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TORONTO METROPOLITAN UNIVERSITY

2025

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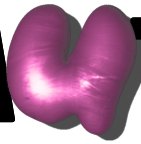

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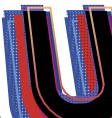

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2025 STUDENT JOURNAL

TMUTAGA

TECHNICAL ASSOCIATION OF THE GRAPHIC ARTS
TORONTO METROPOLITAN UNIVERSITY
STUDENT CHAPTER © 2025

Toronto is in the 'Dish With One Spoon Territory'. The Dish With One Spoon is a treaty between the Anishinaabe, Mississaugas and Haudenosaunee that bound them to share the territory and protect the land. Subsequent Indigenous Nations and peoples, Europeans and all newcomers have been invited into this treaty in the spirit of peace, friendship and respect.

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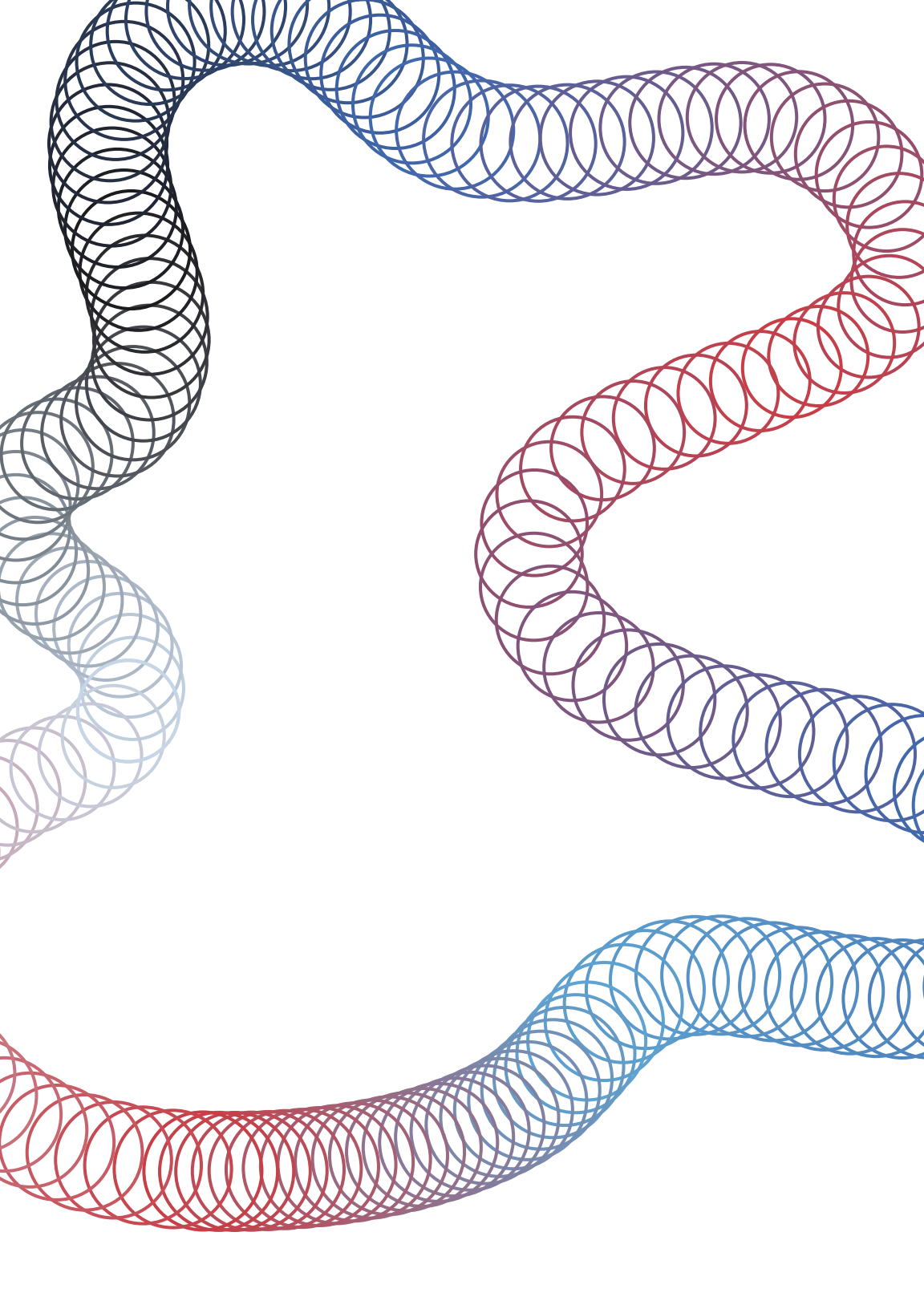
OUR INSPIRATION

Two years ago, our student chapter rebranded ourselves to its new name: TMUTAGA. This has led us down a journey of rediscovery, self-exploration and new, innovative forms of creative expression. In 2023, we emphasized tradition, and in 2024 we emerged from our past. Now, we enter a new chapter of our journey in 2025 as a **UNIFIED** team.

We asked ourselves, who are we? **Who is TMUTAGA?**

What makes TMUTAGA is **you**. Each and every one of you is integral to our journey. Our team, our 'U', this journal is for you. You have put everything into this project. You make us unique. You make us better. You are the future of Graphic Communications. You are the future of print.

U are TMUTAGA.



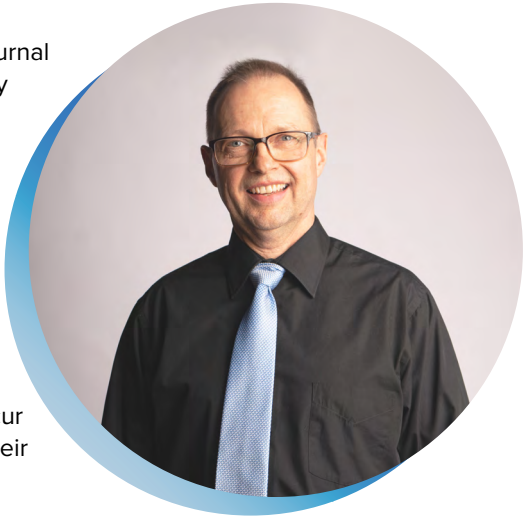
TMUTAGA

2025

A LETTER FROM

OUR FACULTY ADVISOR

Dr. Martin Habekost *He/Him*



Dear TMUTAGA student chapter,

You did it again! Another fantastic journal was designed, printed and bound, ready for the competition to win the Kipphan Cup. A lot of hard work, sweat and probably some tears went into this journal.

Every year, I am amazed by the team's creative ideas. It is simply amazing to see how a vague idea turns into a design idea and how the theme is finally chosen. I might not be privy to any friction points that are bound to occur between the executive members and their teams, but it was all worth it in the end.

You made fantastic connections to the industry this year, and I am very proud of that. These connections contributed to the journal. I am sure that TMUTAGA student group is the only group with some pages printed on a very special machine. You even travelled to Dallas in December 2024 to see this machine and equipment for special embellishment effects.

It has been an honour to serve as your advisor for many years. Being the advisor to this group is a big part of why I love my job.

Now go and rip the cup off CalPoly's hands.

Have a fantastic conference, and make many new connections!

Martin Habekost, Dr. rer. nat.
Professor
Advisor of TMUTAGA

A LETTER FROM

OUR PRESIDENT

Diana Carnovale *She/Her*

Dear TMUTAGA,

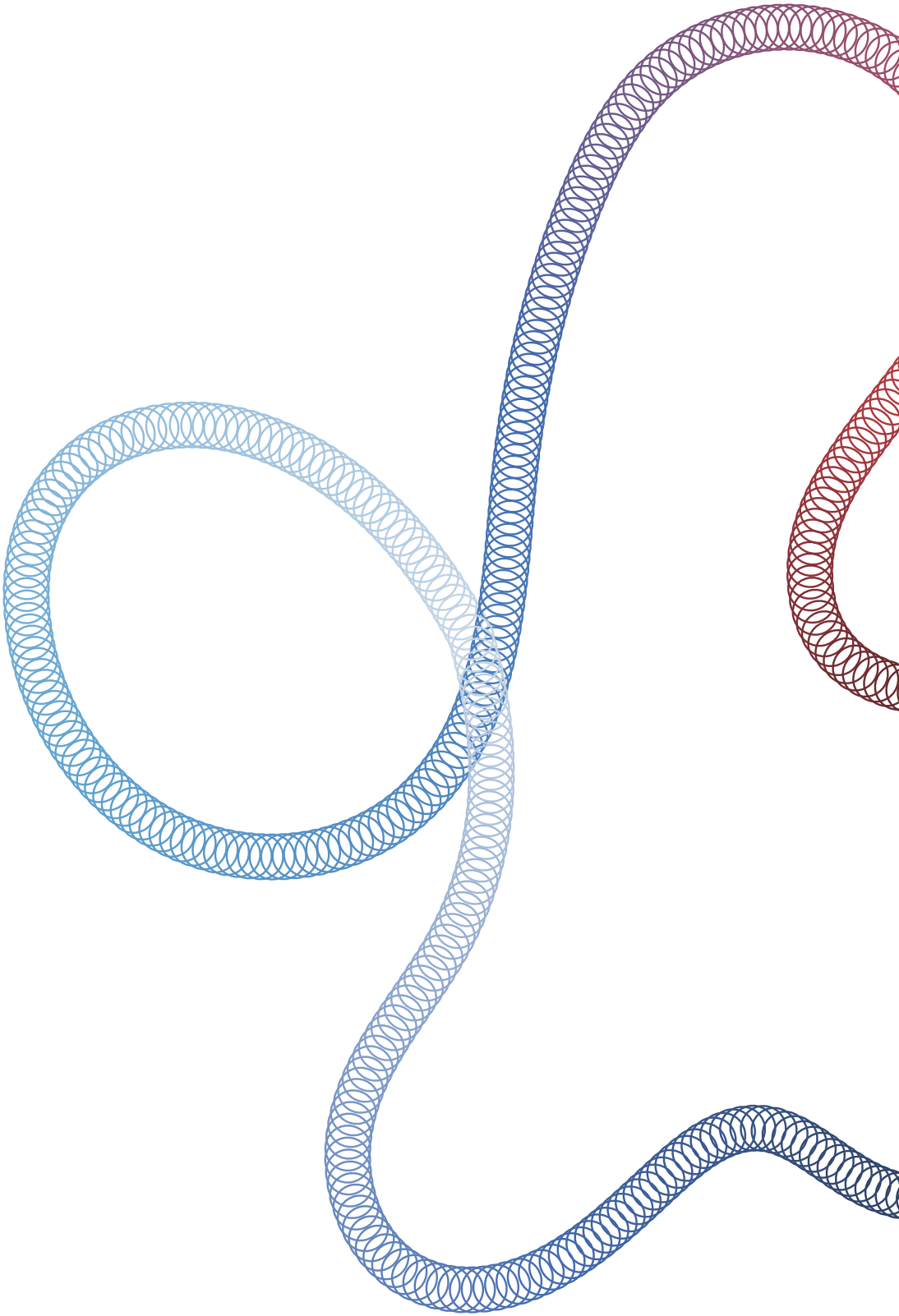
We've made it to the end! It's with great pleasure that we present to you Toronto Metropolitan University's 2024/2025 TAGA Technical Student Journal. Our journey began a year ago in Dallas, Texas, when I decided to take up presidency for the 2024/2025 year. The joy of seeing everyone's hard work come together and be celebrated at the TAGA Conference inspired me to embark on this ambitious journey and see where TMUTAGA could go next.

After nine long months of planning, testing, execution and most importantly unwavering passion, I am so incredibly proud to present this year's journal. It is a testament to the hard work and dedication of what makes Graphic Communications Management students stand out– in other words what makes you, U. None of this could've been possible without the truly incredible team heading this project. With a total of thirty talented TMU students, comprising of nineteen Associates, three Team Leads and eight Executives, TMUTAGA would not be possible without any of you. As well, thank you to the student authors who have allowed us the use of their theses in this year's journal. As you flip through please invest yourself in five inspiring GCM student's work which explore the topics of extended colour gamut, packaging accessibility and sustainability. These are just some of the minds who will be heading the future of our industry.

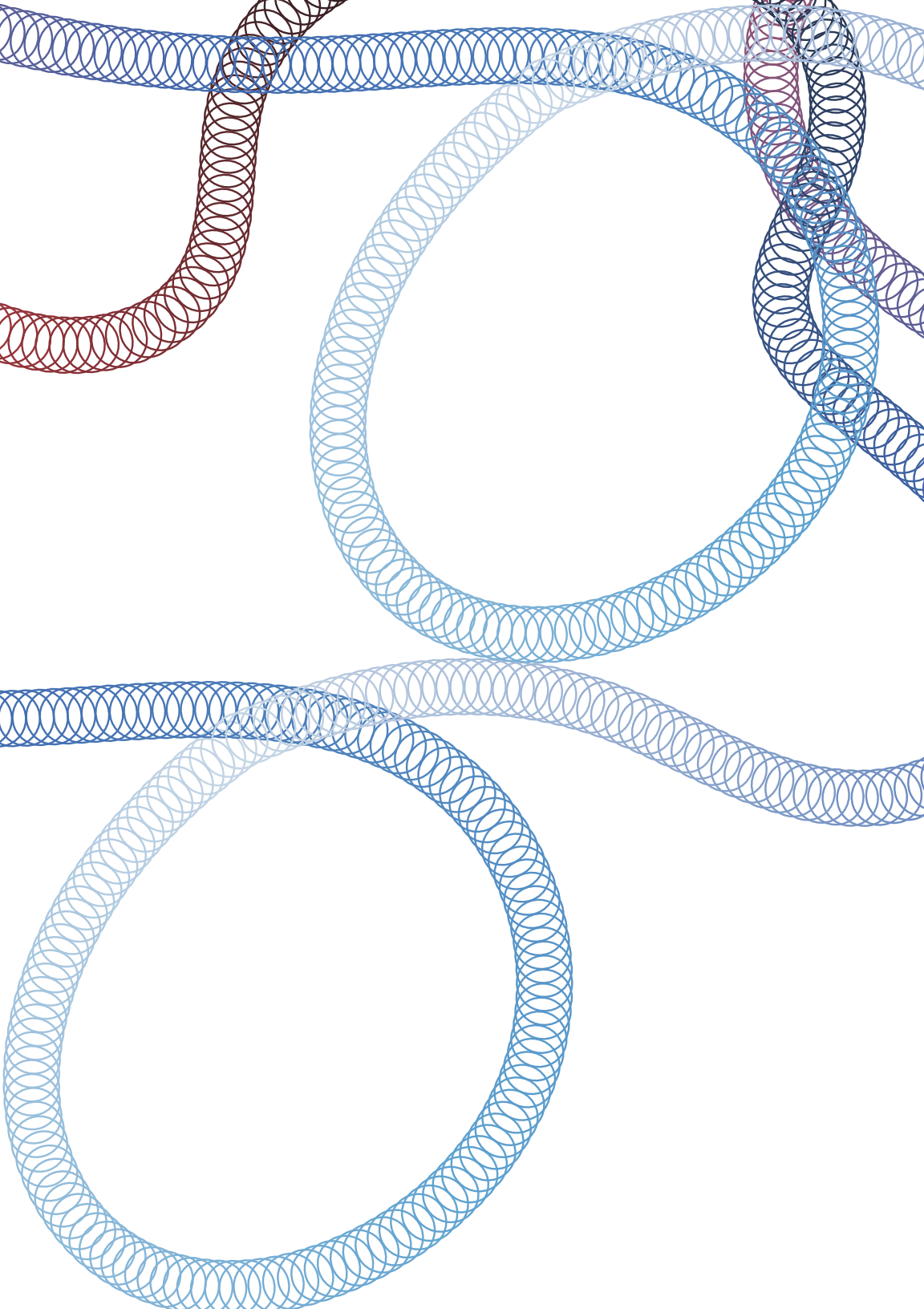
From everyone who keeps TMUTAGA inspired, to the unwavering support from the GCM faculty, Martin our Faculty Advisor, and our industry donors– thank you for continuing to provide us with the environment to create. This journal would not be possible without your generosity. On behalf of the entire TMUTAGA team, I hope you all enjoy the 2024/2025 journal as much as we have enjoyed creating it.

Never stop being U!

Diana Carnovale,
President of TMUTAGA



CONTENTS



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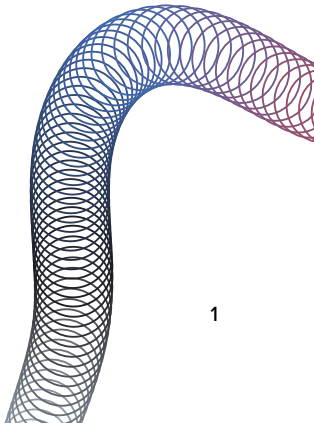
IMPACT OF FLUORESCENT TONER ON PROFILING AND EXTENDED COLOUR GAMUT

Rebecca Karton

Rebecca Karton is an avid crafter, musician, and baker, though master of none. They live life with humour and humility, viewing the world through a scientific lens that magnifies the wonder of arts. Previously published in the White Wall Review with a flash fiction, Rebecca's writing aims to engage readers and question assumptions. They hold a Bachelor of Technology in Graphic Communications, inclusive of a publishing concentration, a packaging concentration, and an English minor. Winning scholarships for premedia and colour management excellence, they are passionate about the technological side of the graphic arts industry. Rebecca works as a workflow integrator for automation solutions.

To listen to Rebecca's thesis, use this link:



Acknowledgement:

In no particular order, I am grateful to Dr. Abhay Sharma for being my thesis advisor and Dr. Krzysztof (Kris) Krystosiak for his enthusiasm. Much appreciation goes to Begum Walji for taking time out of her day to speak with me. Jasmine and Ayesha deserve recognition for listening to me talk only about this thesis for several months. Deepest thanks to Peter Roehrig for switching out the toner on my behalf multiple times, Darsan Sivanantharajah for loaning me space to store an i1Pro3, and Khaled Ahmed for research suggestions after listening to my half-formed idea. To Scott Millward, who repeatedly told us we can't print the sun in his colour management course: I was inspired to try. The support over the past year when I tried, failed, matured, and persevered to finish this project means a lot and this couldn't have happened without them.

Abstract:

Digital toner printing has become a mainstay, particularly in short run applications. With companies like Xerox and Ricoh providing additional toner variations such as fluorescents, printers are given the opportunity to expand their gamuts beyond what cyan, magenta, yellow, and black are capable. This study found an increase in gamut between 0.4% and 2.9% using Neon Pink and Neon Yellow toners with the traditional process toners, dependent on the presence of ultraviolet and violet wavelengths in the light source. Using fluorescent toners without their respective process toners is not recommended in most cases, as darker colours are cut from the gamut, replaced by a smaller volume of lighter saturations. Fluorescent toners were also found to combine with process toners to create distinct "Super" saturation variations—Super Pink, Super Yellow, and Super Green—which extended the gamut in small ranges beyond what process, and fluorescent replacing process, toners could achieve individually. Further premedia and profiling techniques must be identified to make the greatest use of the potential gamut size through fluorescent overprints to increase the vibrancy of reds, greens, and violets, while maintaining the darker process toner overprints.

Introduction

The School of Graphic Communications, found in the Heidelberg Centre on the Toronto Metropolitan University campus, uses a Ricoh Pro C7210X digital toner press for student projects and internal publications (i.e. welcome packages and school event materials). This press includes a 5th colour station for specialty colours such as Gold, White, Invisible Red, and the focus of this study, two fluorescents: Neon Pink and Neon Yellow.

While fluorescents are often used as 100% solids in graphics and text, they can be printed at various tints like process colours and/or be incorporated as UV-reactive security (Roesch, 2024). With digital press solutions entering university in-plants, and digital embellishments on the rise as a result (VanDewater, 2024),

this research aims to answer whether fluorescent toners are appropriate to extend the cyan, magenta, yellow, and black (CMYK) gamut through ease of use in premedia and effectiveness under three light sources. Over several decades of experimentation, extended gamut printing (ECG) has settled on a CMYKOGV process—adding orange, green, and violet—as the usual effective method (O'Hara & Congdon, 2016; Sharma & Seymour, 2019). However, advances to technology and the prominence of 5 units in digital toner presses, along with certain Xerox presses' ability to exchange process colours with fluorescent equivalents (Marin, 2022; VanDewater, 2024, Elizabeth, 2023), begs the question of whether the currently available fluorescent toners can be used as a practical, alternative extended gamut method that creates significant results.

Research in this area is limited; a relatively new phenomenon, companies hope to keep their advances ahead of the competition. This paper aims to lay a foundation on which research can be built by examining the process from creating test charts to applying profiles on final artwork, with heavy focus on profiling fluorescent toners and whether using them in the printing process adds value for those who want to increase the amount of printable colours and do not have access to the seven colour ECG method. Tests were performed on glossy coated stock to ensure the CMYK baseline performed to its fullest; should CMYK outperform the fluorescent toners, then CMYK should remain in use for those applications. At the core, this research analyses the effectiveness of gamuts built with fluorescent toners on a Ricoh Pro C7210X and whether they are noteworthy for further studies to assert best practices in this developing field.

Literature Review

Digital printing is a complex and fast-moving market with a lack of in-depth research, in part due to trade secrets locked behind patents. This review covers the general market with focus on toner presses, ECG across the printing industry and its relevance to digital printing, and the measurement of fluorescent pigments using instruments in combination with mathematics to match the average perception of a human visual system. To provide an overview of the components which come together to create a fluorescent ECG process, several patents from attempts at ECG over the past thirty years are summarized, along with a look at modern premedia softwares to support ECG, and the specifics of creating fluorescence in print. The term "fluorescent" is preferred for consistency, but "neon" may be used throughout as it relates to Ricoh specifically and has the same meaning.

The Digital Market & Embellishments

Digital printing is known for its small waste, high print quality, and milder chemicals, which is why the technology continues to grow rapidly in a niche market of short-run, cost-effective and sustainable solutions, and for large-volume print personalization with variable data printing (VDP) ("Digital Printing Market," 2022). The digital press market involves large companies such as Epson, Kodak, Konica Minolta, HP, Xerox, Ricoh, and suppliers such as Canon, who include additional software for print quality and colour management. Table 1 illustrates the different offerings digital presses may have for print units and specialty colours. While the prices of these machines are quite high—the initial purchase and installation, support, and consumables driving up cost to operate—the market flourishes with diversity in colour capabilities, sizes, and materials, where each company has its own competitive advantage.

Table 1. Example Comparison of Select Available Toner/Dry Ink Presses and their Spot Colours.

Press	Print Units	Spot Colours
Ricoh Pros (Series)	5	Clear, White, Neon, Gold
HP Indigo 7K	5-7	White, Metallic; HP IndiChrome adds OGV
NexFinity & NexPress	5	Dimensional Clear, Gloss, Red Fluorescent, Gold
Xerox Iridesse	6	Clear, White, Silver, Gold, Fluorescent Pink

Note. Retrieved from Marin (2022) and VanDewater (2024); not meant to be comprehensive.

Embellishments in digital printing are a solid part of the market, special in their ability to be VDP-enhanced in addition to the usual benefits of standing out with look and touch: crucial points in perceived ownership and emotional engagement (Marin, 2022). These embellishments often come as additional spot colour stations to produce designs outside traditional CMYK gamuts, such as fluorescents and metallics. Being digital, short runs of specialty designs become much faster and cheaper to make, and can combine processes inline, like printing CMYK or varnish over foil. This type of printing—sometimes referred to as fifth colour—is pushed as excellent for marketing. Clear enhancements add a luxurious gloss, white adds contrast on a coloured media or simulates metallics, and invisible red UV can print security codes (Accuprint, n.d.). Fluorescent colours can be used by themselves or blended with CMYK to expand the printed gamut, encompassing more brand colours. Accuprint claims Neon Pink helps with the oranges and purples, and Neon Yellow helps in the yellows and greens, although they do not provide quantitative measurements with this claim.

VanDewater (2024) provided an overview of trends for university in-plants like University of Delaware, University of Tennessee, Western Carolina University, and Oregon State University, the latter adding digital embellishments to a third of their pieces. The main trend is embellishments creeping into stickers, book covers, pamphlets, and official letters—if it is printed digitally, it may get a finishing touch of fluorescence, metallic, or varnish. Due to print increasingly being used in transactions that result in recycling immediately after use ends, clients may be hesitant to ask for embellishments, particularly if the digital solution costs more than normal CMYK printing; they are familiar with weeks of lead time from outsourcing and the hefty cost of a die. However, digital presses can quickly create as little as one sheet, adding value with the ability to proof the actual embellishments. University of Delaware's in-plant increased interest in in-house options through offering these digital options, at minimum extra cost to all parties. In essence, unique uses of digital embellishments can make small, digital plants stand out, such as marketing material for university programs from acceptance to graduation.

Xerox Presses

Providing spot colour kits for a variety of press series, Xerox is particular about the toner order depending on the market segment (Elizabeth, 2023). Two of their smaller presses can replace CMY with fluorescent versions of themselves, or replace all of CMYK with gold and silver metallics, white, and clear in specific spots related to click charges. For example, in the PrimeLink C Series, white replaces cyan, and in the Versant 280, white replaces black. This change is made so that white underlays all of the following toners to help bring out the colours or embellishments. In the Xerox Iridesse, CMYK always falls in the middle, with the ability to print one underlay and one overlay from their two metallic options, White, Fluorescent Pink, Clear, or Low Gloss Clear. The above-mentioned presses are ordered KCMY, with their iGen 5 Press printing KCYM. The iGen 5 has an enhancement category of fifth station colours—Fluorescent Yellow, White, and Clear—and gamut extending Orange, Green, and Blue available.

Using the PrimeLink C series, clients can use CMYK files to print as fluorescent process colours, expanding the gamut especially towards bright greens and yellows, oranges and reds (Xerox Support, 2020), though again, no quantifications are given. Their Fluorescent Yellow is very bright, their Fluorescent Magenta less so, and Cyan visibly least impactful, which is average across the industry. Limitations include the toner potentially fading within a week, avoiding rich black with fluorescents, and the inability to perform colour management, thus being unable to match to Pantone. Therefore, it is suggested to print example swatches to reference. Additionally, stock with high fluorescence enhances overall brightness, while dull clay coatings reduce impact.

Expanded Colour Gamut (ECG) for Printing

ECG is an inclusive term for anything beyond CMYK in an attempt to create a larger gamut with process colours, prevalent in all types of printing, though most often adds orange, green, and violet to create a seven colour process (O'Hara & Congdon, 2016; Sharma & Seymour, 2019). The market share was estimated to increase to 40-50% from 15% in the packaging industry over 4 years, with steady growth in the digital press market (O'Hara & Congdon, 2016). At this point, it is accepted that providing pigments in corners opposite to CMY creates greater stability in printing, as less control is needed on overprints, similar to black being redundant for neutral greys (Sharma & Seymour, 2019). Extra colours were already in use to create certain brand colours regardless of gamut; however, ECG aims to use a consistent batch of additional colours as process to increase gamut rather than continue to swap out job specific spot colours for each press run, creating the ability to gang more jobs, saving time and cost from front-end estimating to print floor wash-ups, and storage and disposal of many different colours (O'Hara & Congdon, 2016; Sharma & Seymour, 2019). Sharma & Seymour (2019) conclusively showed successful ECG on digital presses is possible, expanding the gamut volumes far beyond SWOP 2013 and GRACoL 2013, using multi-channel-enabled software vendors (see Table 2). They used the OGV capabilities of the presses and on an Epson SureColor P9000, light versions of traditional CMY process to reach lighter, still saturated, overprints.

Table 2. Gamut Volume and Theoretical In-Gamut Pantone Colours in CMYK and ECG Profiles.

Profile/Printing Condition	Gamut Volume (cubic L*a*b*)	In-Gamut Patone
GRACoL 2006 Coated 1v2	N/A	40%
SWOP 2013 (CRPC 5)	331,355	68%
GRACoL 2013 (CRPC 6)	388,960	70%
Clemson Flexo CMYKOGV	N/A	72%
HP Indigo 7900	639,411	89%
Epson SureColor P9000	760,624	97%

O'Hara & Congdon (2016) focused on the print order of ECG on a flexographic press. They started their experiment by establishing their traditional Clemson method of printing KCMY, and adding OGV before, between, and after the usual process colours. They found that changing the order of inks caused a colour

difference up to 9.5 ΔEAB and laying down the most opaque inks first shrunk the gamut. Different overprint pairs had a varying change, with the order of yellow and green, magenta and orange, and cyan and green relative to each other making the highest impact in gamut volume changes.

In comparison, the Xerox iGen 5 Press features OGB as gamut extenders in its 5th station, claiming to encapsulate more brand colours [than CMYK] and over 93% of the Pantone Plus swatches (Elizabeth, 2023). Digital presses, unlike traditional impact printing, rely on manufacturers to set the order of colours and what colours are available, so while ECG is being embraced, limitations on thorough experimentation by third parties still exist. One such experiment resulted in an inkjet press using RGB fluorescents instead of CMYK (Ataeefard & Nourmohammadian, 2015).

Overview of ECG Patents

Methods such as Hexachrome differ from the newest versions of ECG, which makes it difficult for scholarly literature to keep up, particularly when news mainly appears in the form of the trade press and the strict protections patents provide (Sharma & Seymour, 2019). To get a deeper idea on ECG, three patents have been reviewed—the first for the basic process of ECG, the second for its desire to move the primary hues, and the third for its use of fluorescents.

U.S. Patent No. 7,032,517 B2. Invented by Bestmann (2006), this patent involves red, green, and blue as secondary process colours which are used to reduce variability in spot colour reproduction. The method is to first print a CMYK test form, then replace cyan, magenta, and yellow with their complementary secondary process colours over three more test forms, creating the combinations RMYK, CGYK, and CMBK. An ICC profile is derived from each, and the spot colour to be printed is compared to the reliability of each combination to produce said colour, and the best fit is then used to officially print. Green and yellow inks together appeared to make the most difference in gamut increase. Patents EP 0 131 145 B1 (splitting the red segment into orange-red and magenta-red inks, and adding violet-blue and green inks, along with only printing two colours plus black and potentially white), and U.S. 5,734,800 (using YOMCGK, where the first three inks of the process are fluorescent to increase brilliance) are mentioned.

U.S. Patent No. 9,649,868 B2. Invented by Simoni et al. (2017), this patent uses between 4 and 6 colours to increase the gamut by moving the primary colours away from the standard under traditional RGB-based separation, shifting the cyan towards green, the yellow towards green, and the magenta towards blue. With digital screening, one ink can use two different inks' screens in the same image, and all inks can be shifted relative to each other, as opposed to adding additional primaries on top as necessary. If desired, a red-orange or orange and/or blue or violet could become a fifth and sixth unit to further grow the gamut. The goal of moving the primaries, adjusting their hues and densities, is to keep the

required print units low for presses with maximum six stations who either cannot handle a seven colour ECG system or could use a sixth station for other purposes. Pantone Hexachrome's additions of orange and green are credited to increasing the CMYK gamut to cover over 90% of Pantone swatches, and U.S. 5,734,800 is mentioned again as using Pantone inks with fluorescence—this time in magenta, orange, and green—with criticism to the colour management abilities when fluorescents change drastically depending on illumination, making it impossible to create a truly neutral grey press calibration. Fluorescent inks are relegated to special effects.

U.S. Patent No. 5,734,800 A. Invented by Herbert & DiBernardo (1994), this patent hoped to improve on the quality of SWOP 1993 by moving away from the economic standards of subtractive colours. It acknowledges the issues of 7 or 8 unit presses being uncommon, and the registration issues of a second pass, so aims to fit within the technology of presses and colour screening of the time, settling on a preferred six colour system. Three of the primaries should be more saturated through fluorescent inks, such as a fluorescent yellow and fluorescent magenta combining into a saturated orange or red, eliminating the need for an additional ink in that range. Alternatively, a four colour process with only fluorescents is suggested. They claim that due to Stokes' Law, these daylight-triggered inks convert less light the closer their wavelength to violet, as the pigment can only convert the wavelengths between the base colour and violet. Following that logic, red is the most fluorescent colour as it can convert yellow, green, blue, and violet wavelengths to red wavelengths; therefore yellow, orange, and magenta are suggested as the altered process inks, and cyan, green, and black as the regular inks. Although fluorescent inks are less light-fast and have weaker strength, physically combining them with regular inks before printing reduces the negative impact. A main reason this ECG method did not catch on was the colour management aspect of creating accurate separations and the inability to account for the weaker strength of fluorescents in the technology of the time.

Fluorescent ECG Premedia

Owners of the Xerox Iridesse are encouraged to use their Fluorescent Pink toner blended into CMYK designs (Xerox Support, 2021). The prepress process demonstrated is manual and arguably counter-intuitive: creating two separate Adobe Illustrator files, adding a spot colour, and combining them in Adobe InDesign with the CMYK file on top set to the Multiply layer effect. The digital file does not represent the physical printed appearance, so combinations must be known and input by the operator regardless how it appears on screen. Colour management consists of printing many swatches and choosing the final result visually (Xerox Support, 2020).

Touch7 offers the ability to print swatches, colour charts, and shade cards on a printer-by- printer basis for fluorescent cyans, magentas, and yellows, along

with ECG capabilities to separate out fluorescent orange and green in a relatively short amount of time and mouse clicks (Khaos Technology, 2023). To separate a fluorescent magenta out of red or orange in a photograph, the Touch7 Adobe Photoshop plug-in uses its Neon and ECG tabs by generating a red or orange separation, assigning an L*a*b* value from a preset of a specific press' fluorescent magenta, and subtracting it from the other channels to create CMYK + Pink separations (Khaos Technology, 2021). In this case, the printed version should match what is on screen—but only after returning the image to RGB mode and merging the spot channel back in. This method also leads to dot contamination in skin tones which must be removed by the prepress operator.

A third prepress method is to create multichannel ICC profiles, as they inherently support fluorescent channels and can be applied to bitmap or vector files (Roesch, 2024). As long as the profiles are created correctly and the images are busy to distract from slight colour inaccuracies, metamerism can even hide graphics by masking out certain areas to different profiles that are then revealed under chosen light sources. Depending on the complexity, Adobe Photoshop may not be ideal, since the software does not support transparency for multichannel files.

Colour Testing and Comparison. Although IDEAlliance released a characterization target for ECG, a standard for ECG test charts was yet to exist when Sharma & Seymour (2019) experimented, never mind for fluorescent-based ECG. The range in various profiling software was 875 to 3536 patches for digital ECG presses, averaging at 2523. A decent sample must be measured to gauge the true volume of a gamut but unlike for CMYK, the amount of patches needed to be thorough and efficient has not been established.

As a baseline, less than 2 ΔE, either CIEDE1994 or CIEDE2000, has been the usual tolerance for colour differences (Gonzalez & Fairchild, 2000; Sharma & Seymour, 2019). Human perception depends on the light source, object characteristics, proximity to other objects, and the person themself observing (Karma, 2020). For example, while a computer monitor can change red, green, and blue steps at small increments between 0 and 255, the minimum distance between points in a 3D graph—factoring in eye sensitivity—was found to be 11.68 for humans to identify a difference. Perceptual differences in colour and between individuals are important to take into account when quantifying colour. Habekost (2013) found that while some people could spot a colour difference as little as 1.86 ΔE_{ab}, others may consider 4.49 ΔE_{ab} a perfect match. By 8.27 ΔE_{ab}, the colours were considered definitely different by all participants. He concluded that using more recent models, like CIEDE2000, perceptual differences written into the equations increased the likelihood of the mathematical colour differences matching human perception. Updating the tolerances to CIEDE2000, green and yellow had the lowest tolerances at 1.70 $\Delta E_{CiE2000}$, the majority of the process

colours and overprints were under 3.00 $\Delta E_{CiE2000}$, blue had 3.60 $\Delta E_{CiE2000}$, and black had the highest, at 4.50 $\Delta E_{CiE2000}$.

Science of Fluorescence

Fluorescence is a natural occurrence broadly defined as a narrow range of light absorbed by a molecule that is re-emitted at a longer wavelength, sometimes in an entirely new hue than the initial source (Marshall & Johnsen, 2017). Extra-white fabrics, highlighter pens, and paper all contain fluorescent-promoting molecules triggered by different areas of the wavelength spectrum, from greens and blues to ultraviolet (UV) light, 330 to 500 nm being strongest, with longer emitted wavelengths such as red, yellow, and green more likely triggered by the visible light spectrum. Johnsen (2012) explains that when the light is absorbed, its energy is partially converted to other energies and the remainder is then emitted as light. Fluorescence is generally caused by reaching the energy requirement to move a molecule from its ground state to the first level of excitement, where the excitement energy is then released; fluorescence either happens or does not happen. This change in energy—increasing the wavelength—is the Stokes shift. As the process is less than perfect efficiency, the illusion of the glow is more so from an exaggerated emission of a certain range compared to other materials nearby, and is undermined by a white patch with better reflective efficiency (Marshall & Johnsen, 2017). While viewing fluorescents, the eye's photoreceptors will see a higher contrast when sensitivity is regulated to small ranges, as residual sensitivity to a pigment can span a couple hundred nanometres of the visible spectrum. Humans' visual range includes a sensitivity to green and yellow 50 times more than red or blue, increasing the ability to see fluorescence. Green and Kriss (2010) clarify that humans cannot perceive a distinction between reflection and fluorescence.

Fluorescence in the Printing Industry

Back in 1988, the International Commission on Illumination released the news that not even laboratories could remove instruments' one order of magnitude of uncertainty when measuring the total spectral radiance factor of fluorescent paper or ink (ICC, 2005). Issues included applying colour management with the variation in UV component strength of daylight sources in instruments and when greater exposure of fluorescence to the instrument caused progressively less accuracy. Fifteen years later, the technology may have improved—to the opinion of the reporter—but no large study existed to prove it. Gonzalez & Fairchild (2000) suggest using bispectral instruments to better measure not only the reflected light, but also the light being emitted by the instrument, and create light source independent results through a series of equations. They mention that the typical accepted error in colour difference is likely through the optical brightening agents (OBAs) in paper revealed through low ink coverage or the natural fluorescence which occurs in some inks.

Considering OBAs are present in most papers to strengthen the white point (Green & Kriss, 2010), focus on measurement of fluorescents has increased. The molecules in question are stilbene, which react best in the UV 350 nm range, creating visible emissions around 440 nm. Bispectral measurements continue to be the best solution because UV-cut filters still let through the blue range (380-420 nm) to measure the reflectance of the visible spectrum, which includes the absorption and emission range of potential fluorescents. Additionally, with the variability of UV content in light sources of measurement instruments and viewing conditions, using M1 or M2 mode will only create consistency in one specific condition. When measuring with a xenon source on OBA paper, the difference between with and without UV was 4 ΔEab with solid inks and 12 ΔEab in areas absent of printing. It was also found that yellow inks are best able to absorb UV light before it reaches the paper, reducing the amount of fluorescence measured. Two recommendations were put forth: when the product's viewing condition will be absent of UV, use M2 to create more consistent measurements in colour and between papers, and when the viewing condition will have a significant amount of UV, use M1 with a D50 source. Roesch (2024) recommends only using M1 for fluorescents, due to the UV reactive nature being the main attraction, and so it is the conditions viewers should always be using.

Having a true D50 light source is difficult to produce in terms of a spectral match, rather than matching overall colour temperature (Wyble & Seymour, 2015). Alternatively, an instrument can combine light sources to recreate D50 through one or two readings. The two readings are one from each light source weighted into a final M1 measurement. This is more accurate than one reading, along with being able to provide M0 and M2 values simultaneously, though it is difficult to implement for inline applications. The X-Rite i1Pro uses a method similar to two readings, combining an Illuminant A with a UV LED source. This type of set-up performed most consistently of their tests, although all set-ups thought fluorescence was much higher than reality due to the strength of their UV LED source.

Progress has been made in identifying the effect of OBAs: Hersch (2014) applies a similar theory as the two-reading method to better predict and characterize paper fluorescence and its impact surrounding halftone coverage, which was an issue previously. Through the Neugebauer reflectance prediction model, he takes into account the movement of the light through the halftones, reflectance and emissions from the paper, and the travel back through the halftones. Measurements involve separating the emission-producing range (330-420 nm) from the purely reflectance range (420-530 nm), which are also combined with the Yule-Nielsen model to predict ink-spreading and mathematically account for the different components contributing to final fluorescence.

Fluorescence in Ink and Toner. Related to OBAs, fluorescent inks contain UV reactive chemicals in addition to colourants, often becoming thinner (Roesch,

2024). OBAs in the substrate impact the fluorescence, and more than 30% non-fluorescent ink in the mix destroys the effect. Fluorescent inks still need a white reflecting substrate and could need a second pass to strengthen the colour. The impact is larger under a UV light source, such as the sun, though when exposed to light, the colour often fades quickly. Since fluorescent colours need to be mostly pure to have the intended effect, artwork should be specially planned around L*a*b* values close to the pure fluorescent colour to make it pop. The expectations should be for a subtle effect, like the boost substrate OBAs give. Expanding the gamut using white ink with OBAs for highlights was suggested. Under predominantly UV light, colours and white appear to go dark, except for where fluorescents are present, allowing for two different images. This technique may be used for hidden graphics, watermarks, or counterfeit security.

The main molecules to produce fluorescence for electrophotographic printing according to Ataeefard and Nourmohammadian (2015) are benzoxazolyl and benzimidazolyl coumarin derivatives. These daylight fluorescents absorb UV light within 320 to 380 nm, emit within the range of 380 to 730 nm, and have been in use since the mid 1900s for highlighters, OBAs, and high visibility applications. Pigments should be added in as an optimal percent volume of toner, a non-linear set of values that, after a certain point, sees emission intensity drop with quenching. The pigments can be used in the emulsion aggregation method of forming toner, a more sustainable approach, which Xerox uses (Xerox Support, 2020). Fluorescent toner is also prone to fading, sometimes within a week. Since it absorbs UV light, a similar process to Hersch's (2014) separations of wavelengths, should be observed with and without UV light.

Research Methodology

Four test chart sets (see Appendix H) were printed on a Ricoh Pro C7210X, using the fifth colour station to swap in Neon Yellow and Neon Pink toner—Ricoh's version of fluorescents. Similar to a Xerox Iridesse, the order of printing was Neon Yellow, black, cyan, magenta, yellow, and then Neon Pink. The Neon Yellow toner was printed alone on a first pass.

The first chart consisted of 66 patches with screens of 5% and intervals of 10% for each of cyan, magenta, yellow, black, and the two fluorescent toners. This was to examine the toner colour hooking, and particularly of interest were the colour differences between the fluorescent and process colour equivalents, their hooking patterns, and impact of UV light.

The second through fourth were default i1Profiler (v3.7.0.17442) 2033 patch profiling charts to compare three methods of printing. The first method was a baseline CMYK print. The second method was, as in U.S. Patent No. 5,734,800, to replace magenta and yellow with the Ricoh fluorescent equivalents, Neon Pink and Neon Yellow, which will be referred to as CPYK. The third method was using the process and fluorescent equivalents together to form a six colour process,

from this point referred to as 6C. Total area coverage was set to the max, 400% for CMYK and CPYK, and 600% for 6C.

These charts were exported as TIFFs with CMYK and, for 6C, alpha channels. They were separated into two press runs using Adobe Photoshop to prepare spot channels with proper naming conventions, manually imposed as PSD files in Adobe InDesign, then exported as PDF files with untagged CMYK profiles. The digital front end used was Fiery Command Workstation 6 with Colorwise turned off and specialty colour turned on. The test charts were printed on coated 100 lb Opus Digital Gloss cover stock, which has an opacity of 99.0 and a brightness of 94 (Sappi, n.d.). This stock was chosen to compare gamuts and methods of extension on what is traditionally CMYK's most favourable environment, a strong white, bright and reflective background (Xerox Support, 2020). The pressroom was 25.1°C and had 26% humidity.

After printing, the charts were separated and measured using i1Profiler and an i1Pro3 to make large, default ICC Profiles. According to its certificate of performance, the i1Pro3 had a Mean Colour Difference to Population of ≤ 0.3 ΔECIE2000, Maximum Colour Difference to Population ≤ 0.8 ΔECIE2000, and short term repeatability of ≤ 0.04 ΔECIE2000 Mean Colour Difference to Mean. These measured values were mapped in ColourThink Pro (v3.0.5) to compare gamut volumes and their 3D visualizations in three lighting conditions and between CMYK and the fluorescent gamuts in the same lighting conditions. The lighting conditions chosen were Illuminant A, ambient fluorescent lighting measured from a premedia lab in the Heidelberg Centre [ambient fluorescent] and D50.

To further quantify, a fail of concept consisted of a colour difference between the 100% solid patches of process and related fluorescent toners in the range of the accepted 0-3 ΔECIE2000 tolerance for colour difference and a pass was 4-8 ΔECIE2000 of some visual colour difference (Gonzalez & Fairchild, 2000; Habekost, 2013; Sharma & Seymour, 2019). A greater value was deemed worth more exploration for future study.

A final qualitative examination was held by the researcher's eyes to ensure the measured values corresponded with a visual difference, in terms of how humans register reflection and fluorescence as the same (Green & Kriss), and whether the resulting profiles could create pleasing colours in bitmap images. To prove adequacy for performing this test, the results from two online colour blindness tests were collected (see Appendix F; Colblindor, n.d.).

Based on prior knowledge of the Ricoh C7210X's fifth station neon colours, the expectations for more than a borderline pass were low—while the fluorescents were distinct from CMYK images in student projects, so too would a large solid of regular process stand out. However, looking at the consistency (or lack of) in the fluorescent colours between measurement modes and light sources compared to

process colours was of interest to examine if colour management could improve and—should fluorescent toners take on different hues—be used in ECG. Since X-Rite uses an Illuminant A and UV source in its i1Pro (Wyble & Seymour, 2015), and fluorescent toner is produced to harness UV light as its emissions energy (Ataeefard and Nourmohammadian, 2015), the differences between Illuminant A and D50 profiles should distinguish between the pure reflectance of the toners, and then fluorescence in addition.

Results

Though not deliberately incorporated in the testing methods, the ability of available premedia softwares was put to the test to handle expanded colour gamut workflows for digital presses. In particular, it was found that support for spot colours and multi-channel profiles impacted how smoothly the test charts sets came together and were printed. These test charts could be exported from i1Profiler as EPS or TIFF files. To print efficiently and mimic a designer, they were imposed in Adobe InDesign, which did not support the multichannel space accompanying the EPS export with all channels correctly named. The TIFF contained alpha channels which needed to be manually renamed and turned into spot channels, but this was accepted by Adobe InDesign as a CMYK + Spot file. Fiery Command Workstation accepted the resulting PDF files and recognized the designated Neon Yellow or Neon Pink as the specialty colour in its print settings. The first file that printed only contained Neon Yellow, and the second file contained all the other toners. From that point, the test chart sets could be measured like any other chart in i1Profiler.

As a side note: Fiery Command Workstation accepts multichannel profiles and will correctly map to CMYK when the specialty colour setting is turned on. That being said, it assumed both spot colours were the same fifth colour, whatever was in the press at the time. No matter which file type is used, to print with both fluorescent toners on the Ricoh, a second PDF containing either Neon Yellow or Neon Pink needs to be created and a second pass done.

Process Toner Compared to Fluorescent Toner UV Reactions

The measurement values from the toner hooking chart were exported as L*a*b* values in M0, M1, and M2 mode (Figure 1; see Appendix D). The legacy M0 and current M1 mode, both including UV light, acted similar, so M0 mode results were discarded. The fluorescent toners had a similar hook pattern to their process equivalents, though existed along different coordinates in L*a*b* space, with overall higher L* values; Neon Yellow emulated and surpassed the paper brightness as it increased in coverage. Process magenta and cyan shifted their hue under UV light by similar amounts as the dedicated fluorescent toners, indicating levels of fluorescence.

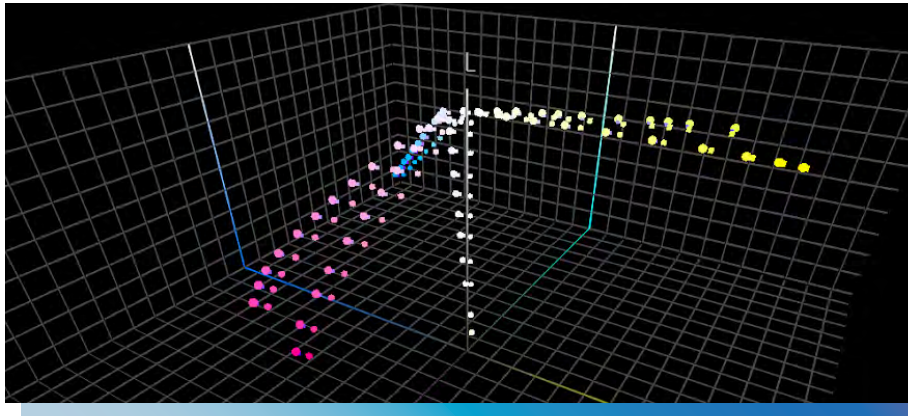


Figure 1. 3D Visualization of Colour Hooking Across All Six Toners.

The difference between M1 and M2 modes on the 100% cyan patch was 0.95 $\Delta E_{CIE2000}$. Cyan remained mostly linear even with the presence of OBAs. Black was a very stable toner with UV-cut; however when UV light was introduced, the lightest tints swung blue. The colour change between measurement modes for 100% black was 0 $\Delta E_{CIE2000}$. At 5% tint, black toner had a difference of 6.82 $\Delta E_{CIE2000}$. The OBAs present impacted all the results—the lighter tints of toners had a larger distance between M1 and M2 modes as more paper was revealed, and therefore as more OBAs could absorb UV and emit blue light (see Figure 2). For the black, magenta/pink and yellow toners, OBAs more significantly decreased b* rather than increased L*, directly decreasing the saturation in the yellows' positive b* values. Process yellow had a small change between 100% patches between measurement modes, at 0.18 $\Delta E_{CIE2000}$, and Neon Yellow had a difference of 1.49 $\Delta E_{CIE2000}$. Process magenta's 100% patch had a marginally greater difference than Neon Pink's 100% patch, 1.64 $\Delta E_{CIE2000}$ compared to 1.57 $\Delta E_{CIE2000}$ respectively.

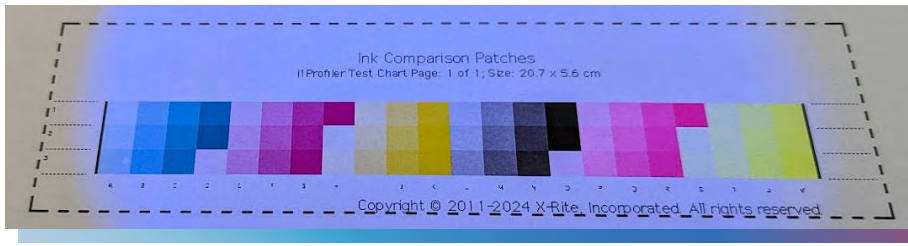


Figure 2. UV Light Shone on Toner Hooking Patches to Reveal OBA Presence.

The difference between process and fluorescent yellow in M1 mode was 8.68 $\Delta E_{CIE2000}$, while the difference between process and fluorescent magenta/pink was 14.51 $\Delta E_{CIE2000}$. This exceeded the set out colour difference for further exploration, though barely in the case of yellow. Neon Yellow toner had a gentle hook in

the heavier tints (60-100%), and had a lower a* value, giving a greener tinge. Its maximum saturation was the greatest difference—process yellow's b* value being 94.64, and Neon Yellow's value being only 74.35. In contrast, Neon Pink was more saturated than magenta by a small margin, and significantly lighter: at 100% in M1 mode, their a* values were 79.76 and 76.48, and L* values were 61.88 and 47.02, respectively.

Table 3 records, for each light source and an average across them, the largest $\Delta E_{CIE2000}$ between the CMYK, CPYK, and 6C profiles' 100% coverage patches and white points, which should be 0 when measured consistently. The colour measurement differences for all toners are given in $\Delta E_{CIE2000}$ for the sake of providing human perception context. The cyan and black toners both had an instance of 0 $\Delta E_{CIE2000}$ between the respective cyan and black patches of two profiles under a light source, but having three L*a*b* values to compare between, the largest difference was recorded in the table.

Table 3. Variance of Measurement in All Toners.

Largest Measurement Variance in $\Delta E_{CIE2000}$

Illuminant	C	M	Y	K	NP	NY	W
A	1.89	0	0	2.53	1.03	1.62	1.90
Amb. Flour.	0.97	0.43	0.49	0.73	0.77	1.23	1.12
D50	1.03	1.05	0.50	1.55	1.39	1.49	2.62
Average	1.30	0.49	0.33	1.60	1.06	1.45	1.88

Neither of the fluorescent toners were able to achieve identical L*a*b* values across all three axis at the same time, though the L* value for Neon Pink stayed consistent for each light source, and the a* values under ambient fluorescent and b* values under Illuminant A for Neon Yellow remained consistent in measurement. Neon Pink fared better than the worst values of black and cyan, though the overall impression was that OBA/fluorescent presence still created some difficulty in measurement. The dedicated fluorescent toners and the OBA-rich substrate never had an instance of 0 $\Delta E_{CIE2000}$ difference in this sample, the substrate only consistent in having the highest values.

Mock and Actual Light Sources on Gamut Changes

In i1Profiler, an approximate visualization of the wavelengths in the source was provided before continuing ICC profile creation (Figure 3). Illuminant A contained little to no UV light and relatively small amounts of blue light compared to its

linear increase into the red light. The ambient fluorescent source contained more violet and UV light, particularly below the 400 nm range and holding steady off the extent of the graph out of the visible spectrum, with major spikes around the yellow-green range. The D50 light source contained relatively equal amounts of the visible spectrum, unlike the previous two, though dropped significantly in the 400-450 nm range, with very little below 380 nm into the UV range. As the white point of the paper moved with the light source, so did the placement and size of the gamut according to the wavelengths available to reflect, though each method of printing held its own distinct gamut shape (see Appendix E). Illuminant A gamuts from all processes contained the most reds/pinks/violets, to the detriment of the yellows and greens. The ambient fluorescent gamuts had the most vivid yellows and overlapped with most of the other two. The D50 gamuts were concentrated in the relatively blue range, cutting off much of the yellow, red, and magenta range that the Illuminant A and ambient fluorescent gamuts could create.

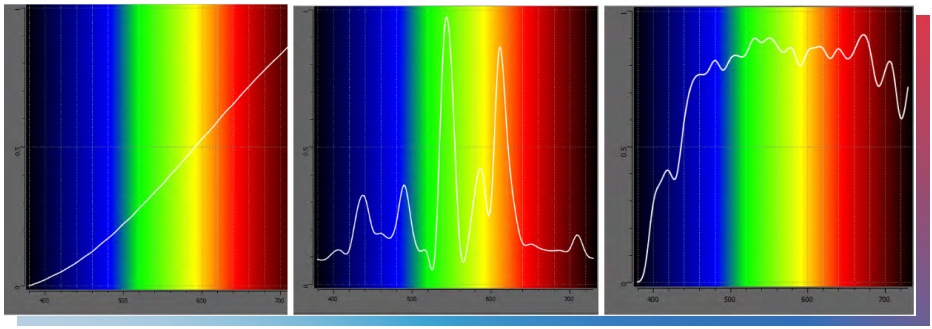


Figure 3. Light Sources Used in Creating Gamuts.
Note. Order is Illuminant A, Ambient Fluorescent, D50 source.

Appendices A-C compare gamut volume and 100% solid patches for each toner, along with white point—to be sure the i1Pro3 measured consistently across test charts—and maximum black point. Trends across all light sources included the black point (100% K) keeping consistent L* values, while the maximum black point became a brown hue with CPYK, 6C having an even stronger (lighter brown) effect. An increase in UV light present in the source decreased the difference between regular CMYK and CPYK gamut sizes, and increased the difference between CMYK and 6C gamuts, while the wavelength intensities in the source itself determined overall gamut size for all methods of printing. CPYK was consistently the smallest gamut, but it contained large pockets of lighter hues and/or more saturation in the green and red/orange/yellow areas which were outside the gamuts of the other two methods of printing. The less saturated Neon Yellow cut the in-gamut yellows of CPYK, and the overall fluorescence increased the L* values, detracting from the gamut size by quite significantly cutting the reproducible darker colours in all hues. When combined with process CMYK to

form 6C, CPYK overlapped and extended the gamut by a minimal amount, as its strengths were dampened by the process magenta and yellow also present. Table 4 summarizes the gamut size changes across light sources and methods of printing, using CMYK as the baseline comparison point.

Table 4. Differences in Gamut Volume Between CMYK and Neon-based Printing Processes.

Printing Method	Illuminant A	Ambient Fluorescent	D50
	Gamut Volume from Profile (cubic L*a*b*)		
CMYK	351,363	386,145	480,381
CPYK	323,718	381,155	447,415
6C	352,950	397,170	485,976
	Gamut Volume as % of CMYK		
CPYK	92.1	98.7	93.13
6C	100.4	102.9	101.2

The 6C profiles consisted of a sharp magenta hook in a different hue/saturation than either process magenta or Neon Pink could reach at 100% according to their M1 toner hooking measurements—a Super Pink occurred where the two toners combined. Although less pronounced, a Super Yellow in the form of a sharp point beyond process yellow's saturation also appeared in 3D visualizations (see Appendices A-E). Most prominent under D50 lighting, the 6C printing process created an additional bump which could be a Super Green that neither CMYK or CPYK could reach by themselves.

Visual Inspection

To the human eye, the CMYK charts had rich darks—black, brown, green, dark pinks—while the same test sheet for CPYK was closer to pastel—bright pinks and purples, along with pops of brighter greens, though missing a richness and breadth of variation in brightness values. The 6C test chart had many vibrant reddish-oranges and greens which appeared on par with the brightness of the paper, though most of the darker overprints appeared a similar brown hue despite allegedly being dark greys, black, and sometimes dark green/navy.

To verify the profiles were created correctly, the final profiles were reapplied to the original test charts and compared to the printed sheets. The CMYK and CPYK profiles were assigned in Adobe Photoshop with ease. Neon Pink depended on the type of lighting conditions and screen to exactly match relative brightness, but otherwise the hues and brightness of the screen versions matched with their printed counterparts.

The 6C profiles were multichannel—semi-supported in Adobe Photoshop, though the colour accuracy of spot colours and their tints is limited (Sharma & Seymour, 2019). Rather than being able to assign a multichannel profile to the multichannel test chart directly, the two options were to merge the spot channels in the TIFF, or convert the EPS into a duller CMYK or perceptually inaccurate RGB/L*a*b*. From there, the result could be converted to the multichannel profile. The original toner coverage values had been discarded to convert using incorrect L*a*b* values and so was highly inaccurate. The most accurate (still visually incorrect for overprints like vibrant reds and oranges) was to use an unassigned CMYK + Spot test chart and change the spot colour values to the L*a*b* measured from the toner hooking chart. For a design going from RGB or CMYK to multichannel for printing, this would have been a non-issue.

In Appendix G, the D50 profiles for each method of printing were applied to an RGB photograph to compare their capabilities of maintaining the gamut. To exaggerate the difference, a saturation rendering intent was used. The photograph contained mainly purples and greens, which were some of the stronger hues for this light source according to the 3D visualizations in Appendix E. The CMYK and 6C profiles excelled at the green hues. Though the exact purples could not be matched, the CPYK and 6C profiles were closer than CMYK because of Neon Pink—in the 6C version, it was used almost exclusively for the purple. All the profiles created pleasing colours for the image.

Discussion

The main limitation to this research was the lack of current, highly available information to avoid prior failures and to target established best practices. The digital press industry is on the move to capitalise on fluorescent ECG, but keeps current information confidential within the company and/or client base. Relying on limited knowledge to form a hypothesis and methodology, the testing minimized variables like stock choices and toner order which continue to be avenues for more experimentation. Additionally, the press on which this study was conducted was four years old, rather than the most advanced on hand, and prone to issues like excess cyan and black toner on the transfer belt which lowered the brightness of the paper and meant “pure” solids were truly, for example, 100% magenta with ~1% cyan and black toner.

This discussion is broken into four categories of discovery: whether the fluorescents boost what companies claim, premedia and print process control at the RIP, influence of human perception, and whether fluorescence or light source choice have a bigger difference in gamut. These combine to quantitatively and qualitatively analyse whether fluorescents are a viable and valuable solution for toner-based ECG.

Fluorescent Improvement in Colour and Measurement

Accuprint (n.d.) and Xerox (2020) claim fluorescent pink toner boosts orange and purple, while fluorescent yellow boosts yellow and green, Xerox additionally claiming that reds are boosted with their fluorescents. Ricoh has also been working on fluorescent ECG charts with similar findings (B. Walji, personal communication, March 26, 2024).

This study confirms these findings are true—in specific conditions and ranges. Depending on wavelengths in the light source and the combinations of toner, CPYK in particular can make much brighter red/oranges. CPYK and 6C both boost the light green, blue, and violet range, though lose the darker versions of the hues as a result so that a bright red brand colour cannot be reached while also having a dark, rich overall design in one pass without manual work in prepress. Like Roesch (2024) suggests, artwork should be chosen for fluorescents, rather than applying fluorescents mindlessly to all print applications and mixing them too much with regular process. 6C printing dulls the maximum saturation of the turquoises compared to CPYK, with a similar impact through the yellows and reds, but also manages to reach the darker values of the hues.

Although Xerox (2020) did not believe fluorescent toners could be colour managed, this research found it possible and within the same error range as process colours impacted by OBAs in the stock and fluorescence in the process toners (Gonzalez & Fairchild, 2000; B. Walji, personal communication, March 26, 2024). Shown in Appendix D and previously discussed in the results section, the fluorescent and process toners had similar reactions to UV light, with process magenta showing the most perceptual change. Additionally, when comparing the values in Table 3 to Habekost's (2013) perceptual tolerances for $\Delta E_{CIE2000}$, the variance in measurement between all toners and paper white are a pass. Neon Yellow was the closest to failing, its highest difference being 1.62 $\Delta E_{CIE2000}$ and the tolerance at 1.70 $\Delta E_{CIE2000}$, just 0.08 between them. Neon Pink passed easily, at an average of 1.06 $\Delta E_{CIE2000}$ compared to a tolerance for magenta at 2.90 $\Delta E_{CIE2000}$. This indicates the ability to colour-manage to a degree where soft proofs perceptually match the final print, the potential to hide alternative images in what at first glance appears to be a regular CMYK graphic, and at the minimum, profiles can be applied to create pleasing fluorescent ECG images in one click.

Still, fluorescent ECG has very specific applications and process toners cannot be replaced 1:1 with fluorescents while maintaining good results; a

consistent colour management system and premedia process is required. It is overall a much weaker digital press ECG solution than an HP Indigo 7900 or Epson SureColor P9000 (see Table 2), and so investments on digital presses to cover wide swathes of colour are better spent on CMYKOGV devices. By gamut volume, 6C does outperform CMYK in ambient fluorescent lighting by nearly 3% and has a larger volume than GRACoL 2013—but under standard D50 lighting, the CMYK gamut is already much larger than GRACoL 2013 and 6C has less impact on gamut. The potential is there for university in-plants and anyone else with fluorescent toners, to provide accurate soft proofs of their fluorescent embellishments and have a fluorescent ECG process on hand, particularly if they want to avoid one-off spot colours for short run jobs slightly out of CMYK gamut.

Premedia and Toner Order

The order of printing was Neon Yellow, followed by black, cyan, magenta, yellow, and Neon Pink, with 2033 patches making up the data to create profiles. The majority of testing involved manual set up and profiling, where using the profiles for real designs would follow similar methods. It is recognized that this merely grazes the surface of possibilities.

The CPYK process created the most vibrant saturations, while CMYK filled out the darker hues. 6C printing was an average of both, rather than bringing the two sides together for a maximum gamut size. Therefore, when creating test charts and profiles for fluorescent ECG, it is necessary to take into account the fluorescents interacting with each other through defining those patches along with their CMYK interactions. Creating multiple profiles to compare between, like Bestmann (2006), showed the entire range of colours available. Had just the CMYK and 6C charts been printed and measured, this study would have found fluorescent ECG almost always not worth the effort. Knowledge of redundancy and stability is needed for proper ink builds (Sharma & Seymour, 2019). Further research into profiling, ensuring data with pure CMYK for dark hues and pure CPYK for light hues are included in the final 6C profile, will certainly prove fruitful at expanding the gamut more than ~1%.

As suggested by Simoni et al. (2017), the ability to profile means the primaries can be adjusted where a full ECG press may not be available; Neon Pink is closer to blue than magenta and Neon Yellow is closer to green than yellow, both movements the patent suggests. More specifically, as O'Hara and Congdon (2016) found with CMYKOGV, order of the colours matters in gamut, and as Bestmann (2006) details, certain colours together make bigger changes in gamut. Neon Pink as an overlay meant that it fluoresced magenta on top of any overprints, turning rich blacks to warm browns as predicted by Xerox (2021) and used as an intentional effect. As an underlay, Neon Yellow did not appear to have the same effect, though each toner should be tested individually as over- and underlays to confirm order matters. 6C was able to create a Super Pink, Super Yellow, and

Super Green, and the higher L* values of both Neon Pink and Neon Yellow meant that combined as CPYK they produced very bright reds/oranges. However, 6C maintained more of CPYK's greens than reds—this may indicate an underlay, much like substrate OBAs fluoresce beneath process colours, is preferred to an overlay. Then again, the 6C test chart focused on overprints of multiple toners at a few tint levels, where the fluorescent toners were 31.16% at their lowest, if they weren't at 0%. In contrast, the four colour test chart had a wider variety of tints, dipping below 10% on occasion, so the CPYK profiles have more data about the lighter overprints, such as in the reds. Regardless, public research on the reflection and emission interactions of fluorescent toners with process toners, like Hersch (2014) aimed to accomplish for paper OBA fluorescence would prove useful—are there applications where overlay and underlays of the same fluorescent toner should exist in the same print job? Where should process yellow sit in print order since it absorbs UV light and greatly reduces fluorescence (Green & Kriss, 2010)? Does Roesch's (2024) declaration that 30% or greater process colour contamination destroys the fluorescent components matter when the bigger change is a different base hue, albeit with less difference than OGV? More questions such as the degree to which the colour fastness of fluorescents impacts the fluorescent components, base hue, or both, over time should also be explored.

Ricoh developed their own proprietary test charts, that with the latest technology, means their presses work with Fiery Command Workstation to ingest a CMYK file and determine whether to provide an underlay or overlay for one fluorescent toner, removing from magenta and cyan channels for Neon Pink or yellow and cyan for Neon Yellow, with little to no operator intervention and in one pass (B. Walji, personal communication, March 26, 2024). On the Ricoh Pro C7210X press used for this research paper, the fifth colour station is manual overprint only. The method for one pass underlays is to physically switch the specialty colour into the K slot, though this was only available for White, and black is then put in the fifth colour station as an overprint. With more options on the horizon, using fluorescent toners as ECG tools will become more viable. The Xerox Iridesse can provide an underlay or overlay of Fluorescent Pink (Elizabeth, 2023), and should they provide a Fluorescent Yellow for this series, it would run the test charts for this research in one pass.

Human Perception and Stock Choice

The significance of changing certain pigments can have a greater effect than expected—with humans being 50 times more sensitive to green and yellow (Marshall & Johnsen, 2017), hence the lowest tolerances to changes in colour at 1.70 $\Delta E_{CIE2000}$ (Habekost, 2013), it is no wonder that green and yellow inks for Bestmann (2006), orange and green inks in Pantone Hexachrome (Simoni et al. 2017), and changing the order of inks for yellow/green, magenta/orange, and cyan/green for Clemson (O'Hara and Congdon, 2016), were most impactful for expanding the gamut. While Neon Yellow expanded the gamut to lighter greens,

it also could not reach the buttery yellows as a less saturated yellow-green. In Appendix G, Neon Yellow is the least used in the 6C separation for an image heavily featuring green, a green that requires a richer yellow to produce. Under these conditions, keeping process yellow is necessary for fluorescent ECG to be successful.

The human eye either sees or does not see a wavelength of light: reflection and fluorescence are perceived as one and the same, like when OBAs are added to create a brighter white (Green & Kriss, 2010). Fluorescence from a pigment will emit less light than it absorbs (Marshall & Johnsen, 2017), and the hue of the pigment's reflected light also needs to be taken into consideration; Neon Pink and Neon Yellow are not invisible in absence of UV light. A clean white background is still required to reflect the base hue and emissions to the viewer, such as 98 brightness for paper (Roesch, 2024, Xerox, 2020). When a white substrate (e.g. the coated paper from this research), is able to reflect all wavelengths efficiently in addition to fluorescing OBAs, it forces the human eye to compare that relative brightness to a select range of light reflecting and emitting from the fluorescent pigment, and find the latter less impressive. Being a subtractive model, the gamuts were tied to how well the paper reflected, and using a glossy stock meant much of the light was able to reflect into the human eye and measurement device. The go-to advice and general practices for making fluorescents pop off the page are to use uncoated papers and place them next to deep black colours which provide the most contrast (B. Walji, personal communication, March 26, 2024; Xerox, 2020; Roesch, 2024). For these reasons, the CMYK and 6C gamuts appeared quite similar.

A goal of this research was to quantify whether fluorescent toner could significantly improve a CMYK gamut compared to the largest gamut CMYK could achieve. Although the results were mediocre in this domain, further testing on uncoated, lower brightness papers is likely to reveal perceptually brighter gamuts, especially compared to the usual CMYK gamuts. The fluorescent toners introduced yellow and magenta wavelengths, like OBAs introduced blue light, triggered from a UV light source invisible to human perception. The ability of fluorescent toners to absorb UV light allows them to translate otherwise lost wavelengths into the visible light spectrum, which may strengthen and lift the brightness of process toner overprints, as seen happening to cyan and black in this study. Neon Yellow in particular was brighter than paper white at its higher saturations, and when contrasted with a duller paper could perceptually boost overprints to look like the design is on glossy papers, even if the measured gamut size is actually smaller than on coated and shiny substrates.

Importance of Light Source or Toner Choice?

As has been established, process toners can also contain fluorescents with similar or greater effect than dedicated fluorescent toners. The largest difference

between CMYK printing and CPYK or 6C printing is in the base hues. The final viewing condition will be either with UV light, and colour should be measured in M1 mode, or without UV light, and colour should be measured in M2 mode (Green & Kriss, 2010), which can be accounted for in colour management during premedia. Metamerism between light sources, not already impacting process toners, only becomes relevant for security printing and creating flashy pieces which change graphics under UV light (Roesch, 2024). The gamut extent is primarily determined by the L*a*b* values of each toner's 100% solid to set the maximum saturation—excluding the Super hues of 6C, where the related fluorescent and process toners boost each other into a new hue. Overprints are then derived from them, sometimes to a detrimental effect, such as Neon Yellow being too weak and too green to cover the gamut of CMYK. Additional process toners, OGV or light versions of CMYK, expand the gamut with more pure saturated colours and in turn printing requires less precise overprints through redundancy (Sharma & Seymour, 2019). Similarly, the base CMY hues can be moved with digital technology and ICC profiling, using less print units to achieve the necessary gamut. Beyond that, Simoni et al. (2017) notes that the gamut can be filled out with red/orange and blue/violet similar to seven-colour ECG, potential options for more specialty colours on a digital toner press, especially as all of the gamuts were unable to recreate the purple hues in Appendix G. In the case of CPYK and the theoretical better 6C, Neon Pink and Neon Yellow overprints are currently sufficient for creating more brilliant reds as predicted by Herbert & DiBernardo (1994) despite their lack of fluorescent colour management at the time.

The expectation is that given a pure UV light source, process toners and non-OBA substrates look black, or absent of light—they may reflect UV light, but those wavelengths are outside the human visible spectrum (Roesch, 2024). Fluorescents on the other hand, absorb UV light and emit in the human visible spectrum; for example the OBA-rich paper turns blue-purple under a UV flashlight in Figure 2. Thought fluorescence present in nature can emit at a different wavelength than the reflection hue (Marshall & Johnsen, 2017), fluorescent toners marketed as "Fluorescent" or "Neon"—as opposed to process toners with fluorescence in them—are specially designed to absorb UV light around 320 to 380 nm, and emit in the visible spectrum near the reflection hue, anywhere between 380 and 730 nm (Ataeefard & Nourmohammadian, 2015). That latter range of light is what i1Profiler focused on measuring, and was enough to fluoresce Neon Pink and Neon Yellow. The CPYK and 6C gamuts were their biggest in size relative to CMYK under ambient fluorescent light, which had the most amount of wavelengths at 380 nm according to Figure 3. Ignoring fluorescence triggered by 380 to 420 nm wavelengths in UV-cut filters, the accepted inconsistency of measurement due to natural fluorescence, and variation of UV sources used in measurement instruments, including being stronger than a real world scenario (Green & Kriss, 2010; Gonzalez & Fairchild, 2000; ICC, 2005) indicate a square problem being pushed into a circular solution that always returns to relegating fluorescent

printing as an embellishment. It is no wonder that fluorescent colour management continues to be a mystery, solved by holding printed charts to the light and being surprised at the colour change, in part from UV light in the viewing condition. Having known wavelengths leave the light source, as measured by a bispectral instrument, provide more detailed information on what the pigments and substrate have available to reflect or absorb, and increase accuracy when estimating impact of light source (Gonzalez & Fairchild, 2000).

In addition to knowing the exact wavelengths used to measure a patch, choosing the appropriate light source, a standard or custom values, is crucial to the size and placement of a profile's gamut. D50 by far created the largest gamuts with its fairly consistent light in all areas of the spectrum, and yet compared to different light sources for the same test chart, it could not encompass its sister gamuts (see Appendix E). While D50 contained many more blues and violets, those gamuts were missing the yellows of ambient fluorescence and reds of Illuminant A. The human observer in colour management has been set as a standard, and so too does the light source often become a standard (e.g. D50), with focus on how to change the pigments to create the maximum number of colours. However, simply by changing the light source for the same toners, new colours could be produced on the same test chart; each gamut had its own shape seen throughout the light sources, but it grew, moved white point, and shrunk depending on the wavelengths available to reflect. The results have shown that while 6C printing can make a difference by adding more base hues, light source choice for the final viewer matters as much or more. The largest positive change in gamut size from the fluorescent toners was 2.9%, and the largest negative change was 7.9%. The change in gamut for CMYK by going from Illuminant A to D50 as a light source was 37%; for CPYK and 6C it was 38%. Light source and pigment choices are variables which must work together to create more colours, rather than fluorescent ECG alone.

Conclusion

The L*a*b* values of Neon Pink and Neon Yellow, along with their ability to create Super variants with process toners, does extend the gamut in a noticeable manner, however small. Premedia software and profiling techniques must be optimized to take advantage of the rich dark colours that only CMYK provided, while keeping the vibrant reds and greens of CPYK. This theoretical 6C will outperform the awkward medium of the studied 6C process. As companies like Ricoh and Xerox perfect the internal calculations of the RIP and integrate their special colour stations with the expectation of expanded gamut purposes, these wrinkles should be smoothed. Currently the fluorescent toners mimic process hues, so the base hue is a lighter, and in Neon Yellow's case, less saturated, version meant to be eye-catching in 100% solids, rather than purposeful for gamut extension at tints, which were unhelpful qualities during this research. Advances like more fluorescent toner options should make an appearance on

the market to compete with CMYKOGV as a simpler, automated way to achieve a bigger, brighter gamut.

Creating gamuts is a science and an artform, dependent on light source and toner interaction, where fluorescents have been dismissed for being too difficult to incorporate in colour management. In toner form, profiles can be made within human visual tolerance, allowing fluorescents to be quantified and added to the usual workflows with more success. Though jobs should be checked to ensure fluorescents are useful for the design before spending the extra click cost, this accuracy level of profiles brings adding fluorescent toner separations to complex images on the fly, along with providing soft proofs, closer to being as easy and as colour accurate as CMYK printing. The importance is on where in 3D colour space the gamut lies, what the printer wants to achieve, and on what stock. The CPYK process includes brighter colours that will stand out against dull or dark surroundings, and should a project only require colours within that gamut, it is a much preferable option to CMYK. The final viewing condition and use are also key components, as a potential low cost way to add security or make a built-in light source indicator on client proofs to double check their location before signing off.

A new wave of printing technique is about to crash down on the shores of digital printing, giving new access to shops and in-plants who own these fifth colour stations and the streamlined software. The next few years promise greater saturation and bold pops of colour to more short run printed products as this technology improves and becomes commonplace.

Appendix A

Differences Between Process and Fluorescent Reactions to Illuminant A

The colour legend is: cyan for the CMYK gamut, yellow for the CPYK gamut, and white for the 6C gamut. See Figure A1 for a visual comparison of the three profiles assuming an Illuminant A source, and Table A1 for gamut volume and related raw data.

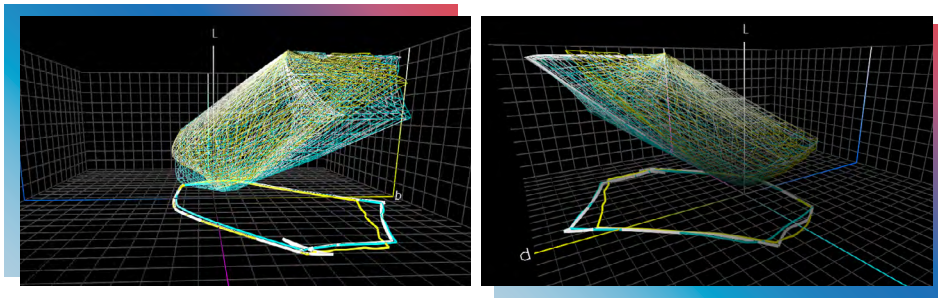


Figure A1. ICC Profiles Visualized in ColourThink Pro 3D Grapher Under Illuminant A.

*Table A1. ICC Profile Gamut Volume and 100% Solid L*a*b* Values Under Illuminant A.*

Printing Method	CMYK	CPYK	6C
Gamut Volume	351,363[3]	323,718[3]	352,950[3]
	L*a*b* Values (as L,a,b)		
White Point	93, 21, 42	94, 21, 43	92, 20, 39
Max. Black Point	11,8, 11	18, 22, 22	21, 26, 28
Black	10, 6, 11	8, 5, 8	10, 5, 10
Cyan	44, -43, -24	45, -43, -23	46, -43, -24
Magenta	54, 88, 34	N/A	54, 88, 34
Neon Pink	N/A	69, 93, 35	69, 90, 32
Yellow	91, 17, 110	N/A	91, 17, 110
Neon Yellow	N/A	94, 10, 97	92, 8, 97

Appendix B

Differences Between Process and Fluorescent Reactions to Ambient Fluorescent

The colour legend is: cyan for the CMYK gamut, yellow for the CPYK gamut, and white for the 6C gamut. See Figure B1 for a visual comparison of the three profiles assuming an ambient fluorescent source, and Table B1 for gamut volume and related raw data.

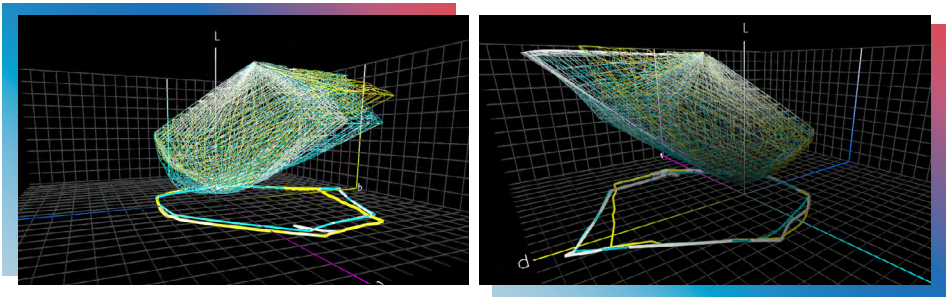


Figure B1. ICC Profiles Visualized in ColourThink Pro 3D Grapher Under Ambient Fluorescent.

*Table B1. ICC Profile Gamut Volume and 100% Solid L*a*b* Values Under Ambient Fluorescent.*

Printing Method	CMYK	CPYK	6C
Gamut Volume	386,145[3]	381,155[3]	397,170[3]
	L*a*b* Values (as L,a,b)		
White Point	93, 5, 26	93, 4, 27	92, 4, 25
Max. Black Point	11, 4, 8	16, 22, 17	19, 26, 22
Black	10, 1, 9	10, 1, 8	10, 1, 8
Cyan	46, -30, -35	46, -30, -34	47, -30, -34
Magenta	51, 77, 17	N/A	51, 77, 18
Neon Pink	N/A	66, 86, 19	66, 85, 17
Yellow	90, -3, 111	N/A	90, -4, 111
Neon Yellow	N/A	94, -11, 96	92, -11, 97

Appendix C

Differences Between Process and Fluorescent Reactions to D50

The colour legend is: cyan for the CMYK gamut, yellow for the CPYK gamut, and white for the 6C gamut. See Figure C1 for a visual comparison of the three profiles assuming a D50 source, and Table C1 for gamut volume and related raw data.

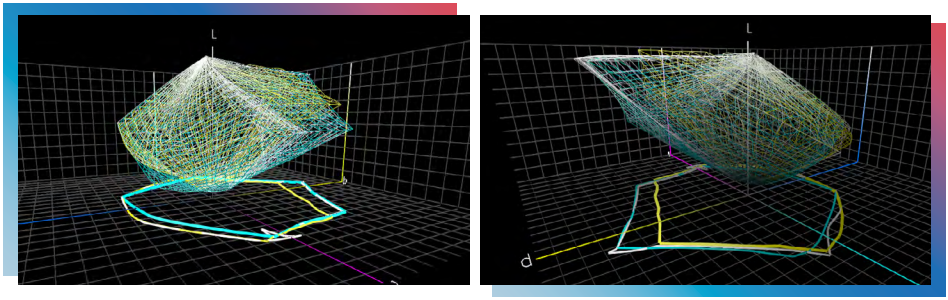


Figure C1. ICC Profiles Visualized in ColourThink Pro 3D Grapher Under D50.

*Table C1. ICC Profile Gamut Volume and 100% Solid L*a*b* Values Under D50.*

Printing Method	CMYK	CPYK	6C
Gamut Volume	480,381[3]	447,415[3]	485,976[3]
	L*a*b* Values (as L,a,b)		
White Point	93, 1, -6	94, 0, -5	92, 0, -8
Max. Black Point	11, 1, 2	17, 17, 8	19, 21, 14
Black	10, 0, 2	8, 0, 1	9, 0, 1
Cyan	51, -33, -55	51, -33, -55	52, -33, -56
Magenta	48, 77, -6	N/A	47, 77, -7
Neon Pink	N/A	63, 80, -13	63, 77, -16
Yellow	90, -13, 94	N/A	90, -14, 94
Neon Yellow	N/A	94, -22, 75	92, -24, 77

Appendix D

Toner Hooking of Process Colours (Including Fluorescents) and Impact on Gamut

The M# legend is: [when visible] tiny squares for M0, the large spheres for M1, and the medium cubes for M2. For example, in Figure D1, M1 mode for magenta/Neon Pink is on the left trail of each set. Neon Pink's M0, M1, and M2 are the visually two most left (Figure D1) and higher (Figure D2) trails. Neon Yellow are the two most right (Figure D2) and higher (Figure D1) trails.

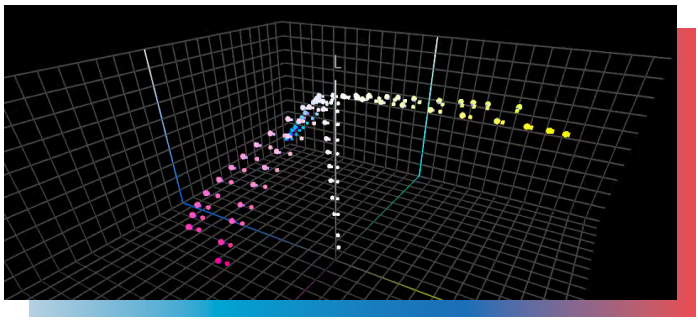


Figure D1. Toner Hooking of Process Colours—Focus on Magenta/Neon Pink.

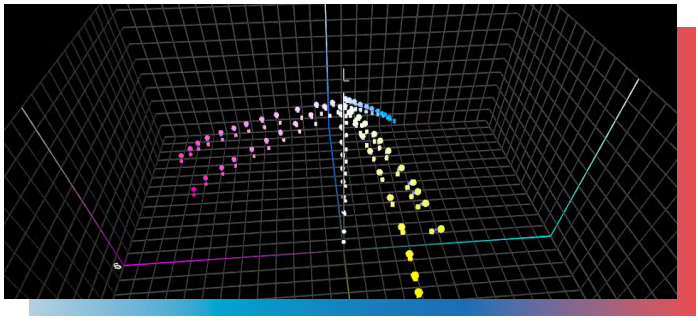


Figure D2. Toner Hooking of Process Colours—Focus on Yellow/Neon Yellow.

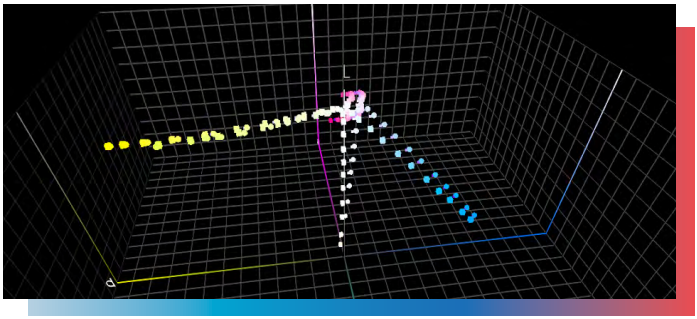


Figure D3. Toner Hooking of Process Colours—Focus on Cyan and Black.

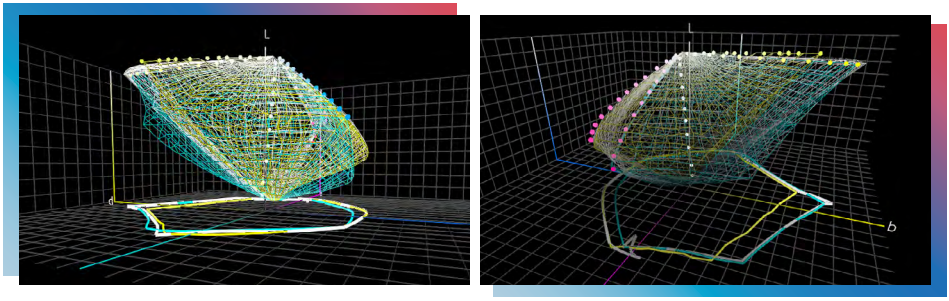


Figure D4. Toner Hooking Plot Points for M1 Mode over D50 Printing Process Profiles.
Note. Colour legend the same as Appendices A-C: CMYK = cyan, CPYK = yellow, 6C = white.

The following Table D1 and Table D2 are the raw L*a*b* measurements from M1 and M2 for the hooking patches. Each toner has 11 patches, for a total of 66 measurements per mode. NP stands for Neon Pink, and NY stands for Neon Yellow.

Table D1. Toner Hooking Patches in M1 Mode.

Patch #	C	M	Y	K	NP	NY	L*	a*	c*
1	5	0	0	0	0	0	91.43	-1.74	-10.2
2	10	0	0	0	0	0	89.31	-3.71	-12.56
3	20	0	0	0	0	0	86.02	-6.51	-16.79
4	30	0	0	0	0	0	82.02	-9.84	-21.16
5	40	0	0	0	0	0	77.25	-13.92	-27.05
6	50	0	0	0	0	0	72.94	-17.49	-32.02
7	60	0	0	0	0	0	67.94	-21.69	-37.91
8	70	0	0	0	0	0	63.37	-25.05	-42.76
9	80	0	0	0	0	0	59.82	-27.71	-47.12
10	90	0	0	0	0	0	55.13	-31.45	-51.96
11	100	0	0	0	0	0	51.03	-32.67	-56.96
12	0	5	0	0	0	0	90.98	4.21	-8.21
13	0	10	0	0	0	0	88.81	7.69	-9.16
14	0	20	0	0	0	0	84.02	14.05	-10.62
15	0	30	0	0	0	0	91.43	-1.74	-10.2
16	0	40	0	0	0	0	89.31	-3.71	-12.56
17	0	50	0	0	0	0	91.43	-1.74	-10.2
18	0	60	0	0	0	0	89.31	-3.71	-12.56
19	0	70	0	0	0	0	91.43	-1.74	-10.2
20	0	80	0	0	0	0	89.31	-3.71	-12.56
21	0	90	0	0	0	0	91.43	-1.74	-10.2
22	0	100	0	0	0	0	89.31	-3.71	-12.56

Patch #	C	M	Y	K	NP	NY	L*	a*	c*
23	0	0	5	0	0	0	93	-0.61	-1.58
24	0	0	10	0	0	0	92.82	-2.13	3.51
25	0	0	20	0	0	0	92.56	-3.85	11.73
26	0	0	30	0	0	0	92.1	-5.82	19.95
27	0	0	40	0	0	0	91.83	-7.55	29.51
28	0	0	50	0	0	0	91.27	-9.47	41.73
29	0	0	60	0	0	0	90.7	-11.32	55.03
30	0	0	70	0	0	0	90.36	-12.82	68.85
31	0	0	80	0	0	0	90.16	-13.19	80.44
32	0	0	90	0	0	0	90.06	-13.24	88.69
33	0	0	100	0	0	0	89.86	-13.17	94.64
34	0	0	0	5	0	0	86.42	0.42	-5.56
35	0	0	0	10	0	0	80.25	0.4	-4.93
36	0	0	0	20	0	0	72.51	0.03	-4.41
37	0	0	0	30	0	0	65.61	0.22	-3.42
38	0	0	0	40	0	0	58.37	0.02	-2.75
39	0	0	0	50	0	0	50.52	-0.09	-0.69
40	0	0	0	60	0	0	40.7	-0.05	1.59
41	0	0	0	70	0	0	31.2	-0.09	-0.69
42	0	0	0	80	0	0	18.05	-0.05	1.59
43	0	0	0	90	0	0	10.01	0.23	2.14
44	0	0	0	100	0	0	89.33	11.31	-10.19

Patch #	C	M	Y	K	NP	NY	L*	a*	c*
45	0	0	0	0	5	0	89.33	11.31	-10.19
46	0	0	0	0	10	0	86.38	20	-12.15
47	0	0	0	0	20	0	82.63	29.94	-14.52
48	0	0	0	0	30	0	79.62	37.26	-16.37
49	0	0	0	0	40	0	77.05	45.05	-17.37
50	0	0	0	0	50	0	74.36	51.47	-18.44
51	0	0	0	0	60	0	71.65	58.35	-19.3
52	0	0	0	0	70	0	68.84	65.66	-19.74
53	0	0	0	0	80	0	66.08	70.95	-19.77
54	0	0	0	0	90	0	63.99	75.17	-18.6
55	0	0	0	0	100	0	61.88	79.76	-16.12
56	0	0	0	0	0	5	92.67	-3.24	1.98
57	0	0	0	0	0	10	93.39	-5.75	7.47
58	0	0	0	0	0	20	93.37	-7.63	13.01
59	0	0	0	0	0	30	93.27	-10.28	20.66
60	0	0	0	0	0	40	93.23	-12.01	25.19
61	0	0	0	0	0	50	93.29	-14.15	31.95
62	0	0	0	0	0	60	93.23	-17.31	42.36
63	0	0	0	0	0	70	93.56	-19.76	51.16
64	0	0	0	0	0	80	93.82	-20.35	56.32
65	0	0	0	0	0	90	93.73	-21.74	62.12
66	0	0	0	0	0	100	93.95	-23.97	74.35

Table D2 Toner Hooking Patches in M2 Mode.

Patch #	C	M	Y	K	NP	NY	L*	a*	c*
1	5	0	0	0	0	0	91.09	-3.7	-2.81
2	10	0	0	0	0	0	88.98	-5.75	-5.48
3	20	0	0	0	0	0	85.73	-8.69	-10.15
4	30	0	0	0	0	0	81.72	-12.01	-14.99
5	40	0	0	0	0	0	76.91	-16.08	-21.35
6	50	0	0	0	0	0	72.65	-19.81	-26.82
7	60	0	0	0	0	0	67.64	-24.04	-33.28
8	70	0	0	0	0	0	63.07	-27.42	-38.64
9	80	0	0	0	0	0	59.56	-30.13	-43.46
10	90	0	0	0	0	0	54.9	-33.83	-48.89
11	100	0	0	0	0	0	50.79	-34.98	-53.41
12	0	5	0	0	0	0	90.65	2.32	-0.83
13	0	10	0	0	0	0	88.47	5.85	-1.91
14	0	20	0	0	0	0	83.72	12.28	-3.74
15	0	30	0	0	0	0	78.92	19.77	-5.49
16	0	40	0	0	0	0	74.29	27.52	-6.44
17	0	50	0	0	0	0	69.26	35.17	-8.05
18	0	60	0	0	0	0	64.42	43.03	-9.02
19	0	70	0	0	0	0	59.28	52.87	-8.97
20	0	80	0	0	0	0	55.29	59.97	-8.38
21	0	90	0	0	0	0	50.51	69.36	-7.12
22	0	100	0	0	0	0	46.88	75.87	-3.55

Patch #	C	M	Y	K	NP	NY	L*	a*	c*
23	0	0	5	0	0	0	92.7	-2.3	5.39
24	0	0	10	0	0	0	92.54	-3.66	9.97
25	0	0	20	0	0	0	92.33	-5.14	17.88
26	0	0	30	0	0	0	91.85	-6.74	25.69
27	0	0	40	0	0	0	91.68	-8.34	34.28
28	0	0	50	0	0	0	91.14	-9.98	45.83
29	0	0	60	0	0	0	90.59	-11.55	58.3
30	0	0	70	0	0	0	90.26	-12.79	71.15
31	0	0	80	0	0	0	90.08	-13.1	82.07
32	0	0	90	0	0	0	90.01	-13.18	89.77
33	0	0	100	0	0	0	89.81	-13.06	95.4
34	0	0	0	5	0	0	89.71	-1.05	0.83
35	0	0	0	10	0	0	86.13	-1.17	0.48
36	0	0	0	20	0	0	79.98	-1.17	0.57
37	0	0	0	30	0	0	72.32	-1.14	0.51
38	0	0	0	40	0	0	65.39	-1.19	0.42
39	0	0	0	50	0	0	58.24	-0.99	0.65
40	0	0	0	60	0	0	50.41	-1	0.72
41	0	0	0	70	0	0	40.54	-0.81	0.92
42	0	0	0	80	0	0	31.13	-0.64	1.26
43	0	0	0	90	0	0	18.04	-0.14	1.93
44	0	0	0	100	0	0	10.01	0.23	2.14

Patch #	C	M	Y	K	NP	NY	L*	a*	c*
45	0	0	0	0	5	0	89	9.53	-3.09
46	0	0	0	0	10	0	86.09	18.25	-5.26
47	0	0	0	0	20	0	82.38	28.31	-8.12
48	0	0	0	0	30	0	79.34	35.8	-10.16
49	0	0	0	0	40	0	76.83	43.56	-11.28
50	0	0	0	0	50	0	74.14	50.17	-12.75
51	0	0	0	0	60	0	71.42	57.18	-13.82
52	0	0	0	0	70	0	68.61	64.64	-14.55
53	0	0	0	0	80	0	65.91	69.95	-14.96
54	0	0	0	0	90	0	63.8	74.33	-14.03
55	0	0	0	0	100	0	61.75	79	-11.73
56	0	0	0	0	0	5	92.28	-4.33	8.25
57	0	0	0	0	0	10	92.59	-6.33	13.08
58	0	0	0	0	0	20	92.87	-7.71	24.84
59	0	0	0	0	0	30	92.79	-9.78	24.84
60	0	0	0	0	0	40	92.65	-11.22	29.07
61	0	0	0	0	0	50	92.63	-12.95	35.19
62	0	0	0	0	0	60	92.48	-15.49	44.66
63	0	0	0	0	0	70	92.76	-17.58	52.61
64	0	0	0	0	0	80	93	-18	57.55
65	0	0	0	0	0	90	92.89	-19.19	62.77
66	0	0	0	0	0	100	93065	-21.12	74.27

Appendix E

3D Visualizations for Impact of Light Sources on All Printing Process Profiles

The colour legend is: red for Illuminant A, green for ambient fluorescent, and blue for D50.

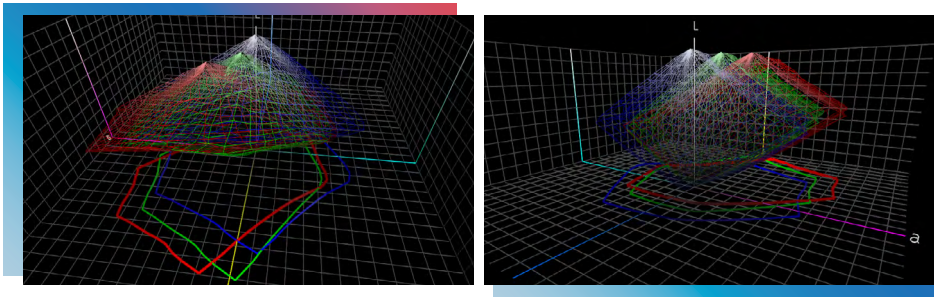


Figure E1. Impact of Light Source on CMYK Gamuts.

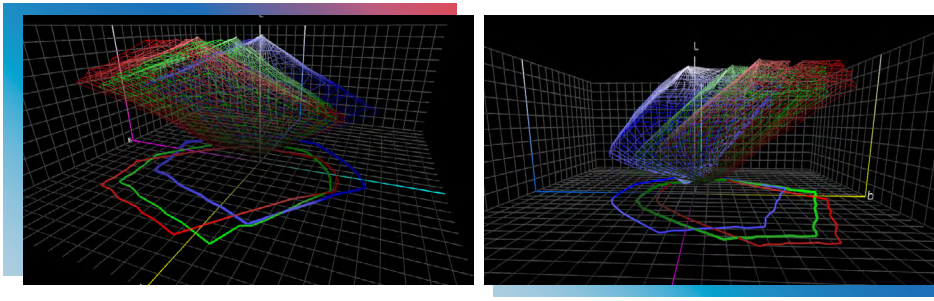


Figure E2. Impact of Light Source on CPYK Gamuts.

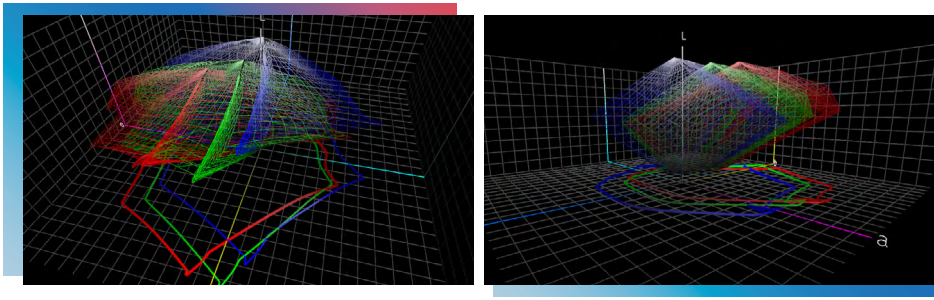
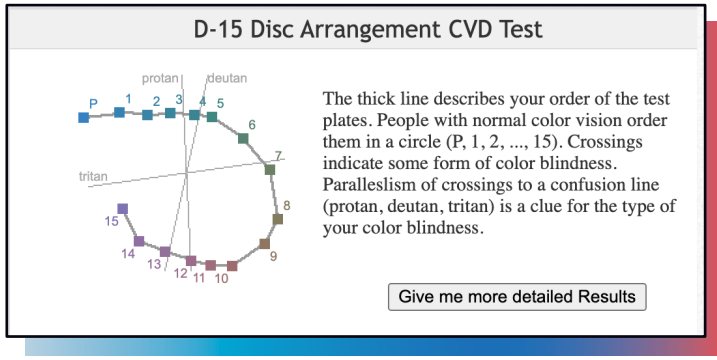


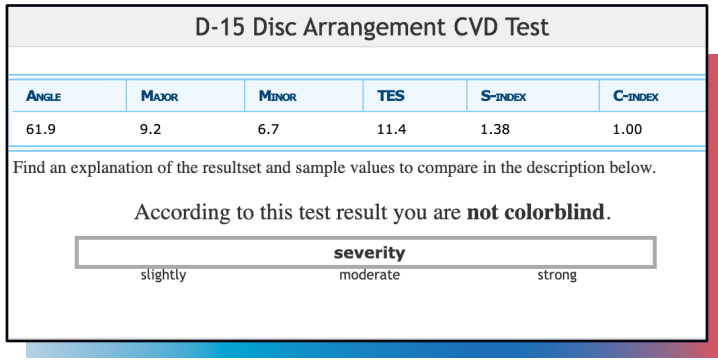
Figure E3. Impact of Light Source on 6C Gamuts.

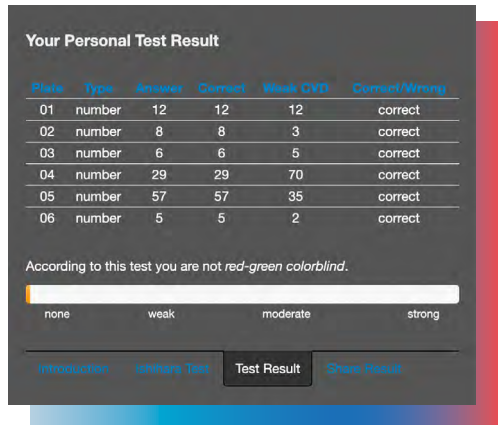
Appendix F

Internet Colour Blindness Test Results

The researcher took two tests: the Colour Arrangement Test and an online version of the Ishihara 38 Plates CVD Test found on Colblindor (n.d.) to assess suitability for qualitative visual assessment. No colour deficiencies were found that would hinder analysis.







Appendix G

Application of Profiles to a Photograph in Adobe Photoshop

The following are the visual differences between an RGB photograph and the D50 profiles made for this study when exaggerated through a saturation rendering intent. Of note, the preview Adobe Photoshop provided for the 6C multichannel differed from the actual view once accepting the changes. Additionally, with the 6C profile applied to a photograph, the method with which the profile applies Neon Pink and Neon Yellow relative to hue is explored in Figure G4. Neon Pink is applied only to the purple of the flower petals, while process magenta is applied everywhere else that needs a reddish tone. Neon Yellow and process yellow are applied to all the greenery, but Neon Yellow used more as a highlight to yellow-greens rather than a full yellow. Although none of the profiles can recreate the purples of the original, the combination of Neon Pink and cyan toners is closer than the heavily magenta hue of pure CMYK. CPYK cannot recreate as vibrant darker green/yellows, relying on desaturated hues. Figures G1-G3 are to give an approximate idea, as the viewing condition and format (i.e. screen or print) changes colours.

Figure G1. Original RGB Photograph with no editing.

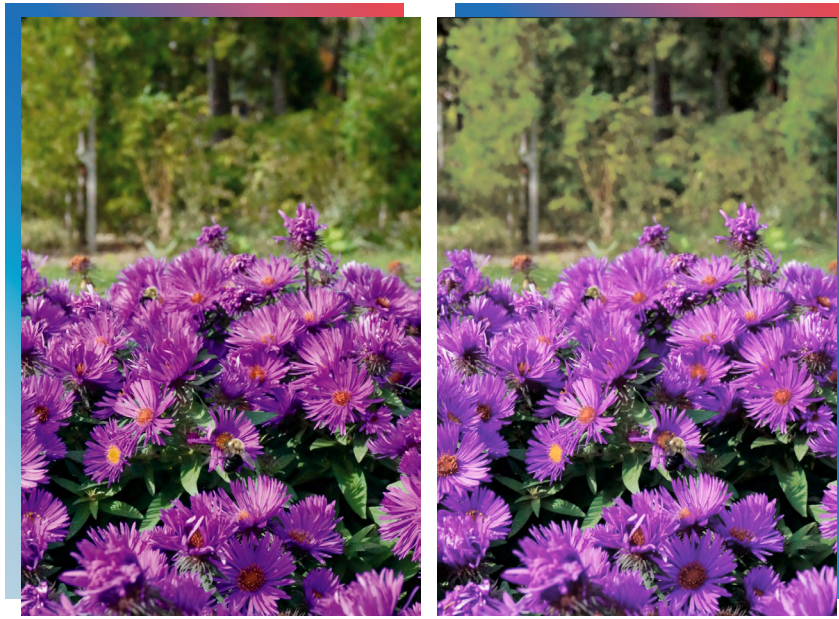


Figure G2. Saturated CMYK (left) Compared to Saturated CPYK (right) D50 Profiles.

Figure G3. Before (Preview, left) and After (Accepted Conversion, right) Saturated 6C D50 Profile.

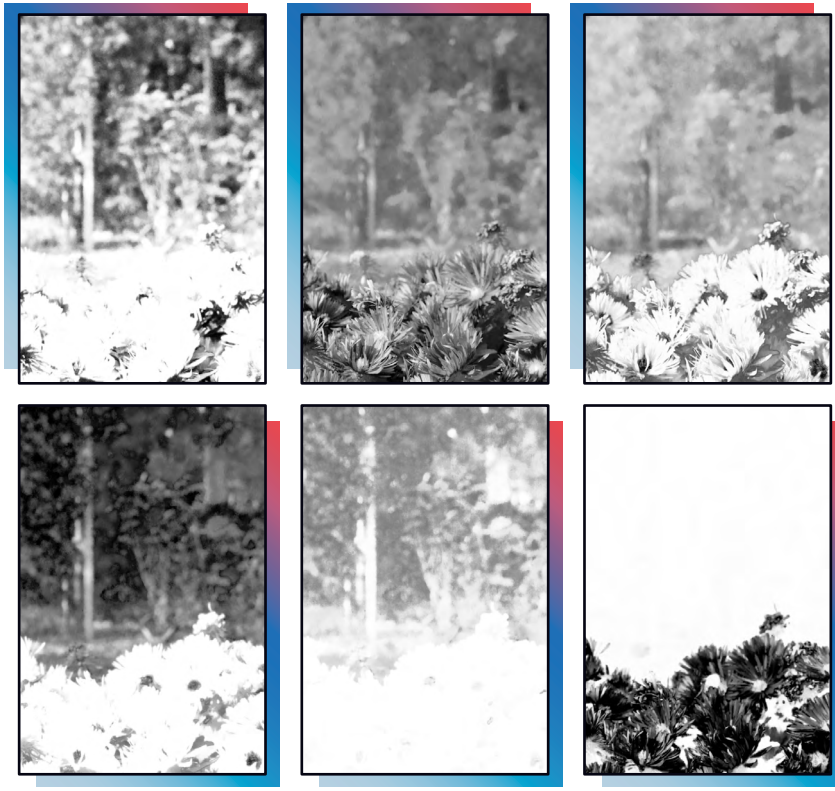


Figure G4. 6C Profile Separations of Toner.
Note. Top order is: black, cyan, magenta. Bottom order is: yellow, Neon Yellow, Neon Pink.

Appendix H.

i1Profiler CMYK and CMYK + Neons Test Charts

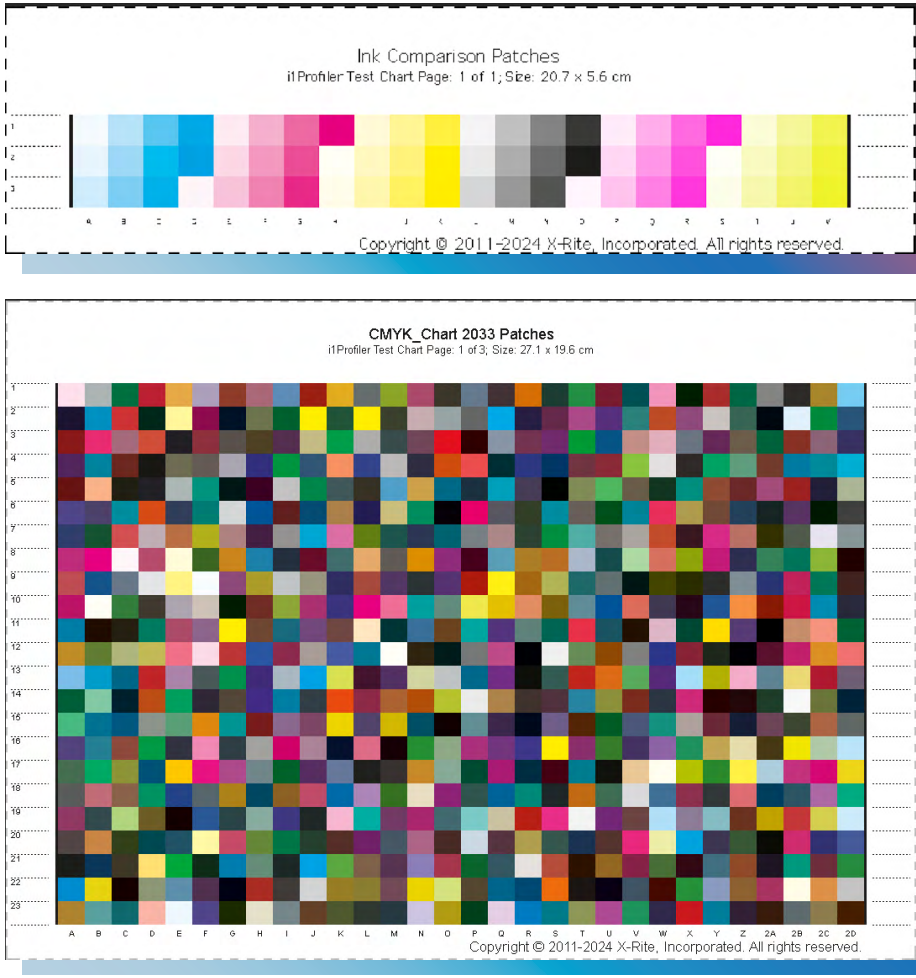
Using Adobe Photoshop, the following test chart sets were split into CMYK + Neon Pink and CMYK + Neon Yellow, where the latter files held no colour information in the CMYK channels but maintained them for Adobe InDesign to recognize them as CMYK images. The CMYK test chart contained no spot colour information and was left alone. A duplicate of the CMYK chart set was reused for CPYK by cutting and pasting the magenta channel into a Neon Pink spot channel, and cutting and pasting the yellow channel into a Neon Yellow spot channel.

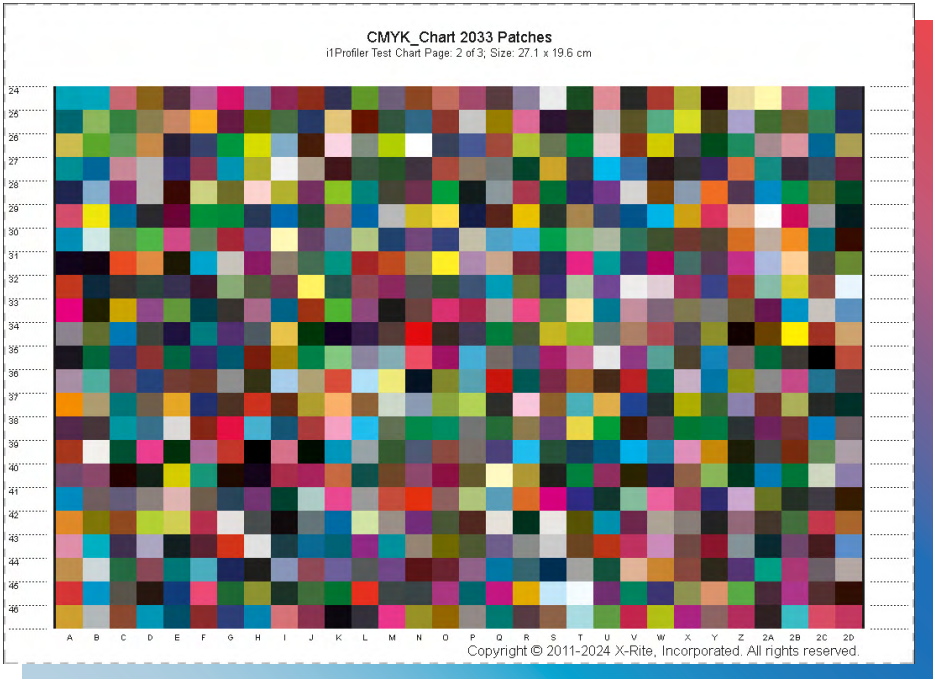
Two Adobe InDesign files—exported as PDFs—were used to print the test charts, one with all the CMYK + Neon Pink colour data, and a second with all the frames replaced with the Neon Yellow colour data, allowing for better printing efficiency on the stock size.

Upon printing, charts were verified to be printing without colour management. However, the press was applying excess cyan and black toner across the entire sheet, leading to a noticeable shift, consistent over all press sheets, on the paper colour. As the coverage was even, printing proceeded under the assumption that all results would be equally altered as if the paper white point were slightly darker and more blue.

The first chart in Figure H1 is self-labelled “Ink Comparison Patches”—this is incorrect. It should be labelled “Toner Comparison Patches,” but the research methodology did not include proof-reading temporary labels for researcher reference, and with regret this error reached press.

Figure H1. Various Test Charts Used for this Research.




CMYK_Chart 2033 Patches
i1Profiler Test Chart Page: 2 of 3; Size: 27.1 x 19.6 cm
24
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A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 2A 2B 2C 2D
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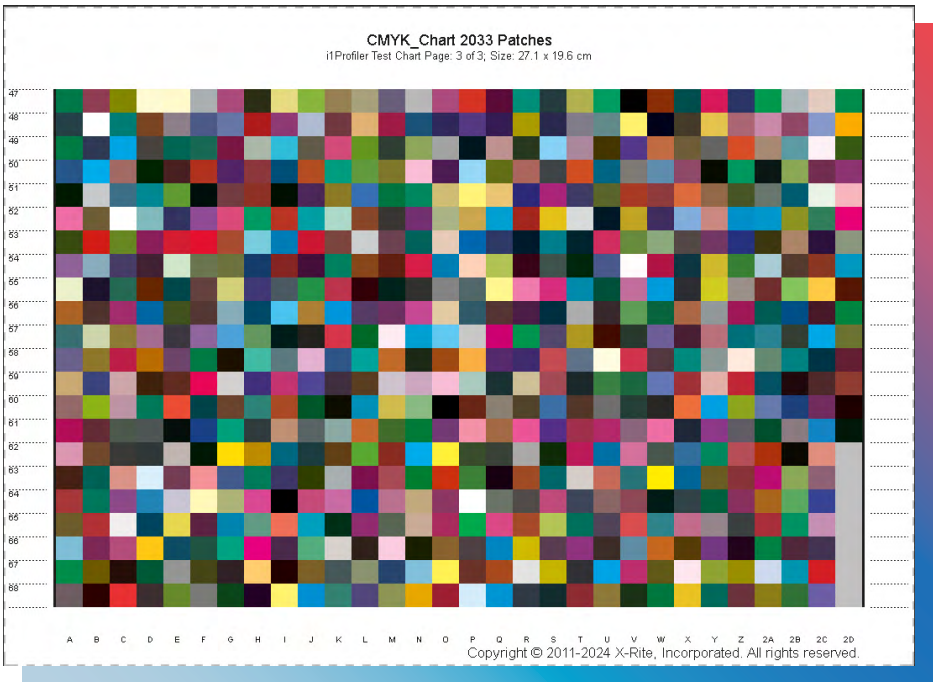
CMYK_Chart 2033 Patches
i1Profiler Test Chart Page: 3 of 3; Size: 27.1 x 19.6 cm
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A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 2A 2B 2C 2D
Copyright © 2011-2024 X-Rite, Incorporated. All rights reserved.

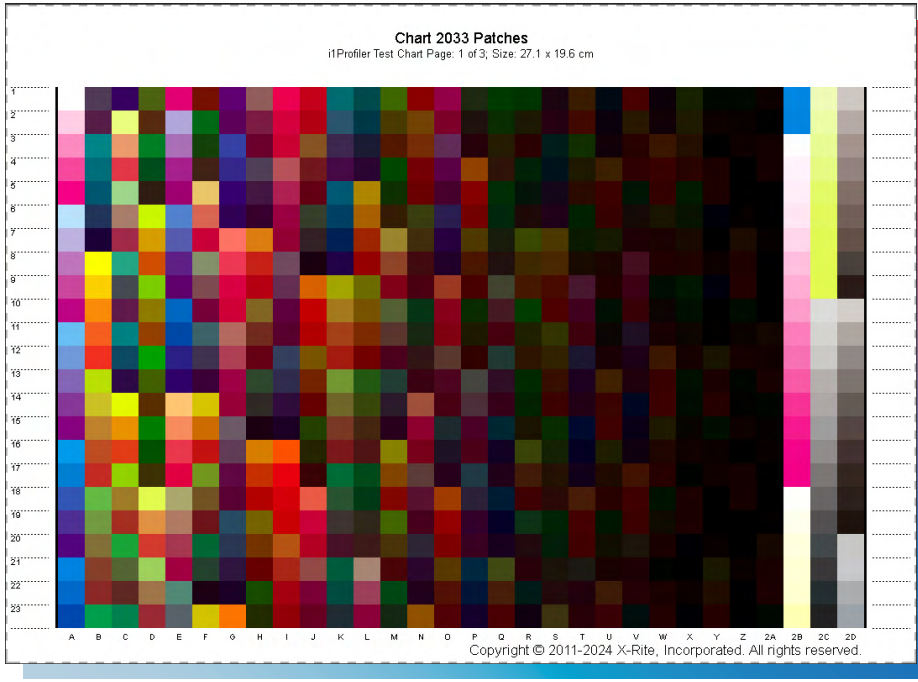
Chart 2033 Patches
i1Profiler Test Chart Page: 1 of 3; Size: 27.1 x 19.6 cm
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 2A 2B 2C 2D
Copyright © 2011-2024 X-Rite, Incorporated. All rights reserved.

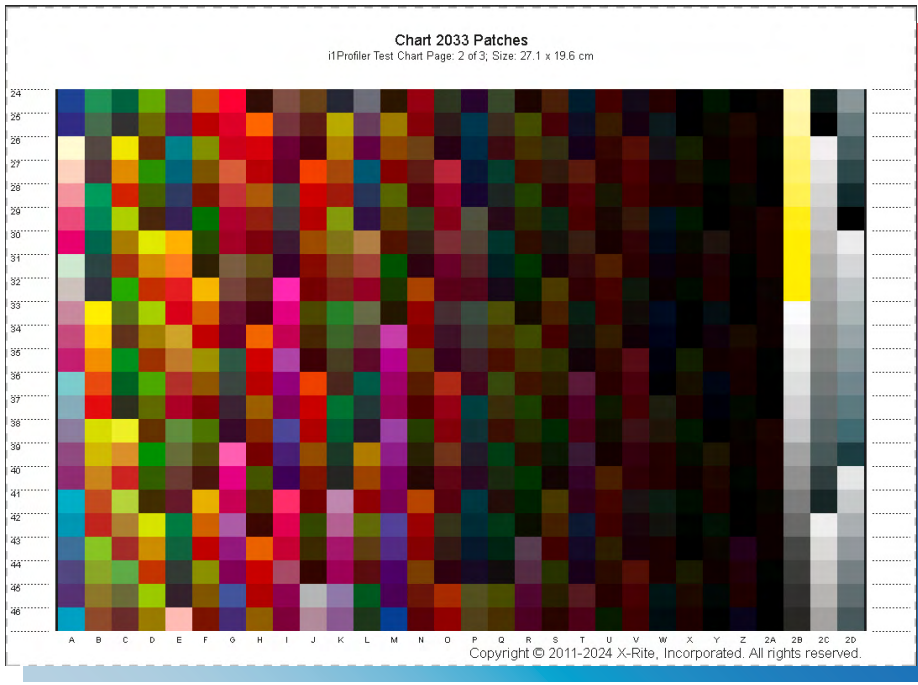
Chart 2033 Patches
i1Profiler Test Chart Page: 2 of 3; Size: 27.1 x 19.6 cm
24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 2A 2B 2C 2D
Copyright © 2011-2024 X-Rite, Incorporated. All rights reserved.

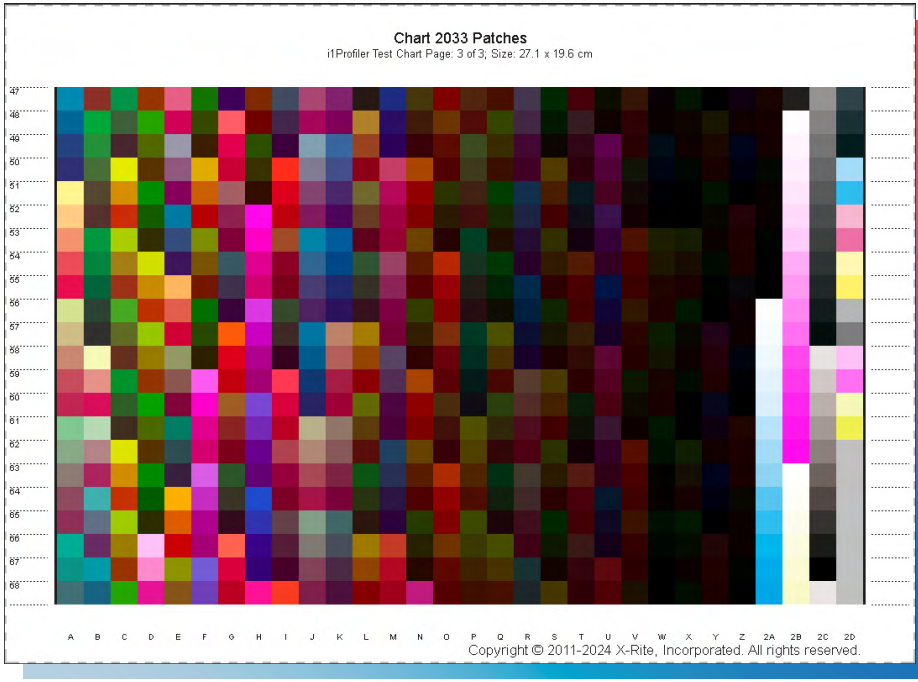
Chart 2033 Patches
i1Profiler Test Chart Page: 3 of 3; Size: 27.1 x 19.6 cm
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A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 2A 2B 2C 2D
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TMUTAGA

02

EXPLORING AN INCLUSIVE DIGITAL EXPERIENCE FOR INDIVIDUALS WITH DISABILITIES: LEVERAGING GENERATIVE AI FOR WEB ACCESSIBILITY ON DIGITAL ASSETS

Aisharja Chowdhury

Aisharja Chowdhury is a digital experience designer based in Toronto, ON. She holds a degree in Graphic Communications Management from Toronto Metropolitan University, with a minor in Computer Science and a specialization in Packaging. Currently, she is pursuing a Masters of Information in User Experience Design at the University of Toronto. Passionate about user-centered design, she blends technical skills and creative insight to create accessible and engaging digital solutions. Her background in packaging and digital design offers a unique perspective on solving complex problems. Aisharja is dedicated to creating inclusive and intuitive experiences for diverse audiences.

To listen to Aisharja's thesis, use this link:

2

Acknowledgement

I extend my deepest gratitude to everyone who has contributed to my academic and professional journey, culminating in the completion of this thesis paper and the past four years of growth and learning. Special shout out to my thesis supervisor, Dr. Reem El Asaleh, whose guidance and support have been invaluable throughout my research endeavors. Her expertise, insights, and suggestions have enabled me to delve into this research topic with confidence.

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Abstract

This study addresses the effectiveness of Generative AI in generating alt text compared to manual creation methods in the context of web accessibility. With the increasing reliance on digital platforms and the imperative to ensure inclusivity for all users, understanding the viability of AI-driven solutions is crucial. The objectives are to assess Graphic Arts students' perceptions of alt text creation, explore their familiarity with web accessibility guidelines, and evaluate the effectiveness of Generative AI in alt text generation. The research employed a mixed-methods approach, including an online survey completed by Graphic Arts students and an interview with an accessibility expert. The survey gathered quantitative and qualitative data on students' perceptions and practices regarding alt text creation, while the interview provided insights into the challenges and opportunities in web accessibility. The survey revealed varying levels of confidence among students in alt text creation, with a significant proportion expressing challenges in describing complex visuals and lack of guidelines. However, there was a notable interest in incorporating Generative AI technologies into their workflows. The interview highlighted the importance of human involvement in alt text creation despite advancements in AI technology. Overall, the study found that while Generative AI shows promise in alt text generation, human involvement remains crucial for ensuring accuracy and relevance, particularly for complex images. Businesses and educational institutions can benefit from integrating both human and AI-driven solutions to enhance web accessibility and foster inclusivity for individuals with Disabilities.

Glossary

Disability - An individual that has a physical or a mental impairment that limits their movement, senses or activities.

Web Accessibility - When designing and developing websites, tools and technologies, individuals with are kept in mind so they can use them as well

Alt Text - Also known as alternative (alt) text, ensures that all non-text content is available in 'Text' and helps provide context/description.

Generative AI - Is an artificial intelligence capable of generating text, images, videos and other data.

Screen Reader - A form of assistive technology that renders text and image content such as speech or braille. This device is used by many individuals with disabilities, but is especially common amongst individuals with various types of visual impairment.

Section 508 - All federal agencies must ensure accessibility for any information and communication technology that they develop, procure, maintain or are using.

WCAG - Web Content Accessibility Guidelines.

Metadata - A set of data that describes and gives information about other data.

Tags (metadata) - A keyword or term that is assigned to a piece of information to help describe an item and allow users to be able to find it again by searching.

Introduction

In an increasingly digital world, where there are an estimated 45 million visually impaired individuals worldwide (Babu, Singh, & Ganesh, 2010), ensuring the accessibility of online content is crucial for fostering inclusivity and equitable access for all users. This thesis delves into the critical aspect of alt text generation, particularly exploring the effectiveness of generative AI compared to manual creation methods. As technology continues to advance, the need to address accessibility challenges becomes more pressing, making this topic both timely and important in the context of digital inclusivity.

This research focuses on examining the efficacy of generative AI in generating alt text, narrowing the scope to explore its application within the realm of web accessibility. The study encompasses a demographic of Graphic Arts students, aiming to understand their perceptions, practices, and challenges in alt text creation. While the research primarily revolves around alt text generation, it does not delve into broader aspects of web accessibility or other forms of assistive technologies.

The motivation behind this topic stems from the growing significance of web accessibility in fostering inclusivity and equitable access to digital content. As existing literature emphasizes the importance of alt text in ensuring

accessibility for individuals with disabilities, this research aims to contribute to the ongoing discourse by evaluating the effectiveness of generative AI as a potential solution. The study bridges the gap between theoretical discussions and practical applications, offering insights into the challenges and opportunities in alt text generation.

The primary aim of this research is to investigate the extent to which generative AI is effective in generating alt text compared to manual creation methods. The objectives include assessing Graphic Arts students' perceptions of alt text creation, exploring their familiarity with web accessibility guidelines, and evaluating the effectiveness of generative AI in alt text generation. The hypothesis predicts that generative AI will be equally or more effective than manual creation methods in generating alt text.

Literature Review

The Need for Web Accessibility in Design

In today's digital era, the widespread adoption of technology poses a significant challenge for many individuals, particularly those with disabilities. A study conducted in 2019 by Nucleus Research Inc. indicated that over 70% of websites, including e-commerce platforms, are unusable for many individuals with disabilities and have been deemed to be a "Critical accessibility blocker" (David, 2019). The lack of accessibility in digital content hinders their ability to fully engage with and utilise technological advancements. As Tim Berners-Lee, the Director and Inventor of the World Wide Web, stated, "The power of the web is... Access by everyone regardless of disability is an essential aspect." This highlights the key role of creating an accessible platform which ensures that individuals with disabilities can access, navigate, perceive, and interact with digital content seamlessly (Beyene, 2017).

Numerous international guidelines were created to make sure designers and developers follow accessibility guidelines. One of the most notable ones is the Web Content Accessibility Guidelines (WCAG) proposed by the World Wide Web Consortium (W3C) through the Web Accessibility Initiative (WAI) in May of 1999. Aiming to establish accessible environments for digital asset usage. The latest version that is currently being used as of October 2023 is WCAG 2.2 which focuses more on the responsiveness of digital content. The WCAG guidelines revolve around four core principles of accessibility, known as POUR: Perceivable, Operable, Understandable, and Robust. In Table 1, the guidelines and checkpoints for each principal have been summarized based on WCAG 2.2 for a better understanding of what one must follow.

Table 1. WCAG 2.2 Guidelines and Checkpoints (Web Content Accessibility Guidelines (WCAG) 2.2, 2023).

Guideline	Checkpoints
Perceivable	• Non-text content must have text alternatives to ensure accessibility, allowing users to perceive and interact with the content effectively. • Provide alternatives such as captions, audio descriptions or sign language interpretation for time-based media like audio and video to ensure accessibility for users with Disabilities. • Create content that can be presented in different ways without losing information or structure, ensuring accessibility across various devices and users preferences. • Ensure that content is distinguishable by making it easier for users to see and hear, including considerations for colour usage, audio control, contrast and text resizing. • Ensure that additional content triggered by pointer hover or keyboard focus is dismissible, hoverable and persistent, providing users with control over the content visibility.
Operable	• Ensure that all functionality can be accessed and operated using only a keyboard interface, without requiring specific timings for keystrokes. • If keyboard focus can be moved to a component using a keyboard interface, ensure that focus can also be moved away from that component using only a keyboard interface, without trapping the user. • Provide users with enough time to read and use content by allowing them to adjust or extend time limits set by the content. • For moving, blinking, scrolling, or auto-updating content, provide mechanisms for users to pause, stop, or hide it, unless it's essential for an activity. • Ensure that all functionality using multipoint or path-based gestures can be operated with a single pointer without a path-based gesture, unless such gestures are essential.

Understandable	• Ensure that the language of the entire web page and individual passages or phrases can be programmatically determined, allowing assistive technologies to accurately interpret and present the content. • Provide mechanisms for identifying specific definitions of unusual words or phrases, as well as expanded forms or meanings of abbreviations, to enhance understanding, especially for users with cognitive or language difficulties. • Offer supplemental content or versions of text that do not require reading ability beyond lower secondary education level, ensuring that users with varying literacy levels can comprehend the information presented. • Maintain consistency in navigational mechanisms and functional identification across web pages to help users predict and understand how to interact with the content. • Clearly identify input errors to users and provide suggestions for correction where possible. Additionally, offer context-sensitive help to assist users in avoiding and correcting mistakes throughout their interactions with the website.
Robust	• Ensure that all user interface components have programmatically determinable names and roles, along with states, properties, and values that can be set by the user. Additionally, provide notifications of changes to these components to ensure compatibility with assistive technologies. • Implement status messages in a way that allows them to be programmatically determined through role or properties, enabling assistive technologies to present them to users without requiring focus. • Meet the appropriate level of conformance, which may be Level A, AA, or AAA, by satisfying all the corresponding success criteria. Ensure that conformance claims accurately reflect the level of accessibility achieved.

As seen above, each of these principles is supported by a set of guidelines and success criteria that one must follow. By addressing all four principles, designers and developers can create content that can be interpreted by a wide range of user agents, including assistive technologies. Accessibility not only enhances individual experiences, but can also contribute to the overall quality of life for citizens. Designers play a crucial role in promoting accessibility

by incorporating mobility features into built environments, thereby upholding human rights and freedom. Moreover, accessibility fosters social interactions and inclusivity, enriching societal dynamics. By following these guidelines, digital content can be classified into one of three categories: low accessibility (A), high accessibility (AA) and highest accessibility (AAA). Implementing level AA or higher is recommended to designers because it addresses the needs of users with and without disabilities (Sonderegger, 2016).

However, despite the progress in addressing accessibility challenges, there are persistent issues, particularly in the integration of social media platforms like LinkedIn into the employment landscape. While LinkedIn offers significant opportunities for job seekers, including individuals with disabilities, its accessibility shortcomings hinder their full engagement with the platform's features. Despite the platform's popularity among recruiters, with a staggering 95% utilising it to assess potential candidates (Wild, 2016), accessibility issues persist, underscoring the need for continued efforts to address these challenges. Embracing accessibility as a fundamental principle is essential for promoting universal access across all environments and upholding the rights of individuals with disabilities.

While accessibility remains an ongoing challenge, increased awareness among designers can drive continuous improvement efforts. Emphasising accessibility as a fundamental principle means enabling universal access across all environments. The declaration of disabled people's rights within the framework of Human Rights by the United Nations General Assembly in 1948 underlines the importance of prioritising accessibility as a cornerstone of societal progress.

Alternative Text (Alt Text) & How It Fits into Web Accessibility

Worldwide, approximately 285 million individuals live with visual impairments, many of whom rely on screen readers, such as JAWS and NVDA, to access digital content (Ab Shaqoor Nengroo & Kuppusamy, 2017). Alternative (alt) text is vital for ensuring the accessibility of images to assistive technologies like screen readers. Without alt text, screen readers may either skip images altogether or read file names, resulting in a lack of context and understanding for users with visual impairments.

Despite recommendations from organizations like the World Wide Web Consortium (W3C) through guidelines like the Web Content Accessibility Guidelines (WCAG), many web developers find the task of providing alt text to be time-consuming and repetitive (Ab Shaqoor Nengroo & Kuppusamy, 2017). This challenge can lead to inconsistencies and incomplete accessibility across web pages, further increasing the barriers for users with disabilities.

The concept of usability, as defined by ISO 9241-11, is "the extent to which a product can be used by specified context of use" (Amaia Aizpurua et al., 2016). In the context of web accessibility, providing alt text is a fundamental aspect of ensuring that digital assets are usable by all users, including those with disabilities.

Public library websites often fail to comply with accessibility standards such as Section 508, which negatively impacts the accessibility of information services for individuals with disabilities (Brobst, 2009). To overcome such accessibility barriers, assistive technologies like screen readers and text transcoders play a crucial role (Bambang Parmanto & Zeng, 2005).

Studies have identified various barriers to compliance with web accessibility standards, including budget constraints and lack of awareness or knowledge among web developers (Brophy and Craven, 2007). Without alt text, all digital assets would be inaccessible to screen reader users, rendering essential features, such as image submit buttons, unusable for assistive technology users (Wild, 2016).

Alt text, embedded within HTML code as an attribute, serves as a textual description of images, enabling screen readers to convey the content to visually impaired users (Hogle & Elliott, 2020). However, the effectiveness of alt text depends on its conciseness and relevance. While decorative images may not require detailed descriptions, providing brief descriptive text remains beneficial. Alt text must adhere to plain text conventions, avoiding formatting such as bold, italics, or all capitalization.

The increase of digital assets on the web has presented challenges in facilitating image search services. Traditional methods of image retrieval, relying on manual identification and tagging, have become impractical due to the sheer volume of web images. Consequently, automated image annotation has emerged as a research area, aiming to streamline the process of categorising and describing images. Despite its significance, recent studies have shown that approximately half of the digital assets on the web lack alt text, highlighting a critical gap in web accessibility practices. Addressing this shortfall requires concerted efforts to prioritize the inclusion of alt text in web content creation and management processes, thereby fostering a more inclusive digital ecosystem for all users.

A study conducted in 2019 by Nucleus Research Inc. indicated that over 70% of websites, including e-commerce platforms, are unusable for many individuals with disabilities and have been deemed to be a “Critical accessibility blocker” (David, 2019). The lack of accessibility in digital content hinders their ability to fully engage with and utilise technological advancements. As Tim Berners-Lee, the Director and Inventor of the World Wide Web, stated, “The power of the web is... Access by everyone regardless of disability is an essential aspect.” This highlights the key role of creating an accessible platform which ensuresthat individuals with disabilities can access, navigate, perceive, and interact with digital content seamlessly (Beyene, 2017).

Metadata is the Saviour?

Metadata plays a crucial role in promoting accessibility by facilitating the matching of user needs and preferences with available accessibility solutions. Acting as the bridge between accessibility and usability, metadata enables experts in the field to achieve the ideal outcome desired. An example of its significance is highlighted in the research conducted by Brady et al., who utilized the PDF Accessibility Checker tool, leveraging metadata/tags for evaluating accessibility (Beyene, 2017).

Content metadata can be used to store textual descriptions of images, which can serve as alternative text for accessibility purposes. However, challenges such as privacy concerns and the risk of metadata removal from image files limit its efficacy (Ab Shaqoor Nengroo & Kuppusamy, 2017). Nevertheless, automated systems, like those developed by McCoy et al., leverage metadata to generate personalized information for screen reader users, exemplifying its potential (Ab Shaqoor Nengroo & Kuppusamy, 2017).

Moreover, metadata serves as a guiding light for designers and developers, reminding them of necessary features to ensure accessibility. Its role extends to automated accessibility checks, streamlining user experiences and assisting assistive technologies in processing information resources efficiently. Yet, the vast majority of digital content poses challenges in manually tagging metadata to each object. Hence, exploration into Machine Learning (ML) and AI methods for generating descriptive metadata has emerged as a potential solution.

In digital image management, metadata proves to be particularly essential for cataloguing and maintaining large image collections, as well as facilitating search and retrieval processes. The International Press Telecommunications Council (IPTC) was the first to successfully develop a standard for storing descriptive metadata within digital images, providing a standardized format for creating, processing, and exchanging digital image metadata (J. Tesic, 2005). This standardization enables effective image management, analysis, indexing, and search applications. Standards like EXIF and IPTC, proposed by organizations like JEITA and IPTC, provide a framework for standardized metadata creation, processing, and exchange, enhancing image management and search applications.

Notably, metadata's significance extends to digital asset management areas including digital rights management and universal searches. Initiatives like the Information Interchange Model (IIM) by IPTC and the Newspaper Association of America (NAA) establish structured metadata schemes, ensuring clarity and consistency in describing digital image content, thereby enhancing accessibility and usability (J. Tesic, 2005).

Metadata is poised to become a critical component in various aspects of digital asset management, including digital rights management, universal searches, and the automation of repetitive tasks. Recent advancements from Adobe and the International Press Telecommunications Council (IPTC) exemplify milestones along this trajectory (Roszkiewicz, 2005).

Defined by the National Information Standards Organization, metadata serves as structured information that facilitates information retrieval, use, and management. Its role as a safeguard for future accessibility underscores its importance (J. Tesic, 2005).

Embedded image metadata standards like EXIF, XMP, and IPTC are vital for describing image subjects, licensing, and recording creation details, as observed in various projects like eMonocot (Baker, 2013). Standardization of metadata ensures seamless integration and interoperability across diverse platforms and systems, enriching digital asset management practices.

Generative AI & Its Implementation in the Industry

Generative AI, a subset of Artificial Intelligence (AI), demonstrates the remarkable ability to produce a wide array of content, spanning from ideas and text to images and videos (Thomas, 2023). Despite its promising potential, the integration of generative AI within industries is still in its beginning phases, leading to increased widespread uncertainty regarding its practical application in day-to-day business operations. As this technology continues to advance, professionals across various sectors find themselves struggling with the complexities of leveraging generative AI to effectively enhance their work processes and outcomes.

In recent years, many design platforms have begun incorporating features powered by generative AI (Wu et al., 2023). Notable examples include Canva and Adobe Creative Cloud, where designers can now access tools that utilise generative AI to streamline their creative processes. While these features aim to assist designers in their workflow, the implementation of generative AI in design tools is still relatively new, prompting designers to adapt to and explore the potential benefits of this innovative technology.

The exposure of generative AI encourages collaboration between humans and AI agents in creative endeavours (Muller et al., 2022). This collaborative model, known as human-computer co-creativity, involves both parties influencing each other's contributions to produce creative outputs. Unlike traditional AI systems that make decisions or provide descriptions, generative AI produces creative outputs, sometimes indistinguishable from human-made content. This technology presents unique challenges and opportunities for human-computer interaction (HCI), particularly in understanding how humans interpret and interact with generative AI algorithms and outcomes.

Generative AI offers opportunities to enhance accessibility by creating alternative formats and personalized content tailored to individual needs (Muller et al., 2022). For example, AI systems can generate alternative text descriptions for images, making visual content accessible to users with visual impairments. By streamlining the creation of accessible content, generative AI can help automate accessibility processes, saving time and effort for content creators and improving the overall accessibility of digital resources. However, despite its potential, generative AI also presents challenges and limitations in ensuring accessibility, including privacy concerns, the risk of biased or inaccurate content generation, and the need for human oversight.

In the field of metadata annotation, generative AI methods utilise machine learning techniques, including supervised, unsupervised, and semi-supervised learning, to train mathematical models by learning from provided data and making predictions (Wu et al., 2023). However, challenges persist in matching or substituting human curators or experts due to the lack of high-quality annotated datasets and the cognitive-intensive nature of annotating metadata, which requires both domain knowledge and general knowledge of cultural and social contexts.

Traditional manual tagging of metadata to digital objects is labour-intensive and impractical due to the massive volume of digital objects (Muller et al., 2022). This has led to investigations into using machine learning and AI methods to automatically generate descriptive metadata. Despite its success, generative AI poses challenges such as the lack of commonly available high-quality annotated datasets and the uncertainties surrounding the creative process in domains like art and design (Wu et al., 2023).

The effectiveness of automated metadata annotation depends on the quality of the training dataset and the rules available for the domain (Wu et al., 2023). There's a need to understand the type of data content a pre-trained machine learning algorithm has been trained on to comprehend its limitations and potential biases. Additionally, the availability of scholarly and historical content often lacks consumable, homogenised, and interoperable formats required for machine learning (Muller et al., 2022). While exceptions exist, such as, in science and medicine, where large, well-documented collections are available, other domains face challenges due to the unavailability of suitable datasets.

Generative AI holds significant promise in transforming various industries, including design and accessibility, but challenges such as data quality, bias, and human oversight remain critical considerations in its implementation. Collaborative efforts between AI researchers, designers, and HCI experts are essential to overcome these challenges and harness the full potential of generative AI in

improving workflow efficiency, creativity, and accessibility. As the technology continues to evolve, ongoing research and innovation will be necessary to address emerging issues and further refine the application of generative AI in diverse fields.

Methodology

The concept of generative AI and metadata is still evolving and expanding. Therefore, concluding solely through quantitative methods is not feasible. Alt text generation is a subjective process, making it challenging to cater to users with diverse needs. To grasp the current landscape of generative AI, consulting with experts in the field is essential. Analyzing existing generative AI systems that produce alt text can provide deeper insights into the user experience across various demographics.

Conducted Methods

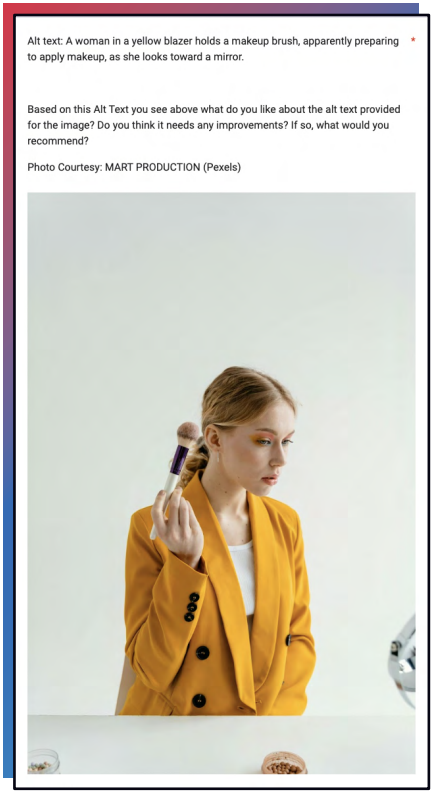
Method 1: Survey

A mixture of quantitative and qualitative data was gathered via an online survey completed by 12 Graphic Arts students. The survey aimed to understand their perceptions of alternative (alt) text, their familiarity with web accessibility guidelines, and their confidence in applying them in both personal and professional contexts. Below is a list of questions that were asked of the 12 Graphic Arts students:

Table 2. Survey Questions for Graphic Arts Students.

On a scale of 1 to 5, how confident are you in your ability to create effective alternative (alt) text manually?
How do you currently approach creating Alternative (Alt) text for digital assets?
What challenges, if any, do you face when creating alt text? (Select all that apply)
Do you currently incorporate alternative (Alt) text descriptions for images and other multimedia content when posting on social media? If yes, how frequently?
Do you think there is a need for more awareness and education among social media professionals regarding the importance of accessibility in digital content creation?
Would you be interested in tools or resources that automate the generation of Alt text and other accessibility features for digital assets shared on social media?

How do you perceive the effectiveness of Generative AI in generating Alternative (Alt) text compared to humans creating Alt text manually?
Have you ever heard/used the WCAG guidelines to your design practices?
Do you believe that adherence to WCAG guidelines positively impacts the overall user experience of digital assets? If yes, please explain why
Do you think it is important to know WCAG guidelines for web accessibility in the current market? If so, why?
Are you familiar with alternative methods or technologies for generating Alt text automatically?
What challenges, if any, do you face when creating or encountering digital content with Alternative text descriptions?
How important do you think it is for social media platforms to prioritize accessibility features like Alt text descriptions?
Have you ever used Generative AI to generate Alt Text? If yes, what are they and have you used them for your digital assets?
How do you think technology, such as Generative AI, could improve the accessibility of digital content for individuals with disabilities?
Have you ever created Alt text for a social media posts? What were the key advantages and disadvantages you have encountered?
Would you be willing to incorporate Generative AI technology for Alt text generation? (Choose what applies)
How do you envision the future of Alt text creation in digital design and development?



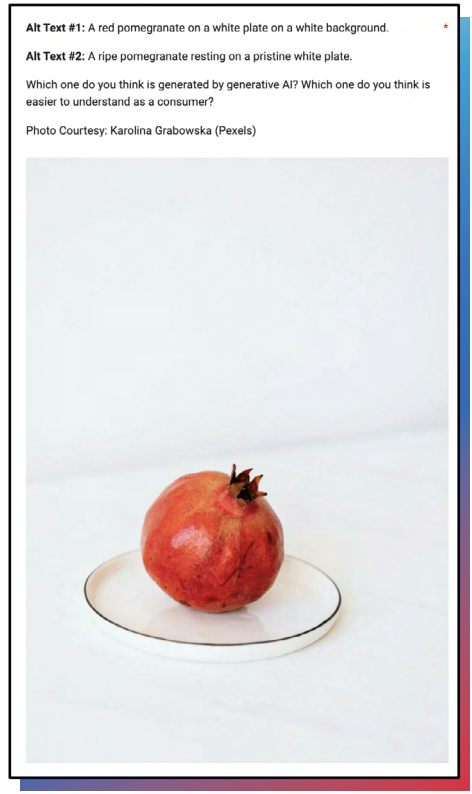


Figure 1. (Left): Asking users their opinion on an AI-generated alt text.

Figure 2. (Right): Asking users to choose between two versions of alt text, one generated by AI and another by a human.

Two such notable questions in the survey focused on assessing the user's perspective on generative AI vs. alt text. Presented in Figures 1 & 2, these questions asked participants to compare what they liked best and what recommendations they had for the alt text. The objective of the questions was to understand the readiness of the next generation to address web accessibility needs in their future careers. The collected data underwent statistical analysis to identify trends and patterns in the participants' responses.

Method 2: Interview

To gain deeper insights into the current state and future trajectory of web accessibility within the industry, an interview was conducted with Caroline Desrosiers, the founder and owner of Scribely, a California-based company specialising in accessibility solutions. Scribely's core focus is on providing alt text and extended descriptions for images, as well as audio descriptions for videos,

aiming to create a more inclusive, equitable, and sustainable digital environment (About Scribely, 2020). The interview comprised the following questions posed to Caroline:

Table 3. Interview Questions for Caroline Desrosiers.

As a representative of Scribely, a company specializing in accessibility solutions, how do you perceive the role of Alt text and extended descriptions in promoting inclusivity and accessibility in digital content?
Can you share insights into the current challenges faced by businesses in ensuring accessibility for individuals with disabilities, particularly in terms of providing Alt text and audio descriptions for digital assets?
Have you personally utilized or implemented Generative AI tools or solutions for Alt text generation in your digital content creation processes?
In your experience, how effective is manual creation of Alt text and extended descriptions compared to utilizing Generative AI for generating these accessibility features?
What are some key considerations or criteria Scribely uses when crafting Alt text and extended descriptions to ensure compliance with WCAG guidelines and to provide an inclusive digital experience?
How do you envision the future of Alt text generation and accessibility solutions evolving with advancements in Generative AI technology?
Can you elaborate on the impact of accessible digital content on businesses, particularly in terms of customer engagement, brand reputation, and legal compliance?
How does Scribely ensure that the Alt text and extended descriptions it provides align with the diverse needs and preferences of individuals with disabilities?
What role do you believe Generative AI can play in scaling accessibility solutions and addressing the growing demand for Alt text and audio descriptions in digital content?

In your view, what are the potential limitations or drawbacks of relying on Generative AI for Alt text generation, and how can these be addressed or mitigated?
How do you envision the future role of Generative AI in improving web accessibility for individuals with disabilities, particularly in relation to Alt text generation?
How do you ensure that Alt text generated by Generative AI aligns with accessibility standards such as WCAG guidelines and effectively communicates the content of digital assets?

This interview aimed to provide valuable insights into the current challenges, trends and prospects of web accessibility, particularly regarding alt text generation and accessibility solutions within the digital landscape.

Results

Survey Results

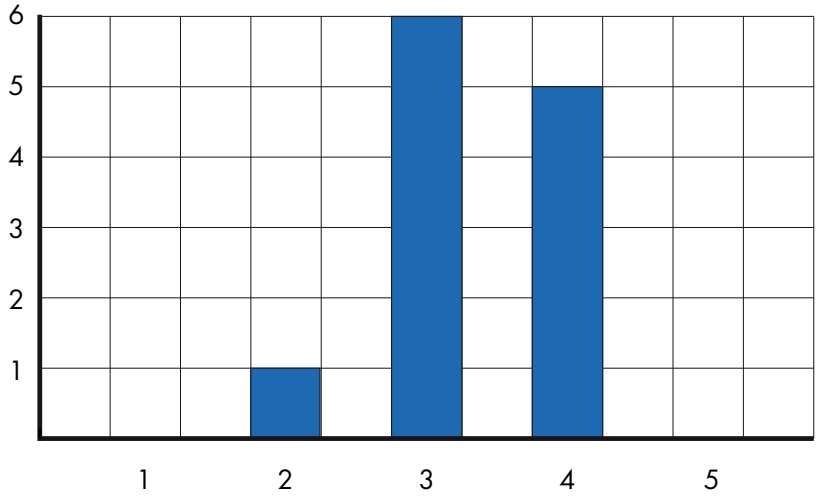


Figure 3. On a scale of 1 to 5, how confident are you in your ability to create effective alternative (alt) text?

When the students were asked about their confidence level in effectively generating alt text manually, 50% of respondents indicated even though they know how to generate alt text manually, they are not too confident in doing so independently. On the other hand, 41.7% of the respondents chose level four showing more confidence in their ability to generate alt text whereas only one person chose level two indicating lesser confidence in generating alt text.

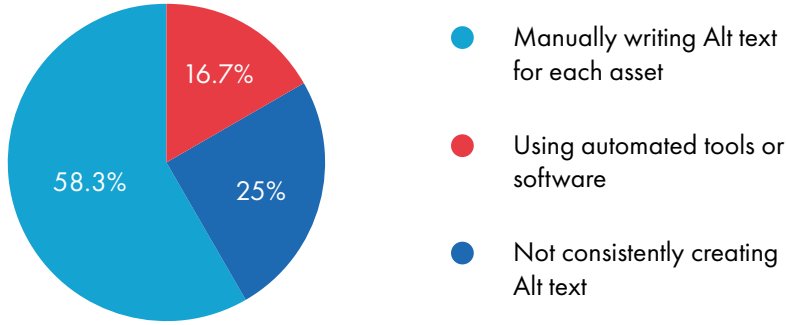


Figure 4. How do you currently approach creating alternative (alt) text for digital assets?

58.3% of respondents mentioned they currently write their alt text manually. However, from this survey, about 17% of Graphic Arts students use automated tools/software to aid them in this task. Through this survey, a quarter of these students have mentioned that they are not consistent with creating alt text for their digital assets.

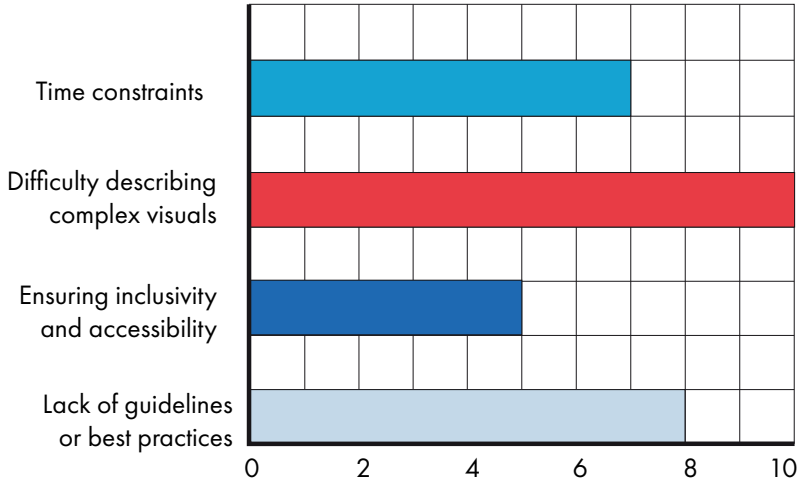


Figure 5. What challenges, if any, do you face when creating alt text?

While many encounter various kinds of challenges when generating alt text, this survey indicated the number one challenge in performing this task is “Describing complex visuals”. This option had the highest votes whereas “Ensuring inclusivity and accessibility” was voted as the least challenging part of creating alt text.

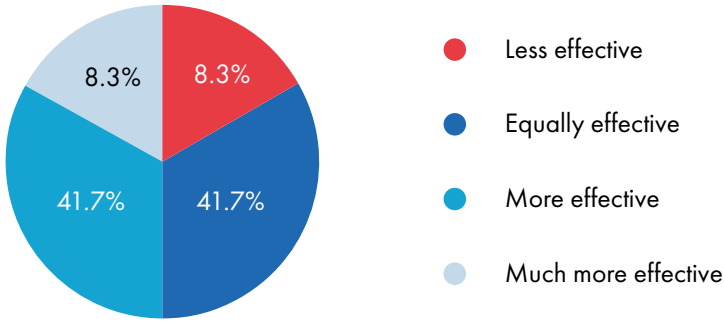


Figure 6. How do you perceive the effectiveness of generative AI in generating alternative (alt) text compared to humans creating text manually?

In this section, there was a divide in the respondents’ answers. The question was about how they perceive the effectiveness of generative AI generating the alt text compared to humans creating them manually. 41.7% of the respondents responded that they find it ‘More effective’ while the other 41.7% responded to ‘equally effective’. 8.3% answered ‘Much more effective’ while another 8.3% of the respondents answered ‘less effective’.

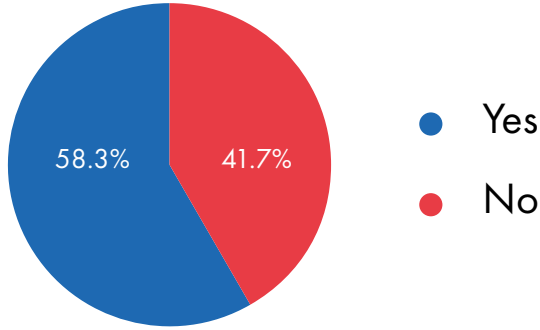


Figure 7. Have you ever heard/used the WCAG guidelines to your design practices?

58.3% of the graphic arts students answered that they have heard and used the WCAG guidelines in their design practices while 41.7% answered that they were not aware of these guidelines or they never used it.

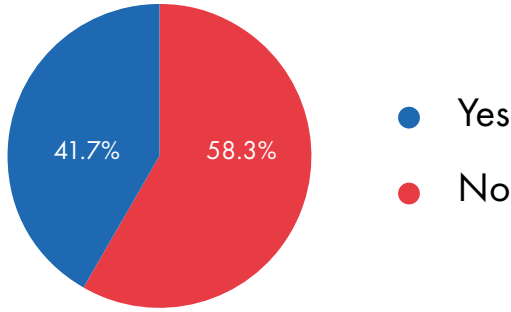


Figure 8. Are you familiar with alternative methods or technologies for generating alt text automatically?

58.3% of the respondents were unaware of the alternative methods or technologies for generating alt text automatically while 41.7% knew regarding a few technologies that offer this alternative advantage.

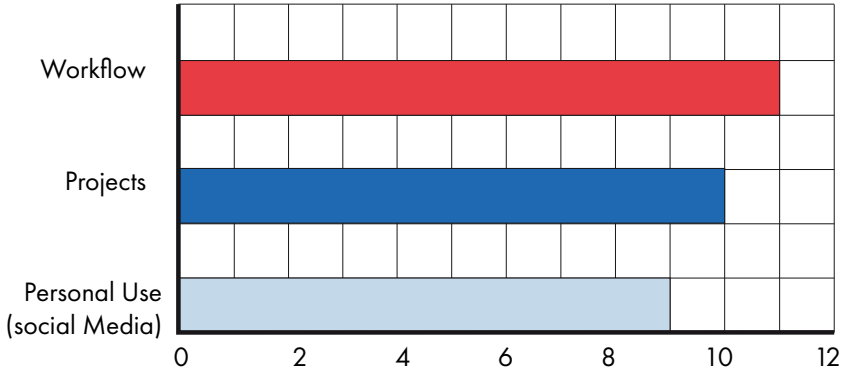


Figure 9. Would you be willing to incorporate generative ai technology for alt text generation?

When asked about their willingness to incorporate generative AI technologies, the responses showed strong interest in integrating AI into their workflows (91.7%), projects (83.3%), and personal use (social media) (75%). Participants were able to select all that apply.

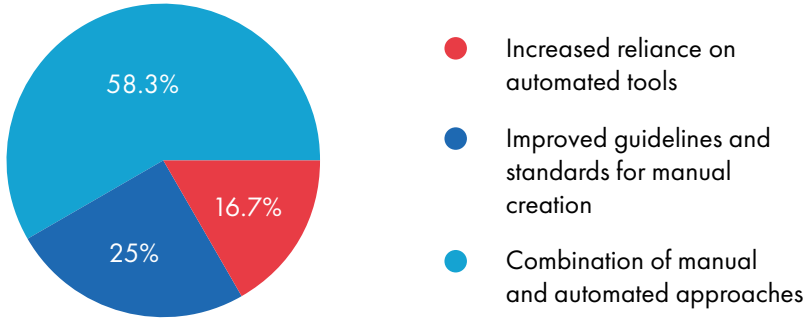


Figure 10. How do envision the future of alt text creation in digital design and development?

When asked about what they envision for the future of alt text creation with digital design and development 58.3% of the respondents answered there will be a combination of manual and automated approaches. 25% answered there will be more improved guidelines and standards for manual creation while 16.7% answered that we will have more reliance on automated tasks.

Table 4. Question asking respondents if they currently incorporate alt text descriptions.

'No'	4 respondents
'Not for personal social media but for business instagrams and a couple of assignments'	2 respondents
'Sometimes, if the imagery is a vital piece in my work and isn't self-evident'	2 respondents

This question asked the respondents if they currently incorporate alt text descriptions for images, other multimedia content or even social media posts. Here, the majority of respondents indicated that they do not, while a few mentioned that they do so occasionally, but mainly for business and assignments rather than personal purposes.

Table 5. Question asking respondents to provide their opinion on an AI-generated Alt text.

'Add description of race, colour of makeup and being more descriptive by providing direction she is looking at'	8 respondents
'the word 'apparently' is a bit ambiguous which could be confusing as to what she is actually doing in the image''	2 respondents
'It's a good Alt text, gives a story about the picture which is good''	2 respondents

As seen in Figure 1, there was a question asking students to take a look at an alt text generated by generative AI, without knowing it was AI-generated. They were asked to share their input on how they felt about the alt text and if there is any improvements needed. Based on the responses, it looks like the majority of the respondents advised adding more details or characteristics about the person so that one can visualise what the person looks like.

Table 6. Question asking respondents to choose the effective alt text between two options.

Believe that Alt text #1 is generated by generative AI due to it being easier to understand and it is detailed. They believe keeping the text simple helps users to understand what the image could be and makes it relevant.	5 respondents
Believe that Alt text #2 is generated by generative AI due to words such as 'ripe' and 'pristine'.	7 respondents

As seen in Figure 2, this question asks respondents to choose which alt text they believe is generated by generative AI and which one they believe is easier to understand as consumers. More than half of the Graphic Arts students chose alt text #2 as they found the words "ripe" and "pristine" to be an effective description of the objects in the picture.

Interview Findings

The interview with Caroline Desrosiers, the Founder and owner of Scribely, provided valuable insights into the role of alternative (alt) text and extended descriptions in promoting inclusivity and accessibility in digital content. Caroline emphasized the critical importance of image descriptions in building inclusive online environments, particularly for individuals who rely on assistive technologies such as screen readers. Alt text serves as the primary means for users to access non-text content, and it must be meaningful, contextual, and aligned with WCAG guidelines. She highlighted that alt text descriptions are a Level A requirement, indicating their significance in ensuring accessibility for all users.

Caroline discussed the current challenges faced by businesses in ensuring accessibility, both in terms of content creation and workflow processes. Many organizations struggle with incorporating accessible writing into content creation workflows, and existing systems often lack support for managing alt text for large media galleries. Despite advancements in generative AI, Caroline stressed the importance of human involvement in alt text creation, as AI-generated descriptions still exhibit inaccuracies and incompleteness. Human-generated descriptions, while labour-intensive, offer better quality and accuracy, particularly for complex images.

In terms of the impact of accessible digital content on businesses, Caroline highlighted the potential benefits in terms of customer engagement, brand reputation, and legal compliance. Businesses that prioritize accessibility can reach a wider audience and enhance brand reputation while avoiding legal repercussions associated with inaccessible content. Caroline emphasized the importance of involving the disability community in ensuring that alt text and extended descriptions meet diverse needs and preferences.

Discussion

The findings from the survey provide valuable insights into the perceptions and practices of Graphic Arts students going into the industry regarding alt text generation and web accessibility. Several key findings emerged from the analysis, shedding light on the challenges faced by students, their attitudes towards different alt text generation methods, and their awareness of accessibility guidelines. In Figure 3, the data shows that there is a notable variation in the confidence levels of students when it comes to generating alt text manually. While a significant proportion (50%) expressed a lack of confidence, the majority (41.7%) reported a higher level of confidence in their ability. This suggests a need for further training or support in alt text creation among students to ensure consistent and effective practices. Figure 4 reveals that the majority of respondents (58.3%) are currently writing alt text manually, indicating a preference for hands-on approaches to accessibility. However, it is concerning that a quarter of respondents (25%) are not consistent in creating alt text for their digital

assets, highlighting a potential gap in awareness or commitment to accessibility standards. The most common challenge reported by respondents was describing complex visuals. This highlights the difficulty in conveying nuanced information through alt text.

Additionally, in Figure 5 issues such as a lack of guidelines, time constraints, and ensuring inclusivity and accessibility were also identified as significant challenges. These findings underscore the need for comprehensive training and resources to address the diverse challenges faced by students in alt text creation. The responses in Figure 6 indicate a divided opinion among students regarding the effectiveness of generative AI for alt text generation. While a considerable portion found it more or equally effective compared to manual creation, some respondents viewed it as less effective. This suggests a need for further research and development to enhance the accuracy and reliability of AI-driven features. Feeding guidelines and improving the data would bring more confidence within people to use AI in generating alt text for digital assets. In Figure 7, when asked about the awareness of the WCAG guidelines, the majority of respondents (58.3%) are aware of these guidelines for web accessibility. However, the fact that 41.7% of students are either unaware or have never used these guidelines highlights the importance of increasing education and awareness around accessibility standards within graphic arts programs.

The findings in Figure 8 reveal a lack of awareness amongst students regarding alternative methods or technologies for generating alt text automatically. This suggests a potential gap in knowledge and training in emerging accessibility tools and solutions within the graphic arts curriculum. However, Figure 9 shows a high percentage of students willing to incorporate generative AI technologies into their workflows, projects, and personal use, highlighting the potential for AI-driven solutions to support alt text creation in the future. However, such technologies must be developed and implemented ethically and in accordance with accessibility standards. The responses in Figure 10 suggest that students envision a combination of manual and automated approaches to alt text creation in the future. This reflects a recognition of the value of human input in ensuring accuracy and relevance while also leveraging technology to streamline the process.

The responses provided in Table 4 offer valuable insights into students' current practices and perceptions regarding alt text incorporation and evaluation. These findings can inform curriculum development and training initiatives to better prepare students for creating accessible digital content. Tables 5 & 6 show us that alt text is subjective and thus as seen above each respondent had different answers and they were divided in choosing which one was created by generative AI.

No guideline would specify which alt text is better. Due to this, in Table 6 we see some respondents found alt text #1 easier to understand whereas some found alt text #2 easier to understand. Five respondents answered Alt text #1 as being

the one that was generated by AI whereas the remaining students voted for Alt text #2. It was also noticed that the option that was chosen to be generated by AI we usually deemed as the one that was easier to understand. This shows that the respondents believe that AI would generate an alt text that would describe the image perfectly.

The interview findings highlight the critical role of alt text and extended descriptions in promoting inclusivity and accessibility in digital content. Caroline's insights align with existing literature reinforcing the importance of meaningful alt text in ensuring equitable access for individuals with disabilities. As Caroline pointed out, "Businesses that prioritise accessibility can reach a wider audience and enhance brand reputation." However, she also noted that "existing systems often lack support for managing alt text for large media galleries," highlighting the challenges faced by organizations in implementing accessible writing practices.

According to Caroline, "Image descriptions are a critical part of building inclusive online environments. Many people who use assistive technologies like screen readers rely on text alternatives (alt text and extended descriptions) as their primary form of accessing non-text content". She emphasized that alt text must be meaningful, contextual, and aligned with WCAG guidelines, as it serves as the primary means for users to access non-text content.

Caroline also discussed the current challenges faced by businesses in ensuring accessibility, both in terms of content creation and workflow processes. She highlighted that "Many organizations struggle with incorporating accessible writing into content creation workflows, and existing systems often lack support for managing alt text for large media galleries". Despite advancements in generative AI, Caroline stressed the importance of human involvement in alt text creation, as AI-generated descriptions still exhibit inaccuracies and incompleteness.

In terms of the impact of accessible digital content on businesses, Caroline highlighted the potential benefits in terms of customer engagement, brand reputation, and legal compliance. According to her, "Businesses that prioritise accessibility can reach a wider audience and enhance brand reputation, while avoiding legal repercussions associated with inaccessible content". She highlighted the importance of involving the disability community in ensuring that alt text and extended descriptions meet diverse needs and preferences.

Furthermore, Caroline noted the limitations of relying solely on generative AI for alt text generation, stating that "AI-generated descriptions still exhibit inaccuracies and incompleteness." She stressed the importance of human involvement in alt text creation, highlighting that "human-generated descriptions offer better quality and accuracy, particularly for complex images." Overall, the interview findings highlight the importance of a holistic approach to accessibility, involving both technology and human expertise. Businesses can enhance their digital accessibility efforts by prioritising inclusive content creation practices

and leveraging both human and AI-driven solutions to ensure equitable access for all users.

In summary, the survey results retrieved from the Graphic Arts students, highlight the need for ongoing education, training, and support in alt text creation and web accessibility within graphic arts programs. As many are not aware of what alt text is and how they are supposed to generate it, their answers reflect their level of understanding in this area and the lack of use thereof. Additionally, the valuable insights provided by Caroline Desrosiers give us more reasonings as to why incorporating AI would be the right step towards promoting inclusivity and accessibility in digital content. By addressing the challenges identified and leveraging emerging technologies responsibly, educators and practitioners can work towards creating a more inclusive digital landscape for all users.

Conclusion

In conclusion, this research has shed light upon the effectiveness of generative AI compared to manual creation in generating alt text, a crucial component of web accessibility. Through a mixed-methods approach involving surveys and interviews, valuable insights have been obtained from Graphic Arts students and industry experts like Caroline Desrosiers.

The survey results revealed varying confidence levels among students in generating alt text manually, with a significant portion expressing challenges in describing complex visuals. While there is a growing awareness of accessibility guidelines such as WCAG among students, there remains a gap in knowledge regarding alternative methods or technologies for automated alt text generation. However, there is a willingness among students to incorporate generative AI technologies into their workflows, highlighting the potential for AI-driven solutions in the future of alt text creation.

On the other hand, insights from the interview with Caroline Desrosiers from Scribely emphasized the critical role of alt text and extended descriptions in promoting inclusivity and accessibility in digital content. Despite advancements in generative AI, Caroline stressed the importance of human involvement in alt text creation due to the limitations of AI-generated descriptions in accuracy and completeness, especially for complex images. Moreover, businesses that prioritize accessibility can benefit from enhanced customer engagement, brand reputation, and legal compliance.

In light of these findings, it is evident that a balanced approach integrating both human expertise and AI-driven solutions is necessary to ensure effective alt text generation and overall web accessibility. Moving forward, it is recommended to continue educating and training students and professionals in alt text creation and web accessibility, leveraging emerging technologies responsibly. Additionally, further research and development are needed to enhance the accuracy and reliability of AI-driven alt text generation tools, addressing current limitations

and ensuring alignment with accessibility standards. Recent developments in generative AI methods, such as Generative Adversarial Networks (GANs), have enabled the creation of convincingly human-like results based on vast datasets. These advancements democratize access to powerful models, allowing more people to harness their creative potential.

This research contributes to the understanding of alt text generation and web accessibility, highlighting the importance of inclusivity in digital content creation. By prioritising accessibility efforts and embracing technological advancements responsibly, we can work towards creating a more inclusive digital landscape for individuals with Disabilities, ultimately advancing towards an equitable online experience for all users.

Appendix A

Raw Data for Survey Questions

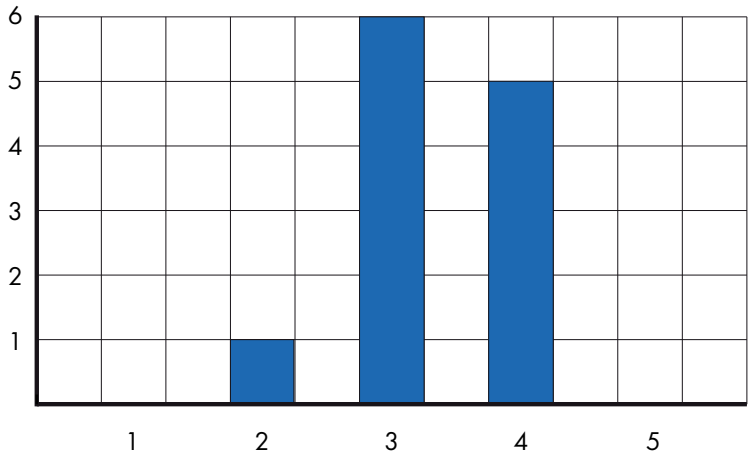


Figure A1. On a scale of 1 to 5, how confident are you in your ability to create effective alternative (alt) text?

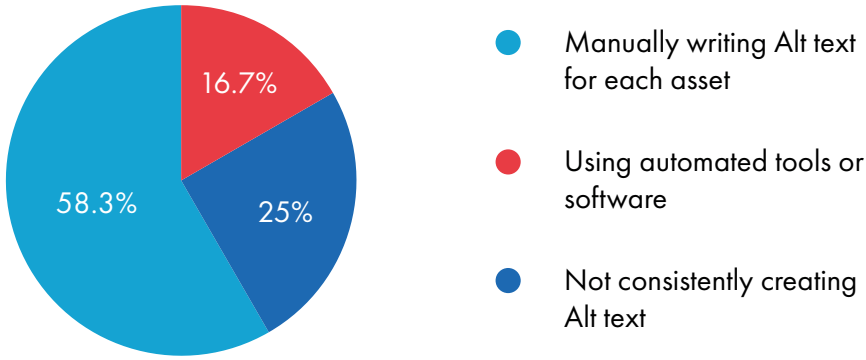


Figure A2. How do you currently approach creating alternative (alt) text for digital assets?

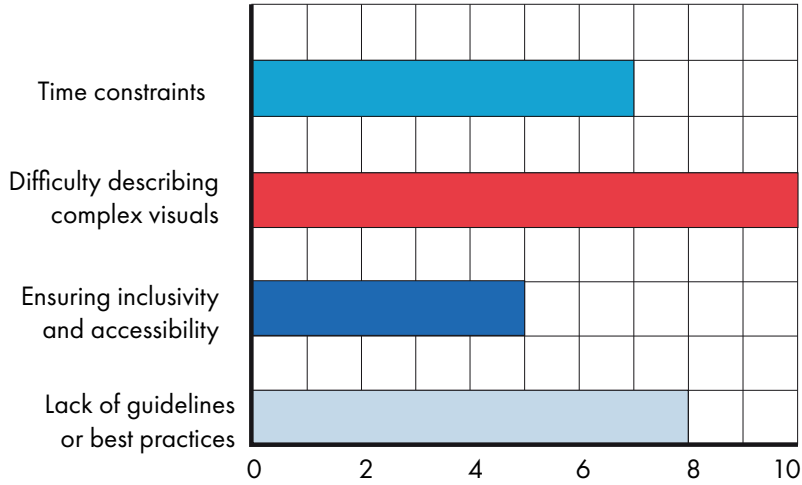


Figure A3. What challenges, if any, do you face when creating alt text?

Table A1. Do you currently incorporate alternative (alt) text descriptions for images and other multimedia content when posting on social media? If yes, how frequently?

No.
Not on my personal social media but for business instagrams.
No.
I don't.
Yes, I try to do it all the time if the caption isn't self-evident what's in the image.
I've only had experience adding alt text for assignments a couple times, but would like to beyond that.
I do sometimes if the imagery is a vital piece in my work and if there is a lot of wording then I added in alt text but otherwise not really.
I currently do not.

Table A2. Do you think there is a need for more awareness and education among social media professionals regarding the importance of accessibility in digital content creation?

Yes.
Yes, because not many people attempt to add alt text unless it is required.
Yes.
Yes, but also overall: images anywhere online have a tendency to break, and it makes so much difference having alt text instead of just a missing image icon.
Yes, I think it is considered like an afterthought but it really should be integrated directly into the design process.
Yes I do as it can help out individuals that need that information.
Yes.

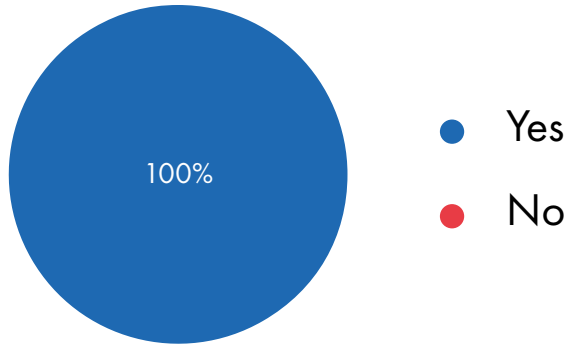


Figure A4. Would you be interested in tools or resources that automate the generation of alt text and other accessibility features for digital assets shared on social media?

Table A3. Alt text: "A woman in a yellow blazer holds a makeup brush, apparently preparing to apply makeup, as she looks toward a mirror". Based on this Alt Text you see above what do you like about the alt text provided for the image? Do you think it needs any improvements? If so, what would you recommend?

Note. Photo Courtesy of Mart Production (Pexels). In reference to Figure 1.

Add description of race and colour of makeup.
I like that it describes a scene rather than objects. It is more difficult to construct an image from object than it is describing a scene (e.g. script writing) but I would say that a bit more details would be nice.
The wording is weird.
I would say that the alt text provided gives a story about the picture which is good but, I would simplify it further by saying "A woman in a yellow blazer holds a makeup brush while looking at a mirror"
My biggest grievance is the "apparently preparing to apply"- the uncertainty on what is happening is confusing, and the makeup is definitely mostly applies at this point, so it's not a completely accurate description. She's going to apply additional makeup, not starting from a fresh face which is what I would interpret the above as.
Maybe also describing what ethnicity she is or what the background is or other objects on the table.
It does a pretty good job, but the word 'apparently' is a bit ambiguous which could be confusing as to what she is actually doing in the image.
I think the text could be more descriptive and provide directions of where she looking.
I would say the alt text could mention she is in the middle of doing her makeup and would also be good to specify the shade of yellow she is wearing. Also that she is holding the brush with her right hand while her left hand is on her lap.
I like how descriptive and easily you worded it and it didn't get to spefic and losing the bigger picture.
I think this is a good alt text.
Adding her race, colour of hair, adding that their are buttons on her blazer.

Table A4. Which one do you think is generated by generative AI? Which one do you think is easier to understand as a consumer?
Note. Photo Courtesy of Karolina Grabowska (Pexels). In reference to Figure 2

Alt Text #1: A red pomegranate on a white plate on a white background.	Alt Text #2: A ripe pomegranate resting on a pristine white plate.
I think alt text 2 is AIgenerated. Alt text 1 is easier to understand.	
Two is generated by AI. I also think that two is better if only that it sets an expectation for a product which makes it more convincing.	
I think #2 is created by AI, and number 1 is easier to understand.	
It feels that Text #1 is generated by AI versus Text #2 which has very descriptive words that are used to describe the objects in the picture. I believe Text #1 is better as it tells people how it looks like versus Text #2 people may have different definitions of the words "ripe" and "pristine". Keeping it simple helps one to understand what the image could be and makes it relevant.	
My guess is the first alt text is the AI one, because of the amount of detail. The second one is better to understand, because the focus is on the (assumed) product and gives detail more applicable to whether the pomegranate is desirable (red probably has less meaning than ripe to someone unable to see the colours).	
The first text is easier to understand, I would assume this one is AI generated.	
The first option is easier to understand as it describes exactly what is in the image in basic terms. The second option is too descriptive which leaves room for the image to be interpreted in different ways. I think AI was used to create the first option.	
Text 2 seems to be generated by AI and give a descriptive text of the image. However, text 1 provides more details (such as the background colour).	
I think the second one is generated by generative AI as usually generative AI used descriptive words such as "ripe" and "pristine". I think the first one is easier to understand as it clearly describes the colour of the pomegranate and also mentions the background colour.	
Again I like how you described it but I think I would have added the detail of the black ring around the plate to give a differentiating quality to make it easier to visualize	
Alt Text #1: Easier to understand, Alt Text #2: Generated by AI.	

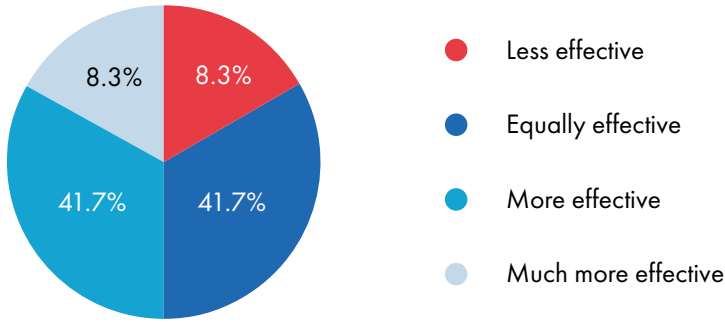


Figure A5. How do you perceive the effectiveness of Generative AI in generating alternative (alt) text compared to humans creating alt text manually?

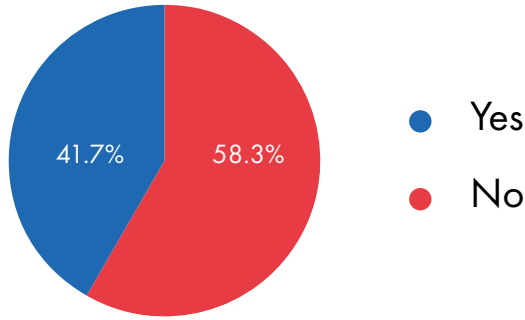


Figure A6. Have you ever heard/used the WCAG guidelines to your design practices?

Table A5. Do you believe that adherence to WCAG guidelines positively impacts the overall user experience of digital assets? If yes, please explain why.

Yes, because it standardizes the experience.
Yes, provides guidelines.
Yes, because the guidelines help us to create an experience that is inclusive and easy to follow. These guidelines also help us to be aware of how our design decisions impact our end-users.
Yes! Usually anything with better organization and flexible use increases the chance that a person can find their way around (like having two separate ways to get back to the home menu) and get meaning.
Yes because it seems to have a lot of topics regarding how to make things more accessible.
Yes, it creates a standard/baseline which will create consistency in alt text descriptions.
Yes, it provides a starting point for designers/developers to create an inclusive design experience.
I think WCAG guidelines definitely have a positive impact on the overall user experience of digital assets as they not only make the assets easier to understand for users, but also make them more accessible for them.

Table A6. Do you think it is important to know WCAG guidelines for web accessibility in the current market? If so, why?

Yes, because of standardization.
I guess, makes it easier to make alternate text.
Yes. Due to the pandemic, majority of the businesses had to transform their in-person services onto an online platform. In order for today's market to retain their customers it is important for them to also incorporate WCAG guidelines so their content stays inclusive and the business stays relevant.
Yes! Even if it's just colour contrast, it helps people to use the website, and with less friction of use, the more likely someone has a positive experience. WCAG is a standard to aim for, rather than making it up as a website is developed.
Yes any kind of resources would help the market.
Yes, accessibility is always important but web accessibility is still evolving which leaves more room for mistakes or confusion - standards are always helpful.
Yes, because a lot of people are in the digital space and so it's important to create an inclusive experience.

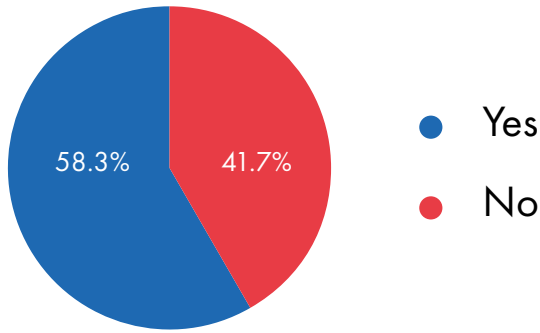


Figure A7. Are you familiar with alternative methods or technologies for generating alt text automatically?

Table A7. What challenges, if any, do you face when creating or encountering digital content with alternative text descriptions?

Time consumption.
The alt text can sound weird sometimes.
Sometimes its hard to keep the alt text short and concise while also giving all the relevant information about the image.
The main challenge is the time it takes to write it out and figure out what might be most important in an image, especially with a lot going on in it.
Describing them accurately in a way that is easy to understand.
I don't have much experience.
Being descriptive enough to paint a picture in the user's head.
A challenge that I encounter when creating digital content with alt text descriptions is not being able to properly describe the complex details, textures etc of certain images.
Agian, I don't use it much but I think would be is that is that it's not talked about enough.
Accuracy and relevance of the descriptions.
Never had challenges.

Table A8. How important do you think it is for social media platforms to prioritise accessibility features like alt text descriptions?

Very important.
It's important.
I think prioritizing this feature would make a big difference as our social media posts would reach a larger audience. This creates a sense of community which is inclusive and welcoming.
Very! It'll bring accessibility to the front of everyone's minds and close the gap of social media like instagram being very picture-based.
I think pretty important, especially for people who need it.
I think it is very important as accessibility features can help to make the overall experience smoother for everybody, even those without disabilities.
I would give it an 8 out 10 in terms of importance.
I think it is very important for social media platforms to prioritize accessibility features like alt text descriptions as it would make the space accessible for users with certain disabilities who deserve to have the same experience as other users on the platform.
I think its very important to include everyone and this is one they can and should.
I think it is extremely important.
It is important to ensure inclusivity for everyone.

Table A9. Have you ever used Generative AI to generate Alt Text? If yes, what are they and have you used them for your digital assets?

No.	N/A
I have not.	I have used it but not on digital assets.
No.	I have not.
I have not.	Never did.

Table A10. How do you think technology, such as Generative AI, could improve the accessibility of digital content for individuals with disabilities?

It allows for technology to automate accessible content.
People can understand the picture through reading alt text.
I think generative AI would make it easier to create alt text as it would provide concise and relevant description for the image that is helpful and usable for the end-users. However, its important that the information fed into the Generative AI system produces alt text that is understandable and unbiased.
For people who are too lazy to make alt text but have an audience with low vision sprinkled in, AI could help caption the images with the person who posted it not needing to lift a finger.
It could improve by describing things accurately but easy to understand.
I think so as it could generate descriptions much faster and more standardized than manually, where there is room for human error.
It would be more efficient resulting in more designers using generative AI in their designs/platforms.
I think it could improve the accessibility of digital content for individual with disabilities as Generative AI can be used to generate alt text for the images that the users come across online. It would be a great idea to create an extension that individuals can use which would automatically create alt text for images on a particular website.
I think it can act as an aid and make lives more easier for them.
It can enhance accessibility by automatically generating image descriptions, improving screen reader experiences, creating adaptive interfaces, etc.
Generative AI can improve accessibility by automating tasks like generating alt text for images and creating captions for videos instantly.

Table A11. Have you ever created alt text for a social media post? What were the key advantages and disadvantages you have encountered?

No.
It was wordy and still didnt feel enough info was added.
I have never created alt text for social media posts unfortunately however, I have created alt text for blog posts that hold images.
The advantages I have seen from creating alt text is that if for some reason the browser is unable to load the images I have uploaded, the alt text provides a perfect description of what was to be expected in my blog post.
Some of the disadvantages that I have come across is when I am unable to find the right words to describe an image. Also making sure that it does not become too wordy and confusing for the end-user to understand my image.
Finding the instagram alt text is not easy unless it's being looked for, though having a preview of the image while typing alt text is helpful to refer between the two. It takes time and effort which, when I know my audience all have full sight, becomes just practice.
I only did it once for a class, advantage for people who need it and disadvantage it is somewhat time consuming.
I have only a couple times. One main disadvantage was how it was difficult to locate the feature to add in alt text. It should be more visible so more people can access it.
Yes, the advantage is that it had a greater impact on people (larger audience reached) and the disadvantage would be that it took a significant chunk of time to generate the alt text.
I have not.
Never did.

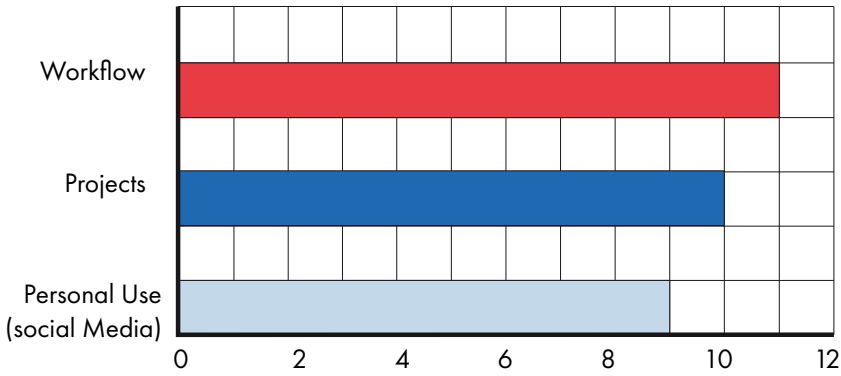


Figure A8. Would you be willing to incorporate generative ai technology for alt text generation?

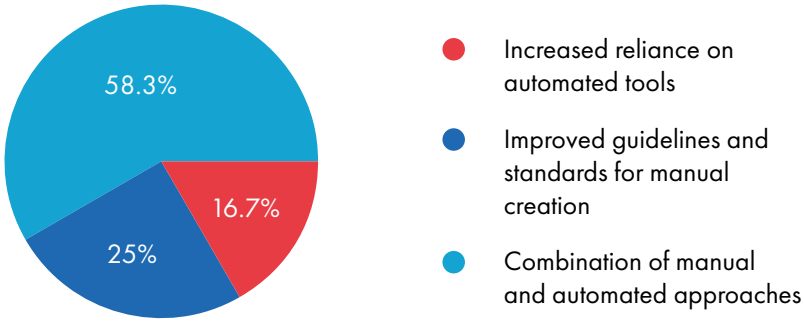


Figure A9. How do envision the future of alt text creation in digital design and development?

Appendix B:

Interview Transcript of Caroline Desrosiers from Scribelyt

1. How do you perceive the role of alt text and extended descriptions in promoting inclusivity and accessibility in digital content?

Image descriptions are a critical part of building inclusive online environments. Many people who use assistive technologies like screen readers rely on text alternatives (alt text and extended descriptions) as their primary form of non-text content. Without image descriptions, screen readers skip over images on the page as if they don't exist. It's also important that image descriptions are GOOD! It's not okay to put just anything in the <alt> attribute. Alt text must be meaningful and contextual. Per WCAG Success Criterion 1.1 (Non-Text Content), "All non-text content that is presented to the user has a text alternative that serves the equivalent purpose" (w3.org). That means, if an image is complex and cannot be described in a brief alt text description, it's necessary to provide an extended description that continues the information provided in the alt text. Image descriptions are a Level A requirement which means they are required to reach all levels of WCAG conformance.

2. Can you share insights into the current challenges faced by businesses in ensuring accessibility for individuals with disabilities, particularly in terms of providing alt text and audio descriptions for digital assets?

When it comes to alt text and audio descriptions, businesses are faced with challenges with both content (creation/writing) and workflows (systems/processes). With regards to content, many people working within organizations don't feel qualified or have the time to tackle technical accessibility writing among other responsibilities. With regards to workflows, many organizations are still lacking the processes and procedures for incorporating accessible writing into content creation workflows. This work is often saved until the very end of the publishing process when it is the furthest away from the original creators. Organizations also struggle with the systems they are currently using to manage media/content. A lot of these systems are not set up to empower content creators to manage alt text for large media galleries. And even if they do have a place to enter alt text, they often don't support extended descriptions or multiple versions of alt text for different contexts (social media, article) and languages.

3. Have you personally utilized or implemented generative AI tools or solutions for alt text generation in your digital content creation processes? In your experience, how effective is manual creation of alt text and extended descriptions compared to utilising generative AI for generating these accessibility features?

While generative AI is improving, it is still producing inaccurate and/or incomplete image descriptions more than half the time and struggling to describe images and videos in context. Text alternatives must be accurate and

informative – and they definitely can't be wrong! AI is not an adequate excuse for creating digital accessibility barriers. We need to keep humans in the loop and create human-triggered workflows as long as we are still finding any errors with generative AI. Human-generated descriptions have their own challenges. Writers can experience burnout describing too many images in one session. Humans also come with their own biases. Having said that, I think specialized alt text writers who have knowledge and experience will always produce a better quality description because they are tackling a lot of complex intellectual tasks at once: analyzing images in context, thinking about the most relevant information to include, getting specific about people, places, objects when relevant, navigating logical pathways through images, making the tough decisions on when to use interpretation to convey information. These are complex tasks that are better suited to humans right now.

4. What are some key considerations or criteria Scribely uses when crafting alt text and extended descriptions to ensure compliance with WCAG guidelines and to provide an inclusive digital experience?

Generally speaking, we put ourselves in the position of the user. How would we quickly and efficiently convey the purpose and meaning of the image to a friend? What do you want that friend to know so they understand what makes that image unique, distinctive, or meaningful? We have a six-step process that we use. The first three steps involve pre-work that happens before a writer begins to write a description. These steps include: analyze the context (stop, look, and think about info surrounding the image), identify the purpose for the audience, and decode the message to the audience. The next three steps involve writing the description: identify the image (map, diagram, painting), describe the focus, and include relevant details.

5. How do you envision the future of alt text generation and accessibility solutions evolving with advancements in generative AI technology?

We may be able to use gen AI to take a first pass, but humans should remain in the loop as long as we are finding errors. People shouldn't question or distrust the information contained in alt text. That defeats the purpose of providing alt text in the first place. Humans play an extremely important role in verifying accuracy of information and making sure the information contained in images in inclusive for everyone. Having said that, I do see the benefit of creating "user tools" powered by gen AI. It should be up to assistive technology users whether they want to deploy gen AI to provide more information about images. And they can explore more about images if they are starting with great alt text provided by the organization/individual who published the content.

6. Can you elaborate on the impact of accessible digital content on businesses, particularly in terms of customer engagement, brand reputation, and legal compliance?

Businesses that are not prioritising accessibility are missing the opportunity to reach a wider audience with a lot of buying power. Accessibility can either help or hurt brand reputation. Socially-conscious consumers want to support businesses who are taking action and following through on DEIA promises. Alternatively, when these consumers hear about a digital accessibility lawsuit, that violates trust and send them to a more socially responsible competitor. It's not only people with disabilities but also their network of family and friends. This market represents $13T in annual disposable income. When it comes to legal compliance, it's a lot less expensive to fix accessibility than pay legal fees! With digital accessibility lawsuits continuing to rise, it's reckless for businesses to continue to create content without a plan for making that content accessible.

7. How does Scribely ensure that the alt text and extended descriptions it provides align with the diverse needs and preferences of individuals with disabilities?

We work directly with the disability community and assistive technology users to get feedback on our methods and practices for describing images. Scribely's founder contributes to the W3C Silver Alt Text Subgroup responsible for writing the standards for alt text. She is also currently involved in a collaborative research project with a university to measure the quality of human vs. genAI-generated alt text.

8. What role do you believe generative AI can play in scaling accessibility solutions and addressing the growing demand for alt text and audio descriptions in digital content?

I think it may be helpful to use gen AI to give alt text writers a strong first pass. If and when we can determine that the error rate for gen AI is extremely low, based on defined quality standards for alt text (we don't even have these yet!), then can we consider moving away from moderated gen AI descriptions. Because we don't even have quality standards for alt text, it's reckless to even consider leaving humans out of the loop. The downsides are unacceptable – screen reader users must have equal participation and access to information online... for their education, careers, entertainment, and general experience of daily only culture.

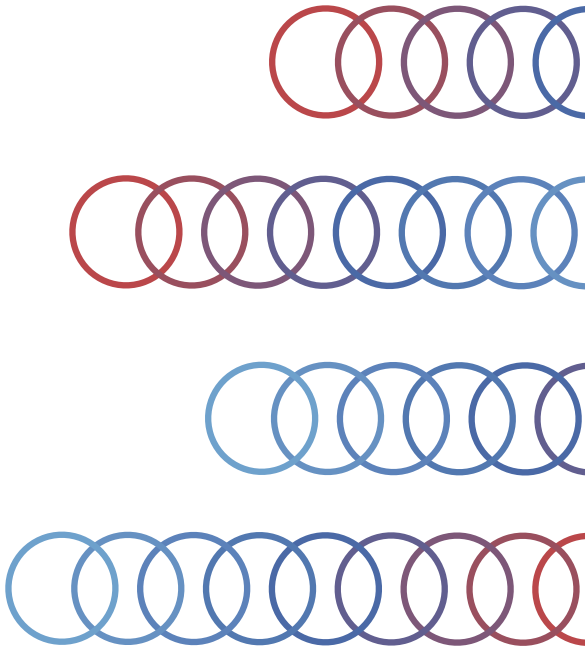
9. In your view, what are the potential limitations or drawbacks of relying on generative AI for alt text generation, and how can these be addressed or mitigated?

I have concerns beyond limitations and drawbacks. We simply cannot have access barriers to information. That creates inequities in our society that have persisted for far too long. Just like we have ramps to buildings, we need ramps to websites. And it doesn't help if those ramps are built fast, cheap, and unreliable. We have construction standards for safety reasons – same deal with accessibility standards. Image descriptions are a MINIMUM accessibility requirement for all levels of standard compliance. Upholding accessibility barriers and not budgeting

for proper ways to fix them is ableist. We have accommodations for non-disabled people everywhere. We turn the lights on in classrooms so sighted people can see the chalkboard. We have volume controls in conference rooms so the people in the back can hear a video that's playing. Image descriptions are just another form of accommodation for people to access information.

10. How do you ensure that alt text generated by generative AI aligns with accessibility standards such as WCAG guidelines and effectively communicates the content of digital assets?

Long story short, it's too early to answer this question. We need more data on this topic. We don't have defined quality standards for image descriptions, so we can't build generative AI descriptions that meet those standards. More work needs to be done by standards bodies like the W3C and research organizations, involving assistive technology users every step of the way.



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03

AN ANALYSIS OF SUSTAINABILITY AND SUSTAINABLE MATERIAL OPTIONS FOR 3D PRINTED PROTOTYPES

Jasmine Dawdy

Jasmine may be the type of person to have a dozen different hobbies on the go at any given time, but 3D printing has really kept her interest over the years. A highlight of her university experience was attending a summer course on 3D Printing and Modelling at Artevelde University of Applied Sciences in Ghent, Belgium. Her strong interest in technology and passion for learning ensures she is always up to date with the latest gadgets and tech trends.

To listen to Jasmine's thesis, use this link:

3

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Abstract:

When considering how temporary each iteration of a prototype is, its end-of-life phase should be evaluated just as thoroughly as the prototype itself. So, as more companies prioritize sustainability, can 3D printing be viewed as a practical technology for prototyping when considering the plastic waste it produces? 3D printer plastic waste and 3D printing's use in prototyping have already had their share of academic research done about them, but the gap where these topics overlap lacks content. After looking at alternative prototyping methods, 3D printers were a very strong prototyping method because of their accuracy, material efficiency, and ability to create unique one-of-a-kind forms. The material used for 3D printing was evaluated next, and while it was found that the most common material, PLA, was a big contributor to plastic waste, it was recyclable Prototypes using 3D printing as their fabrication method are likely not concerned about accurate colour, material finish or strength, and if that was needed, it would be recommended to use the materials or fabrication method of the final product. What really matters on 3D printed prototypes is their dimensional accuracy and ability to create forms as intended. To test the viability of using recycled PLA instead of virgin, both materials were acquired, used to print the same test model, and evaluated on their outcome. Visually both prints had similar results on the official tests done, but the differences began to show when the prints were measured, looked at in detail, and handled. The virgin PLA printed closer to the intended dimensions, with both prints being within a millimetre of the expected results, plus they had cleaner text detailing and were more durable than the recycled PLA print. This study finds that 3D printing can be considered a great prototyping method for companies looking to increase their sustainable practices, as long as they ensure recycled materials are used when possible and virgin materials used are properly disposed of.

Introduction

A paradox is arising in 2024 as companies who stay up to date on the latest trends and technologies are the ones investing in sustainable practices, but also the most likely to consider using technology which produces plastic waste such as 3D printing. As more companies prioritize sustainability, can 3D printing be viewed as a practical technology for prototyping when considering the plastic waste it produces? This study will not focus on the use of 3D printing in any specific industry, but will centre around its use in prototyping as the iterative nature of prototypes leaves these plastic products destined for disposal after a very short lifespan.

3D printing is also known as additive manufacturing, as pieces are formed by adding layer on top of layer to create a final product. It differs from traditional subtractive manufacturing's milling or carving process to take away material from a larger mass to achieve a final shape (Savini, 2015). There are many different processes classified under the term "3D printing", but this study will focus on Fused Deposition Modeling(FDM), which is the most common process currently used in prototyping (Apaçoğlu-Turan et al., 2024). In the early 2000s, 3D printers were almost exclusively used for prototyping by large companies (Savini, 2015), but as the technology has grown in popularity and become accessible to small businesses, students, and hobbyists, the material waste associated with it has also increased dramatically. To explain the FDM process simply, plastic filaments are fed into a heated nozzle that moves as it extrudes the material, carefully building a 3D shape layer by layer as the plastic solidifies, following a digital file that acts as a blueprint for the final product (Apaçoğlu-Turan et al., 2024). Other methods of plastic fabrication that are still classified as 3D printing include resin printing in the form of stereolithography (SLA) or digital light processing (DLP), which hardens each layer in resin with UV light, and selective laser sintering (SLS) where each layer is formed with a laser and material in the form of powder (Schwaar, 2024).

This study will first review literature that explores why 3D printing has grown as a prototyping method,its benefits compared to other fabrication methods, and alternative processes and materials that could be used in prototyping. Next, a comprehensive review of the literature identifies how relevant the available sources are to this specific topic, as well as how forums, blogs and the general internet are filling in gaps in academic studies. Focusing on two polylactic acid materials, tests were chosen to compare virgin material to recycled material, evaluating a potential solution to reducing plastic waste. Finally, the results of these tests were compared based on the factors tolerance, detail, overhangs, bridging, durability, and dimensional accuracy to determine if the recycled material could be a replacement for virgin material with its current characteristics. This study aims to be a resource for companies who are interested in reducing their plastic waste, but still find value in 3D printing as a technology for creating their prototypes, as well as companies who may have resisted purchasing

3D printing equipment in the past and are still looking to learn more about the emerging technology and the least wasteful way to use it before they begin their investments.

Glossary:

ABS - Acrylonitrile-Butadiene-Styrene. A common thermoplastic used in 3D printing made from petroleum. Known for having high heat resistance and durability properties at its affordable price point.

Additive Manufacturing - Another term for 3D printing. A 3D form is built up as material is deposited layer by layer by an automated machine.

CAD - Computer Aided/Assisted Design. Software used to assist a designer in their work. Common CAD software used in 3D modelling is used to create a digital version of the prototype, which can be tested or shared virtually before physical fabrication.

FDM - Fused Deposition Modeling, sometimes referred to as Fused Filament Fabrication or FFF. The most common 3D printing process used in prototyping currently. The material is extruded through a nozzle in layers to create complete 3D forms.

Infill - To save time and material, most 3D printed objects are not printed completely solid, but the structure also usually needs interior support. Infill settings determine what percentage of the interior will be filled and what shape the filling will take.

PLA - Polylactic Acid. The most popular thermoplastic used in 3D printing. Known for its low cost, low melting temperature, and ease to work with.

Slicer - A software that connects and translates a 3D model to a printable, layer by layer form and provides instructions to the printer on how to complete the print.

Supports - Removable material added to a piece to support overhanging structures during printing. Additive manufacturing relies on always having a previous layer available to add the new one on.

TPS - Thermoplastic Potato Starch. A compostable bioplastic being tested for its use in 3D printing as an alternative to PLA.

Literature Review

Introduction

While vast research has already been conducted on both the use of 3D printing technology as a prototyping method and on the environmental impacts of 3D printing materials, there is still a large gap in knowledge on how these two topics overlap and affect each other. The first group of researchers optimistically argued that 3D printing technologies are the future of the prototyping industry (Pavlov, 2021) and the second group focused on the reality of microplastics that enter the environment as a result of disposed plastic products (Chiodoni et al., 2020); it is time that the evidence for both sides is compared. There is a final group that is also quickly growing a strong body of research related to these topics, and just might be the answer to finding a compromise for sustainable prototyping with 3D printing technology. This group is looking at the possibility of recycling and reusing common plastic materials used in 3D printing to give them more than a "single-use" life, and also, alternative materials that could be used as a replacement for traditional plastic materials.

This literature review will first look at works that analyse the benefits of using 3D modelling and 3D printing in a company's prototyping process, what makes it unique and why it has been predicted to become so popular in many industries for this application (Formlabs, 2022). Next, it will review the opposing side and what environmental issues have been found with the process, and specifically, the environmental concerns related to the common plastic materials used. After that, literature on other possible prototyping methods will be analysed to compare and contrast prototyping options available to companies other than 3D printing. Finally, it will look into what research has been done on alternative, more sustainable filament materials that can be used with 3D printing technology.

Benefits of 3D Printing as a Prototyping Method

To start off, what are the benefits and advantages of using 3D printing as a prototyping method? If there are concerns surrounding the environmental impact of the technology, then what are the incentives to use it for such a temporary product? These questions are quickly answered by looking at literature covering a process called "rapid prototyping" and literature on how computer aided design, or CAD, modelling is being used to prototype products first virtually, and then easily come to life through the additive manufacturing process that works with the same, already made CAD files (Budinoff & Kramer, 2022). Overall, there are many reasons why companies have recently been investing more to get 3D printing into their product development processes.

Traditionally prototyping has been known to be the bottleneck of the product development process because of the associated high cost and time contribution needed to produce visually or dimensionally accurate designs. It is not uncommon for a prototype that is intended to

look or function as the final design will, to need the same traditional, expensive manufacturing processes as that final part (Formlabs, 2022). With all these complications involved in making an item never seen by the public, it is clear why rapid prototyping methods are growing so quickly in popularity. In fact, the market size for the rapid prototyping industry is expected to grow from a value of $2.76 billion USD in 2023, to $14.78 billion in 2032 (Precedence Research, 2023). One way that 3D printing proves itself as a rapid method of making these prototypes is that the manufacturing, the actual layer by layer construction of the physical piece, can happen overnight and unattended (Formlabs 2022). The product construction can happen outside of working hours, or even in the background as the next version of the design is being created. In addition, the speed benefits of using 3D printing to prototype also allows complex, freestanding shapes to be created easily (Nida et al., 2021). A 2021 study explored the unique ability to enclose other materials into a 3D print while a piece is being fabricated on a printer for seamless integration of multiple materials in one part. A few examples use cases of this concept to reinforce the product's strength with a layer of wire or mesh placed down between layers, encapsulating glass to act as a window in a frame, or adding magnets, near field communication chips or screw nuts seamlessly into a product to add functionality and push the prototype closer to the final product's design (Pavlov, 2021).

A fascinating and impressively committed experiment of 3D printing's capabilities was done by GE Aerospace, who, in 2018, began rethinking their new product development process to centre it around additive manufacturing. The company transitioned from creating its fuel nozzle tip for its LEAP Jet engine with 20 individually cast, forged, and welded pieces, to creating it in additive manufacturing in just one piece (Roscoe et al., 2023). The company realized this manufacturing method produced a piece that weighed 25% less, was 5 times more durable, and 30% more cost-efficient than the original piece and decided to make the commitment to invest enough in their 3D printing operations to start using it for mass production (Kover, 2018). It is commonly known that time is money in any business, so 3D printing supporting rapid prototyping is a huge benefit of the technology (Cole, 2023).

Generally, a 3D print starts as a CAD file that has been produced using a 3D modelling software or through a 3D scan of a real world object (Roscoe et al., 2023), so even before the actual printing of the physical product begins, this manufacturing method has many benefits. One use that has been growing in popularity, especially as remote work becomes more common, is the ability to have digital files that can be shared, collaborated on, and reviewed instantly by an entire team, regardless of the distance between members (Cole, 2023). Furthermore, the ability to simulate tests on a virtual prototype before committing to making a physical piece saves time, money, and resources for a business. This technique was looked at in 2022 in the area of fresh fruit package design and the study came up with some great virtual prototyping tests, including compress

strength and airflow ventilation simulations (Ambaw et al., 2022). As computers become more powerful, the ability to access and perform these complex situations becomes more accessible to businesses of all sizes. Other applications for prototyping with CAD models include virtual or augmented reality testing to visualise a product in use or on display in store and, 3D renders which are excellent tools to allow team members, supervisors or customers to visualise their product and be sold on its design (Budinoff & Kramer, 2022).

Environmental Concerns

Although additive manufacturing produces less material waste than subtractive manufacturing, as the shape is not formed through the reduction of a larger piece of material (Mark Forged, 2022), prototyping is still a very iterative process where each finished product is not intended to last long and becomes a source of waste in manufacturing. While there is much debate on the overall carbon footprint of 3D printing compared to traditional plastic moulding methods, such as injection moulding, this literature review will focus primarily on plastic waste. However, an example of this overall sustainability debate is that while 3D printing is found to use more energy when producing each part, it was also found that 3D printing's shorter supply chain could offset this (Bezzina & Refalo, 2023).

Currently, the most common material used for 3D printing is polylactic acid, or PLA, making up 47.2% of the global filament market (Vidakis et al., 2020). PLA has gained its popularity because it has a relatively low cost, does not release fumes during printing, prints at a low temperature and can easily be sanded and painted for further development of the prototype (TWI, n.d.). PLA is technically labelled as a bioplastic, but a life cycle analysis conducted on the material is quick to point out that most of PLA's sustainability claims are dependent on the user's care to properly dispose of the material after use (Rezvani et al., 2021). PLA is recommended to be sent to specialized composting facilities if the bioplastic is intended to break down. A 2017 study testing PLA's ability to biodegrade at ambient temperatures found no change to the plastic after one year of being out in a seawater environment (TWI, n.d.). As any degradation that happens to the material outside of a specialized facility becomes another source of nanoplastics released into the environment (Chiodoni et al., 2020).

Another commonly used material is Acrylonitrile-Butadiene-Styrene, or ABS, which holds 29.1% of the global filament market (Vidakis et al., 2020). ABS immediately presents itself as the less sustainable filament option as it is made from petroleum, as opposed to PLA's corn or sugarcane starch base (Prior, 2023). ABS is popular as it is similar in price to PLA, but has a higher heat resistance and durability. The possibility of saving ABS from the landfill at its end of life has been explored in a study that tested low density polyethylene/ABS blends and the possibility of improving structural, thermal, mechanical, and gas barrier properties of the final material (Saxena & Maiti, 2021). However, this still requires careful,

specialized disposal of the material by the user to ensure it ends up in the right facility.

Alternative Prototyping Methods

If 3D printing is not an option for a company, there are still other ways to create a prototype. As mentioned earlier, subtractive manufacturing is an alternate process that creates a 3D shape and was a popular method before additive manufacturing entered the market. This technique involved CNC milling, cutting, drilling, and/or carving away material to result in a finished prototype (Laszeray, 2019). Benefits of this method include smoother surface finishes, eliminating the "layer steps" visible on most additive manufactured parts before finishing, a wide variety of materials such as woods, =metals, and plastics whilst not being limited to meltable (often proprietary) thermoplastics like 3D printing is, and the close imitation of tolerances to injection moulded parts, which is often used as a mass production process after the prototyping stage. This process so similarly reflects injection moulding, as a method called 'rapid injection moulding' falls under the subtractive manufacturing category. Injection moulding is already a very quick process, so what classifies this method as "rapid" is the aluminium mould being much faster to manufacture than a steel mould made for durability and reuse (Langnau, 2011). The drawbacks of this process include material waste and the inability to create certain geometries, for example not being able to create a hollow shape with CNC milling (Savini, 2015).

If multiple of the same prototype is being made, casting is a potential alternative method to consider. Perhaps many different tests or repetitions of the same test need to be conducted on a group of prototypes, and a mould made will need to be used more than once. This method provides far more consistency between each piece than what could be produced through a 3D printing method, as a rubber mould is filled with resin to produce identical parts (Laszeray, 2019). However, this method is only justifiable for producing high quantities of prototypes with its high associated time costs.

Alternative Material Options

Perhaps the most obvious material option to turn to with the goal of increasing sustainability is the post-consumer, or recycled version of the already common PLA and ABS materials. The Canadian filament supplier Filaments.ca makes a recycled PLA product out of waste from the manufacturing of their non-recycled filament options. These are available for consumers to buy for the same price as their other standard PLA (Filaments.ca, 2024). To maintain quality in recycled PLA products, only 60-80% of the material can actually be recycled material, with the remaining still composed of virgin plastics (Gil Muñoz et al., 2020). This material is made from different colours in each batch, so not only is it not possible to order a specific colour from this recycling method, but filaments ordered at different times will also vary in appearance (Filaments.ca, 2024).

Alternatively, Filaments.ca also offers a program that accepts and recycles consumer 3D printer waste. Materials accepted include PLA, PETG (Polyethylene terephthalate glycol), and ABS, but these materials must be sorted from each other and not contaminated with any other material in order to be accepted. They offer this service free of charge but note that “The process of recycling plastic from 3D printing scraps is very labour intensive, time consuming, and is significantly more costly than processing virgin material” (Filaments.ca, 2024). The consumer does not get a specific benefit for contributing material other than responsible disposal of their waste. This recycling program stands out, as it has a specific workflow for handling old prototypes. Filaments.ca accepts prototypes of any size that will be discreetly broken down with proof of destruction. This incentivises companies to recycle their old prototypes instead of sending them to a landfill, as it adds an extra security layer which ensures internal designs are not discovered by the public or the company’s competition (Filaments.ca, 2024).

If you stray away from traditional filament materials there are more options, many of which are still in the development stage, but could soon become a viable material alternatives. One example tested in a 2021 study is sugarcane bagasse. This biodegradable material was used for 3D printed package casing for low-moisture foods, as its absorptive properties result in swelling and loss of strength when exposed to moisture over several days. Likely prototypes at the 3D printing stage will not need to actually contain products and would align with the study’s findings that this material would be best used for one time use products like take-out cutlery (Nida et al., 2021). Another interesting material combined PLA with TPS (thermoplastic potato starch) to make a bioplastic with excellent printing capabilities. However, there is an issue with moisture absorption (Haryńska, 2021).

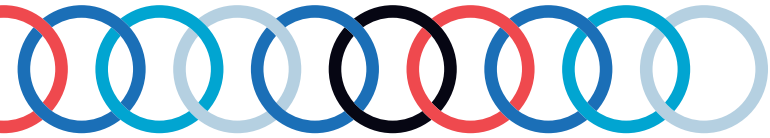
Finally, using other recycled plastics to create filament is a possibility currently being explored. A pre-consumer recycled polypropylene filament showed similar tensile strength values to a typical 3D printer filament, but required a custom retrofitted printer and printing bed due to its lack of adhesion (Stoof & Pickering, 2018). Interestingly, all seven main types of recyclable plastic (polypropylene, polyvinyl chloride, high-and low-density polyethylene, polystyrene, polyethylene terephthalate, and others such as ABS and polycarbonate) technically have been considered for their re-use in filament. The main reason development has not gone beyond just testing the possibility is the loss of strength and stability properties after several recycling cycles, and more prominently, the lack of economic incentives for the use of recycled materials (Mikula et al., 2021).

Conclusions

The literature reviewed collectively points to 3D printing as a strong prototyping method with many benefits as far as time efficiency, low cost, and the convenience of printing off a CAD file. However, the need to reduce plastic waste cannot be overlooked and supposedly compostable PLA is not going to biodegrade unless properly taken in by a specialized facility (TWI, n.d.). 3D printing has excellent material utilization in comparison to a subtractive manufacturing method, even when accounting for failed prints and removable supports (Bezzina, 2023) and does not require a new mould to be made for each prototype iteration as injection moulding or casting would. Overall from a company's point of view, the ease of making a component without a huge investment in tooling makes 3D printing a favourable technology for disposable prototypes, and proves the technology will not be leaving the space anytime soon (Mikula et al., 2021).

So instead of looking for an alternative process of creating prototypes, alternative materials and disposal methods for current 3D printing technologies are likely the best solution. Progress is already being made in materials that are not as durable or long lasting as traditional plastics,, such as the easily biodegradable option sugarcane bagasse or the recycled plastic options. After all, if the material is properly disposed of by a composting facility for PLA or a recycling facility for PLA or ABS, the plastic does not cause as much harm to the environment as it would in a landfill (Chiodoni et al., 2020). If a company is looking to do more 3D printed prototyping, then it is likely in their best interest to become educated on the proper disposal of their old prototypes. This can even get some benefits of this proper disposal, like the destruction of sensitive prototypes.

Currently, recycling plastics into filament is an energy intensive process with little to no economic incentive for companies to use virgin material for their work, unless they are using it as a method to hit corporate sustainability goals. If more research and development is put into making the recycling process of common 3D printed waste cheaper and easier, with more consistent colour and lower ratios of virgin material used in each batch, then this would likely be the best solution for sustainable additive manufacturing prototyping in the future.



Comprehensive Review

Literature Sources

The database websites used to find academic literature for this literature review were Google Scholar and the Toronto Metropolitan University (TMU) Library. These databases came back with many results for topics related to parts of this thesis, but the lack of literature on the overlap between 3D printed prototyping and sustainability is clear.

Searching the TMU Library first for peer-reviewed and scholarly articles using the keyword “3D printing” yields an impressive 66,047 results. When filtered to include only literature published within the last five years (2019 to 2024), the results narrow down to 48,890. To narrow the search down further, more keywords were then added to the search. Searching the database for articles containing both the keywords “3D printing” and “prototyping” from the past 5 years cuts down results to 3,414 options. Finally, adding all three keywords “3D printing”, “prototyping”, and “sustainability” while looking for work from the past 5 years, a manageable 142 results come up. If just the keyword “prototyping” is used to search, the database comes up with 43,693 results, and with just the keyword “sustainability” 1,339,834 articles appear.

If the same keywords are run through Google Scholar, with its much larger database, the results for each topic are nothing but overwhelming. A search for “3D printing” returned about 2,780,000 results, “prototyping”, the lowest numbers returned from each database, returned about 1,120,000 results and “sustainability” returned about 4,770,000 results. When the same techniques of using all three keywords and only returning literature from 2019 to the present day are applied, about 16,800 results were returned, greatly cut down from the previous millions of results.

Topic Relevance

Within the results of the used databases, many results were not particularly relevant to this study, covering topics such as 3D printing with concrete in construction, metal in the aircraft industry, or biomedical application of 3D printing. If the search for sources was to be redone, another filter with the keyword “plastic” would be added to narrow down results even further. Focusing on the academic articles that contributed to this study, many can be divided into broader topics as a wide variety of articles from different industries had to come together to complete this literature review to its fullest extent. Table 1 illustrates the general topics of the literature sourced for this review. Each source is put into one or more broad categories based on the topics it covers.

Table 1. Literature Topics Used For This Review.

Topic	Relevant Literature
CAD & Virtual Prototyping	Fresh fruit packaging design verification through virtual prototyping technique, CAD as a Virtual Prototyping Method: Uses and Timing of Computer-Aided Design Artifacts in Hardware Design, A short history of 3D printing, a technological revolution just started.
3D Printed Prototyping	3-D Modelling and prototyping of complex-shaped heterogeneous parts, Transitioning additive manufacturing from rapid prototyping to high-volume production: A case study of complex final products, A short history of 3D printing, a technological revolution just started.
3D Printing	Evaluation of the Circularity of Recycled PLA Filaments for 3D Printers, Transitioning additive manufacturing from rapid prototyping to high-volume production: A case study of complex final products, 3D printed food package casings from sugarcane bagasse: a waste valorization study, A short history of 3D printing, a technological revolution just started.
FDM Printing	Numerical Modeling and Analysis of Transient and Three-Dimensional Heat Transfer in 3D Printing via Fused-Deposition Modeling (FDM), Sustainable composite fused deposition modelling filament using recycled pre-consumer polypropylene.
FFF Printing	Fused Filament Fabrication and Injection Moulding of Plastic Packaging: An Environmental and Financial Comparative Assessment,PLA–Potato Thermoplastic Starch Filament as a Sustainable Alternative to the Conventional PLA Filament: Processing, Characterization, and FFF 3D Printing.
Plastics & Sustainability	Fused Filament Fabrication and Injection Moulding of Plastic Packaging: An Environmental and Financial ComparativeAssessment, 3D printer waste, a new source of nanoplastic pollutants, 3D printing filament as a second life of waste plastics — A review.
Traditional Plastics	Evaluation of the Circularity of Recycled PLA Filaments for 3D Printers, The Life Cycle Assessment for Polylactic Acid (PLA) to Make It a Low-Carbon Material, Utilization of ABS from plastic waste through single-step reactive extrusion of LDPE/ABS blends of improved properties, Sustainable composite fused deposition modelling filament using recycled pre-consumer polypropylene, Sustainable Additive Manufacturing: Mechanical Response ofAcrylonitrile-Butadiene-Styrene over Multiple Recycling Processes.
Alternative Plastics	3D printed food package casings from sugarcane bagasse: a waste valorization study, PLA–Potato Thermoplastic Starch Filament as a Sustainable Alternative to the Conventional PLA Filament: Processing, Characterization, and FFF 3D Printing.

Since 3D printing is growing in popularity at the consumer level, some of the most relevant sources covering all keywords of this research were found on websites, blogs, and forums. It is understood that these sources are not peer-

reviewed and likely have their own biases or knowledge gaps, however sources used for this article were critically examined for their credibility before their addition to this research. Internet sources came from: 3D printer manufacturers speaking to the capabilities of their different products, companies currently using 3D printing as a prototyping method and reporting how successful they have been and what challenges they have had to overcome, and hobbyists having genuine questions on the quality of different materials or what to do with their own 3D printed waste. While much of the current academic literature covers new, niche, or non-traditional materials and methods, future academic literature is needed in this area that internet sources currently cover, addressing additive manufacturing's use in different industries and in a variety of company sizes, with materials and equipment available to the average business creating prototypes.

Research Methodology

Selected Materials

To investigate the possibility of companies switching to recycled filament materials for their 3D printed prototypes, these next tests will compare and contrast different aspects and characteristics of recycled PLA and virgin PLA materials. Both filaments tested are ordered from Filaments.ca, with the recycled PLA coming from their filament recycling program mentioned earlier. Both the Recycled PLA and the EconoFil™ Standard PLA Filament were ordered as a 1kg spool of 1.75mm thickness. These filaments were both newly ordered at the same time for these tests, as opposed to using filament that was already on hand or had been owned for a while. Purchasing new filament for these tests was done to ensure results were not skewed due to one material having a higher moisture content or more wear and tear from previous use and handling. Both materials have the same 215˚C recommended printing temperature, 55˚C - 60˚C recommended hot bed temperature and price when purchased (Filaments.ca, 2024).

Selected CAD Model

To test many characteristics of each filament in one print, a free downloadable model was found that includes 6 different tests in one print (Figure 1). The "Micro All In One (AIO) 3D Printer Test" was created by Marián Trpkoš in 2018 and has been downloaded from the popular CAD model sharing website Thingiverse.com over 16,000 times. This model is an updated version of an even more popular model made by the same designer. This 5cm x 5cm x 5.6cm "micro size" version was chosen for this research as it included all the same tests, but in a more compact layout reducing the print time for each piece. The tests included in this model and their purposes are shown below (Table 2).

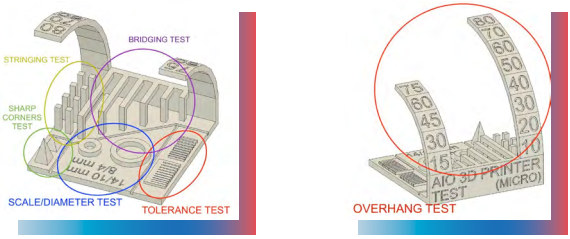


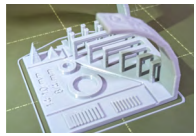
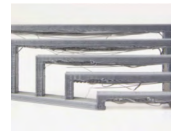
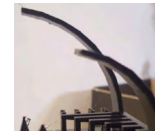
Figure 1. Labelled test areas on the 3D calibration model.

Table 2. Test Names, Purposes, and Examples.

Test Name	Test Purpose
Stringing Test	When the print head moves from one section to another, over an open area, or gap, filament drips from the nozzle causing a stringy connection between pieces (Jennings, 2022). This effect happens if the nozzle is too hot, or the filament is melting below the recommended temperature, or if there is excessive moisture present in the filament (Obudho, 2024).
Sharp Corners Test	A well calibrated 3D printer should have the ability to print sharp corners and not struggle to show fine detail. This test often exposes cheaper filaments from more expensive options as the chemical composition has an impact on the filament's flow and set (Jennings, 2022).
Scale/Diameter Test	This test is generally used to help visualize a printer's abilities with dimensional accuracy. Ideally the circle is symmetrical and round. This test applies more to printer calibration than filament quality.
Tolerance Test	Another test for dimensional accuracy in a print, this one is specifically important when making pieces that fit closely together. When referring to "tolerance" in filament, the term refers to the filament's diameter. In this case filament tolerance can be measured with digital callipers and, based on the purchased filament, should register between 1.73 mm-1.77 mm as the 1.75 mm product claims to have a ±0.02 mm tolerance (Galiki et al., 2023). When the print is finished, the overall print tolerance and dimensional accuracy can be measured with calipers as well.
Bridging Test	Unsuccessful bridging will have filament sagging between two supports on either side when printing over a gap. If filament is melting at a lower temperature than the recommended setting, this can cause unsuccessful bridge tests (Jennings, 2022).
Overhang Test	This test demonstrates the printer and filament's ability to print unsupported offset angles branching out from the base of the print. If the filament material is not cooling quickly enough to harden in place attached to the previous layer, this can cause issues with overhangs. Low quality filaments with a high level of impurities or filaments that have a high moisture content will also struggle to produce clean results in this test (AnyCubic, 2023).

Users on Thingiverse.com can post pictures of how their model printed to share what worked for them, what did not, what settings they used, etc. With over 250 prints shared, these images provide an excellent idea of successful and unsuccessful prints of each test and what to look for when the test is conducted to compare the recycled and virgin filaments for this research (Table 3).

Table 3. Example Prints Shared by Users.

			
Successful	Unsuccessful	Successful	Unsuccessful
Stringing Test (Thorton, 2024 & Fisher, 2020)		**Sharp Corners Test** (Holmes, 2013)	
			
Successful	Unsuccessful	Successful	Unsuccessful
Scale/Diameter Test (Zach_Prints, 2021 & ReadyPlayerThirty, 2020)		**Tolerance Test** (Weldishofer, 2019 & Seegers, 2023)	
			
Successful	Unsuccessful	Successful	Unsuccessful
Bridging Test (Zach_Prints, 2021 & UltiMaker, 2023)		**Overhang Test** (Clayton 2018 & Griffiths, 2021)	

While this test is also useful for troubleshooting printer settings such as an uncalibrated nozzle, over extrusion or issues with belt tension, both prints will be done with the same printer settings, so any printer-related issues found will

appear on both test prints and will not affect the results when comparing the filaments. In the case that a printer setting needs to be tweaked in between prints in order to continue printing, both prints will be restarted so that the filaments were compared as accurately as possible.

This CAD model emphasizes dimensional accuracy in its tests, making it a great choice to use for the testing of different materials for their use in prototyping. If a company is choosing to create a prototype using PLA and additive manufacturing, instead of the final product's materials and manufacturing process, colour, strength, and finish are likely less important to accurately reproduce.

Chosen Settings and Specifications

This test model will be printed on an Ender 3-Pro FDM printer, which is designed and manufactured by Creality (Figure 2). This model is an extremely popular choice for 3D printers at the consumer level, and will be printing with a hardened steel 0.4mm nozzle. The CAD model will be prepared for print using the free-to-download Ultimaker Cura slicer software. This is a recommended software option for the Ender 3-Pro as their functionality and complexity match the same target audience of medium to high level 3D printing hobbyists. The chosen hotbed and nozzle temperature will be kept at the default recommended settings for the two filaments, and will only be changed if there are major issues with printing or adhesion.

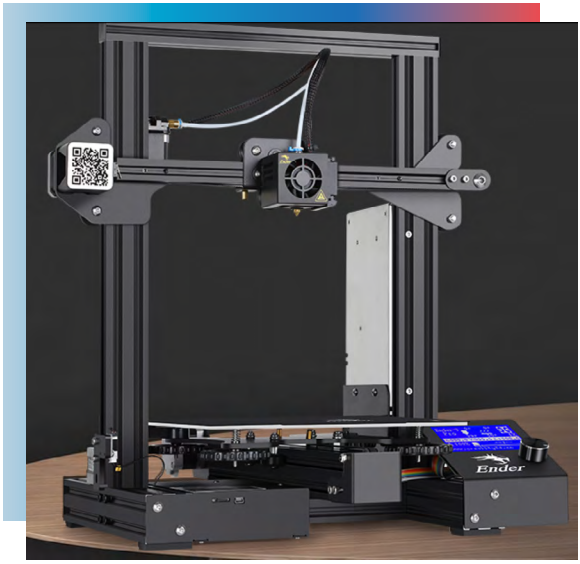


Figure 2. Ender 3-Pro.

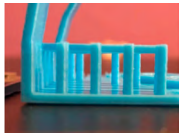
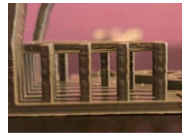
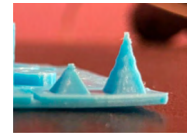
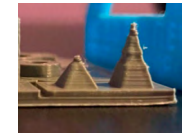
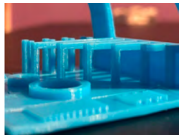
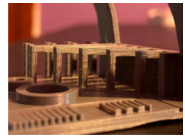
Table 4. Settings and Specifications.

Slicer Settings	
Model Scale:	100%
Quality:	0.16 mm
Infill:	40%
Print Speed:	50 mm/second
Wall Speed:	35 mm/second
Supports:	Off
Adhesion:	On
Estimated Printing Time:	3 hours 13 minutes
Filament Specifications	
Nozzle Temperature:	215C
Bed Temperature:	60C
Diameter:	1.75 mm ± 0.02 mm (Virgin PLA) 1.75 mm ± 0.05 mm (Recycled PLA)

Results

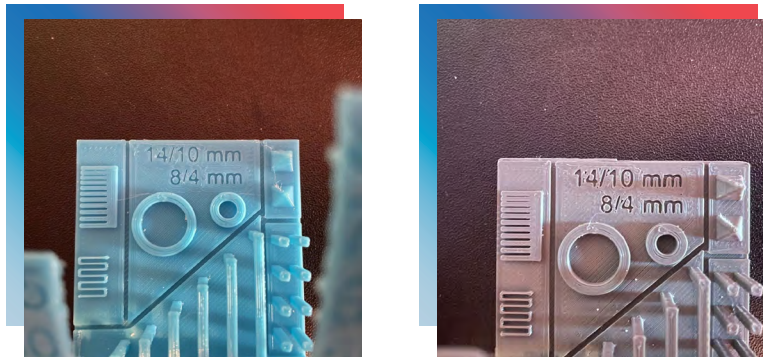
Both prints were printed on the same day, by the same printer with no adjustments to printer settings made in between the prints. The prints were both done in a 19˚C - 20˚C and 36% - 37% humidity environment with the printer running at 100% fan speed.

Table 5. Comparison of the Virgin and Recycled PLA Prints.

 Virgin PLA	 Recycled PLA	 Virgin PLA	 Recycled PLA
Stringing Test		Sharp Corners Test	
 Virgin PLA	 Recycled PLA	 Virgin PLA	 Recycled PLA
Scale/Diameter Test		Tolerance Test	
 Virgin PLA	 Recycled PLA	 Virgin PLA	 Recycled PLA
Bridging Test		Overhang Test	

Tolerance and Detail

Overall, both prints performed well in the tolerance test by recreating very thin lines and gaps without pieces merging together (Table 5). A greater difference in quality can be seen in the text-based tolerance section, which pushes the abilities of the filament past just printing in straight lines (Figure 3). With the added curves, diagonals, and filler space, the virgin PLA has cleaner gaps where the text is defined, as well as having a more solid, filled-in surface for the areas in between.



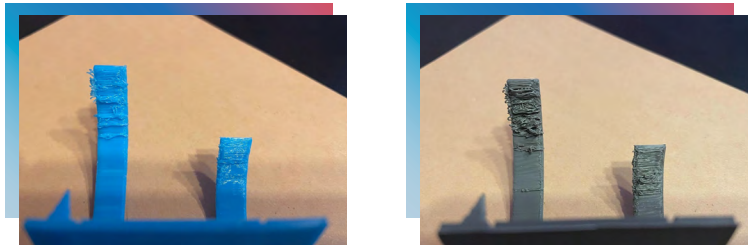
VIRGIN PLA **RECYCLED PLA**

Figure 3. Comparison of the Text-Based Tolerance Tests.

The sharp corners test was another area where the virgin PLA stood out compared to the recycled PLA. The virgin PLA not only has a smoother, more consistent build up to the top point of the pyramid shapes, but also has a cleaner top point itself, with less bulging and stringing (Table 5).

Overhangs, Bridging, and Durability

Both the virgin PLA and recycled PLA prints handled the bridging tests quite well, spanning even the largest 2.5cm gap with no noticeable sagging or collapsing issues (Table 5). The difference between the filaments becomes more apparent in the overhang tests, where the virgin PLA outperformed the recycled PLA with a cleaner print surface (Figure 4). Both prints began to have sagging issues at the 60˚ angle, but the issues are much more prevalent on the recycled PLA print, where the overhang shape gets significantly messier in the 70˚, 75˚, and 80˚ sections than what defects occur in the virgin PLA print. While overhang issues are often solved with the use of supports added to the print during the slicing process, ideally these are used as little as possible or only when necessary as the extra material and time required to carefully remove them adds up when producing many prints or prototypes.



VIRGIN PLA **RECYCLED PLA**

Figure 4: Comparison of the Overhang Test

While an official test of durability was not done in this study, it is notable that while handling both prints for measurements and photos, a break did occur on the recycled PLA print (Figure 5). Two of the pillars that made up the stringing portion of the Micro AIO test were snapped off accidentally while handling the print. A small amount of pressure was next put on the same pillars on the virgin PLA print in an attempt to recreate the break, but those pillars held steady. Having a low durability could impact prototypes that get transported or handled frequently and, if this result repeats, could discourage the use of recycled PLA filament.

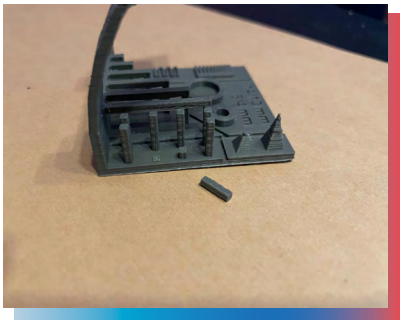


Figure 5. Broken Pillars on the Recycled PLA Print.

Dimensional Accuracy

Likely the most important metric to determine if recycled PLA is suitable for use in prototyping is dimensional accuracy. From the first visual inspection, both prints have no clear defects, look symmetrical in size, and have good symmetry in the Micro AIO dimensional accuracy test. For more accurate inspection, a digital calliper was used to measure these dimensions (Figures 6 & 7).

Figure 6. Comparison of the Dimensional Stability Tests. Measured with a digital calliper in millimetres, at two points with 90˚ rotation.

VIRGIN PLA **RECYCLED PLA**

Figure 7. Comparison of the Print Size. Measured with a digital calliper in millimetres, at two points with 90˚ rotation.

The virgin PLA has more consistent dimensions in both tests, having only a 0.02mm variation in the scale/diameter test and no variation in the overall size of the print. The recycled PLA print falls just slightly behind with a 0.11mm variation in the scale/diameter test and a 0.1mm variation in overall size.

Discussion

Use of Recycled PLA

After analysing the results of the test prints it can be seen that the recycled PLA did not quite perform to the same standard as the virgin PLA filament. The most drastic variations occur in the dimensional accuracy and detail tests, which are very likely the most important factors when creating prototypes. If the colour accuracy or durability of the prototype was crucial to match the final product design, 3D printing would not be the recommended prototyping method for a company to use. They would likely be advised to use the same material or fabrication process as the final product. However, if the 3D printed prototype was made to be accurate to the size and form of the final product, for example, to create packaging, the shape, dimensional accuracy, and detail could be crucial. Based on the results of this study, virgin PLA does slightly outperform recycled PLA. The dimensional variation on the recycled PLA print is still less than a millimetre and could remain an option for prototypes that do not need to be extremely accurate.

Another study looking at the mechanical properties of recycled PLA filament also found the material to be less durable, with the main factor affecting this property being how many times the plastic had been recycled before. This study found that by the third time the material was recycled, it had lost almost 40% of its original short-beam strength, a test that essentially describes putting pressure in the middle of a beam to

test its bending properties before breaking (Lanzotti et al., 2019). The recycled PLA acquired from Filaments.ca had no indication how many times the material had been previously recycled, furthermore, in the instructions for contributing consumer or industry waste to the recycling process, did not specify if already recycled PLA waste could be included in the drop-off (Filaments.ca, 2024). Likely, users who are aware of and contribute to the recycling program have also purchased recycled PLA from the supplier, so there is a high chance that PLA which has already gone through the recycling process has ended up in the batch of filament used for these tests, and could, in turn, explain the fragility of the recycled PLA print.

Future Research Potential

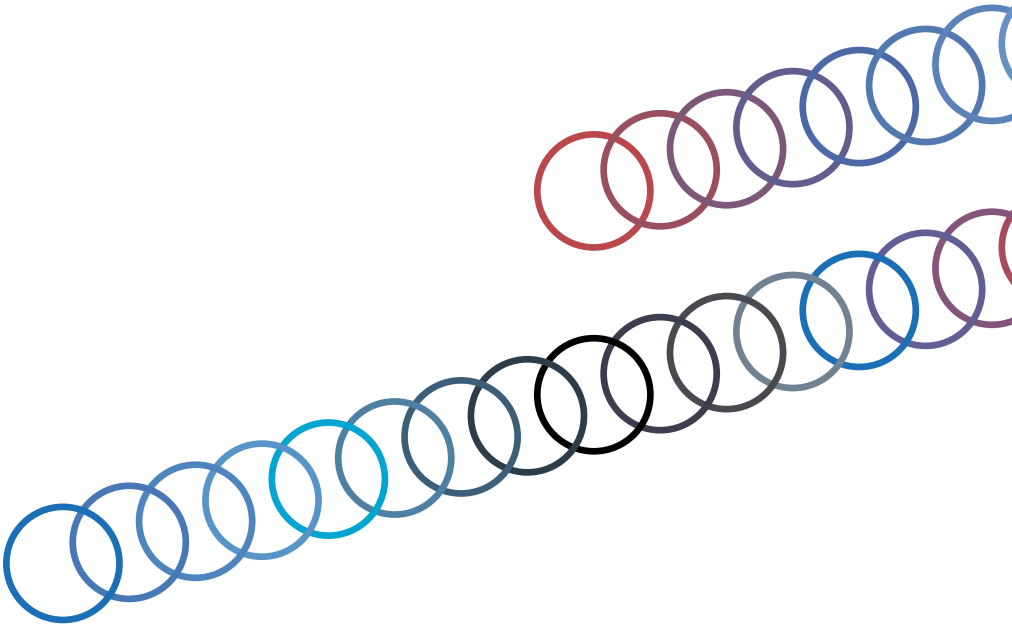
While this study ran one test with one alternative filament option to fit into the time constraints of the semester, research on this topic would greatly benefit from more studies that examine other filament options and either run tests multiple times, or run a greater variety of tests to confirm the results found here. Since recycled PLA is not the perfect solution for accurate prototype printing, or the perfect filament disposal method, as it can only be recycled a couple of times before material degradation begins to drastically affect quality, research in this area should not stop any time soon. Research on better composting methods of PLA, or materials such as the filaments being developed from sugarcane or potato starch, would also be beneficial to 3D printing as a whole. From large companies to hobbyist printers, many would benefit if old material did not have to be taken to a specialized facility for proper disposal.

Another area of research that would be beneficial to be covered in the future would be examining the difference in life cycles of prototypes used in different industries. Research on this topic could answer questions regarding which industries keep their prototypes for multiple uses, which go through many temporary prototypes in their iterative design process, and whether specific industries differ in how accurate their prototypes need to be. This research could help determine where alternative materials should start being implemented, even if they are not yet up to the same standard as the traditional virgin PLA, ABS, or PETG filaments.

Conclusion

Overall, using alternative materials rather than virgin plastics allows companies to use 3D printing as a fabrication method for their prototypes and incorporate sustainable processes into their workflow. While more material options such as easily, or consumer biodegradable 3D printer filaments made from sugarcane or potato starch are still in development, recycled PLA is a decent filament material with similar properties to virgin PLA. Differences between these two filament options are minor and only prototypes that need to be extremely

accurate or as durable as possible should opt for the virgin PLA option. Additive manufacturing still presents itself as a sustainable alternative for prototype creation, as opposed to traditional subtractive methods such as milling that produce greater amounts of waste. Further research on alternative materials for this process and how to get them up to the same dimensional stability and durability standard as virgin PLA, or how to better recycle or compost PLA would be beneficial to many industries as the creation of iterative prototypes spans many different fields of work. So, despite the plastic waste currently produced by 3D printing materials, additive manufacturing technology is still a great option to invest in today for prototype creation, even for companies looking to increase their sustainable practices, as long as research and improvement in material and waste disposal options are continued.



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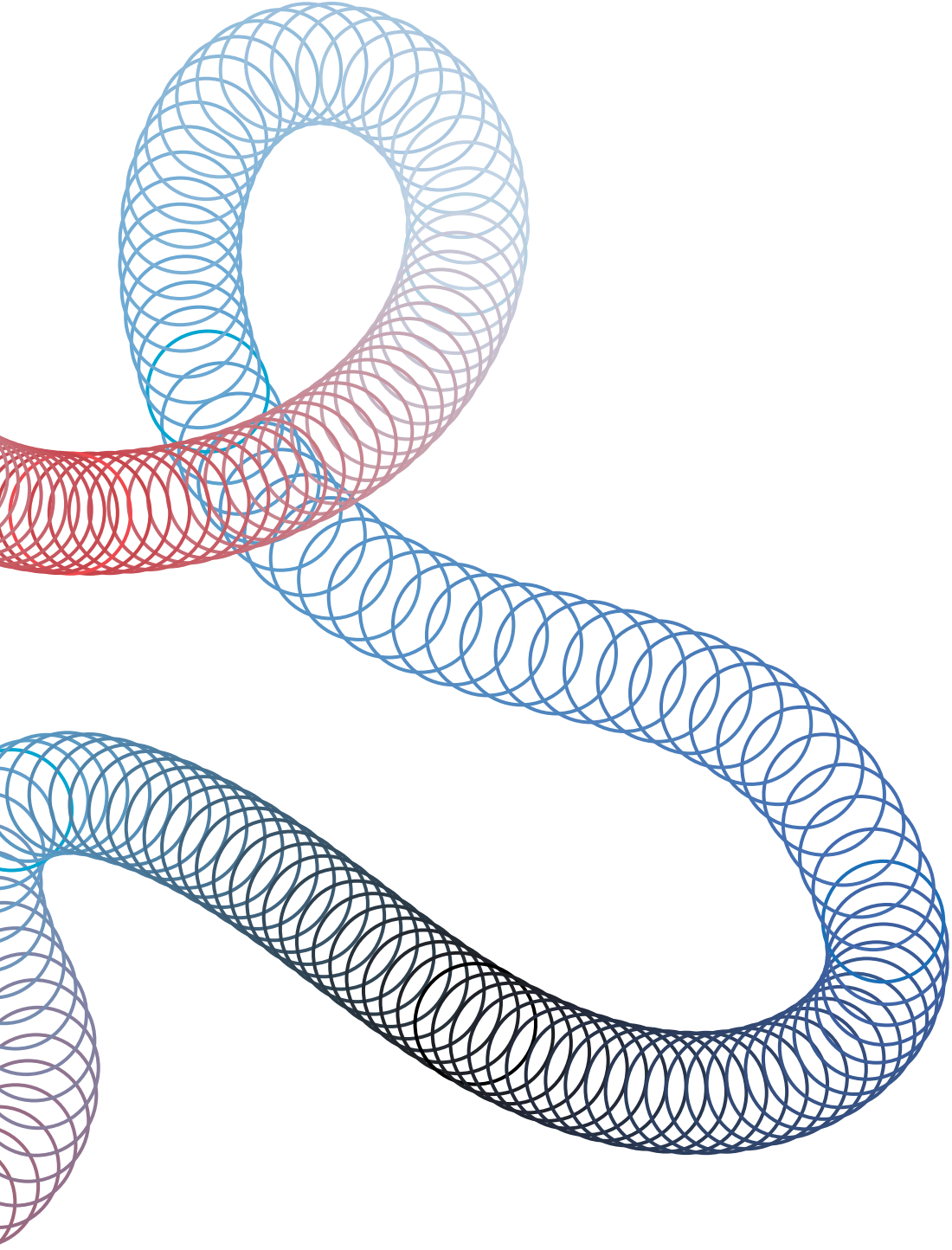

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04

BRAILLE STANDARDIZATION IN PHARMACEUTICAL PACKAGING: ADVANTAGES, DISADVANTAGES AND THE POTENTIAL BENEFITS FOR CANADIANS

Sophie Dreu

Hi there! I'm Sophie Dreu, and I wrote my thesis on accessibility in pharmaceutical packaging. I spent the summer between my 3rd and 4th years at GCM studying in Italy as part of a Creative School program, and visiting friends across Europe. I visited a pharmacy while I was there, and the packaging on the shelves really caught my eye – of course, I'm a GCM student, after all! But what really intrigued me was the braille on every single box. I took a picture because I thought it was interesting, I had no idea I would end up writing my thesis on it! I will always recommend studying abroad if possible, because it offers unique perspectives on everyday occurrences that you wouldn't normally think twice about. If accessibility interests you, I hope you'll give my thesis a read!

To listen to Sophie's thesis, use this link:

4

Acknowledgements

I would like to take this opportunity to thank my thesis advisor and professor, Dr. Krzysztof (Kris) Krystosiak, for being incredibly knowledgeable in this area of research, guiding me forward and overall being a great help in this capstone project. Not to mention, a wonderful and helpful professor whose class is fun and engaging! I will definitely miss him (and his donuts) once I graduate. Thank you for always being there for me and my incessant questions, Kris!

I would also like to thank the plushies I keep on my desk for all the moral support and happiness they've brought me for the duration of this paper. They have witnessed the entire range of human emotions over the past few months, and for that I thank their soft, fluffy bodies and their cute and gentle smiles. Thank you for keeping me sane, little fellas.

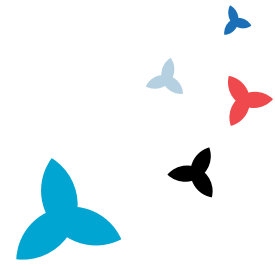
Abstract

This paper investigates the European Union's Directive 2001/83/EC, relating to the mandate in accessibility of pharmaceutical packaging (prescription and over the counter). This requires that all pharmaceuticals require certain information to be included in braille on the package. This paper explores whether steps should be taken towards implementing similar laws regarding braille on pharmaceuticals, as it relates to the Canadian market and demographic of visually impaired individuals. The purpose of the original implementation in the European Union was analyzed in order to determine whether it would be applicable to Canada. The opinions of industry professionals were taken into account when considering their perspective on how braille on pharmaceuticals would help the visually impaired. The statistical differences between the demographics of the European Union and Canada were also considered, such as the total visually impaired/blind populations and total population capable of reading braille.

It was concluded that the current Canadian pharmaceutical packaging is outdated and is not accessible to those with visual impairments, and that the country needs to update their packaging legislation to be more inclusive. While braille would be a beneficial addition to packaging, it was found to only affect portions of the visually impaired populations. Alternatives such as NFC (Near Field Communication) were explored, and it was concluded to be a possible solution because it requires an individual to utilize their mobile device rather than requiring the ability to read braille, therefore being more inclusive to a wider population. Whether braille, NFC, or another alternative is considered for implementation, Canada's current packaging laws are not sufficient and would benefit from similar accessibility legislation as the European Union.

List of Abbreviations:

ACB	American Council of the Blind
AODA	Ontarians with Disabilities Act
CNIB	Canadian National Institute for the Blind
CRPD	Convention on the Rights of Persons with Disabilities
EAA	European Accessibility Act
EU	European Union
FDA	Food and Drug Administration
FRA	Agency for Fundamental Rights
NFC	Near Field Communication
WHO	World Health Organization



Introduction

Directive 2001/83/EC, passed in 2001, mandated that all pharmaceuticals (both prescription and over the counter) sold in the European Union (EU) include braille on the packaging for maximum accessibility for those who are visually impaired or blind. This includes information such as the name of the medication, strength, and dosage, as well as making leaflets associated with the medication available in braille upon request. The EU has approximately 26 million individuals who experience some form of visual impairment (European Blind Union, n.d.), and even though not all of them are capable of reading braille, there is a significant number of people that are capable of benefiting from this technology. Despite having been mandatory for around 20 years, the rest of the world has not caught up to the standards of accessibility set by the EU.

The EU isn't the only place in the world that has individuals with visual impairments or blindness, so what solutions does Canada have in place to support this demographic when it comes to pharmaceuticals? The answer is not as straightforward as one might think. Some pharmacies may have additional resources available on request that cater to those with low vision or blindness, but there are no laws or legislation in place to standardize an "acceptable" level of accessible care. The research question that will be focused on is as follows: should Canada take steps towards implementing similar laws and legislation regarding braille on pharmaceutical packaging similar to that of the European Union in order to increase accessibility for the visually impaired? The question proposed aims to analyze the circumstances under which the EU implemented such mandates in order to determine the impact it has made in partially sighted and blind communities, and whether this could be applied to similar communities in Canada.

Currently, individuals who are visually impaired struggle completing tasks that seeing individuals may not consider to be particularly difficult. In countries that do not have accessibility standards for pharmaceutical products like Canada, the task of going to the pharmacy and taking medication can be extremely daunting and difficult, and requires creativity on the part of the patient in order to make this experience more personally accessible to them. According to a study from 2019, a survey was conducted asking visually impaired or blind individuals on their experience with taking medication, and how easy or difficult it was. 46% of participants stated that they struggled with identification of different medications (for example, medication in similar containers, pills being similar shapes, etc), and another 42% stated that they struggled with identifying specific information, such as the dosage, dosage schedule and expiration date (Lee & Lee, 2019). Furthermore, individuals were asked how they were able to determine the information that they stated they struggled with, and almost 92% stated they required assistance from a third party (for example, family members, caretakers, etc) whereas the other 8% stated they either guessed or didn't know at all (Lee & Lee, 2019). Clearly, this is an issue, as not all people have the assistance of a third party available, and regardless of this, individuals who are otherwise able to take care of themselves should be able to identify such information on their own. Finally, it was determined that, second to the reliance on others, individuals would utilize a different sense in order to identify their medication. Oftentimes, this involved creating their own touchable identification to attach to the outside of the bottle, which was particularly useful for medications that came in the same bottle (for example, prescription medication that often comes in the iconic orange, tube like structure), such as putting rubber bands, staples, stickers, or other tactile items on the outside of the container (Lee & Lee, 2019).

There has been little research into how this affects Canada specifically, however studies have been conducted around the world on the topic of accessibility and braille in pharmaceuticals, many of which are outdated. This project aims to focus on the specific comparison of Canada and the European Union, in terms of accessibility standards, and where each region may differ (for example, a greater number of individuals with visual impairments requiring a greater level of accessibility). This project will also be focusing on the individual and societal impact of braille in pharmaceutical packaging, and less so on the technical and manufacturing implications on adding braille to existing packaging. As accessibility becomes more and more important in today's North American society, it is worth considering why something as important as medication is not more accessible to more people, or at least has accessible alternatives that are available to the people who need them.

Literature Review

What is Braille?

Invented in 1824 by a 16 year old blind French boy named Louis Braille, this technology was the first “reading” system to accommodate those with visual impairments (Britannica, 2024a). Modern and international versions of braille are made of “cells” that consist of six braille dots in a two by three pattern. Each dot can be raised, so that a person touching it would be able to feel the difference between the regular flatness of the substrate and the raised portion of the braille dot. By raising certain dots in a specific pattern, this correlates to one of sixty three combinations that correspond to a letter, number or punctuation mark. In Figure 1, the enlarged dots represent the raised and touchable portions of the braille cell, whereas smaller dots indicate the cells that are blank. The organization of these cells can create text, so that a person moving their fingers across the cells would be able to tell each letter apart and “read” the braille (Britannica, 2024a). The process of creating braille can vary depending on the type of substrate it is being applied to, but many substrates are compatible with it. For paperboard, common in pharmaceutical packaging, there are three braille options: embossing, UV ink structures, and thermographic printing (Mohamed, 2016). The process of embossing consists of a die made of metal in the shape of a braille cell being pressed (embossed) into a substrate. This physically raises the substrate in the shape of a cell, so that it is able to be touched and differentiated (Mohamed, 2016). Screen printing with UV ink can create a physical ink structure that dries in a solid form that is slightly raised than the substrate it is printed on. As this is common in clothing, this is comparable to certain screen printed clothing that have raised designs (Mohamed, 2016). Finally, thermographic printing utilizes a special ink that is mixed with unique resin structures, so that when it is heated (dried), the resin melts and forms a raised area (Teo, 2014). While some methods are more cost effective, efficient and practical to implement on a large scale (as such would be required in packaging production), all three methods are viable (Mohamed, 2016).

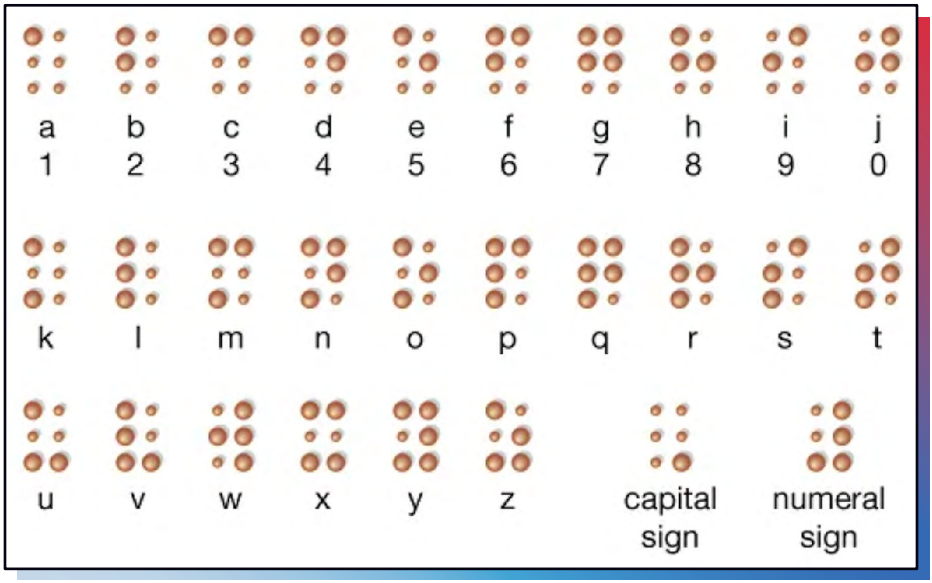


Figure 1. The English Alphabet and Numbers Depicted in Braille (Britannica, 2024b).

Blindness, Braille and the Impact of Pharmaceuticals

According to the World Health Organization (WHO) there are an estimated 40 - 45 million people who are blind, and an additional 135 million who have low vision/are visually impaired, and this number is only continuing to grow (World Health Organization, 2003). Across Canada, 1.5 million Canadians self identify as blind, Ontario alone making up 681,000 of that number (CNIB, n.d.). In comparison, statistics from the European Union (EU) show that the population of the visually impaired is approximately 26 million (European Blind Union, n.d.). Particularly with pharmaceuticals and packaging where ingesting the correct dosage in the correct intervals is extremely important for both over the counter and prescription medication, the European Union demands that braille is added to packaging to increase the accessibility to those visually impaired in order to prevent incorrect consumption. According to the Directive 2001/83/EC, the European Union states that "The name of the medicinal product, as referred to in Article 54, point (a) must also be expressed in Braille format on the packaging. The marketing authorization holder shall ensure that the package information leaflet is made available on request from patients' organizations in formats appropriate for the blind and partially sighted" (European Parliament, 2001). Passed in 2001 as the name suggests, this mandated the information that must be available in braille: the name, strength and dosage without the use of abbreviations. Coming into full effect in 2005, this gave manufacturers four years to implement braille into their packaging (European Parliament, 2001). Other countries have attempted passing similar legislation, such as the United Arab Emirates in 2015 (Almukainzi

et al.,2020), and South Korea recommending it to pharmacies in 2014 (Lee & Lee, 2019).

It is important to remember, however, that not all visually impaired/blind people can read braille. According to the WHO, there are around 26,350,000 visually impaired individuals in the European Union, but only around 10% of them can actually read braille (European Blind Union, n.d.). This means the actual number of people this technology benefits is approximately 2,635,000 people across the entire EU. In Canada, this percentage is a little bit higher, according to the Canadian National Institute for the Blind, an estimated 26% of the visually impaired population are able to read braille (CNIB, n.d.), adding up to about 390,000 people across the entire country. It is worth noting that, despite the modern development in technologies that can aid the visually impaired population (eg. screen readers, etc), the European Union has mandated the teaching of braille to blind students in school (European Blind Union, 2022). On top of this, visual deterioration is common in individuals 65 years of age and older (European Blind Union, n.d.), so those who may have become visually impaired/blind in their adulthood would not have learned braille in school.

Canadian legislation in terms of accessibility in pharmaceutical products concerning the blind or visually impaired, is lacking compared to other countries aforementioned. This is similar to the current situation in the United States, as the American Council of the Blind (ACB) has been struggling with convincing the Food and Drug Administration (FDA) to consider increasing accessibility in packaging. Even though some advancements have been made in prescription drugs in the US for those with low vision, the same cannot be said for over the counter medication. In summary, without the mandate of the FDA, it is unlikely that further progress will be made (Botta, 2017). A study conducted in the US set out to create a prototype braille label for an over the counter medication and asked those with vision impairments to identify the name of the product, frequency of ingestion, and serving size. The study found that, across each question, all 15 participants who were able to read braille were able to answer each question correctly, except for one participant who misread the frequency of ingestion (Chavez Dowd, 2001). It was also stated that the participants felt more independent and comfortable taking things like both medication and vitamins. People outside of Europe with vision impairments can benefit from this technology if it was more widely implemented, and could thus lead to better overall health and comfort. Another report from Egypt, another country that does not have any braille-related laws regarding pharmaceuticals, aimed to determine the best method of braille dots on packaging for maximum readability. With multiple methods, such as embossing the actual paperboard to make the dot raised, screen printing with UV ink structures, and thermographic printing, it was determined that any of these three methods is suitable for packaging purposes. With three different options available, it seems that the implementation of this technology on a wider scale is not as impractical (Mohamed, 2016). It is worth noting, however, that implementing braille into

pharmaceutical packaging is not cheap. According to Interpack, braille increases costs for some printers by up to 25%, and in Germany alone, the addition of braille to packaging costs an estimated 160 million euros per year (Interpack, n.d.)

Dealing with Accessibility Challenges

In a study conducted in South Korea across multiple pharmacies, the researchers set out to determine how visually impaired patients differentiated between their medications, and how they ensured they were taking the correct dosages at the correct intervals. Visually impaired patients who visited pharmacies who did not use braille were then asked what they struggled with the most in terms of their medication. 45.9% stated they struggled with identification of the medication itself, whereas another 30.6% stated they had difficulty obtaining information related to the medication, such as side effects, expiration dates, etc. In terms of the pharmacies that did use braille, 75.0% utilized multiple strategies in combination with it, in order to aid patients in being able to identify their pharmaceuticals faster and effectively. For example, in addition to the name, dosage and strength being written in braille, patients were given uniquely shaped containers so that they would be able to be identified through touching/picking up the bottle. This also helped patients who were taking multiple medications at the same time, as they could tell the difference between which container had which medication (Lee & Lee, 2019). Considering that many patients were forced to take their own measures to modify their containers in some way in order to tell the difference between their medication, it is worth noting that this is not accessible.

Alternatives Proposed Around the World

Some studies conducted have proposed alternative methods to increase accessibility for those with visual impairments that do not involve braille on packaging, thus overall reducing the cost of manufacturing. One article by Packaging Europe stated that accessibility does not have to be anything new or revolutionary. Blister packs, packaging that holds each dosage in its own compartment, are already in use and provide easier identification and dosage size than a bottle of pills loose inside. Utilizing sensors, QR codes or Near Field Communication (NFC) can also be used to identify expiration dates, to ensure those who cannot see these dates are not taking expired medication or otherwise incorrectly (Packaging Europe, 2024). While blister packs are used for smaller dosages, they are not as common as the traditional bottle of pills format that many medications come in. Sensors, QR codes and NFC are not commonly used and overall lack studies to determine their effectiveness in accessibility.

In countries where pharmaceutical packaging is less accessible to those with visual impairment, those affected are forced to come up with alternatives on their own. Another study asked those with vision impairments how they managed their medication and other pharmaceutical products. The most common method was discovered to be reliance on help from family members/caretakers at 56.3%.

Following this was a strategy of using other senses to distinguish medication (smell, flavour, texture, shape, etc) at 23.2%. Finally, 16.9% created their own touchable identification by applying items with specific textures to the outside of the medication bottle, or created their own braille stickers to apply to each medication themselves (Lee & Lee, 2019)

Methodology

In order to determine whether similar legislation to the European Union's legislation surrounding accessibility for the visually impaired should be incorporated into Canada's pharmaceutical industry, the first step will be to analyze secondary data in terms of the pros and cons of this implementation according to professionals from around the world. For example, foundations for the visually impaired, blind people, industry professionals like pharmacists, doctors, packaging engineers, etc. On the other hand, implementing this kind of technology comes with negatives, as well, as it can be argued that the amount of people that it benefits is relatively low compared to the cost of implementation, and it is important to consider all perspectives from those like pharmacists, doctors, etc, and others who may work with the visually impaired on a regular basis. Pre-existing government legislation in terms of rights for accessibility in Canada, such as the Ontarians with Disabilities Act (AODA) already exist, and it is worth looking into whether legislation similar to the EU's may fit into standards established by Health Canada or other similar organizations for standardization.

With the EU's legislation in mind, the history, data and implementation reasons for Directive 2001/83/EC relating to braille on pharmaceutical packaging will be examined and compared to Canadian standards. Furthermore, statistics between the two regions will be compared so that differences in demographics can be considered (eg. does the EU have more visually impaired/blind people that can read braille, thus necessitating more accessibility in their pharmaceutical packaging?) Finally, case studies of attempted implementation done in other countries will be examined, as well as the results in terms of government acceptance and how accessibility in pharmaceutical packaging has evolved (eg. availability of braille pamphlets for medication, government recommendations in terms of braille, etc). Case studies and data from those who may have first hand experience in this field, such as caretakers/family of visually impaired/blind people, as well as pharmacists will also be analyzed for their benefits/challenges (eg. Does braille on pharmaceuticals help those who are visually impaired feel comfortable and independent when taking medication? Does this technology benefit pharmacies/pharmacists in any way?). This includes research articles published in journals about similar topics considering braille implementation into packaging in general across a wide variety of countries, as well as local organizations advocating for accessibility in Canada, such as the Canadian National Institute for the Blind (CNIB). In order to determine whether braille on pharmaceutical products

should be implemented in Canada, aspects outside of law and legislation must also be considered.

From this research, it is expected that the accessibility of pharmaceutical packaging is very important to the visually impaired/blind community, as it can both decrease the likelihood of incorrect medication ingestion (eg. wrong medication, wrong dosage, expired medication, etc), as well as increase independence as they would no longer require family members or a caretaker to aid in medication administration. It is also assumed that there are many advocates for the inclusion of braille in pharmaceuticals across Canada, as well as the rest of the world, such as those a part of the visually impaired/blind community, as well as pharmacists, doctors, and others who may interact with members of this community regularly. There are also potential disadvantages to consider, such as factors that pharmaceutical packaging manufacturers are likely not willing to compromise on, such as the increased cost of production (and therefore less profit). While this technology being included in packaging would benefit many, it is unlikely that manufacturers themselves would go out of their way to create new packaging unless the Canadian government creates a mandate or law for this kind of accessibility to be mandatory.

Results

It was determined that the original reason for implementation of braille in pharmaceuticals in the European Union is in part due to major concerns over incorrect dosages of medication. According to medical professionals in the field, braille on pharmaceuticals in particular were considered to be more important than braille on other types of packaging (eg. food packaging) because of the potentially severe consequences of taking the wrong medication or incorrect dosages (Chadwick, 2010). In comparison to the relatively low risk of buying or using the incorrect product or food product, taking the wrong medication at an incorrect dosage due to being unable to read the packaging could have potential life or death consequences (Chadwick, 2010), and thus was deemed more important to be as accessible as possible.

In addition to this, the European Union has been increasing the accessibility requirements for businesses since the implementation of braille in pharmaceuticals. The European Accessibility Act (EAA), implemented in 2011 had the intention of standardizing accessibility across every country in the European Union. While this act was only instated after Directive 2001/83/EC, it increased standards for disabilities that affect usage of electronic devices, as well as services associated with them. For example, this includes television equipment and television programs and broadcasts, but also encompasses banking services and associated operating systems (eg. ATMs, deposit machines, etc) (Ronen, 2022). This meant that physical devices, such as a television remote control or an ATM would require braille on its buttons. This is somewhat comparable to

the standards set by Ontario's Accessibility for Ontarians with Disabilities Act (AODA), however unlike the AODA, which is primarily is designed to cater towards those with mobility-related disabilities and the accessibility of public buildings (for example, wheelchair users accessing a government building), rather than braille standardization on certain equipment (Government of Ontario, 2018). While they are not exactly the same, specific legislation in terms of certain types of accessibility exist in both regions. Both countries also have rights for those with disabilities written into their charters. In Canada, this is included in the Canadian Charter of Rights and Freedoms, and in the EU, this is the European Union's Charter of Fundamental Rights, both of which outline the protection of minorities, including those with disabilities, from discrimination (Rahman, n.d.; European Union Agency for Fundamental Rights, 2017).

Statistics between the two regions were compared in terms of their visually impaired/blind populations. The following Figures 2 and 3 show a comparison of statistics between the European Union and Canada, adjusted for population size and expressed in a percentage (CNIB, n.d.; European Blind Union, n.d; World Health Organization, 2003). In order to obtain this information, calculations were performed with numbers obtained from official government websites or medical groups associated with the government. This is expanded upon in Appendix A. Total population and total visually impaired/blind population data was gathered from sources in an approximate time frame of 2022 - 2023. Ultimately, approximately 5% of the European Union's population experiences some form of visual impairment in varying severity from minor to completely blind, whereas it is only around 4% of Canada's population. Because not everyone can read braille, it is important to consider this separately from the total population of visually impaired individuals. While the European Union has quantifiably more people that can read braille due to the larger population size, a higher percentage of the visually impaired in Canada can read braille at 26%, in comparison to the European Union's 10%.

Table 1. Comparing Various Visually Impaired Statistics in the European Union.

European Union

Variable	Total	Percent
Total population	447 million	—
Total visually impaired/blind population	26 million	5%
Total capable of reading braille	2.6 million	10%

Table 2. Comparing Various Visually Impaired Statistics in Canada.
Note. Own elaboration based on CNIB, n.d.; European Blind Union, n.d; World Health Organization, 2003.

Canada

Variable	Total	Percent
Total population	38 million	—
Total visually impaired/blind population	1.5 million	4%
Total capable of reading braille	390,000	26%

In a study conducted in South Korea, pharmacies and their associated pharmacists were asked about their usage of braille in their pharmaceutical packaging, and if they did, whether they found there to be a benefit for those who required this technology. The following pie chart displays the usage of braille findings:

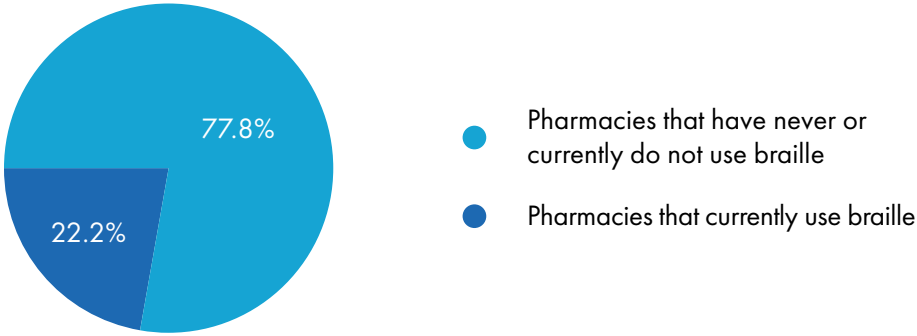


Figure 4. Pie Chart of Pharmacies in South Korea that Use Braille.
Note. Own elaboration based on Lee & Lee, 2019.

77.8% of pharmacies stated they had never used braille technologies, whereas 22.2% said they had (Lee & Lee, 2019). In consideration of the usage being relatively low amongst the pharmacies included in the study, the opinions from the pharmacists in these locations differed depending on whether their location used braille or not:

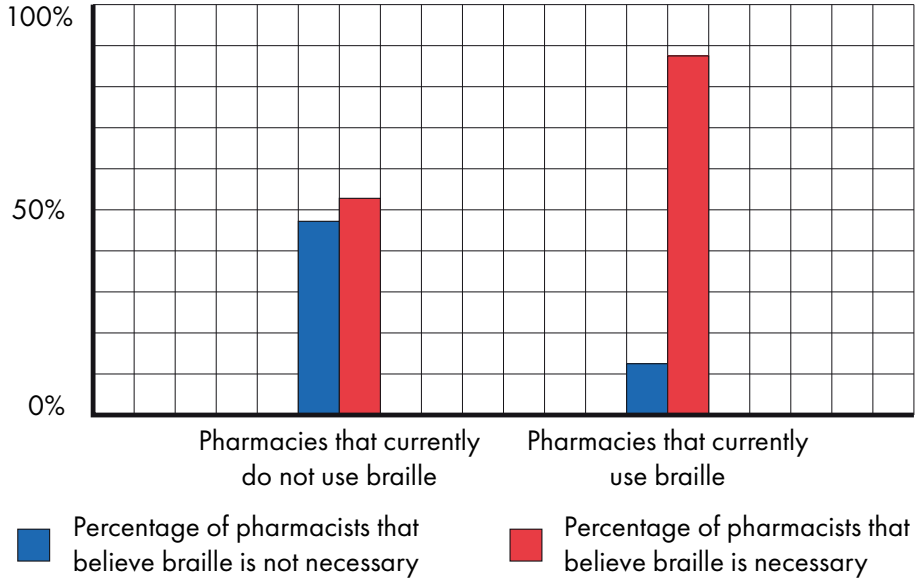


Figure 5. Pharmacist Opinions on the Necessity of Braille on Pharmaceutical Packaging.
Note. Own elaboration based on Lee & Lee, 2019.

The necessity of braille in pharmacies in the study was deemed to only be 52.8%, but this number comes from the pharmacies that do not currently use braille in their packaging. Pharmacists working at locations that did utilize this technology responded positively at a much higher rate of 87.5%. In place of braille at certain pharmacies, it was discovered that pharmacists would instead instruct a family member or caretaker of the visually impaired patient. This resulted in the patient becoming somewhat "infantilized" even if they are otherwise capable of comprehending audibly provided instructions (Lee & Lee, 2019). The study found that this method often resulted in the visually impaired individual becoming an afterthought in their own medicinal counsel. Despite my study on this topic pertaining to the Canadian market, it is assumed that the opinions of pharmacists from other countries are likely applicable to Canada as well. For example, if a South Korea pharmacist states that they believe braille is/is not necessary in pharmacies, this opinion applies to pharmacies around the world and not only those in South Korea.

In a 2009 article from PharmaBraille, an association that has created braille specifically for pharmaceutical products in Europe, a prediction was made that braille would become more common in pharmaceutical products across the United States and Canada. This prediction was based on the recent (at the time) legislature in the European Union, Directive 2001/83/EC, coming into effect as discussed earlier. It was predicted that North America would follow suit soon after (Steel, 2009). This, evidently, has not been the case, though PharmaBraille as an organization has been working with diemakers to create accessible packages for these products. Ultimately, because they are optional, they have not been used very much. Despite this, there have been more local organizations that have attempted to take steps in making pharmaceutical products more accessible for the visually impaired. Organizations such as the Canadian National Institute for the Blind (CNIB), as well as similar organizations located in the United States, such as the American Council of the Blind (ACB), have been in discussion with their associated government agencies that preside over pharmaceutical packaging. In the United States specifically, little progress has been made, and it has been stated that without mandates from the Food and Drug Administration (FDA), it is unlikely that further progress will be made in this matter (Botta, 2017), and Canada is in a similar situation with Health Canada.

Discussion

In order to determine whether Canada should take steps towards implementing and standardizing braille in pharmaceutical products, the original reason for implementation in the European Union was to be examined. The reason for this implementation in 2001 was the concern over ingestion of the wrong medication or the incorrect dosage of a medication, and the consequences that this could potentially have. Notably, certain medications have higher risks associated with improper ingestion, such as improperly taking prescription opioids, antibiotics that have to be taken consistently for a specific length of time, etc, and the incorrect consumption could lead to serious consequences for the patient. This is why pharmaceuticals were given higher priority in braille standardization than the likes of food packaging, as the risk of incorrect consumption in comparison is generally lower (though there are some exceptions to be considered, such as severe reactions to common allergens). As predicted, the reason for the implementation of braille is not an issue that is exclusive to the EU, and obviously the visually impaired population in Canada are at an equal risk of consuming their medication incorrectly without preventative measures in place to provide information that can be accessed in an appropriate format, like braille.

Because both Canada and the European Union have rights that protect people with disabilities, it is worth comparing them to determine whether people with disabilities in the EU, specifically those with visual impairments, are more protected than those in Canada. This would reasonably explain why the EU would take such steps in ensuring the maximum accessibility of their pharmaceutical

products. Canada's Charter of Rights and Freedoms, as well as the Accessible Canada Act, state the following:

> Every individual is equal before and under the law and has the right to the equal protection and equal benefit of the law without discrimination and, in particular, without discrimination based on race, national or ethnic origin, colour, religion, sex, age or mental or physical disability. (Government of Canada, 2022).

It is also stated that "[you] must not have a worse/lesser experience with services because of your disability. For example, you must not be denied access or given reduced access to stores, restaurants or any other services that other people can enjoy" and that "[you] must be given reasonable accommodations by employers and service providers in order to participate fully in and access these areas of your life" (Rahman, n.d.). In comparison, the EU's charter states the following:

> The EU's Charter of Fundamental Rights prohibits discrimination on the ground of disability and recognises the right of people with disabilities to benefit from measures to ensure their independence, social and occupational integration and participation in the life of the community. The European Union's Agency for Fundamental Rights (FRA)'s work on the rights of persons with disabilities is framed by the principles of self-determination, participation and inclusion set out in the UN Convention on the Rights of Persons with Disabilities (CRPD). FRA examines where legal and social barriers exist, and identifies practices EU Member States have introduced to empower people with disabilities. (European Union Agency for Fundamental Rights, 2017)

In examining these two portions of each region's charter, it seems that Canada's outlines more specific examples and rights for those with disabilities (eg. having full access to a grocery store), whereas the EU's focuses more on the person's independence and personal empowerment of one's individual rights. Braille on pharmaceuticals seems to fall more under independence, as this allows for those with visual impairments to take their medication with confidence, as they are personally able to determine what medication they are taking, as well as the accuracy of the dosage, rather than requiring the help of a seeing individual, such as a family member or caretaker. It could be argued, however, that Canada's charter's inclusion of the phrase "reasonable accommodation [from] service providers" would apply to pharmacies, as it falls under the health sector, and that braille on packaging (or any other proposed alternative that would be beneficial to a visually impaired patient) would be considered a reasonable accommodation.

There was also a possibility that the European Union simply had a greater population of visually impaired/blind people in comparison to Canada, thus necessitating braille on pharmaceuticals, so statistics between the two were compared. As seen in Figure 2 and 3, the total population of each region were compared, as well as the total visually impaired/blind population, and the total

number visually impaired/blind that were actually capable of reading braille. Not all visually impaired/blind people are capable of reading braille, and that most people who are able to read it have been blind from birth or a significant portion of their life (thus necessitating the learning of it in school). It is important to note, however, that there is also a large population of people who lose their vision in their adulthood/old age that would not have had the opportunity to learn braille in their youth (European Blind Union, 2022). According to the information gathered from the CNIB,(n.d.), European Blind Union, (n.d), and World Health Organization (2003), the total visually impaired population in the EU that are capable of reading braille is only 10%, in comparison to 26% of Canada's visually impaired population. This would seem to necessitate the inclusion of braille in pharmaceuticals to be even more important in Canada. It is important to remember, however, the total population of the two region is vastly different, and that even though there is a higher percentage of braille literacy in Canada, the EU has a significantly larger population and the actual number of individuals who can read braille is higher as seen in the "Total" columns in Figure 2 and 3 (The EU's 2.6 million versus Canada's 390,000).

In considering case studies that have analyzed pharmacies attempting to implement braille on a smaller scale, the study conducted by Lee & Lee in South Korea, looked at 47 pharmacies located throughout Seoul and determined that 77.8% did not offer braille alternatives in comparison to 22.2% that did (2019), as is depicted in Figure 4. More importantly, the pharmacists working at each location were asked whether they thought that braille on pharmaceuticals were important and necessary, as seen in Figure 5. Interestingly enough, there was a large divide between the opinion of the pharmacists based on what pharmacy they worked at. The pharmacists who worked in locations that did not offer braille on their packaging answered in around a 50/50 split in whether they deemed this technology to be necessary. On the other hand, pharmacists working at locations that did use braille answered overwhelmingly positively in favour of the necessity of braille at 87.5% (Lee & Lee, 2019). This means that these pharmacists must have first hand experience in seeing the benefits of braille, such as the ease in working with visually impaired patients, the benefits for the visually impaired individual, etc, that would have made them vote in such a positive manner. Pharmacists working in locations that did not offer braille were asked on how they would counsel a visually impaired patient on how to take their medication, and it was discovered that the counsel was offered instead to a family member or caretaker, instead of the patient themselves. This can be problematic on its own, as not everyone has family members or a caretaker that are willing to help in this regard. This also leaves the patient as a secondary consideration in their own counsel, similar to how parents would learn how to administer medication to their young child. Aside from this feeding into the stigma of disabled people being "helpless", this also erases the independence and dignity of a visually impaired person, as even if they are completely capable of comprehending instructions audibly, they

still require someone to go with them to the pharmacy. It may also be beneficial to increase the education of pharmacists as it relates to identifying visually impaired individuals that require additional assistance, and how to best help those that need it.

Despite the incorrect assumption from PharmaBraille and other braille organizations assuming that Canada and the United States would soon follow the European Union in standardizing braille across pharmaceutical products in 2009, there is some merit to this (Steel, 2009). It was assumed that North America would want to follow the steps set by the EU and make pharmaceuticals more accessible to those with visual impairments, but also would take advantage of this and create packaging that met the EU's standards so that they would be able to sell locally manufactured medication/medication packaging overseas in the EU. Unfortunately, without the FDA or Health Canada's input on either creating mandates for braille in packaging, or otherwise offering subsidies or incentives that would benefit both parties (manufacturers and pharmacies) as well as the visually impaired, it is unlikely that any progress will be made in implementing braille into pharmaceutical products in North America. This much is still true today, however braille in itself is an old technology. Despite being invented in 1824 and having been "translated" into many languages (Britannica, 2024a), it is worth looking into newer, and more modern solutions to make pharmaceuticals accessible to those with visual impairments. The use of QR codes or Near Field Communication (NFC) are becoming increasingly popular in not just accessibility, but almost everything from advertisement to self checkout at clothing stores (Packaging Europe, 2024). Also, because mobile smart devices are becoming very common and are an accessibility aid in themselves, is it not unreasonable to assume that the advancement of alternative technologies like QR codes and NFC are capable of benefiting even more people than braille, because it does not require the user to learn an entirely new "language", and only requires a smart device like a cellphone. NFC is significantly more applicable to increasing accessibility in pharmaceuticals than QR codes, as someone who is visually impaired or blind may struggle with lining up their mobile device's camera with the code. On the other hand, the only thing an NFC tag requires in order to be read is a mobile device in its vicinity (Upadhyaya, 2013). This can be combined with something like a screen reader or text-to-speech application that could read the contents of the NFC tag out loud and tell the patient exactly what their medication is, how much to take, and when to take it. This would completely eliminate guessing on behalf of the patient, as well as increasing the amount of information available, as it removes the constraints of the information that can fit on the box when written in braille.

Conclusion

In order to answer the research question—should Canada take steps towards implementing similar laws and legislation regarding braille on pharmaceutical packaging similar to that of the European Union in order to increase accessibility for the visually impaired—it is important to consider multiple perspectives, as well as the pros and cons of this technology. Conclusions for this question were drawn from statistical data in terms of the population braille can serve, as well as opinions from industry professionals like pharmacists, and consider the visually impaired individuals who would actually be impacted by this technology in their day to day life. While these research methods provided solid and useful information overall, it consists of general overarching statements that apply to low vision individuals worldwide, and lacks first-hand data specific to the Canadian population and experience.

Overall, studies have shown that those with visual impairments struggle to identify important information relating to their medication, such as the name, dosage and other important information, and can even struggle to differentiate between different medications themselves. This can have negative consequences, as the incorrect consumption of medication can potentially be dangerous. Because this was the main motivator behind the implementation of braille standardization in the EU and this issue is not exclusive to individuals in the EU as predicted, it is not unreasonable to expect Canada to increase the accessibility of pharmaceutical packaging, as well. From a statistical standpoint, a higher percentage of Canada's visually impaired population are capable of reading braille than in the EU, however because of the EU's larger population, the actual number of braille-literate individuals in the EU is still higher. This was somewhat unexpected as, given the prominence of braille in various packaging both inside and outside of the medical field in the EU, it was assumed that there must have been a high rate of literacy. The rights of those with disabilities were also examined between the two regions, and it was determined that there is a lot of similarities between Canada's and the EU's, so that one could reasonably assume that Canada's emphasis on "reasonable accommodation [for disabilities]" would include a visually impaired individual's ability to confirm the name or dosage of something as important as medication.

Results from the case studies determined that many pharmacists, those who regularly counsel visually impaired individuals on medication, also agree that pharmaceuticals would benefit from being more inclusive with the addition of braille, though the pharmacists working in an environment that already utilize braille provided a higher rate of approval than those that did not. This case study was extremely useful in answering the proposed research question, as the opinion of these medical professionals with firsthand experience was highly regarded. Given these results, it is evident that Canada is lacking in pharmaceutical packaging accessibility for the visually impaired. Even with local organizations

attempting to work with the government to come up with a solution, little to no progress has been made to increase accessibility. When considering whether Canada should implement legislation regarding braille on these packages, the answer is not as clear. While braille would be very beneficial for those who need it, it is important to remember that not all visually impaired/blind individuals can read braille in the first place, and may choose to utilize other, more modern aides in place of it. Alternate solutions, such as the inclusion of NFC tags in pharmaceutical packaging, so that an individual can tap their mobile device to the package and have it read out loud the name, dosage and other important information, may be a better solution simply because of the prevalence of mobile devices, especially due to its usage as an accessibility aide. The use of NFC can certainly benefit more people than braille.

Both proposed solutions have their own advantages and disadvantages, especially considering that there is little research into the benefits of NFC in packaging for the visually impaired and would greatly benefit from more modernized possibilities. Further research into how NFC or other modern technologies could potentially benefit the visually impaired in a pharmaceutical setting would be very insightful. It is also important to remember that the research outlined in this paper is purely from a societal perspective, and does not take into account the technical side of packaging, such as the manufacturing processes and associated costs of either braille application or NFC tags. One thing is for certain, however: Canada's current pharmaceutical packaging is not accessible for those with visual impairments and change needs to happen. Unfortunately, it is unlikely that changes will be made unless Health Canada or other government agencies take action and create mandates or some other incentive for manufacturers to increase accessibility of pharmaceutical packaging for the visually impaired. Hopefully, the information outlined in this paper, along with the research conducted can provide a deeper understanding of the struggle a visually impaired individual may experience when taking medication and the potentially dangerous consequences of incorrect consumption. As learned when conducting research, perhaps the government may consider implementing any of the outlined solutions that may make this experience less of a guessing game, and overall safer for individuals who struggle with medication consumption due to inaccessibility.

Appendix A

Statistics Calculations

This appendix relates to the information gathered for Figures 2 and 3. All the information displayed in these figures came from separate sources (CNIB, n.d.; European Blind Union, n.d; World Health Organization, 2003), and required calculations to come to the final percentage as seen in the third column. In order to determine the totals in each category, the percentage (second row) was multiplied by the original total population (first row). The raw data and calculations can be seen in the excel figure below.

Canada	
Total Pop.	38,000,000
Visually impaired (%)	4%
Total visually impaired	1,520,000
Total visually impaired	1,520,000
Braille readers (%)	26%
Total braille readers	395,200
European Union	
Total Pop.	447,000,000
Visually impaired (%)	5%
Total visually impaired	26,000,000
Total visually impaired	26,000,000
Braille readers (%)	10%
Total braille readers	2,600,000

Figure A1. Canadian and European Union raw data calculations comparison.

It was found that some sources of information conflicted with others. For example, the World Health Organization states that the total population of the European Union is 447 million, but when calculated with the percentage of visually impaired individuals (5%), the number does not add up to the given ~26 million individuals with visual impairment as stated by the European Blind Union. Because of this, all numbers are approximate.

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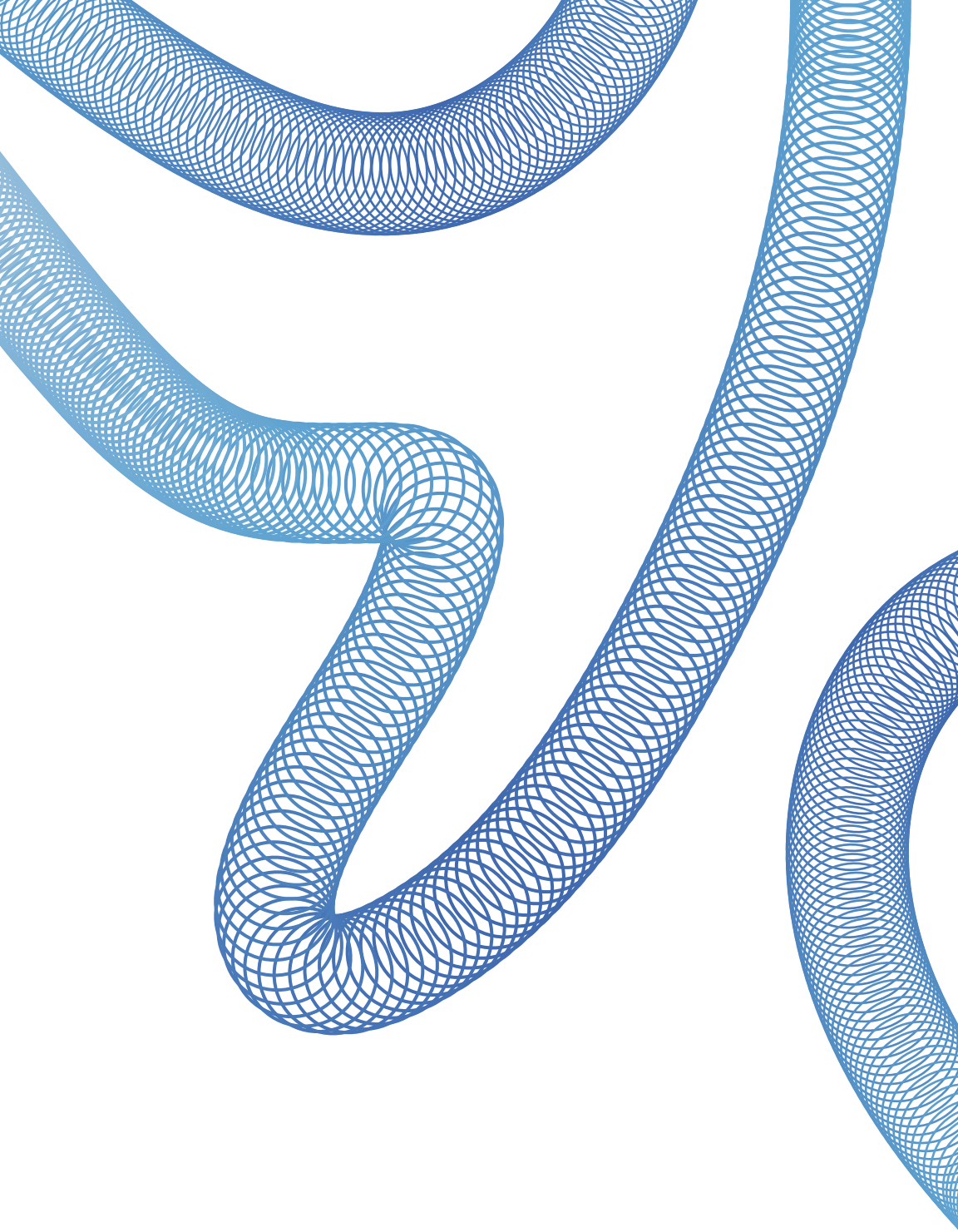

TMUTAGA

05

IMPLEMENTATION OF REVERSE VENDING MACHINES IN TORONTO TO IMPROVE CIRCULAR ECONOMY

Sara Khalili

I am an artistic innovator and entrepreneur. Alumni of Toronto Metropolitan University's Graphic Communications Management and Conestoga College's 3D Animation programs. I am continuing my personal research on the simplification and foundations of living, mindfulness, and interconnection, based upon cosmology, ancient history, and cultural sociology. I planned my thesis of implementing Reverse Vending Machines in Toronto since 2019 and I wholeheartedly express my appreciation and love for those who supported me in my journey. I trust that my thesis will influence the Government of Ontario to timely take initiative to better Toronto and take lead in strengthening the country.

To listen to Sara's thesis, use this link:

5

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Abstract:

As we approach the quarter of the twenty-first century, the city of Toronto faces major environmental crises, primarily plastic pollution, due to unsustainable mass production and improper disposal of recyclable materials. While theoretically consumerism can come to an end, Canada, amongst many first world countries, possesses consumer-driven societies where the common belief is that one's greatest contribution is the money they spend. Most present-day societies suffer division and tunnel-vision within socio-economic statuses as social media overtakes reality and there are no priorities or discipline in sight. Because of this, consumerism cannot realistically be ended overnight. However, consumerist habits can be altered slowly starting with this generation if the city takes steps to better utilize current trends and their impression on residents. Innovations such as reverse vending machines (RVMs) can be a start to an education and introduction to a bottle bill so as to revolutionize waste management and promote Toronto's circular economy, thereby leading by example for the rest of the country. This study explores the many benefits of implementing reverse vending machines (RVMs) in Toronto as a strategic intervention to consumerism and especially plastic pollution to advance into a more sustainable and responsible era, based on pre-existing data from countries that have successfully implemented RVMs such as Norway and Lithuania. This is a method to get residents of Toronto accustomed to Ontario's updated bottle bill, inclusive of any beverage packaging.

Figure 1. TOMRA R1 Reverse Vending Machine.

Introduction:

A report commissioned by the Canada Plastics Pact states that in 2019, of 1.9 million tonnes of plastic packaging that Canada produced, just 12 per cent was sent for recycling and an even smaller percentage was reused (Warnica, 2022). These statistics are shockingly low for Canada considering that other countries countered the recycling problem decades ago, such as Norway, where in 2019 approximately 90% of total plastic bottle and aluminium can sales were recollected solely through RVMs (Infinitum, 2019). Another issue is that plastic on its own is unsustainable. Other materials such as aluminium have proven far more effective in recycling since plastic can only be recycled about seven times before losing its quality, while aluminium can be recycled infinitely (Klein, 2021). The Aluminium Association pointed out that five million tonnes is recycled in Canada and the US each year, with about 75% of all aluminium produced when it first entered the product market as foil and packaging in the early 1900s still in use today in some form (Richmond Steel, 2019). As of 2026, the Extended Producer Responsibility (EPR) will be fully implemented in Ontario, “where innovators are awarded for efficiencies and free-riders are penalised for not following the rules”

(Edwards, 2020). Now, producers, importers, and brands must pay 100 per cent of the cost of recycling just like in Québec and British Columbia (2020).

Before this program in Ontario, producers were required to pay 50 per cent only. This shifts the responsibility and costs of recycling from the government to the producers themselves, which could subsequently motivate them to be more responsible and realistic with their production.

Implementing RVMs in Toronto

Like EPR, Toronto desperately needs an incentivised program for consumers that would not only reward them for recycling with incentives of the city's choice, but could deter consumers from purchasing products with plastic packaging by rewarding the use of more sustainable materials.

This would be the beginning of the end of most plastic production in the beverage industry, starting with Toronto, and the potential success would lead the rest of the Canadian provinces. This system is also a differentiator from other countries' bottle bills as most programs reward the same amount for materials. Implementing reverse vending machines (RVMs) in Toronto could have a great impact on promoting recycling and sustainable waste management practices. This research will assess the effectiveness of RVMs in incentivising individuals' recycling initiatives and their role in bettering the circular economy. RVMs can be a modern solution to a long-foreseen problem as it can be better suitable for future generations that are encompassed by social media trends and technological advances.

Addition to Toronto's Long Term Waste Management Strategy

Currently, the City of Toronto has a roadmap in place that was approved in 2016 after extensive research and public input, emphasizes waste reduction, reuse, and recycling to divert 70% of waste from landfills by 2026 (City of Toronto, 2021). The Community Reduce & Reuse Programs aligns with Toronto's Long Term Waste Management Strategy, as it aims to educate residents on waste reduction and reuse, providing skills training and economic prospects (2021). It focuses on promoting resource conservation and a circular economy, which aligns with the purpose of implementing RVMs in Toronto, especially being user-friendly and easily adaptable to current society.

Literature Review:

Canada is the highest per capita producer of material waste and is the seventh highest per capita emitter of greenhouse gases, according to the World Bank's What a Waste global database (Alessio & Beaudoin, 2022). However, Alessio & Beaudoin claim that many circular economy strategies have been part of federal, provincial and municipal efforts and policies for decades, so the issue is not overlooked (2022). While the root of the problem is the lack of consequences and responsibility within mass production, the solution can start with shifting

consumerist habits to deter mass producers from continuing their production and overuse of unsustainable materials like plastic. This can be done using innovation that can easily catch on within social media trends.

Reverse Vending Machines (RVMs) are not a permanent solution to Toronto's plastic pollution, but a start to re-education using methods that would end the cycle with this generation and completely turn around the next. This literature review utilises a variety of sources, including articles and peer-reviewed journals, as well as global government and corporate commissioned reports to narrow down the root of the problem to Toronto's plastic problem and present a modern solution.

Psychology in Consumerism

Society is no longer living, but rather is hypnotized by the unsustainable façade of consumerism. Corporations have successfully infiltrated and invaded every individual's day to day lives in developed countries through constant unavoidable advertisements and marketing schemes anywhere in sight, with the pressure to buy - at the price of individuals in underdeveloped countries that provide resources and products through unethical, unsafe, and inhumane labour. Health psychologists have shown how actual purchasing and consumption behaviour can be shaped by subtle "nudges", like flyers or posters in grocery stores, butcher shops, and university cafeterias (Bargh, 2021). Bargh mentions that there is a growing disconnect to reality because reliable unconscious mechanisms have been actively invoked by advertisers and marketers (2021). People no longer have uninfluenced thoughts. Everyone must watch the same trending show, drink the same trending beverage, and wear the same trending outfits. Sprite claims that image is everything, yet we are not encouraged to create our own image (Frantz, 2000).

Frantz says that due to this, everyone is suffering, yet the majority don't mind this cookie-cutter culture (2000). For that reason, a start for a healthier society would be informing consumers of the unconscious influences on their purchases and behaviour, at least giving them the chance to adjust or correct for any unwanted influences (Wilson & Brekke, 1994). By admitting that society is no longer aware or in control of their influencers, they simultaneously gain control and "free will" over their choices and behaviour (1994). To do this, current technological advancements must be utilized to capture the attention of this generation, rather than resorting to old-fashioned methods that unfortunately no longer work due to the low attention span of most since the release of short reels on social media.

Ontario's Blue Bin and Extended Producer Responsibility

Greenpeace spokesperson Sarah King says "Canada must take a hard look at its overproduction, consumption and pollution of single-use plastic and the toll it is taking at home and abroad." (Edwards, 2020). Canadians are addicted to plastic.

Edwards states that in a single year, Canadians generate 4.6 million metric tonnes of plastic waste and only nine per cent of plastics produced are recycled; most of it accumulating in landfills in Canada and in other countries as Canada runs out of space (2020). In 2015, Canada exported 100,618 tonnes of plastic waste to China (Montrouge, 2019). In 2017 the amount exported to China reduced to just 48,143 metric tonnes between the first and third quarter as they changed their policies (2019). Later, Malaysia was found to be the biggest new export destination for Canada and other high-income countries, importing nearly half a million tonnes in 2018 (2019). Warnica warns that Ontario is set to run out of landfill space by 2032, and other countries, like China, are now increasingly unwilling to take Canadian trash (2022).

With mass production on the loose, there is a mentality engrained in consumerists meant to pressure them to buy what is advertised to them while simultaneously guilting them into believing they are the problem child when they are merely products of their environment. The blue-bin program in Ontario was a pretence to pin the plastic pollution crisis on consumerists, when the real problem derives from the leeway Canada amongst many countries allows for mass production of wasteful products to take place at all. In the blue-bin program, the government of Ontario allows for a very specific list of items to be recycled such as some glass containers, certain clear plastic containers, certain paper, foam polystyrene, certain stretchy plastics, and aluminium to be recycled but does not allow for another long list of items to not be recycled such as black plastic, cling wrap, straws, drinking glasses, tissues, and more (City of Toronto, 2024). This system is outdated as it is inconvenient for both the consumer and the recovery facility and pins the responsibility on consumerists solely to recycle properly when those same items that are causing inconvenience are advertised to them wherever they look.

The government of Ontario has introduced EPR, and as of 2023, producers are now required to pay 100 percent of the recycling costs as opposed to 50 per cent before, and therefore it privatized the blue-bin program by handing it to Circular Materials Organization that represents the largest packaging producers including Costco, Coca-Cola, Loblaws, and McDonalds (Pender, 2023).

Now, mass producers have more control over Ontario, starting with who receives the blue-bin service and who doesn't. Terry mentions that a lot of commercial-industrial-institutional locations, such as churches, mosques, temples, daycare centres, and downtown business districts, will not be included when the program goes private (2023). "Under the new Blue Box Regulation, producers will be responsible for fully operating and funding the program," the organization says, adding that the transition to the new system is taking place between now until full EPR implementation in the province starting Jan. 1, 2026 (Taylor, 2024). The organization says technological advancements that will improve efficiency and accuracy are in development including artificial intelligence- (AI)- enabled cameras

and optical sorters with advanced sensors at the collection and sorting stages, says Taylor (2024).

Aluminium over plastic

Since Circular Materials Organization claims that it will save each company that is on the board of directors upwards of 100 million if they run the blue-bin program including Loblaws, Costco, Coca-Cola, Maple Leaf Foods, Procter & Gamble, and a dozen more (Crawley, 2024), there would be room to discuss a transition from plastic bottle packaging to aluminium packaging. “Very rarely in Costa Rica do you see aluminium trash at a beach, because it has a market value.” (Klein, 2021). Aluminium is named “infinitely recyclable,” and has a much higher recycling rate in the U.S. compared to plastic, according to the U.S. Environmental Protection Agency (2021).

However, due to its heavier weight, it risks increased greenhouse emissions (2021). A few companies have successfully implemented aluminium packaging like Trivium packaging (2021). The manufacturer makes aluminium packaging accessible for smaller eco-conscious water, cleaning and personal care companies including ThreeMain, RainForest Water in Costa Rica, Petal, By Humankind and Hand in Hand (2021). Because only select suppliers offer aluminium containers, they are pricier than plastic which is mass produced. However, the customisability of both aluminium and plastic containers is similar, where they can both be fitted, shaped, and engraved. They are both safe to drink, but some would prefer plastic over aluminium since it does not have a metallic taste, but plastic risks harmful chemicals being leached into the product especially after expiration date (2021).

Reverse Vending Machines (RVMs)

A reverse vending machine (RVM) is a specialized device designed to automate the process of collecting and recycling waste, most commonly beverage containers such as plastic bottles, glass bottles, and aluminium cans. Their purpose is to increase recycling rates by providing convenient and accessible deposit return systems that deliver incentives to consumers, helping to reduce glass, metal and plastic waste. While today there are a variety of different types in use in countries like the United Arab Emirates, Indonesia, Lithuania, Norway and more, Portilla says that most models work similarly by identifying, sorting, and sometimes cleaning contaminated items, then sending them to recycling facilities (2021). Because consumers use over 1.4 trillion beverage containers every year worldwide, the reverse vending machine’s purpose is to help reduce and recycle this waste (Taylor, 2021). Countries such as Lithuania and Norway, later explored in methodology, prove that RVMs have a positive impact on residents recycling efforts.

Due to rising demand for lowering landfills and expanding recycling rates, the RVM market is anticipated to have considerable growth over the upcoming years as environmental preservation becomes more of a priority (Pandey, 2023).

"The Global Reverse Vending Machine Market was USD 278.20 Mn in 2021 and is growing at a CAGR of 2.90% year on year, and it will reach USD 339.80 Mn in 2029 (2023)". It is important for Canada to follow in the footsteps of countries that implemented RVMs successfully to stay ahead in the market and have better insight into the possibility that investing in RVMs could be more cost effective than solely relying on the blue-bin program and all the uncertainties that come with it.

RVMs offer many benefits and improve recycling rates, states Taylor, starting with incentivised recycling, as users are motivated by rewards like monetary refunds or coupons (2021). This comes with many benefits as it improves circular economy, reduces recyclable material sent to landfills, and gives back to loyal consumers possibly promoting certain brands if so they choose to sponsor the RVMs launch or even purchase their own RVMs with customized perks. Next, they offer convenience to recycling as they can be placed frequently and strategically around Toronto, and some models such as the TOMRA R1 can accept up to 100 plastic bottles and aluminium cans at once (TOMRA, n.d.). Additionally, they serve as educational tools, particularly for newer generations, reinforcing recycling habits and awareness. This can be done by adding advertisements on the RVMs whether they are posters or screens. Moreover, RVMs create employment opportunities and inspire innovation in sustainable recycling solutions, signalling a promising future for environmental consciousness and technological advancement. Efficient material sorting in RVMs is facilitated by advanced technology, enabling identification, validation, cleaning, and sorting of items into different categories like plastic, glass, and metal. In the future, models will most likely include AI considering that the Circular Materials Organization in Ontario is integrating artificial intelligence in their recovery facilities, so this would possibly be done by RVM manufacturers as well. This sorting process ensures that recycling begins with clean and sorted materials, and not only does it minimise contamination throughout the recycling stream, but it also saves time and cost later at the recovery facilities, yielding a higher quality recycling rate (Taylor, 2021)

Tomra is present in 60 countries with over 82,000 reverse vending machines tailored to the needs of the different markets. There is a high probability that Tomra has the perfect RVM model for Toronto. Its portfolio contains a variety of solutions suitable for different types of shops and areas of use – from small newsagents to big hypermarkets (TOMRA, n.d.). The TOMRA R1, for example, is a compact RVM designed for indoor use. It accepts both plastic bottles and aluminium cans, with a capacity to process up to 100 containers at once. It utilises advanced sensor technology and machine learning algorithms to accurately identify and sort different types of containers. It also features an intuitive touchscreen interface for users (n.d.)

Waste-pickers

Incentives such as monetary rewards, coupons, vouchers, and credits for utilities like electricity and water bills motivate people to recycle better by

providing tangible benefits for their efforts, and they give back to consumers. For instance, in Australia, initiatives like Envirobank offer credits for public transportation in exchange for recyclables deposited in machines (meuResíduo, 2021), this would be a good idea for the city of Toronto to explore considering the TTC is not affordable for many. Similarly, in Brazil, the Ecoelce system rewards residents with credits on their electricity bills based on the market value of recycled materials (2021). Indonesia's program in Surabaya allows the use of recycled bottles as payment for public transportation, tackling the plastic problem while incentivizing recycling (2021).

Through the collection and recycling of plastic and glass bottles, and aluminium cans, incentives for recycling can create job opportunities for people who need additional income. So, by implementing RVMs in Toronto, the struggle of unemployed and unhoused individuals would come to light and be presented with some solutions. Barford & Ahmad discuss in their article how in low- and middle-income countries, informal waste pickers play a crucial role in the recycling loop of the circular economy, often under challenging conditions with minimal social protection and low wages (2021). Despite their contribution to addressing environmental issues such as plastic pollution and greenhouse gas emissions, waste pickers typically receive little recognition or support (2021). Implementing RVMs would not only offer them convenience, but it would raise awareness and educate them on the importance of their jobs. With that said, Jandira Morais et al argue that the formalization of waste picking activities into municipal solid waste management sectors could potentially improve waste pickers' lives by providing legal recognition, safer working conditions, and fair bargaining mechanisms (2022). Nevertheless, initiatives such as bottle bills and recycling incentives can directly benefit waste pickers by increasing the volume of recyclables available for collection, thereby creating more opportunities for income generation and simultaneously bettering the circular economy. By acknowledging the essential role of waste pickers and implementing policies that support their formalization and well-being, countries like Canada can create more inclusive and sustainable recycling practices while providing much-needed economic opportunities for marginalised communities (2022).

Methodology

This methodology focuses on analysing data to calculate the potential success of implementing RVMs in Toronto, based on existing data from global bottle bills reports in Norway and Lithuania after successfully implementing RVMs. Using quantitative data was most suitable for this methodology because it assessed regular consumer habits, and it is measurable. It is realistic to compare Ontario's alcoholic beverage bottle bill considering that in Norway and Lithuania there was an influx in their recycling rates after the implementation of a bottle bill and the convenience of reverse vending machines. The data I collected is solely from secondary research where I gathered data from surveys

done by a Toronto Metropolitan University graduate as well as a government commissioned survey on Ontario's blue-bin program, and a global survey with the purpose of understanding the factors and changes in consumerism. Next, I compiled official government commissioned reports on the success rate and redemption rates of bottle bills globally, including Norway, Lithuania, and all provinces of Canada,

To start, I started by extracting data from previous research based around the demographics and psychological factors playing into purchasing behaviours and recycling. The first of which being from a former graduate of Toronto Metropolitan University, Layla Ali Abdi, who wrote her thesis on the waste management system for the City of Toronto's household recyclables. Her survey was gathered using Toronto residents and part of her survey gathered data about the demographics and their likelihood of and interest in recycling, as well as issues they face when doing so. Next, I used a survey done in Ontario and Québec in 2016 highlighting residents' barriers to recycle and what factors would improve their likelihood to recycle. I used one more survey done by the American Chemistry Council that highlighted the consumers willingness to pay extra for environmentally friendly products and their purchasing habits. These three surveys played an important role together in determining the success of the implementation of RVMs in Toronto as they consider many factors that RVMs cover.

Next, I compiled bottle bills from all the provinces in Canada into one table to compare from the official website, and I gathered data from Norway and Lithuania as they successfully implemented a bottle bill and later RVM and recorded their statistics and compared it to the Ontario bottle bill statistics for alcoholic beverages.

Results

Demographics

The following data is extracted from a survey commissioned in 2016 by the Carton Council of Canada (CCC) covering residents of Québec and Ontario, based on a sample from 1000 residents of each province that reveals factors that play into willingness and barriers to recycle. Participation of the survey was limited to people who have access to curbside recycling or the blue-bin program.

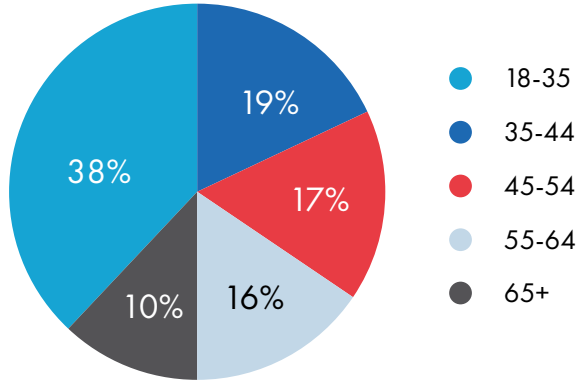


Figure 2. Age of 2000 residents of Ontario & Québec.

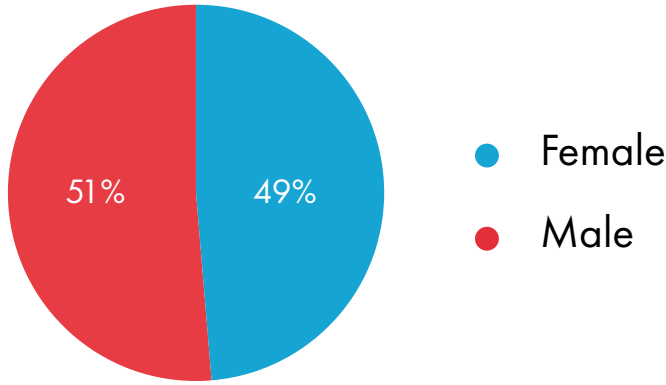


Figure 3. Gender of 2000 residents of Ontario and Québec.

Factors in recycling stage

The following data is extracted from a survey done by Layla Abdi who compiled data from a survey of 211 residents of the Greater Toronto Area, in 2020, where respondents scored a mean of 3.84 (Figure 4), on a (1-5) linear scale on a question asking the interest of residents in recycling. Simultaneously, in another question in the survey, Abdi asked respondents to classify how they determined what items were recyclable (Figure 5) (2020). 172 respondents, representing 82% of the study, selected they had either made an educated guess or relied on the recycling symbol to determine where items went (Figure 4) (2020). Abdi indicates the improper disposal techniques employed by residents of Toronto, with only the "Waste Wizard App" being the correct technique (2020).

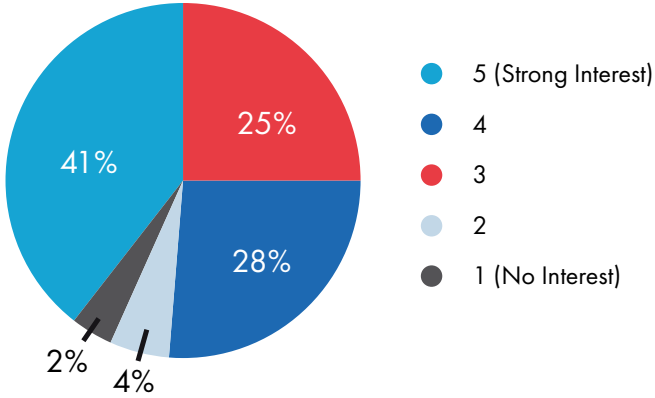


Figure 4. Respondents Interest towards Recycling.

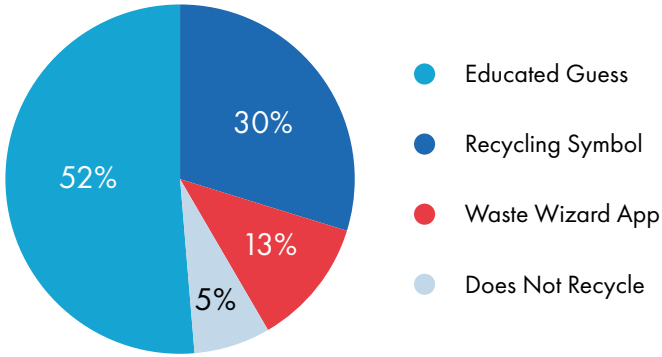


Figure 5. Respondents on Determining What Items were Recyclable.

Barriers and Motivators

Looking at the survey commissioned by CCC, which asked 1000 residents of Ontario and 1000 residents of Québec what their biggest barrier to recycling is, the main barrier to recycling is a lack of knowledge and awareness (Recycle Cartons, 2016).

- "I forget" (55%) (2016)
- "I didn't know I could" (54%) (2016)
- "I'm not sure how" (49%) (2016)
- "I don't have time" (10%) (2016)

Lack of will/commitment and logistical barriers are much less significant (2016).

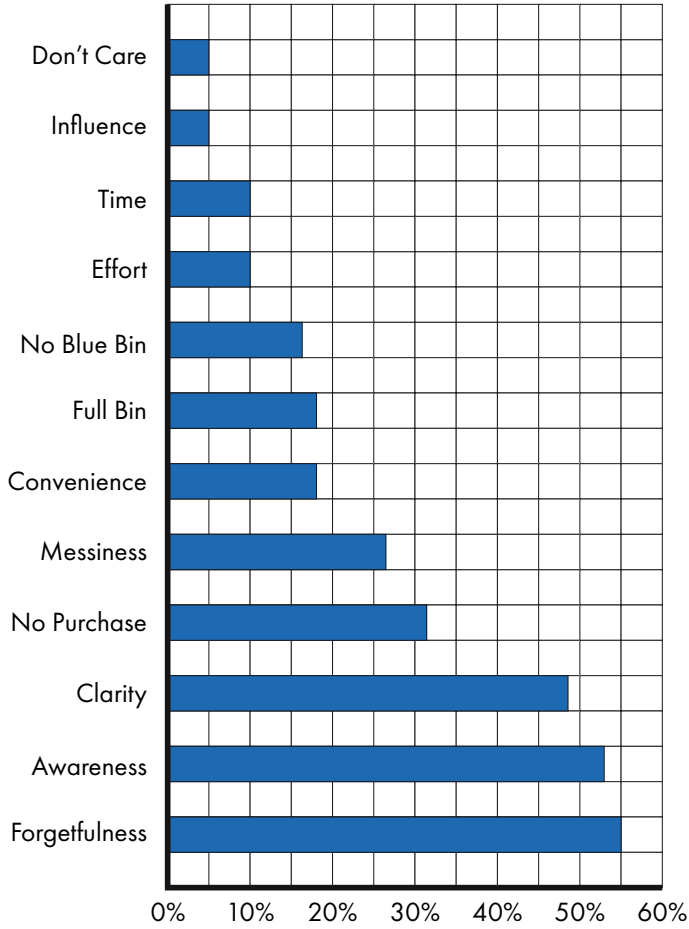


Figure 6. Ontario and Québec Residents' Barrier to Recycling.

Among people who do not regularly recycle food and beverage packaging, "easy to identify recycling information" is the approach most often identified as likely to encourage them to recycle cartons (62%) (2016). A "better understanding of benefits of recycling" comes in second (39%) (2016).

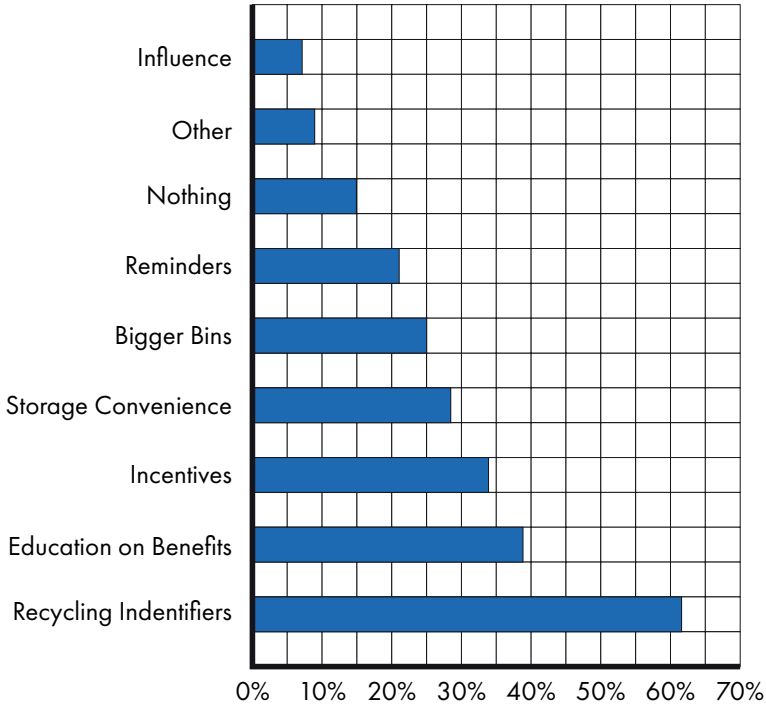


Figure 7. Ontario and Québec Residents Motivators to Recycle.

Factors in Purchasing Stage

The following survey is completed by Accenture Chemicals in 2019 on 6,000 consumers in 11 countries across North America, Europe and Asia, where the results were previewed at the American Chemistry Council (ACC) and they found that while consumers remain primarily focused on quality and price, 83% believe it is important or extremely important for companies to design products that are meant to be reused or recycled (Cantwell, Nolan, & Corser, 2019). Nearly three-quarters (72%) of respondents said they are currently buying more environmentally friendly products than they were five years ago (2019).

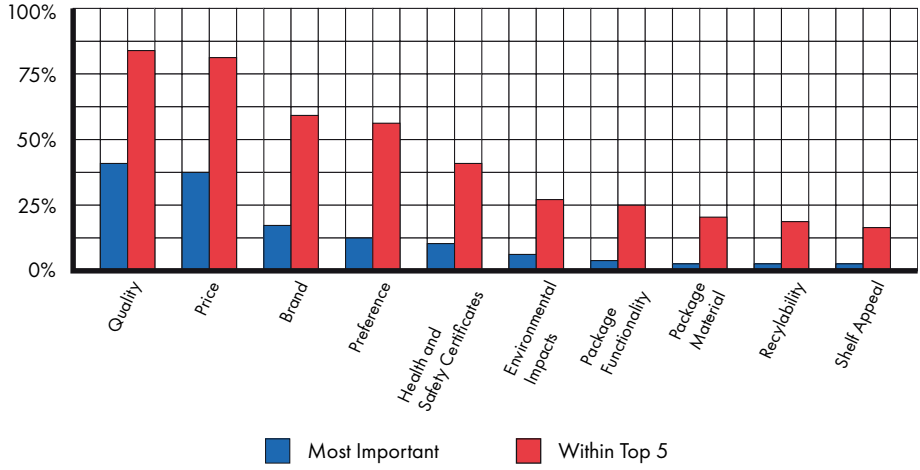


Figure 8. Factors in Consideration During Purchase.

The following graph depicts that 6000 consumers globally cut down on purchases from certain industries, while the vast majority (55%) stopped buying products completely (2019).

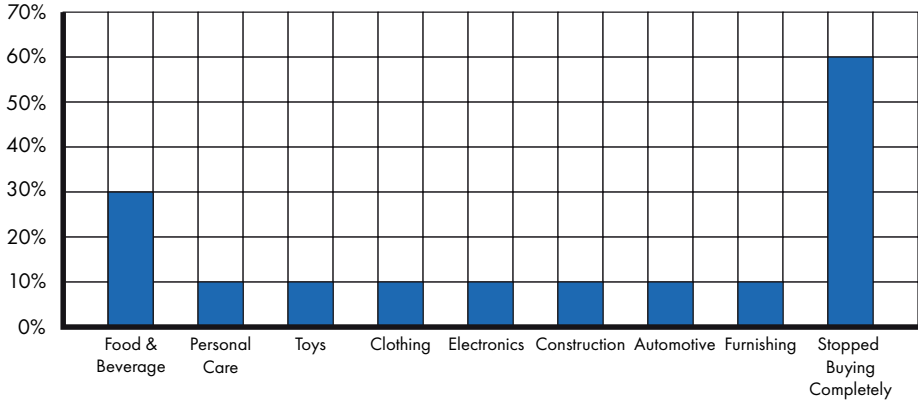


Figure 9. Industries Consumers are No Longer Purchasing From.

The following graph shows consumers' preference in packaging when buying products as it has become a much larger priority and habit to recycle properly. This is a factor that plays into why they would stop purchasing completely, considering that a lot of products especially in food & beverage don't allow for environmental consciousness.

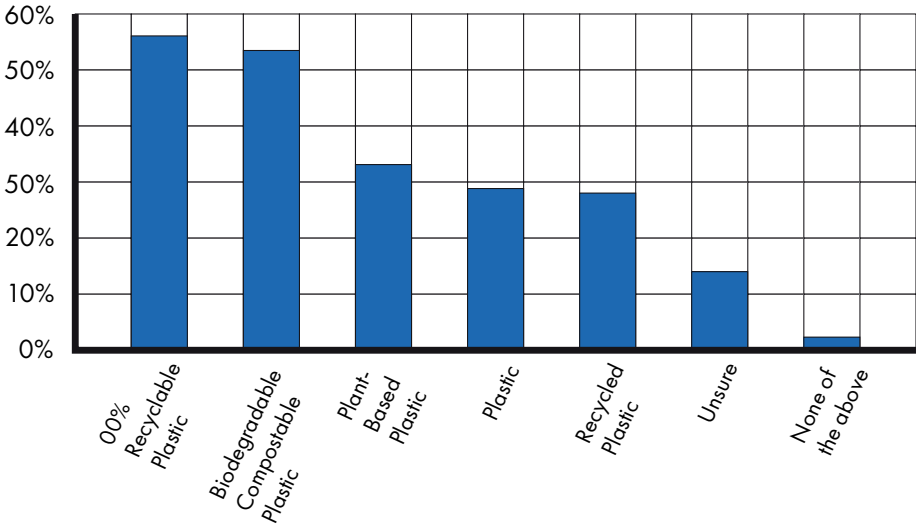


Figure 10. Consumers Preference in Packaging.

10. Bottle Bills by Province

This table is a compilation of all bottle bills in Canada by province, it depicts that aside from Ontario, most provinces with the exception of Nunavut and Manitoba have implemented a bottle bill allowing for residents to return, on average, any container beverages. Currently, Ontario has a successful bottle bill for alcoholic beverage with incentives while non-alcoholic beverage containers are picked up curbside without incentives (Container Recycling Institute, 2023).

Table 1. Canada Bottle Bills by Province from Container Recycling Institute.

Province	Date Implemented	Containers Covered	Amount of Deposit (CAD)	Reclamation System
Alberta	1972	All sealed containers purchased in province	≤1 litre: 10¢ >1L: 25¢	221 operating registered depots and 10 Class-D depots (return to retail)
British Columbia	1970	All types	10¢ for any size	Return to retailer
Mantioba	2008	Beer only	Beer cans and Bottles <2L: 10¢ Beer cans and Bottles ≥2L: 20¢ Reusable metal kegs: $40.00	Return-to-retail for beer only
New Brunswick	1992	All beverage containers 5L and under	Alcoholic beverages ≤500mL: 10¢ / 5¢ Alcoholic beverages >500mL: 20¢ / 10¢ Refillable beer containers: 10¢	Return to licensed redemption centers
Newfoundland and Labrador	1997	All beverage containers 5L and under	Non-alcoholic beverages: 8¢/5¢ Alcoholic beverages (excluding wine and spirits): 8¢ / 5¢ Wine/spirit in plastic, glass, tetra-pak: 20¢/10¢ Other containers: 8¢ / 5¢ *Consumers receive a partial refund of either 10¢ or 5¢, depending on the type of beverage and container of each beverage*	221 operating registered depots and 10 Class-D depots (return to retail)

Province	Date Implemented	Containers Covered	Amount of Deposit (CAD)	Reclamation System
Northwest Territories	2003	Glass bottles, Aluminum cans, Plastic bottles Tetra pak/drink pouches, Gable top containers, Bi-metal containers	Containers ≤ 1L: 10¢ Containers >1L: 25¢	Return to licensed redemption centers
Nova Scotia	1996	Plastics, Metal, Bimetal, Glass, Gable top, Tetra Pak	Non-alcohol containers < 5l: $0.10 / $0.05 Wine/spirit >500ml: 20¢ / 10¢ Wine/ spirit ≤ 500ml: 10¢ / 5¢ Beer: $1.20 per dozen bottles *Consumers receive only half of their deposit back when they return non-refillable containers*	221 operating registered depots and 10 Class-D depots (return to retail)
Nunavut	2001	Aluminum	Cans: 15¢; 10¢	Return to depot
Ontario	2007	Alcoholic beverages only Plastics (PET), metal (aluminium/ tinplate), Bimetal, Glass, Gable top, Tetra Pak, Bag-in-box containers	Glass bottles, plastic bottles (PET), Tetra Pak containers, bag-in-box: ≤ 630mL: 10¢ > 630 mL: 20¢ Aluminium and steel containers ≤ 1L: 10¢ > 1L: 20¢	Return to The Beer Store (TBS), bulk return locations, or contracted empty bottle dealers (LCBO does not accept containers)

Province	Date Implemented	Containers Covered	Amount of Deposit (CAD)	Reclamation System
Prince Edward Island	2007	Plastics, Metal (aluminium/ tinplate), Bimetal, Glass, Gable top, Tetra Pak, Bag-in-box, Pouches	Non-alcoholic beverages ≤ 5L: 10¢ Wine/spirits ≤ 500ml: 10¢ Wine/spirits 501 ml to 5l: 20¢ Beer cans/bottles ≤ 500ml: 10¢ Beer cans/ bottles ≥ 501 ml: 20¢ Refillable domestic beer bottles (fully refundable): $1.20 per dozen bottles *Prince Edward Island operates a half-back system on all non-refillable beverage containers, where non-refillable containers will only have half of their deposit returned*	Licensed beverage container depots
Québec	1984, updated 2022	Aluminium, Plastic, Glass,Multi-layer/ material container	Soft drink containers & beer cans ≤ 450ml: 5¢ Non-refillable beer > 450ml: 20¢ One-way glass containers ≤ 450ml: 10¢ **After November 2023:** Non-glass containers: 10¢ Glass containers ≥ 500mL: 25¢ Glass containers <500 mL: 10¢	Return to retail

Province	Date Implemented	Containers Covered	Amount of Deposit (CAD)	Reclamation System
Saskatchewan	1973	All ready-to-serve beverage containers	Metal/aluminium cans: < 1L: 10¢ ≥1L: 25¢	Not-for-profit SARCAN redemption depots
			Glass: ≤ 300ml: 10¢	
			Glass Between 300mL and 1L: 20¢	
			Glass: ≥ 1l: 40¢	
			Plastic: <1L: 10¢ ≥1L: 25¢	
			Juice boxes/ gable top cartons: <1L: 10¢ ≥1L: 25¢	
			Refillable beer bottles (one size): 5¢	
			All containers are also subject to a nonrefundable Environmental Handling Charge (EHC)	
Yukon	1992	All beverage containers	Containers ≥750mL: 35¢ /25¢	Return to depot
			Containers between 30mL and 750mL: 10¢ / 5¢	
			Milk and milk substitutes (≥30mL): 10¢ / 5¢	
			When purchasing beverages, the consumer pays a deposit, which includes a refundable portion and a nonrefundable Recycling Fund Fee (RFF).	

Over the years 2004 to 2019, most provinces have seen their rates increase gradually, while Ontario's rates fall in beverage container recycling rates from 56% in 2012 to 46% in 2019 (CM Consulting, 2020).

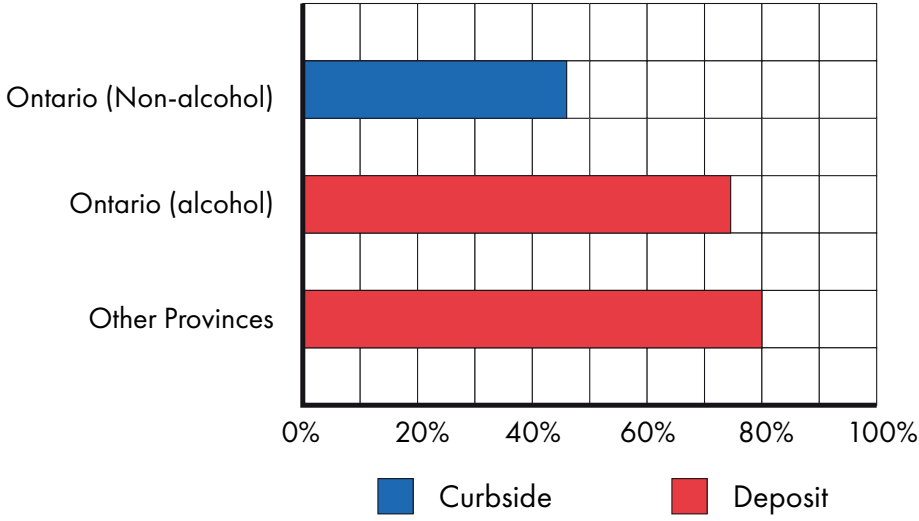


Figure 11. Provincial Recycling Rates in Canada.

Ontario Bottle Bill

This table is from the bottle bill website, it allows for a closer look at what goes into consideration when creating a bottle bill. The same functions will most likely be used in Ontario's new and updated bottle bill that includes all beverage containers.

Table 2. Ontario Alcoholic Beverage Bottle Bill.

Name	Ontario Deposit Return Program (under the Liquor Control Act); Bag it Back
Date Enacted	2006
Date Implemented	02/05/2007
Containers Covered	Plastics (PET), metal (aluminium/tinplate), bimetal, glass, gable top, Tetra Pak, bag-in-box containers [1]
Beverages Covered	All alcoholic beverages (including wines, beers, and spirits)
Beverages Not Covered	-Non-alcoholic beverages -Containers ≤100mL in volume -Containers purchased at duty-free stores
Amount of Deposit	Glass bottles, plastic bottles (PET), Tetra Pak containers, bag-in-box: ≤ 630mL: 10¢ > 630 mL: 20¢
	Aluminium and steel containers ≤ 1L: 10¢ > 1L: 20¢
Reclamation System	Return to The Beer Store (TBS), bulk return locations, or contracted empty bottle dealers (LCBO does not accept containers)
Handling Fee	Proprietary
Other Fees	LCBO pays a per unit service fee to TBS for every bottle returned that was not originally sold by TBS. This fee is currently 10.18¢ as of 2018. [2]
Unredeemed Deposits	Retained by beer distributor/ bottler.
Complementary Recycling Programs	95% of households have access to curbside and depot recycling, as part of Ontario's Blue Box Program.

This table and figure depict the success of Ontario's current bottle bill exclusive to alcoholic beverages only.

Table 3. Ontario Alcoholic Beverage Bottle Bill Redemption Rate (as a percentage).

Material Type	2021	2020	2019	2018
Glass	73.1%	80%	84.2%	86%
PET	46.1%	46%	53.4%	54%
Tetra-Pak/Bag-in-box	24.9%	23%	27.3%	25%
Aluminum	74.9%	70%	78.2%	81%
Overall	73.7%	69%	78.9%	81%

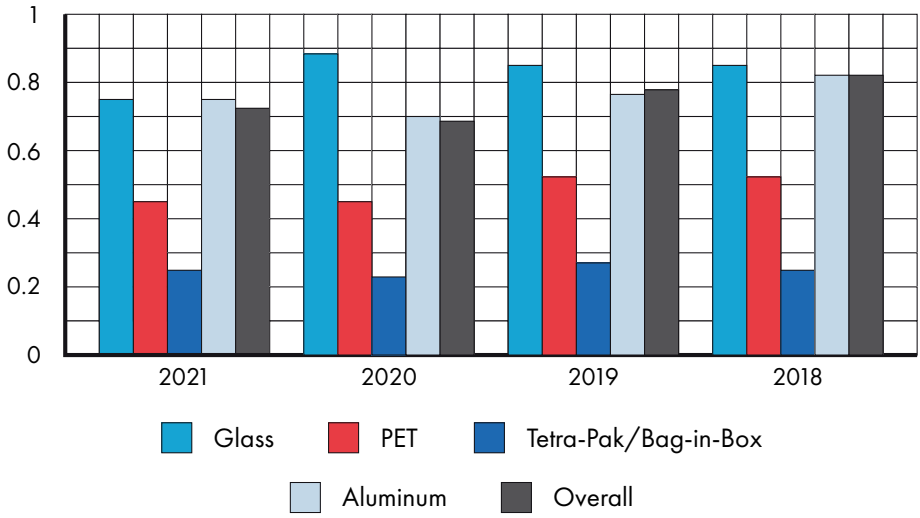


Figure 12. Ontario Alcoholic Beverage Bottle Bill Redemption Rate.

Lithuania Bottle Bill

Lithuania introduced its bottle bill in 2016 with the purpose of reducing litter, cutting local government costs, and improving the circular economy. Before the bottle bill, Noel discusses that Lithuania reports only a third of plastic bottles were collected (34%) (2022). Two years later, the country's deposit initiative, powered by TOMRA, increased return rates to 92% (2022). That is an astounding increase of 170% over a span of two years.

Table 4 Lithuania Bottle Bill Redemption Rate (as a percentage).

Material Type	2021	2020	2019	2018
Glass	83.8%	82.3%	83.9%	79.9%
PET	91.5%	92.7%	93.5%	93.%
Steel	128.9%	91.6%	94.3%	96.1%
Aluminum	91.6%	90.5%	91.2%	93.4%
Overall	88.3%	88.3%	89.9%	88.5%

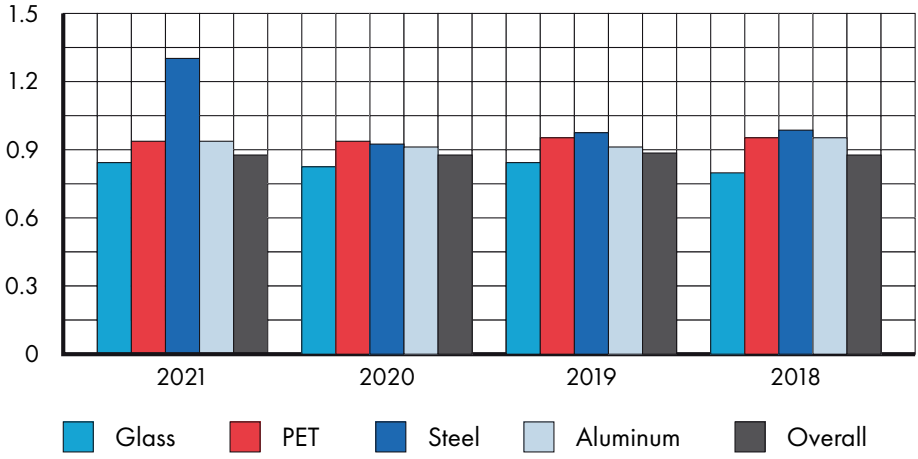


Figure 13. Lithuania Bottle Bill Redemption Rate.

When comparing those figures, one can see the similarity between Lithuania's success rate and Ontario's success rate. The greatest difference would be that Ontario only has a bottle bill currently for alcoholic beverages, while Lithuania's data covers all beverages. There is a noticeable decrease between 2020 and 2021 for Ontario, but factors such as COVID-19 must be taken into consideration as those years there was a lockdown and people may not have prioritized recycling as much.

Norway Bottle Bill

Norway has been a leader for their return deposit systems, with countries around the world replicating its model. Noel says that starting with TOMRA's first innovative reverse vending machines in 1972, return rates in Norway today are

at 89% for both cans and plastic bottles (2022). There are around 3700 reverse vending machines inside the country and more than 12,000 reception points where residents can return plastic for recycling (2022). The success of Norway lies in its strong motivational incentive system, where the refund is paid back by giving the money by cash or deducting the final bill in the end. For reference on costs, refer to Appendix A. to view Infinitum's raw data from 2019.

Table 5. Norway's 2019 Recycling Statistics (as a percentage).

Supply Chain	No. of Cans	No. of PET
Total Sales (+ value chain)	670,013,913	629,893,969
Total returned through RVM	598.643.369 (89.35%)	556,570,503 (88.4%)
Total recycled	659,063,580 (98.37%)	601,260,774 (95.45%)
Total not returned	71,370,544 (10.65%)	73,323,466 (11.64%)

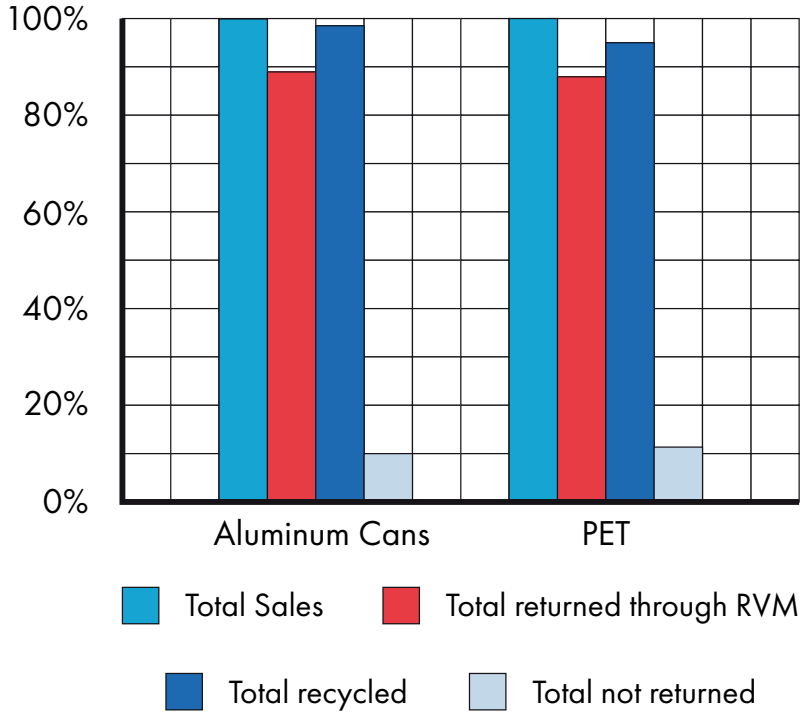


Figure 14. Norway's 2019 Recycling Statistics.

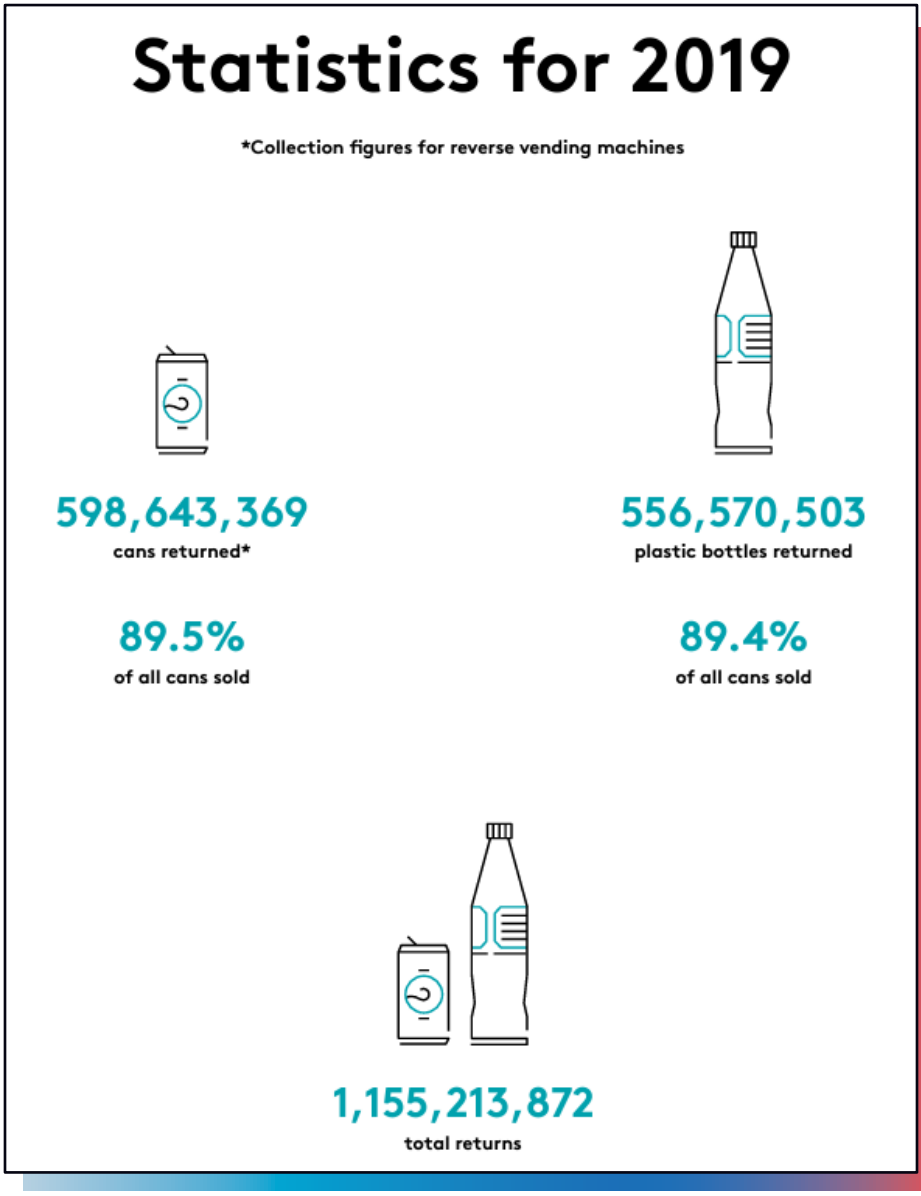


Figure 15. Norway's Infinitum Annual Report for Recyclables Collected by RVM. Note. This is produced by Infinitum to show the figures of retrieval and recycling rates. Infinitum. (2019).

Discussion

This research was compiled to determine the potential success of implementing RVMs in Toronto based on the mindset of its residents and other countries that have recorded their success in the implementation of RVMs alongside the redemption rates of their bottle bill programs. The surveys showed the overall willingness of residents to recycle, but the problem persists where they lack awareness, education, accessibility or convenience when it comes to recycling. Studies from Norway and Lithuania, as well as Ontario's alcoholic beverage bottle bill, prove that these challenges can be overcome. The following are ways in which implementing RVMs would benefit Toronto.

Benefits of Incentives

The survey results highlight a significant lack of knowledge and awareness among residents of Ontario regarding recycling practices. A large portion of respondents guess what is recyclable when recycling, indicating a lack of understanding of proper disposal techniques. In Abdi's survey, 52% of 211 residents in the GTA make an educated guess on what to recycle, meaning they could contribute to contamination at the recycling facilities, and 5% say they do not recycle at all (2020). Additionally, barriers such as forgetfulness, lack of awareness, and uncertainty about recycling methods contribute to low recycling rates. RVMs can address this education gap, with the use of incentives as a motivator. By providing a tangible and interactive recycling experience, RVMs can effectively educate users about proper recycling practices and make it an easier habit for newer generations. For example, RVMs can display information about what materials are recyclable and provide guidance on how to sort items correctly so it becomes a natural habit for most users.

Moreover, RVMs can provide awareness on the direness of plastic pollution in Ontario is, and considering that of 6000 individuals surveyed by ACC, according to Cantwell, Nolan, & Corser, 83% believe it is important or extremely important for companies to design products that are meant to be reused or recycled (2019) and 72% of respondents said they are currently buying more environmentally friendly products than they were five years ago most likely due to influence and better education (2019). These figures can equally reflect Canada as a whole with the implementation of RVMs. Looking at the survey commissioned by CCC, of 1000 residents of Ontario and 1000 residents of Québec, 55% answered that they forget to recycle and a staggering 54% say that they are not aware that they can at all. 49% said they lack the education on how to recycle (Recycle Cartons, 2016). This can be easily solved with a higher frequency of RVMs and the normalization of them in Toronto, considering that around 38% claimed that incentives are a good motivator for them to recycle, and it can be a good tool for education at the same time (2016).

Integrated Bottle Bill

Implementing a bottle bill in Ontario would provide numerous benefits for Toronto's recycling efforts and overall environmental sustainability. By looking at Lithuania and Norway's reports, as well as the Beer Store's model, it is proven that bottle bills would significantly increase the collection and recycling rates of beverage containers, contributing to Ontario's mandate to recover a certain percentage of non-alcoholic beverage containers by 2026 and 2030 (Brown, 2023). Norway's approximate 90% return rate for all their beverage containers is a great motivator for Canada to follow suit (2023). By providing a financial incentive for consumers to return their containers, a bottle bill encourages responsible disposal and recycling behaviour and would help combat litter, reducing the amount of waste ending up in landfills and partially solving that issue. Additionally, implementing a bottle bill would promote the development of infrastructure for recycling collection and processing, such as reverse vending machines (RVMs). Or, it could go the other way, where trying another pilot program of RVMs could be the start of the promotion of Ontario's bottle bill. An initiative outlined in the City Council's report in 2000 details a comprehensive strategy to implement a RVM pilot project and enhance recycling practices in public spaces (Dello, 2000). The project, collaborating with TOMRA and Urban Intelligence, aimed to test RVMs as a means of recovering recyclable beverage containers in high-traffic areas and would incentivize patrons with coupons for returned containers (2000). Dello recorded that the pilot project, funded by the private sector, involved strategic placement of RVMs at prominent locations, including the Toronto Zoo, TTC stations, and City-owned facilities (2000). It is important to highlight that this project seems that it has not been revisited for 24 years and this research may help bring it back into question. In 2023 on the other hand, the government of Ontario began discussing the start to a deposit-and-return system for non-alcoholic drink containers to promote recycling like the Beer Store's model later discussed in methodology (Brown, 2023). Environment Minister David Piccini has formed a working group comprising various stakeholders to explore implementation options (2023). This can be a great start to implementing RVMs in Toronto as a collection method. Provincial regulations mandate the industry to recover 75 per cent of all non-alcoholic beverage containers by 2026 and 80 per cent by 2030 (2023). Insiders say the only way the industry can hit those targets is through a deposit-return system like Québec's as they implemented theirs in 2022 (2023).

Opportunities for Circular Economy

Similarly to the EPR, a bottle bill would shift the responsibility for recycling beverage containers from consumers to producers, encouraging beverage companies to use more sustainable materials. Factors must be taken into consideration regarding Toronto's plastic pollution crisis and the dire need to switch to a more sustainable material, as plastic can only be recycled a

low amount of times before it becomes toxic to use for food and beverage packaging, aluminium can be used an infinite amount of times and can be more sustainable in the long term environmentally and economically (Richmond Steel, 2019). According to the results, there is no shortage of willingness to recycle properly and end the support for products that use unsustainable materials. This would contribute to reducing the overall environmental impact of beverage consumption and production. Overall, implementing a bottle bill in Toronto would be a significant step towards improving recycling rates, reducing waste, and promoting a more sustainable and environmentally friendly approach to beverage consumption and disposal. The 2016 Resource Recovery and Circular Economy Act establishes an outcome-based producer responsibility that holds producers accountable for recovering resources, like EPR, and reducing waste associated with their products and packaging (Container Recycling Institute, 2023). Producers involved in reducing, reusing and recycling waste will need to register, report, meet regulatory requirements and promote and encourage public participation in recycling activities (2023). Currently, the recycling rate in Ontario is low due to the fallible blue-bin system. In 2019, of 1.9 million tonnes of plastic packaging that Canada produced, just 12 per cent was sent for recycling and an even smaller percentage was reused (Warnica, 2022). Whereas in 2019, in Norway approximately 90% of total plastic bottle and aluminium can sales were recollected through RVMs (Infinitum, 2019).

Limitations

While the findings presented in this study offer valuable insights into the potential success of RVMs in Toronto, it is important to acknowledge several limitations that may affect the generalisability and reliability of the results. One significant limitation is the small sample size utilized in the study, which may not adequately represent the diverse population of Toronto as one survey uses 1000 residents of Ontario mixed with 1000 residents of Québec. Additionally, the use of snowball sampling risks sampling bias, as participants may be more likely to share similar characteristics or perspectives. The lack of primary research focused specifically on narrowing down the exact research questions limits the depth and specificity of the study's findings, being that this study is specific to Toronto residents and each country's society differs from the other.

Without a more targeted approach to data collection, there may be gaps in understanding key factors that could influence the success of RVM implementation in Toronto, such as consumer attitudes, behaviours, and preferences. Despite these limitations, the insights gathered from this study still hold value for informing discussions and decision-making regarding the implementation of RVMs in Toronto. While statistics about all of Toronto's residents cannot be made, the findings offer quantitative insights that can

guide policymakers, stakeholders, and researchers in understanding potential challenges and opportunities associated with RVMs.

Moreover, the study's reliance on evidence from other countries where RVMs have been successfully implemented provides some validation for the potential benefits of adopting similar systems in Toronto.

Conclusion and Recommendations

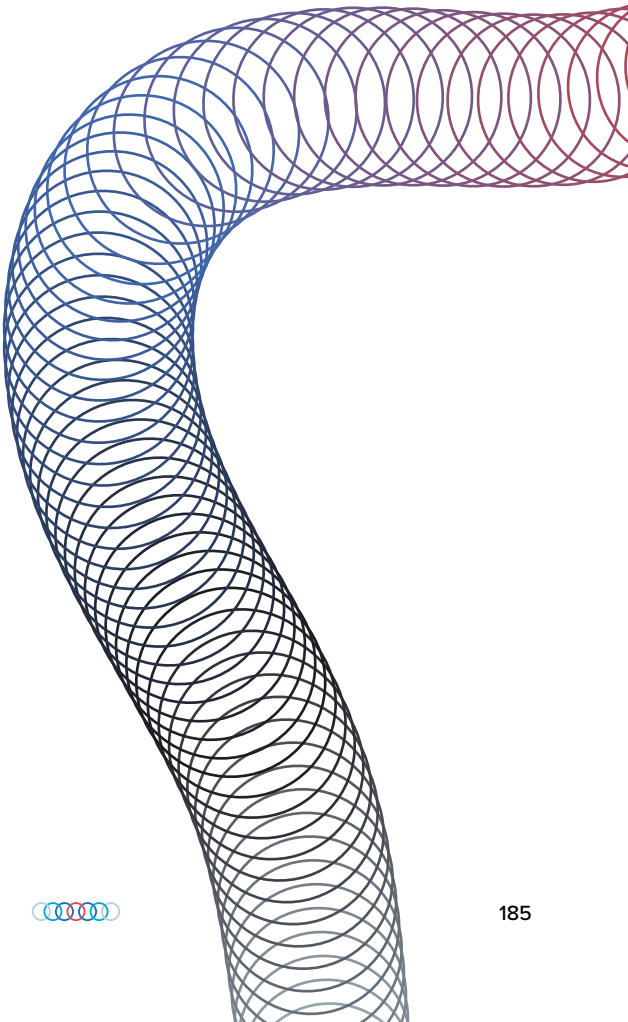
Considering all of the given problems, naming Toronto residents' lack of awareness or education regarding proper recycling methods and their guess-based improper recycling habits, and Toronto's recycling issue, mass production and complicated recycling program, lack of a user- friendly incentivised recycling program, Ontario most certainly has an issue at hand that needs to be dealt with in a timely manner, starting with the overpopulated and continuously growing capital city, Toronto. In looking at the results of all the secondary research, such as the success rate of Norway and Lithuania's implementation of an RVM-powered bottle bill, as well as most of the provinces of Canada's bottle bills, it is clear that the Ministry of Environment must begin the new bottle bill that is inclusive of all beverage containers with the implementation of RVMs in the city of Toronto.

This way, the circular economy of Toronto would improve drastically, with an average 150% increase in redemption rates within, as seen in Lithuania.

Recommendations would be to slowly collect all plastic beverage containers and reuse them only in non-food related industries, such as clothing, while creating and implementing a policy for producers to shift from plastic to aluminium like the ban of single-use plastic straws and cutlery. With demand rapidly changing and consumers having hyper-fixations based on current social media trends rather than genuine fixed interest and pursuit of products, mass production would have to be reduced as it is causing more damage to the environment and only serves for simple, short-term pleasures. Based on EPR, another recommendation would be to request for companies to invest in their own RVMs to shift the costs from the government to the producers, or request for sponsorship of incentives. Lastly, the ministry of education could discuss an addition to the elementary education curriculum to educate younger generations on Canada's current situation with full clarity and teach them the differences between different packaging materials in order to make educated decisions when purchasing as adults and recycle responsibly.

By following through with the implementation of RVMs in Toronto, having drawn from the experiences of Lithuania and Norway, there would be easier accessibility to the new bottle bill in question. Supposing that not everyone has access to a vehicle, if a TOMRA R1 were to be installed in high foot traffic locations, individuals could collect their recyclable beverage containers and conveniently dispose of them.

Overall, to accurately gather statistics and possibly observe increases in recycling rates, the city of Toronto must conduct primary research by revisiting the 2000 pilot program of setting up RVMs in areas with high foot traffic in Toronto. This way, the rest of the Canadian provinces would be able to follow Toronto's example of a revolutionized circular economy.



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Appendix A

Infinitum AS - Income statement (figures in NOK 1,000)

Operating revenues and costs	2019	2018
EPR revenues	40,759	118,075
Deposit return revenues	2,934,976	2,206,991
Sale of collected materials	180,164	182,503
Other operating revenues	45,695	36,413
Net operating revenues	**3,201,594**	**2,543,982**
Deposit return expenditure	2,682,941	2,031,246
Handling fees	249,241	243,089
Transport costs	126,091	114,929
Other production costs	74,569	75,533
Total operating costs	**3,132,842**	**2,464,797**
Profit from operating activities	**68,752**	**79,185**
Admin, marketing and depreciation	64,704	62,426
Operating profit	**4,048**	**16,759**
Net financial items	5,361	1,986
PROFIT AFTER FINANCIAL ITEMS	**9,409**	**18,745**

Figure A1. Infinitum Financial Statements.
Note. This is produced by Infinitum to show the figures of income statement for reference. Infinitum. (2019).

Key figures

Supply chain	No. of cans	Tonnes of cans	% of added	No. of PET	Tonnes of PET	% added to the market
Total sales	684,093,737	9,478	-	619,262,956	22,323	0%
Value chain	-14,079,824	-180	-	10,631,013	405	0%
Added (sales + value chain)	670,013,913	9,297	100%	629,893,969	22,728	100%
Total returned through reverse vending machines	**598,643,369**	**8,324**	**89.5%**	**556,570,503**	**20,316**	**89.4%**
From central sorting plant	5,328,154	74	0.8%	1,132,496	39	0.2 % *
From slag sorting	40,832,520	566	6.1 %	-	-	0.0 % *
From materials sorted at source	4,595,052	61	0.7 %	1,329,523	44	0.2 % *
Waste-to-energy	9,664,485	134	1.4 %	42,228,252	1,343	5.9 %
Total recycled from waste	**60,420,211**	**835**	**9.0 %**	**44,690,271**	**1,426**	**6.3 %**
Total recycled	**659,063,580**	**9,159**	**98.5 %**	**601,260,774**	**21,742**	**95.7 %**
Incineration waste in bottom ash	13,610,840	189	2.0 %	-	-	-
Energy recycling incineration	1,884,106	26	0.3 %	7,536,117	236	1.0 %
Unknown allocations	-4,544,613	-76	-0.8 %	21,097,078	750	3.3% **
Total not returned	**71,370,544**	**973**	**10.5 %**	**73,323,466**	**2,412**	**10.6%**
Total	**670,013,913**	**9,297**	**100%**	**629,893,969**	**22,728**	**100%**
Foreign items	36,729,975			5,854,506		

*** Materials recycling**
**** Also represents uncertainties in the analysis**

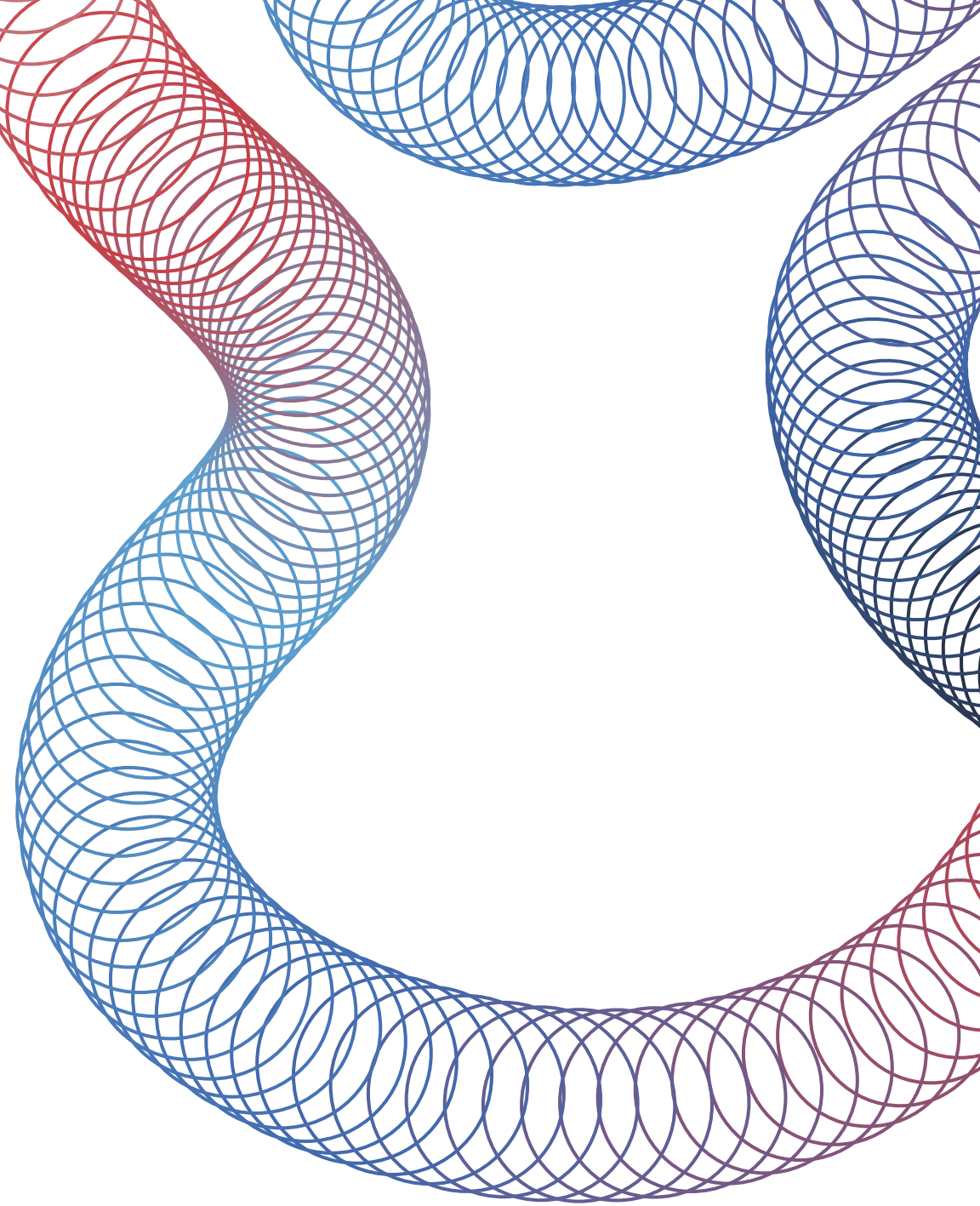
Figure A2. Infinitum Key Figures.
Note. This is produced by Infinitum to show the figures of retrieval and recycling rates. Infinitum. (2019).

Balance sheet (figures in NOK 1,000)

Assets	2019	2018
Non-current assets		
Plant and equipment		
Land, buildings and other real property	115,142	55,821
Plant and machinery, equipment, fixtures, etc.	45,740	44,108
Plant and equipment	160,882	99,929
Financial non-current assets		
Net plan assets	536	577
Financial non-current assets	536	577
Total non-current assets	**161,418**	**100,506**
Current assets		
Receivables		
Trade receivables	278,568	261,797
Other receivables	19,014	21,573
Total receivables	297,582	283,370
Cash at bank and in hand, etc.	309,326	263,076
Total current assets	**606,908**	**546,446**
TOTAL ASSETS	**768,326**	**646,952**

Equity and assets	2019	2018
Equity		
Contributed equity		
Share capital (200 shares in denominations of NOK 7,500)	1,500	1,500
Total paid-in capital	1,500	1500
Retained earnings		
Other capital	51,828	42,418
Total retained earnings	51,828	42,418
Total equity	**53,328**	**43,918**
Liabilities		
Current liabilities		
Trade payables	145,951	139,178
Unpaid government charges and special taxes	2,975	2,839
Other current liabilities	8,330	6,275
Provision for deposit liability	557,742	454,742
Total current liabilities	**714,998**	**603,034**
Total liabilities	**714,998**	**603,034**
TOTAL EQUITY AND LIABILITIES	**768,326**	**646,952**

Figure A3. Infinitum Balance Sheet.
Note. This is produced by Infinitum to show the balance sheet for reference. Infinitum. (2019).



TMUTAGA

MEET THE TEAM

Meet our incredible team who poured countless hours of hard work and passion, spanning a variety of media processes. To the inspiring individuals who brought concept to reality, we introduce 'U'.

PRESIDENT

DIANA CARNOVALE *SHE/HER*

What an incredible 9 months in the making this has been. Without a doubt, TMUTAGA has been a defining highlight of my undergraduate journey. Since joining the team I've been able to not only develop my leadership skills, but build incredible connections and friendships with those around me. As President, I am so lucky and proud to have had such a wonderful team contributing to our 2024/2025 year. From each associate to our new team leads and dedicated executives, nothing could be possible without each and every one of you. Thank you all so much for offering your wonderful creativity and hard work to make this journal a reality. TMUTAGA and these memories will always hold a special place in my heart. I wish you all nothing but success in your futures, U are incredible!

VICE PRESIDENT

JULIE MALONE *SHE/HER*

What a way to wrap up my final year! I first need to thank Diana for taking a chance on me and trusting me to help her and the team on this incredible journey, it's been one to remember. Through my university experience I was familiar with TAGA and the innovation they set out to achieve every year and getting to be a part of this has changed my university experience for the better. The opportunity to experiment, be creative, have important conversations and meet such intelligent people has improved my learning tenfold. I am so grateful for the opportunity and would tell any Graphic Communication newcomer to take a chance and get out there with any of the amazing clubs our program has to offer. The experience and relationships will last a lifetime.

CREATIVE DIRECTOR

MAX BERARDI *HE/HIM*

What a ride it has been. My four years at TMU have came and gone and it feels as though they've all culminated in this. I've poured every ounce of creative spirit I have into this project and grown more than I could've imagined thanks to everyone's support. I'm so thankful for my creative team and the entirety of this year's TMUTAGA group that helped bring my creative vision to life across all kinds of media. I'm honoured to have been your Creative Director for TMUTAGA 2025. None of this would've been possible without every single one of you and all the hard work you've put into this. That's exactly why I chose this year's theme, TMUTAGA is truly nothing without 'U'.

PRODUCTION DIRECTOR

AMY HEISTERBERG *SHE/HER*

Wow, two years as Production Director for TMUTAGA has just flown by! It's been such an honour to be entrusted with the responsibility of bringing this journal to life. This year in particular has been so rewarding, and I am deeply grateful for all the wonderful opportunities we have had and the talented individuals I've been able to work with. This has been such an amazing challenge, and I've learned and grown so much along the way. A huge thank you to everyone who has contributed to this journey—my fellow directors, my team leads and associates, our school's faculty, and our industry partners. This project has only been possible because of your hard work, dedication, and support. Thank you all!

EDITORIAL DIRECTOR

ALICIA DOS SANTOS *SHE/HER*

As a first-time TMUTAGA member, I couldn't have asked for a better team to introduce me to the works and make me feel right at home. As Editorial Director, it has been my pleasure to read the works of my fellow Graphic Communications Management students and share them with our readers. Seeing what students in this program are capable of has been nothing short of inspiring, and I hope that readers feel the same way. My incredible team of associates have worked tirelessly to put together the best version of each paper, and I want to give them an enormous thank you for their dedication. This experience has been enriching beyond words, and I can't wait to see what's next for TAGA in the future!

MULTIMEDIA DIRECTOR

CELESTE GAUTHIER *SHE/HER*

Wow! Truly, what a blast this has been. I can confidently say that I am so proud of our TMUTAGA team and what we have completed together this year. I feel immensely lucky to have been an executive member in the last year of my Graphic Communications Management undergraduate degree. The role of Multimedia Director can be a little bit elusive, but I think that's also what makes it so unique. I was given the opportunity to play around with possibilities that have never been considered before and melt the line between print and digital experience. I fell in love with this role from the beginning and savoured every second of it!

I want to say an immense thank you to my friends and peers I have worked alongside this past year. You all inspired me and pushed the limits of what we were able to accomplish. All the best, I know you'll do great things wherever you go! To all future TMUTAGA members/applicants, good luck, and remember that 'U' are special!

MARKETING DIRECTOR

EIMMIE CHAN *SHE/HER*

What a great year has it been! It has been an honour to be on a team with outstanding people who are creative and dedicated. As a first time TAGA member and executive, it was definitely a learning experience having to navigate my way for the role. I'm truly grateful for my other executive members for being so welcoming and encouraging! The pressure seems a little easier when you have them on your side. I would also like to thank my marketing team; working alongside such committed and creative people has been such a privilege.

I am beyond grateful for having the opportunity to be this year's marketing director. It has been an absolute blast being able to share the team's outstanding achievements. I hope to work with you all in the professional world, and I look forward to the future of TMUTAGA!

ADMIN AND OPS DIRECTOR

ALIYAH JAFFER *SHE/HER*

My first year on TMUTAGA couldn't have been a better experience. I am so grateful to be a part of this amazing team where I've learned and grown so much. The publishing industry is what drew me into Graphic Communications, so seeing that there was a group like TMUTAGA where I could learn more about the industry and my options I was immediately interested. I'm still in my second year, but I am pursuing a concentration in Publishing and a minor in Disability studies. TAGA has been an incredible experience that I hope to continue throughout my years at TMU.

I am in debt to Diana and the team for taking me under their wing as a newbie to all of this. I could not be successful without their guidance and passion. I look forward to the future of TAGA here at TMU!

ASSOCIATES

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Sadiyah Khan

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Matthew Karton

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Gia Sharma

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Andrew Whelan

COLOPHON

Software

Adobe InDesign CC

Adobe Illustrator CC

Adobe Acrobat CC

Fiery Command Workstation

VersaWorks

Typefaces

Futura

Futura PT

Proxima Nova

Stock

Creator Digital Silk 80lb Text

Creator Silk 100lb Cover

Supreme Matte 100lb Text

ORAJET 3651G White Vinyl

Equipment

Ricoh Pro C7210X

Roland SOLJET XR-640

Landa S10P Nanographic Printing Press

Laminator

Scodix Ultra 6000

Polar 78 Paper Cutter

Müller Martini Amigo Plus

Highcon Euclid II+

PRODUCTION NOTES

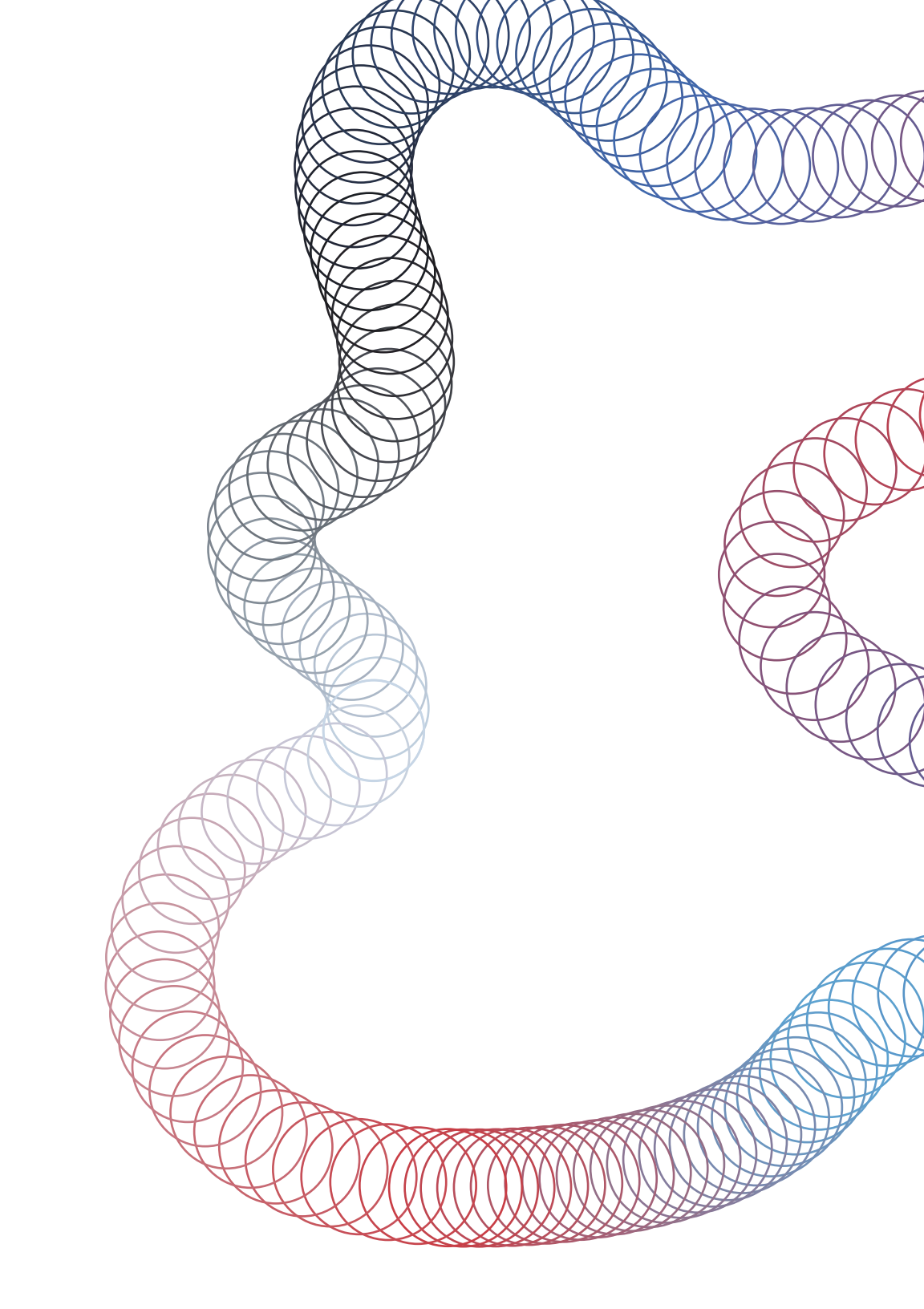
This year's journal was made possible by the efforts of students, faculty, and industry partners, it is thanks to all of "U" that this journal was able to be made.

Our journal was made possible thanks to the resources provided by the School of Graphic Communications Management (GCM) and our industry partners Spicers, Landa Digital Printing and Brodnax 21C Printers. We received help from Scott Millward, GCM's Printing Processes, Binding and Finishing Technician, and Darsan Sivanantharajah, GCM's Client Support Technician.

The interior pages of the journal were printed at GCM on the Ricoh Pro C7210X using Fiery Command Workstation and trimmed into book blocks using the Polar 78 Paper Cutter. The sticker sheet was printed at GCM on a Roland SOLJET XR-640, hand-trimmed, and then inserted into the book block by hand.

The cover was printed by Broadnax on a Landa Nanographic Printing Press S10P, then embellished with a clear varnish using a Scodix Ultra 6000. The journal was perfect bound at GCM on a Müller Martini Amigo Plus then trimmed on a Polar 78 Paper Cutter.

The dustjacket was printed by Broadnax on a Landa Nanographic Printing Press S10P, laminated with a soft touch effect on a ___, then embellished with a clear varnish using a Scodix Ultra 6000, and finally digitally die cut and scored on a Highcon Euclid II+.



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MEET OUR DONORS

On behalf of the 2024-2025 TMUTAGA team, we would like to express our gratitude to our donors for their generous contributions and support in creating this year's journal, none of this would have been possible without 'U'.


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