360-degree videos, or can be placed on a black background, so that the user's attention remains undivided. Similarly, more than one photograph can appear at any given time. A project where these types of resources can be seen is *Embroidering with Björk's Maskmaker* [*The New York Times*, 2017], in which photographs appear to show the result of the masks that the artist is making in his studio.

4.3.3 Presence of a video

As regards the use of 2D video, that is, one that is not recorded in 360 degrees, only 6.4 % (109 pieces) make use of this resource. As in the case of photographs, three kinds of 2D videos have been identified: archive, location or visual support. The differences are similar to those of photographs, since they fulfil the same purposes.

- Archive: these videos correspond to a moment prior to the event narrated in the piece. They have been found in 59 productions, in total. These can show, for example, what a city looked like before a natural disaster, or how a job or process was performed in the past; as in *Nepal Quake Project* [*RYOT*, 2015], where, at the beginning of the piece, images of the earthquake that shook Nepal are displayed, with a later 360-degree video showing its consequences.

- Location: satellite or similar videos that serve to indicate where a certain location is. Generally, these feature maps, with a zoom being applied to the location where the story takes place. However, not many examples of its use have been found: only

3 pieces, including *The Weekend Soldiers* [*Targo*, 2019], where it is used to explain, using a map, troop movements in an episode of World War II.

- Visual support: videos that complement or reinforce what is shown in the piece and which, for some reason, cannot be seen directly in the 360-degree video. This may be a detailed map of a manufacturing process, or images transferred in that format (2D). This "support" function is found in 54 pieces of the analysed sample; this is the case of *John Law – "Bringing people together"* [*Wisdom Teachers*, 2019].

4.3.4 Sound

The narrative element of sound acquires a relevant role. As is already known, the expressive and dramatic meaning of the events narrated is not only translated through the image, but comes fundamentally from the sound. The effect is multiplied through the use of VR and 360-degree video, as it increases the degree of immersion and generates a greater sense of presence in the user-spectator.

On this basis, sound element analysis makes a distinction between diegetic sounds (the voice of the journalist and the sources that speak to the camera and ambient sound) and extradiegetic sounds (voice-over narrator and music).

It is especially significant that a large part of the sample combines both diegetic and extradiegetic sounds within the same piece, highlighting, in this case, the different varieties of sound that the journalist and the source can use. Thus, if the variables linked to the intervention of the journalist and the source are combined, the results are distributed as shown in Table 2.

As can be seen in the Table 2, the pieces in which only the source or the voice-over journalist take part are the most common (extradiegetic sound). Examples such as *Small Innovations – Big Impact* [*Gates Notes*, 2017] or *The Circle of Rice* [*Fresheyes*, 2019] can be mentioned in this regard. Pieces in which the journalist or the source is physically involved (diegetic sound) accumulate a lower volume of productions. This happens in *Philanthropists in Golf Carts Eating Dilly Bars* [*Gates Notes*, 2016] or *Flying High at the Coupe Icare* [*Euronews*, 2016].

However, cases have been identified that combine the voice-over and a physical presence, either that of the journalist or that of the source (diegetic and extradiegetic sound). An example of this can be found in *360 video vr Museum of the History of Medicine First MGMU IM Sec* [360 video vr Mu, 2017].

Likewise, all the pieces examined also include ambient sound, as in the case of *Crossing Cultures: Black K-Pop Fans in America* [*The New York Times*, 2017] or *Refugee: 'We are not animals'* [*CNN*, 2016]. On the other hand, the use of extradiegetic music has been found in a large part of the sample, in 53.7 % of the cases (919 pieces). In this case, projects such as *Experience Michigan's 'Magic Hour' in Virtual Reality* [*USA Today*, 2017] or *Valen's Reef* [*Here Be Dragons*, 2016] are also worth mentioning. Certainly, the treatment of ambient sound in most productions is subject to the incorporation of music.

No relevant results have been obtained that could indicate any kind of relationship between the decision to incorporate music and the topic of the pieces, so it can be deduced that this matter depends more on the author. Thus, by cross-checking the variables of authorship and music, some media such as *CNN* or the *Korean Yonhap News,* or producers such as *RYOT* or *Whitestag*, incorporate this resource into most of their projects. In contrast, other media such as *The New York Times* prefer, in most of their pieces, to dispense with the use of music (352 pieces versus 78 that they do use). However, in other cases, such as *Todo Noticias* or *USA Today*, it has not been possible to identify a clear preference for the use or non-use of music in their immersive productions, so the results are widely distributed.

Table 2: Sound presence of the journalist and the source

		Journalist				
		Physically involved and speaks to the camera	Voice-over and to the camera	Voice-over	Does not take part	Total
Source	Voice-over and to the camera	4	4	19	150	177
	Physically involved and speaks to the camera	12	13	26	122	173
	Does not take part	22	13	237	742	1 014
	Voice-over			34	315	349
	Total	38	30	316	1 329	1 713

4.3.5 Video effects

Video effects have been interpreted to be those that imply some kind of editing by the journalist or editor. In some pieces, we have observed some modifications that affect the playback speed, such as accelerated, slowed down or frozen videos; the colour of the image, converting it to black and white; or the use of opposing images, with two or more 360-degree videos that are played simultaneously. In total, we have identified effects in 266 pieces (15.5 % of the sample), some of which use more than one effect within the same piece.

While no relationship can be observed between the use of video effects and authorship, there does appear to be a relationship to the topic addressed in the pieces, with some showing a preference for using these types of resources, such as those related to sports or tourism. In contrast, productions that address social issues, such as domestic violence, women's situation in the world, death or gender identity and sexual orientation, do not usually introduce this type of effect and, if they do, it is in a limited way.

As regards the modification of the speed to accelerate the image, this occurs in a total of 153 pieces (8.9 % of the total productions) and mostly in topics related to tourism and travel (19 pieces), sport and motorsport (17), production processes (17), lifestyle (12) and culture (16); although, examples of accelerated image have also been identified in other themes, but to a lesser extent. This is the case of *An Art Deco sensory feast in 360 degrees* [*Euronews*, 2017], *Floating University 360* [*Russian Geographical Society*, 2016] or *Autumn in Paris* [*NowThis 360°*, 2017].

On the other hand, 23 pieces (1.3 %) slow down or freeze the image. These are mainly about themes related to sports and motorsports (5 pieces) and tourism (4), although, as happened in the previous case, they also appear in pieces on other topics, to a lesser extent. Examples of the use of this effect can be found in *6 Longest Minutes* [*3DigitalVision*, 2016] or *The Future of New York City* [*The Wall Street Journal*, 2015].

The modification of the video to black and white is present in 34 pieces (2.0 %); most of them correspond to a lifestyle theme (25 pieces), while the rest are widely distributed: migration (2), armed conflict (2), crimes and violent acts (1) or government (1), among others. This effect is used, for example, in all of the pieces in *Alte Handwerke – Folge series* [*Whitestag*, 2018].

As for the use of opposing images, these have only been identified in 6 projects (0.3 % of the sample). The topics of these pieces deal with poverty and inequality (2), but also with migration (1) or culture (1), among others. This effect can be found in productions such as *Bill Gates on how we can bring clean energy to one billion people* [*Gates Notes*, 2019] or "환호 혹은 통곡" 대통령 파면 선고 에 표정 극 과 극 (in English: "Cheers or weeping" The expression on the president's dismissal is extreme) [Yonhap News, 2017].

Moreover, the use of other types of effects has been observed in 2.1 % of the sample (53 pieces). These include the application of colour filters [*Metropolitan Wildlife Haven, FLO*, 2018], spotlights that illuminate different characters to direct the user's attention [*For My Son, RYOT*, 2016], image pixelation [*One-on-one: meet a naturist, Targo*, 2019] or soft focus [*How To Change Your Mind VR: The Whole Earth Experience, Time*, 2018].

4.3.6 Other resources

With regard to resources such as graphics, illustrations, maps (not photographs) and arrows or marks, these do not appear to be specially used either, having only been identified in 9.6 % of the sample (164 pieces). In some cases, more than one may appear in the same piece.

Graphs are used to represent figures and numerical data, but are not very common; in fact, they have been found in only 4 pieces. Among them, we can mention *Bill Gates on how we can bring clean energy to one billion people* [*Gates Notes*, 2019], *Experience A Zero Gravity Flight* [*The New York Times*, 2017] or *The crossing of the Andes in 360°* [*All News*, 2017].

Drawings and illustrations are evident in 24 projects. These are very diverse, so may represent a person or animal, or an object or abstract element. Sometimes, the journalist or source is able to interact with them, as in the case of *I Am Rohingya* [*Contrast VR*, 2017], *Firsthand Account: The Assassination of Malcolm X* [*The New York Times*, 2017] or *Peninsula Valdés and the dance of the Right Whale in 360* [*Todo Noticias*, 2017].

Arrows and markers are used to direct the user's gaze, and are the most commonly used element featured in the pieces containing these resources (85 pieces). Sometimes they are accompanied by a text (for example: look up or turn around) although they can also appear without it. In some cases, arrows or marks can be used to indicate the exact location of an element being discussed in the piece. Examples include *What Do Dogs Do Alone?* [*BuzzFeed*, 2017], *Elephant Rescue in 360°* [*NowThis 360°*, 2017] or *Losiny Ostrov* [*Planetpics*, 2017].

Sometimes, as has been seen in the section dedicated to photographs, they fulfil a location function (satellite photography), but it is also possible to find other types of maps, as occurs in *Experience the Early Sounds* and

Visions of La Paz [*Discovery Communications*, 2017] or in *Preventing Conflict, Promoting Peace* [*World Bank*, 2019]. Forty projects using this resource have been found.

On the other hand, 13 pieces incorporate other resources that do not correspond to any of the aforementioned, such as emoticons, striking transitions or different filters. This is the case of *Desconecta2* [*3GO Video*, 2018] or *Athletes at Home – #MeetTheDetermined* [*Word Games AD*, 2019].

5. Discussion and conclusions

Within the journalistic context, and in order to meet the demands of adapting to the digital reality, new forms of storytelling are imposed and are reviewed in the academic literature by authors such as Lopezosa, et al. (2021). The latest to arrive on this stage have been immersive technologies, and as a consequence, there is a need for research that delves into the issues related to immersive journalism; some recent contributions show an interest in the opportunities and challenges faced by immersive information (Pereira, Zanotti and Rodrígues Bazi, 2020; Uskali, et al., 2021). In this sense, one of the main characteristics of the study carried out here is its novel approach, since it offers important advances in two dimensions: the one that has to do with production aspects and the one related to the narration of the 1713 immersive journalistic pieces. This complements other contributions made recently, which in this case address the motivations of journalists when making immersive stories and which are linked to the contributions of producers and directors (Goutier, et al., 2021).

From the approach set by the starting hypotheses of this research, the results obtained now allow us to establish the following discussions. In relation to the first, it has become clear that after a first phase (between 2015 and 2017) marked by a boom in immersive productions, this production is now in full decline, to the point that the platform under study (*Samsung VR*) is no longer operational. This aspect reinforces what other authors have already corroborated in their latest research, such as those carried out by García Caballero, Sidorenko Bautista and Herranz de la Casa (2021), Rodríguez-Fidalgo and Paíno-Ambrosio (2020), Seijo (2021) and Sidorenko Bautista, Herranz de la Casa and Molina Díez (2020). This fact finds a connection with other results obtained in this study that have to do with the type of producers or filmmakers who are currently making immersive information. In this regard, it can be said that the *Samsung VR* platform shows a loss of the traditional legitimacy attributed to the media as the main producers of information, insofar as VR and 360° video technology now contemplates other producers of information. The main characteristic of these is that they are not directly related to the large media conglomerates, and proof of this is that NGOs, universities, other types of institutions and even individuals have been identified.

These results suggest a reality that clashes with the technological context: while the technological context is favorable in terms of market penetration and consumption of VR (Grand View Research, 2021; Statista, 2021a; 2021b), the production of immersive news content seems to have stagnated. However, it should not go unnoticed that although VR within the journalistic context is losing prominence, there are other fields related mainly to education and the business environment, following the emergence of COVID-19 and, of course, leisure and entertainment that are experiencing great popularity (Demers, et al., 2020; Nalluri, Reshma and Munavalli, 2021; Ying, et al., 2021).

In relation to the second hypothesis, the results obtained show that in the last five years, narrative patterns that are used by most of the producer-directors who are currently making immersive information, which share aspects with the classic narrative and innovate in others, are beginning to consolidate. From this perspective, there are several studies that have been providing guidelines in this regard but, to date, it is not possible to speak of a true consensus when it comes to making such immersive productions (Benítez de Gracia and Herrera Damas, 2021; Seijo, 2021).

For this reason, the following proposal is necessary for what could be called 'immersive journalistic narrative guidelines', which arise from the sample analyzed, which has contemplated a diversity of producers, nationalities, themes and audiovisual resources that are used in these productions.

- Immersive pieces are characterized by a short duration, i.e. of under two minutes.
- Virtual reality and 360-degree video are used to tell all kinds of stories, although topics related to culture, tourism and travel, sports, lifestyles and nature are the most attractive for producers.
- 360-degree video is the preferred option considering the large number of productions identified, in relation to those involving three-dimensional recreations, which have higher production costs. We must bear in mind that 360-degree technology is becoming more democratic thanks to its increasingly affordable prices and its easy treatment from an editing and post-production point of view. Although a combination of both types of technologies is now scarcely used, it may result in a more

attractive product in informational terms. These aspects are linked to one of the lines of research that has been most developed in recent years in relation to immersive technologies, namely the concept of presence and user experience. Here the consensus among authors is evident, as most point out that VR in which the user can interact through haptic devices is more immersive and generates a greater sense of presence in the user than 360° video (Ahn, Bailenson and Park, 2014; Hardee, 2016; Shin and Biocca, 2017; Slater, Steed and Usoh, 2013).

- The use of audiovisual resources within immersive pieces is more directly linked to journalistic process than to the previous elements. These are the ones that allow us to differentiate them from mere recordings that serve no informative purpose. In relation to this aspect, the function of text, photography, video, sound, video effects and other resources can be identified.

  Specifically, text, photographs and video serve the same function that they had in classic narrative: to complement or support information. Moreover, in the case of text, which is the most widely used resource, identification and location functions have not changed and are assimilated within the signs. However, contextualisation, information and quote functions acquire a new meaning within immersive pieces, even replacing the narrator in some cases, which would be inconceivable in traditional information. With respect to photographs and video, the functions of archive, location and visual support can be identified with this type of resource.

  The sound element in immersive productions is used to generate greater immersion and presence for the user. In this sense, sound is used from both a diegetic and extradiegetic standpoint. The first one is associated with sounds linked to ambient sound, the journalist and to different varieties of sources. The second one is related to the use of the music as a soundtrack and voice-overs.

  Video effects and other resources, such as maps, graphics or illustrations, although not widely used, offer a certain visual appeal to the information. The most important of these graphic resources are dates or markers, which direct the user's gaze, and are not normally considered in traditional information.

As a result of the aforementioned narrative patterns, it can be concluded that these are widespread among immersive journalism producers, but it should not be forgotten that they are constantly changing due to their intrinsic relationship to the development and advancement of immersive technologies, both in terms of recording devices and the way in which they are consumed.

It is evident that these virtual technologies are bringing innovations into the field of informative journalism, especially in terms of production and consumption. This study allows us to discuss progress and advances from a production point of view, but not so much from a narrative one. We can conclude that the advances that have taken place in the period analysed are more from the productive point of view, and not so much from the narrative point of view. That is, there is not a complete break with the previous practices in traditional journalism, but rather a redefinition of the meaning of the new uses and functions that informative narrative elements adopt when VR and 360-degree video are used.

The lines of research that arise from the discussion generated by this object of study under the double methodological perspective proposed (production and narration) are diverse. Firstly, comparative studies are proposed that include other platforms that have not been considered here and that allow us to check whether the decline noted in immersive productions can be extrapolated to other journalistic contexts. Secondly, and related to narrative elements and their use within immersive storytelling, it would be interesting to further explore the potential offered by other types of technologies framed within XR, as well as post-production resources that provide greater interactivity, both with the user and with the development of journalistic content.

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TOPICALITIES

Edited by Markéta Držková

CONTENTS

News & more

Recent patents in multimaterial printing

This year's overview of recent patents focuses on those granted since the beginning of 2021 and retrieved for the term "multimaterial printing". The search returned more than five hundred patents available in English, dominated by the Chinese and U.S. patents, each comprising about 40 %. The remaining fifth includes the patents granted by the European (8 %), Japanese and Korean (4 % each) patent offices, along with a few others. Overall, the inventions relate to a variety of fields and applications, although the diversity is somewhat lower than in the case of printed electronics, see this section in JPMTR Vol. 10, No. 1 (2021). The assignees with more than one patent from the current selection comprise about 40 %; however, only over a dozen of them have five or more patents granted recently. The following sections are limited to those with the most documents related to the concept in focus. They represent both academia and industry, from small companies with a few employees to global corporations.

Massachusetts Institute of Technology

The MIT research into 3D and 4D printing, see this section in JPMTR Vol. 9, No. 2 (2020) and Bookshelf in JPMTR Vol. 10, No. 3 (2021), is reflected also in patent documents. The recent ones include EP 3 622 050 B1 Cell-mimetic device, fabricated by projection microstereolithography and comprising an array of fibres including those with diameters below 10 µm and elastic moduli tunable within the MPa to Pa range, US 11,179,878 B2 Methods and apparatus for parametric fabrication, capable to produce objects with a controlled variation of material composition and properties at different locations, and US 11,260,586 B2 Multimaterial 3d-printing with functional fiber, where the intended structure is produced from continuous fibre that consists of at least three different materials, combining electrical conductors with a functional component and encapsulating material. Other examples are US 10,953,605 B2 Additive manufacturing in gel-supported environment (jointly with Steelcase), presenting the approach that is considerably faster and eliminates the need for support structures while allowing to print large parts with complex geometries, US 11,009,020 B2 Vacuum pumps and methods of manufacturing the same (with Edwards Vacuum), employing polyjet printing, US 11,155,025 B2 Methods for additive manufacturing of an object (with Stratasys), describing the production of 3D-printed objects with predicted transformation in response to an external stimulus, and more.

Zhejiang University

The numerous patents granted worldwide to this university, one of the oldest in China, include several Chinese patents in the area of 3D and 4D printing. To provide a few examples, CN 110 171 127 B 3D printing system describes a solution for multi-material alternate feeding and non-uniform mixing; also, it presents a printable biomaterial with suitable mechanical and gel-forming properties. A device described in CN 110 228 193 B Integrated colored light 3D biological printing system based on imaging principle utilises volume imaging for photocuring of different materials at different parts. Another design with multiple spray head assemblies is applied in CN 110 450 405 B

Winners of the 2022 Flexographic Technical Association awards

Recipients were announced during the Awards Banquet at FTA's FORUM in March. The 2022 FTA Technical Innovation Award has two winners – DuPont Cyrel Solutions for the Cyrel Lightning Plates optimised for UV-LED exposure and the Czech company SOMA for its SOMA Changeover Wizard, a user interface of new SOMA Optima flexo presses. The latter technology not only optimises and automates the tasks during the job changeover but also guides the press operator through the whole process, which is seen as even more valuable when considering the current workforce situation. Among the recipients of the FTA Sustainability Excellence Award, the company Industrias de Plasticos (Inplasa) based in Honduras was recognised for its social responsibility. The comprehensive sustainability programme of this Latin American company manufacturing flexible packaging and having more than 300 employees has five main pillars: the photovoltaic plant that provides power for the whole facility, recycling of polyethylene, polypropylene and solvent, and also wood pallets recycling that enabled, among others, to manufacture dozens of desks donated to support the local educational centres. The second winner, the U.S. company Footprint, is focused on the design, development and manufacturing of plant-based fibre solutions. It received the award for the innovations in sustainability, namely for its shelf-stable cup from moulded fibre printed using indirect flexography. The unique printing press employs conical technology to reduce distortion and improve colour densities when printing on the tapered cup. The recipients of the Excellence in Flexography Awards and the FTA President's Award were announced as well, together with the new member of the FTA Hall of Fame.

New paper-based, fire-resistant shipping wrap for batteries

The U.S. company PACT, Packaging And Crating Technologies, has recently developed a new technology to ensure the transport safety of flammable items, especially lithium-ion batteries. The solution called Thermo Shield is based on planar and pleated layers of kraft paper coated with fire-suppressive ink, which releases water molecules when heated and thus cools the internal environment of the container. The company claims that this light-weight, fully recyclable corrugated packaging can suppress thermal runaway and propagation at temperatures up to 800 °C, and restrict the temperature outside the wrap itself to 60 °C, also suppressing the release of fumes or gasses and limiting the external oxygen supply. In this way, the wrap prevents damage to the outside shipping container and protects the surrounding environment.

Interoperability Conformance Specifications (ICS) for colour management based on the ICC.2 specification

These documents provide workflow-specific requirements and restrictions to iccMAX as defined in ISO 20677-1:2019 Image technology colour management – Extensions to architecture, profile format and data structure. In 2021, the International Color Consortium approved a core set of ICS documents as a guide for building iccMAX profiles for given use cases, checking the validity of iccMAX profiles, and selecting profile subclasses and profiles for a particular workflow. The set includes the colorimetric ICS for conversions to and from a custom Profile Connection Space (PCS) in the general domain, the spectral reflectance ICS for ColorSpace or Input Device profiles with conversions between multispectral data and a spectral reflectance PCS, the extended output ICS for printing and output colour reproduction, and the extended dynamic range ICS for displays and images.

Multi-nozzle cooperative biological printing method. Besides these solutions towards bioprinted tissues or organs, the recent Zhejiang University patents include CN 113 601 836 B Robot-assisted large-scale fiber-reinforced heterogeneous multi-material in-situ additive manufacturing system, intended to produce a continuous multi-material composite structure combining more resin materials with selected, typically carbon fibre.

Huazhong University of Science and Technology

This Chinese university is also active in 3D and 4D printing, as shown by its recent patents, such as US 11,110,663 B2 Polymer multi-material high-flexibility laser additive manufacturing system and method thereof, where different filaments are extruded in a sequence and fusing takes place outside the extrusion unit, CN 110 936 605 B Biological 3D printing device suitable for gradient structure multi-material, which employs multiple spray heads, or those presenting printed parts, e.g. CN 110 957 133 B Bionic deformable capacitor based on 4D printing and CN 110 962 161 B Phase deformation execution device based on 4D printing (both jointly with Jilin University).

Inkbit

This company, founded in 2017 as a spin-off from MIT Computer Science and Artificial Intelligence Laboratory, develops a multi-material jetting platform assisted by machine vision. Its recent patents include e.g. US 10,926,473 B1 Multi-material scanning for additive fabrication, US 11,173,667 B2 Precision system for additive fabrication, and US 11,186,033 B1 Material interlocking.

Stratasys

Besides the joint patent with MIT mentioned above, the recent patents of this established company include, for example, EP 2 664 443 B1 Solid free-form fabrication using a plurality of modeling materials, US 11,179,879 B2 Three-dimensional printing combining ring-opening metathesis polymerization and free radical polymerization, and US 11,235,511 B2 Three-dimensional inkjet printing of a thermally stable object.

Desktop Metal

The recent patents of this company, founded in 2015 and focusing on metal and carbon fibre 3D printing, include US 10,974,299 B2 Additive fabrication using variable build material feed rates, US 11,014,163 B2 Calibration of 3D printer via computer vision, and others.

Sakuu

Founded in 2016 as KeraCel, Sakuu develops solid-state printed batteries. Its patents include, among others, KR 10-2316641 B1 Electrophotographic multi-material 3D printer and US 11,224,917 B1 Multi-material three-dimensional printer with underlying adjustable binder.

Align Technology

This company innovates orthodontic and restorative treatment since 1997. Its recent patents cover different aspects, as illustrated by US 11,096,763 B2 Automatic treatment planning, US 11,106,135 B2 3D printed composites from a single resin by patterned light exposures, and US 11,189,021 B2 Machine based three-dimensional (3D) object defect detection.

Bookshelf

Additive Manufacturing

This volume on additive manufacturing technologies and appropriate finishing operations was contributed by almost 60 authors from across the globe. It is the third one from a four-volume series of Handbooks in Advanced Manufacturing, which is intended to give an account of the progress in various manufacturing technologies and provide their understanding by presenting the relevant fundamental research, latest developments and case studies. The first two volumes cover machining, finishing, welding and deformation; the fourth deals with the sustainable manufacturing processes.

The presented handbook is organised into three sections. Nine chapters deal with the technologies for additive manufacturing. The first one introduces the general concept of additive manufacturing, the steps involved in building physical parts from 3D design data, the main technologies used, their applications, benefits and limitations, as well as the option of hybrid manufacturing integrating additive and subtractive manufacturing. The technologies described in detail comprise a powder-bed fusion of polymers, selective laser melting of metallic materials, laser-directed energy deposition, vat photopolymerisation methods, material extrusion processes for polymers and composites (with a separate chapter dedicated to fused deposition modelling as the most popular additive manufacturing technology), electron beam melting process, and 4D printing.

Next, three chapters discuss the post-processing techniques and the need for standardisation. In particular, one chapter describes laser polishing for adjusting the surface roughness of additively manufactured metallic components. Another one deals with the surface roughness typically resulting from various additive manufacturing technologies and utilisation of conventional machining processes, such as turning, milling and grinding, for post-processing of both metal and polymer parts. The last chapter in this section presents the existing international standards for different additive manufacturing technologies and materials, covering the process and output quality, testing procedures, safety and environmental concerns, etc.

The remaining ten chapters focus on selected materials, applications and methods. Their topics include metal matrix composites processed by laser additive manufacturing, laser-aided metal additive manufacturing and post-processing, 3D printing of functional nanocomposite materials for medical, bionic, electronic, sensing, energy storage and structural devices, the technical and economic impact in the automotive industry, specific challenges of large-size product manufacturing, production of personalised pharmaceutical products, 3D bioprinting towards engineered human tissues and organs, processing of biopolymers for medical applications, development of additive manufacturing using space resources, and the current modelling and simulation approaches for advanced fabrication by the processing of metallic powders.

Editors: Juan Pou, Antonio Riveiro, J. Paulo Davim

Publisher: Elsevier
1st ed., May 2021
ISBN: 978-0-12-818411-0
768 pages
Softcover
Available also as an eBook

Advances in Graphic Communication, Printing and Packaging Technology and Materials

Editors: Pengfei Zhao, Zhuangzhi Ye, Min Xu, Li Yang, Linghao Zhang, Rengao Zhu

Publisher: Springer
1st ed., May 2021
ISBN: 978-9811605024
861 pages, 513 images
Hardcover
Also as an eBook

This volume with the Proceedings of 2020 11th China Academic Conference on Printing and Packaging held in Guangzhou, China, brings the selection of almost 120 peer-reviewed papers. As for the previous editions, the content is organised into sections covering areas from colour science to novel functional materials. The topics include observer metamerism for assessing neutrality on displays, ink colour matching method based on 3D gamut visualisation, neutral colour correction algorithm for colour transfer between multicolour images, a simulation study on water-based ink transfer in gravure printing, fabrication of 3D graphene electrodes by direct-write printing, peeling strength of solventless lamination films, interactive design of post-press equipment based on virtual reality, and a study on factors influencing luminescence intensity of rare earth complexes, to name a few.

Quaternions for Computer Graphics

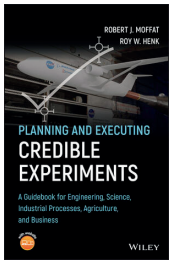
Author: John Vince

Publisher: Springer
2nd ed., September 2021
ISBN: 978-1447175087
196 pages, 41 images
Hardcover
Also as an eBook

The author of this book explains the concept of quaternions and their use for rotating vectors about an arbitrary axis in a clear and easy-to-read way, helping to gain the understanding necessary for their practical use.

Planning and Executing Credible Experiments
A Guidebook for Engineering, Science, Industrial Processes, Agriculture, and Business

With the growing number of studies suffering poor reliability and considering the challenges faced today, credible design, execution, analysis and reporting of experiments gain even more importance. The authors of this book share their deep expertise to guide anyone who needs to experimentally answer questions, including complex ones. The text explains the key role of credibility in research with impact and introduces the basic prerequisites for conducting good experiments. It presents the nature of experimental work and basic concepts, discussing the choice of strategy and tactics. Four chapters deal with experiment planning and refinement while considering the desired accuracy as well as the time and budget requirements. The book guides how to identify the motivating question, choose the approach in terms of techniques, instrumentation, conditions, procedures and data interpretation, and use mapping as a supporting tool to ensure safe and effective operation. The following three chapters provide an overview of fundamental statistical concepts and data distributions, together with the use of the R language, and then present the options for statistical design of experiments and selecting the data points. Then, two chapters discuss in depth how to analyse measurement uncertainty and use uncertainty analysis in experiment planning and execution. Finally, the remaining three chapters cover the phase of debugging, trialling and validation, the ways to trim uncertainty, and good practices in report writing. The book includes many examples, exercises and four appendices with useful information; in addition, it is accompanied by a website providing more resources.



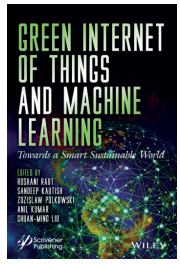
Authors: Robert J. Moffat, Roy W. Henk

Publisher: Wiley
1st ed., January 2021
ISBN: 978-1-119-53287-3
352 pages
Hardcover
Available also as an eBook

Green Internet of Things and Machine Learning
Towards a Smart Sustainable World

Twelve chapters of this book explore the utilisation of machine learning algorithms to improve the energy efficiency of devices and applications and thus achieve a so-called Green Internet of Things. The book explains relevant terms and concepts, introduces techniques for reducing the energy consumption of devices and creating energy-efficient routing infrastructure,

Editors: Roshani Raut, Sandeep Kautish, Zdzislaw Polkowski, Anil Kumar, Chuan-Ming Liu

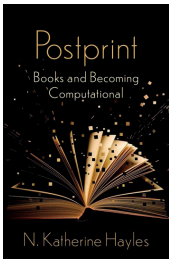


Publisher: Wiley-Scrivener
1st ed., February 2022
ISBN: 978-1-119-79203-1
374 pages
Hardcover
Available also as an eBook

and discusses different aspects of their use in general and in selected areas. The latter include various applications of the Green Internet of Things and machine learning in agriculture and smart farming, healthcare, transportation and banking. The book presents specific examples and case studies, considering the existing possibilities, benefits, disadvantages, challenges, risks and opportunities.

Postprint
Books and Becoming Computational

This volume is part of the series The Wellek Library Lectures; namely, it is based on the lectures in Critical Theory given at the University of California, Irvine, in May 2016. While being aware of past developments since Gutenberg's time, N. K. Hayles identifies the second half of the 20th century, when computational media transformed every aspect of print, from creation to production and distribution to reading, as a crucial period within the evolution of print media. Therefore, she suggests calling the present era, after roughly 2000, a postprint and considers its role in the ongoing evolution of humanity, where computational media take part in some of the cognitive tasks. The text introduces the concept of postprint supported by literature references, interviews and well-chosen examples, including the codes used to produce the final print page. It discusses the position and role of university presses, as well as the anxiety connected with the neurological effects of digital technologies and a new kind of illiteracy the postprint can bring.



Author: N. Katherine Hayles

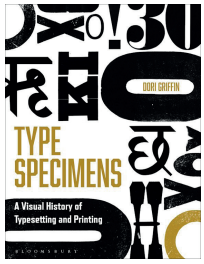
Publisher: Columbia University Press
1st ed., February 2021
ISBN: 978-0-231-19824-0
248 pages
Hardcover
Available also as an eBook

Type Specimens
A Visual History of Typesetting and Printing

As reflected in its name, this book outlines the developments in typesetting and printing technologies through the content of type specimens and specimen books. It aimed to provide not only broad access to resources otherwise available only locally but also historical context, global perspective, and visual reference. Individual chapters deal with the early broadsides, printers' manuals, foundry specimen books, industrial methods and materials, hot metal, ephemera, photographic and binary processes, up to digital type.

Author: Dori Griffin

Publisher: Bloomsbury Visual Arts
1st ed., January 2022
ISBN: 978-1-350-11660-3
256 pages, 200 images
Hardcover
Available also as an eBook



Vision

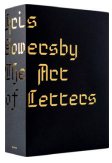
Editors: Andrew Fabian, Janet Gibson, Mike Sheppard, Simone Weyand

Publisher: Cambridge University Press
1st ed., September 2021
ISBN: 978-1108931021
228 pages, Softcover
Also as an eBook

This book brings essays developed from a well-established series of the Darwin College Lectures at Cambridge, where the theme of vision was addressed in 2019. In seven chapters, the experts with different backgrounds elaborate on the biological evolution of eyes, showing their diversity while detailing the morphology and properties of animal and human eyes, especially with respect to photoreceptors and resolution, and explain visions and the processes of perception, as well as colour vision and related phenomena, such as colour constancy and simultaneous chromatic contrast. Further, they examine the role of vision and visual images in science in general, supporting discoveries and understanding, the cameras and telescopes providing the vision of the cosmos, together with their anticipated developments, visions of a digital future with different stages of interaction between human and machine visions, and computer vision from its beginnings to present cutting-edge applications in medicine and autonomous driving.

Kris Sowersby
The Art of Letters

Editors: Mark Gowing, Dave Foster



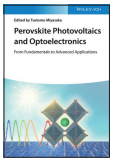
Publisher: Formist
1st ed., July 2021
ISBN: 978-0648596349
800 pages
Softcover

This volume features letterforms by Kris Sowersby of Klim Type Foundry and an essay by Paul McNeil. The selected characters are printed in large size, one per page.

Perovskite Photovoltaics and Optoelectronics
From Fundamentals to Advanced Applications

Editor: Tsutomu Miyasaka

Publisher: Wiley-VCH
1st ed., March 2022
ISBN: 978-3527347483
480 pages
Hardcover
Also as an eBook



The first chapter of this volume provides research background and recent progress of perovskite photovoltaics, including printable solar cells. The next six chapters detail the halide perovskite materials, their various properties and synthesis, physics of perovskite solar cells in terms of efficiency, open-circuit voltage and recombination, electric parameters of halide perovskite materials, and hysteresis of current–voltage performance. Eight chapters then describe the use of perovskite materials in different types of solar cells, for quantum dots, light-emitting diode technologies, photodetectors, and x-ray detectors.

Women in 3D Printing
From Bones to Bridges and Everything in Between

Editor: Stacey M. DelVecchio

Publisher: Springer
1st ed., July 2021
ISBN: 978-3030707354
205 pages, 106 images
Hardcover
Also as an eBook

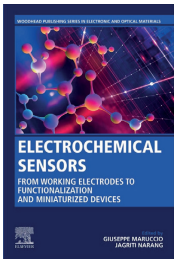
This volume from the Women in Engineering and Science series presents some of the women's contributions to the field of additive manufacturing. The areas include a digital product development platform, patient-specific anatomic models, bone regenerative medicine, inkjet-based 3D printing, the workflow employing laser powder-bed fusion process, direct ink writing of ceramics and ceramic matrix composites for aerospace, printing concrete buildings, and more.

Electrochemical Sensors
From Working Electrodes to Functionalization and Miniaturized Devices

The content of this book covers three areas – the basics of electrochemical sensors used for biosensing, the main types of electrodes, and the miniaturised devices. Two chapters introduce the general principle of biosensors, the devices that use a bioreceptor molecule as a sensing element, the ways of their fabrication and the fundamental concepts of electrochemistry, including both bulk and interfacial techniques. Five chapters present the metal-based electrodes, especially those from gold and platinum, together with immobilisation methods used to improve the sensitivity, selectivity, and stability of biosensors, the carbon and carbon paste electrodes with a focus on the advances in carbon nanomaterials, the mercury electrodes and their biosensing applications, the nanostructured electrodes and the related approaches to next-generation biosensors, and the 3D electrodes, which offer many advantages. One chapter deals with the biological recognition elements, discussing both the conventional and synthetic ones. The remaining two chapters review a nanotechnological approach to the miniaturisation of devices, together with the advantages it brings and concerns it raises, and the lab-on-a-chip devices, focusing on the various aspects of microfluidics. Among the printing techniques, the book includes the applications of screen printing, inkjet printing, and microcontact printing.

Editors: Giuseppe Maruccio, Jagriti Narang

Publisher: Woodhead Publishing
1st ed., January 2022
ISBN: 978-0-12-823148-7
316 pages
Softcover
Available also as an eBook

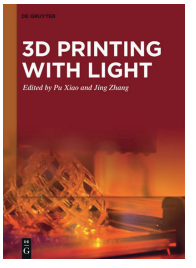


3D Printing with Light

Contributed by the international team of experts in the field, this book reviews the recent progress in 3D printing based on photopolymerisation of liquid resin through controlled irradiation, focusing primarily on chemistry and selected applications. The individual chapters deal with high-performance photoinitiating systems, photoinitiators for two-photon 3D printing, the use of functional dyes, resin design in stereolithography for microfluidic applications, 3D printing of biomaterials, the available technology, dual-wavelength systems, femtosecond laser nonlinear lithography, photocontrolled reversible addition–fragmentation chain transfer polymerisation, and challenges in terms of printing speed and biomedical applications.

Editors: Pu Xiao, Jing Zhang

Publisher: De Gruyter
1st ed., April 2021
ISBN: 978-3-11-056947-6
352 pages, 170 images
Hardcover
Available also as an eBook



Bookshelf

Academic dissertations

Development of Combined Method for Analysis of Facial Images Using Eye Tracking System

Doctoral thesis – Summary

Author:
Andrej Iskra

Speciality field:
Graphic and Interactive Communications

Supervisor:
Helena Gabrijelčič Tomc

Defended:
3 June 2020, University of Ljubljana, Faculty of Natural Sciences and Engineering Ljubljana, Slovenia

Language:
Slovenian

Original title:
Razvoj kombinirane metode za analizo obraznih slik z uporabo sistema sledenja pogleda

Contact:
andrej.iskra@ntf.uni-lj.si

Further reading:
https://repozitorij.uni-lj.si/IzpisGradiva.php?lang=eng&id=116791

The research within this thesis was focused on the field of eye-tracking, namely its application to facial images. The work investigated the influence of observation time and image dimensions on the duration of fixations and recognition performance, also analysing the results for images captured from different angles and the emotion recognition results. In all tests, a combined framework was employed, where the time-spatial analyses were complemented by a new area method utilising the data acquired for the heatmaps, and the results of both approaches were compared.

The theoretical part of the dissertation overviews the human eye, visual perception, methods of its study and related terms, facial anatomy, face perception, the role of observation angles, the basic set of facial emotions and emotion misidentification. The next part describes the experimental setup, choice of face images, test procedures and methods of results analysis. The two main methods used comprise the method evaluating the duration of fixations and the length of saccades and the proposed method based on characterisation of features observed in the image, especially on their area, circumference and circularity. In addition, the analyses considered the recognition performance and response times in the face recognition test, the observation statistics for the three areas of interest, i.e. eyes, nose and mouth, the visit count for the eye area, and the mistakes in emotion recognition evaluated using a substitution matrix. The study proved that the success of recognising and remembering facial images is reflected in the curves depicting its dependence on the observation time and image size. Thus, for the images with sufficient dimensions, it is possible to predict the time needed to achieve satisfactory results. Further, it was shown that profile face images (at 90°) took less time to observe the entire face than frontal images (at 0°), with the transition between 45° in 67.5°. The results confirmed the applicability of the proposed area method for eye-tracking data evaluation, including emotion recognition.

Perovskite Solar Cells With Printed Functional Layers

Doctoral thesis – Summary

Author:
Matej Hvojnik

Speciality field:
Chemical Engineering and Technology

Supervisor:
Milan Mikula

Defended:
23 August 2021, STU, FCFT, Department of Graphic Arts Technology and Applied Photochemistry Bratislava, Slovakia

This thesis contributed to the research on perovskite solar cells with carbon back electrode. Its primary objective was to prepare and optimise the layers applied by coating and printing techniques, namely the electron-transport and hole-blocking layer based on TiO_2 or SnO_2, as well as the TiO_2 mesoporous layer and ZrO_2 scaffold layer. The work also investigated different treatments of the glass substrate pre-coated with fluorine-doped tin oxide and their influence on the quality of the thin blocking layers.

The sections in the first part of the dissertation provide the background on perovskite structure and properties, deposition techniques, perovskite solar cell structure, electron-transport layers, scaffold layers, hole-transport layers and back electrode. After defining the aims, the work describes the materials and methods used and presents the results in two main sections. The study included several types of compact blocking layers: the layers spin-

Language:
Slovak

Original title:
Perovskitové solárne články s tlačenými funkčnými vrstvami

Contact:
matej.hvojnik@gmail.com

Further reading:
https://opac.crzp.sk/?fn=detailBiblioForm&sid=CF9E62B1F4156FE3B4280984D7C8

coated from sol-gel solutions prepared from three common TiO_2 precursors, namely titanium diisopropoxide bis(acetylacetonate), isopropoxide, and butoxide, the spin-coated layers modified by a small addition of $TiCl_4$ to sol-gel solutions, the layers dip-coated from $TiCl_4$ solution modified by $NiCl_2 \cdot 6\ H_2O$ either directly on the substrate or on the spin-coated TiO_2 layer, and the layers spin-coated from $SnCl_2 \cdot 2\ H_2O$ solutions. Individual layers were characterised by optical, atomic force and scanning electron microscopy and spectral techniques. The layers were incorporated in printed mesoporous perovskite solar cells. Based on the measured characteristics, the best efficiency (up to 7.8 %) was achieved for TiO_2 blocking layers from titanium diisopropoxide bis(acetylacetonate) modified by $TiCl_4$. Deposition of the mesoporous layer and use of ZrO_2 scaffold had only a slight influence. Due to the significant effect of substrate purity on the blocking layer quality and thus the performance of the resulting solar cell observed during the experiments, attention also was paid to the substrate cleaning process. It was shown that 10 s of the low-temperature atmospheric plasma treatment are sufficient to reach a conversion efficiency similar to that achieved when the standard, time-consuming chemical cleaning was used. When both these processes were employed, the efficiency moderately increased. For all treatment modes, the changes induced to the electrode surface and the resulting solar cell are characterised and discussed.

Doctoral thesis – Summary

Author:
Timo Hartus

Speciality field:
Paper and Printing Technology

Supervisor:
Patrick A.C. Gane

Defended:
19 November 2021, Aalto University, School of Chemical Technology, Department of Bioproducts and Biosystems Aalto, Finland

Contact:
timo.hartus@helsinki.fi

Further reading:
http://urn.fi/URN:ISBN:978-952-60-8904-1

Thermal Studies of Ink Solvent and Toner Behaviour on Coated Paper: Modelled in Various Printing Methods Using Ink-Coating Component Mixtures and Laboratory Scale Print Tests

The general focus of this thesis was on the amount of energy consumed in print production and its influence on various properties of the resulting output. In particular, the work investigated the possible relationship between energy consumption and the mechanical or optical quality of the print; it also studied the interaction of ink and paper components concerning reaction products that may be formed and have consequences in terms of print quality, recyclability or waste treatment.

The dissertation provides the fundamentals relevant for individual research questions solved within the thesis. These comprise adhesion of toner in electrophotography, setting and drying of inks in the sheet-fed and heatset offset printing, and drying of the water-based inkjet ink. The approaches adopted in the work are presented in detail, including the use of model compounds. The toners were characterised by digital scanning calorimetry, viscosity and surface energy measurements. After toner printing and fixing, the toner adhesion test and adhesion force measurement took place. Also, print gloss and roughness were determined. The experiments in offset studies included, among others, the measurement of splitting force to estimate ink setting, ink and ink-on-paper tack measurements, and thermal and FTIR characterisation. The quality of inkjet prints was characterised using image analysis combined with print smudge and abrasion resistance testing, whereas the model materials were subjected to thermal analyses. For electrophotography, the results show a clear connection between melting energy and print quality. The studies of offset materials and processes demonstrated a more complex behaviour and provided insight into its various aspects, such as poorer abrasion resistance due to fibre roughening caused by high drying temperature. Among the findings from the inkjet ink studies, the effect of water and solvent specific energy and mass loss ratios on drying time and abrasion resistance is shown. The tailored methods used for testing and evaluation also represent a valuable outcome of the work.

Events

SPIE events

SPIE Photonics Europe 2022

SPIE. PHOTONICS EUROPE Strasbourg, France
3–7 April 2022

The 2022 edition of this event is held in person; the recordings, posters and other content will also be later available on demand (9–15 May). The programme again includes the 3D Printed Optics and Additive Photonic Manufacturing conference. The topics include laser bioprinting for organ-on-chip and sensor applications, 3D-printed optical components with properties controllable by external light stimuli, improving print accuracy of volumetric additive manufacturing, the application of volumetric 3D printing for flexible gradient index lenses, and femtosecond direct laser writing as a technology for complex micro-optics, from a 3D-printed micro-pinhole camera to ultra-compact wide-angle cameras, up to a monolithic spectrometer. The use of different 3D printing technologies is also presented in other papers, such as in the one dealing with laser-induced forward transfer for drug thin-film printing. Other papers discuss the characterisation of 3D-printed materials and objects, for example, using the full-field optical analysis.

SPIE Defense + Commercial Sensing 2022

SPIE. DEFENSE+ COMMERCIAL SENSING Orlando, Florida, USA
3–7 April 2022

This SPIE event taking place the same days, but on the opposite side of the Atlantic Ocean, also features some contributions dealing with the utilisation of 3D printing in different areas, such as those presenting the 3D-printed polymer-based flexible electrodes for reverse electrowetting on dielectric energy harvesting, the development of a gastric resident electronics system based on the multiscale integration of nanomaterials in an extrusion-based 3D printing process as a part of the research towards a 3D-printed self-learning robot and free-form biomedical electronics, and the 3D-printed optomechanical positioners for aerospace metrological instruments.

Online Print Symposium 2022

Munich, Germany
28–29 April 2022

ONLINE PRINT SYMPOSIUM 2022 After the last year's edition postponed to September, in 2022 this event returns in its traditional spring term. Topics of the presentations include new opportunities for internationalisation of online print, the lessons learned in the web-to-print business development, benefits of finding customers among companies, the role of automation in the change of the online-print industry, the innovative solutions enabling customised textile production, different examples of the technology driven by artificial intelligence, and more.

Fairs and other events returning to the in-person format

While some events continue in the virtual format, others are announced to take place in person in 2022. On 5–7 April, the 14th 3D Printing Days take place in Kielce, Poland. The London Book Fair (UK) is held on the same days, with the sessions available later on demand (11–29 April). In France, the postponed 9th edition of the C!Print Lyon tradeshow can be visited on 10–12 May. Two weeks later, on 24–27 May, Graphispag takes place in Barcelona, Spain. The postponed 67th Annual Pulp and Paper Industry Conference is planned for 12–16 June in Ontario, Canada.

Intergraf events

INTERGRAF This year's Intergraf Currency+Identity conference and exhibition, open exclusively to security printers and other stakeholders in this area, is also held as an in-person event in Lyon, France (6–8 April). Later on 20 May, the Print Matters for the Future conference is held in Stockholm, Sweden, jointly with NOPA, the Nordic Offset Printing Association.

2022 Continuous Improvement Conference

Scottsdale, Arizona, USA
1–4 May 2022

CONTINUOUS IMPROVEMENT MAY 1-4 · SCOTTSDALE, AZ This established annual event, which is after the merger of Printing Industries of America (PIA) and Specialty Graphic Imaging Association (SGIA) presented by PRINTING United Alliance, offers the pre-conference workshops and three days of keynotes and lectures dedicated to lean manufacturing and other approaches improving management and quality in printing and converting companies.

IMI events

In the USA, the IMI Inkjet Conference 2022 is held on 4–5 May in Orlando, Florida, preceded by the IMI Inkjet Innovation Academy, taking place in the same venue on 2–3 May. The academy offers three comprehensive, one-and-a-half-day courses focused on the industrial inkjet system design, theory of inkjet technology, and evaluation and opportunities of inkjet-printed electronics. The two-day agenda of the conference covers the recent developments in the field, including 2.5, 3D and 4D material deposition, multimaterial printing, decreasing energy consumption and pollution with digital dyeing of textiles, the importance of wetting additives, and more. A week later, on 9–12 May, Digital Print Europe 2022 takes place in Barcelona, Spain, keeping the same format with the Inkjet Academy course followed by the IMI Europe Digital Printing Conference.

CPES2022

Brampton, Ontario, Canada
17–18 May 2022

This Canadian symposium focused on printable, flexible and wearable electronics in 2022 also returns to the in-person format. The programme covers e.g. the circular economy, advances in manufacturing, materials innovations, cybersecurity, smart packaging, and textile electronics.

I3S 2022
9th International Symposium on Sensor Science

Warsaw, Poland
20–22 June 2022

In 2022, the announced presentations discuss, among others, the influence of paste rheology on the performance of screen-printed electrochemical sensors and the potentiometric cell for atrazine sensing made by screen printing.

TAPPICon 2022

Charlotte, North Carolina, USA
30 April to 4 May 2022

This event organised by the Technical Association of the Pulp & Paper Industry covers the areas of coating and graphic arts, management, papermaking, tissue papermaking additives, papermaking fundamentals, process control, recycled paperboard, reliability and maintenance. Also, it offers the Mentor Match Speed Networking event for young professionals and the Women's Summit, with this year's key topic for the latter being Trusted Teams. The technical programme for coating and graphic arts includes panel discussions on fibre recycling as a critical component of sustainable packaging and the role of collaboration across the value chain in the successful development of compostable packaging, presentations of advances in the production of barrier layers and coating processes in general, novel test methods for barrier coatings, the influence of coating pigment particles on offset printing, the relationship between the coating layer and printing defects in a high-quality flexography, and the fully repulpable and biodegradable thermally sealable paper. In addition, this track presents the major topics for research and development in the field, such as perfecting circularity.

INMA World Congress of News Media

https://www.inma.org
5–26 May 2022

The International News Media Association presents this event again in the virtual format, this year comprising seven modules scheduled during May and focused on leadership, smart data, subscriptions, advertising, product innovation, newsrooms, and what is next. The lectures deal with the emerging trends in news media, the maturing data organisation, bundling new value as subscription models evolve, what and how is sold, how product mindsets are lifting results, newsrooms and the bridge to the business of news, and the growth path ahead for news media.

HOPV22
14th Conference on Hybrid and Organic Photovoltaics

Valencia, Spain
19–25 May 2022

After two online editions, this event organised by nanoGe supported by Fundació Scito returns in part to the in-person format, taking place online on 19 and 20 May and face-to-face from 23 to 25 May. The announced keynote speakers are Edward Sargent discussing the progress in inverted perovskite photovoltaics in terms of their thermal and operational stability, with a focus on removing the barrier to electron extraction at the 2D/3D interface, Jenny Nelson presenting luminescence and molecular modelling as tools to probe structure-property-performance relationships at molecular heterojunctions, and Christoph Brabec providing an insight into advanced interface engineering for the long operational lifetime of organic and perovskite solar cells. The topics of the technical presentations include, for example, the bifacial fully printable low-dimensional perovskite solar cells.

Journal of Print and Media Technology Research
A PEER-REVIEWED QUARTERLY

ISSN 2414-6250 (Online)
ISSN 2223-8905 (Print)
UDC 665

Call for papers

The Journal of Print and Media Technology Research is a peer-reviewed periodical, published quarterly by iarigai, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries.

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Vol. 11, 2022
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1-2022

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- Premedia technology and processes
- Emerging media and future trends
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