Two Experiments Investigating Fingerprint Development and Tool Mark Evidence Regarding 3D-Printed Firearms.

Gordy Ha

Under the Supervision of

Dr. Janne Holmgren

An Honours Project Submitted

In Partial fulfilment of the Degree Requirement for the Degree of

Bachelor of Arts-Criminal Justice (Honours)

Mount Royal University

Date Submitted: April 15, 2024

MOUNT ROYAL UNIVERSITY

CALGARY, ALBERTA, CANADA

Acknowledgement

I would like to formally recognize Dr. Holmgren for supervising this project. Her guidance is the sole reason this project was completed, and I will forever be grateful. I want to thank Dr. Winterdyk for our meetings and for encouraging me to start the project; his wisdom encouraged me to search for the unknown and add to an understudied field of research. I would like to recognize Professor Doug King for looking out for me, guiding me through the process, and considering my potential with this project. I want to thank Dr. Aulakh for removing every doubt I had during my Honours project; her encouragement put me at ease and assured me I would finish this project. Thank you, Dr. Narayan. Without you, this project may have never existed. I want to acknowledge Professor Tracey Lowey for being integral in providing contact with Darryl Bar and helping jumpstart this project. Thanks to Darryl Bar for the initial support and encouragement in researching such a difficult topic. Many thanks to Madelaine Vanderwerff for providing me with the literature to build upon this project. Lastly, I would like to recognize Caitlin Helder as the first person to ask for a copy when the project is finished. Her interest in this project convinced me to consider its merits.

Abstract

This thesis will comprise two experiments using an FDM 3D printer; the first experiment will investigate how fingerprints develop on the initial and final layers of a 3D printed cube. The second experiment will investigate the traceability of 3D printed firearms to a specific printer based on imperfections of the build plate. This thesis aims to provide more research on how novel forensic techniques can be applied to 3D-printed firearms. Ultimately, the goal is to increase public safety and assist in criminal investigations. There is a growing threat to public safety with the growing rise of 3D-printed firearms, also known as “ghost guns,” being found in the hands of criminals all across Canada. It may be a matter of time until 3D-printed firearms are used to commit crimes. Currently, there is a lack of forensic techniques when handling 3D-printed firearms. This thesis made two findings. The first was discovering how to produce clearer fingerprint images from 3D-printed objects. The second finding demonstrated how imperfections on a build plate could create unique tool marks that consistently transfer to multiple 3D-printed firearms; this would allow a determination that a collection of firearms was made using the same printer.

Table of Contents

Introduction

Currently, forensic research regarding 3D-printed firearms is limited (Europol, 2022, as cited in Pavlovich, 2023); due to the limited available research regarding 3D-printed firearms and 3D-printed weapons systems, there is vast potential for future exploratory research and potential development of novel identification methods. This project explores novel forensic techniques to provide new techniques to investigate 3D-printed weapons; this project will comprise two experiments. The first experiment will investigate fingerprint development on the top and bottom surface layer of a 3D-printed object. The second experiment will utilize tool marking evidence to trace a 3D-printed firearm to a printer that manufactured that firearm.

Background

While 3D-printing technologies have existed since 1986 (NGO, 2018, as cited in Trincat, 2021), their popularity and accessibility have increased steadily. It is expected that as financial barriers decrease to purchasing 3D printers, criminal opportunists using 3D printers to commit illicit activities may increase in frequency, and potentially, new methods of criminal activities may spawn from using 3D printers.

In 2013, Cody Wilson made the first 3D-printed firearms available to the public through digital distribution (Honsberger, 2018). The files for the firearms released by Wilson under the name “Liberator” had an estimated 100,000 downloads (Honsberger, 2018). The Liberator's notable aspect is its nearly total plastic construction (Honsberger, 2018).

One primary concern of 3D printers is their ability to manufacture critical components for other weapon systems. Within the illicit market is the ability to prototype parts cheaply and quickly with lower technical skills than traditional plastic mould manufacturing techniques, which has the potential for independent individuals to make critical components for novel weapon systems easily. An example of using a 3D printer for manufacturing critical components occurred when the UK Counter Terrorism Policing (2023) published the arrest of Mohamad Al-Bared for 3D-printing a drone designed to carry a chemical-based payload on behalf of the ISIS terrorist group.

Experiment 1: Fingerprint Development on the Top/Bottom of 3D-Printed Objects

Within the Canadian Jurisdiction, fingerprints are not analyzed by the National Forensic Laboratory Service. Rather, it is up to local law enforcement agencies to determine their own independent methods of fingerprint collection and analysis; this jurisdictional issue was brought up in the case of *R v Gray* 2018 ABPC 33. In the case of *Gray*, the defendant argued that fingerprint evidence analyzed within British Columbia should be removed due to not following the ACE -V procedure that is used in Alberta; the judge decided that due to the jurisdictional divide, fingerprint experts in British Columbia do not need to follow the ACE -V procedure (*Gray* at para 56). With the increase of 3D-printed firearms confiscated by law enforcement, investigators across Canada will independently develop novel methods of developing fingerprints from firearms. This first experiment aims to provide novel methods of developing fingerprints from the surface of 3D-printed objects.

Research conducted by Black and colleagues (2019) attempted to examine the clarity of fingerprint development on 3D-printed objects; while the research is foundational for fingerprint development on 3D-printed objects, the data is limited due to several factors: first is the lack of information regarding printer setting used by Black (2019) within the study, the second factor is the lack of data on how fingerprints develop on the final Z-axis layer and the initial bottom layer of the 3D-printed object. Black (2019) investigated two fingerprint development techniques from 3D-printed objects from FDM printers. The research findings suggest that the unique property of 3D-printed objects from FDM printers produces deep ridges, making the development of fingerprints more challenging to extract (Black, 2019, p. 66). In the same study, Black (2019) tested three types of 3D-printed plastic polymers: ABS, PLA and nylon. Each of the three polymers produced different physical characteristics: PLA produced deep ridges, making fingerprint formation difficult; ABS produced better fingerprint development when using magnetic power, while nylon has a smoother surface than both PLA and ABS polymer (Black, 2019, p. 66). Black (2019) tested two techniques of fingerprint development: one group used cyanoacrylate ester fuming, and the other group used magnetic powder application. Black (2019) concluded that magnetic powder without cyanoacrylate ester fuming produced the best development of fingerprints for 3D-printed firearms, and photography is the best method of preserving a fingerprint from 3D-printed firearms (p. 72). This study indicates that contemporary fingerprint development techniques are viable methods for fingerprint development on 3D-printed firearms.

Limitation

The limitations of this study include the lack of data on the object orientation where the fingerprint was developed. While the study does not explicitly state the layer line orientation, images provided by Black (2019) indicate that the fingerprints were placed along the z-axis of the 3D-printed firearm. Fingerprint development along the x or the y-axis orientation may appear clearer on either the top or bottom layers of a 3D-printed object. The practical benefits of furthering fingerprint developments on 3D-printed objects may enhance the ability to develop better prints on the surface of 3D-printed objects.

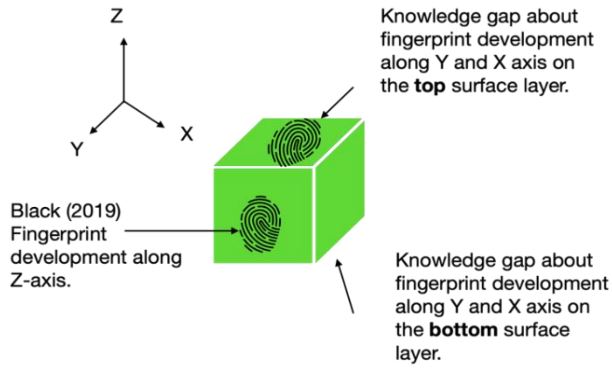

Figure 1. Illustration of the Knowledge Gap from Black's (2019) research regarding Fingerprint Development Along the X and Y axes

Hypothesis

Fingerprint development on the initial layers of a 3D-printed object will provide a clearer image due to the flat surface when the printer deposits plastic polymer on the build plate. The second hypothesis argues that fingerprint development on the final top layers of the 3D-printed object will provide poor results.

Table 1. Experiment 1 *Cura* Software setting for Ender 3 3D-printer

Quality Setting:	Retraction Distance:	Infill Setting:	Build Plate Adhesion:	Top/Bottom Setting:
Layer height: 0.2mm	5mm	Infill Density: 5%	Build Plate Adhesion Type: None	Top Surface Skin Layer: 1

Initial layer height: 0.2mm	Infill Line Distance: 8.0mm	Top/Bottom Thickness: 0.8mm
Line width: 0.4mm		Top thickness: 0.8mm
		Top Layers: 4
		Bottom Thickness: 0.8mm Bottom Layers: 4
		Initial Bottom Layers: 4
		Top/Bottom Pattern: lines
		Bottom Pattern Initial Layer: Lines

Experiment 1 Methods

Three plastic polymer cubes measuring 40 x 40 x 40mm are printed on an Ender-3 3D printer, the plastic polymer used to produce one concurrent batch; each of the three cubes is produced by a plastic polymer labelled under the name of eSUN 1.75mm Pink PLA PRO. The software used to produce the digital file for 3D-printing is Ultimaker Cura.

After the three cubes are printed, each cube is labelled A, B, and C. Each cube is photographed using an iPhone XR, and a Sylvania 8.5W LED light bulb is used as lighting. Each cube is carefully removed from the build plate using a scraper; neither the cubes' top nor bottom will come into contact during handling. Before the fingerprint development process, pictures are taken of the top and bottom of the cube using a microscope under the name of *Pocket Micro™ 20x-60x LED Lit Zoom Lightweight Pocket Microscope* purchased under *Carson Optical, Inc*. Using the researcher's right thumb, the researcher will rub his thumb across his forehead three times, he then firmly placed his right thumb on the bottom of the cube, the research will then rub the same thumb across his forehead three times then place it on the top of the cube, the process is repeated for the remaining two cubes. A bichromatic fingerprint powder purchased from www.crimescene.com will be used, and a fine fingerprint brush will deposit fingerprint powder on the fingerprints. After fingerprint development, using the *Pocket Micro™ 20x-60x LED*, a picture of all the fingerprints on each of the three cubes will be taken.

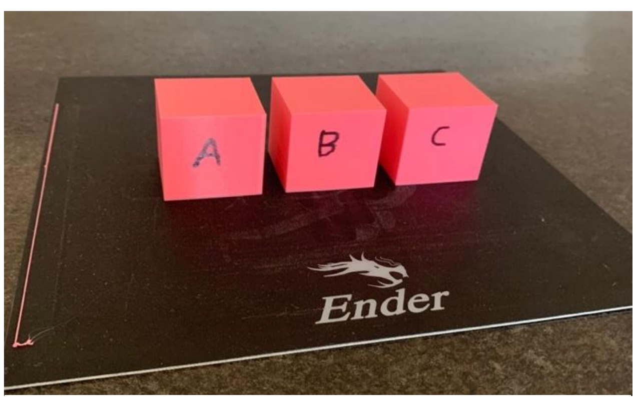

Figure 2. 3D-printed Cubes labelled A, B, C

Figure 3. Photograph of the Top Cubes Pre-Fingerprint Development

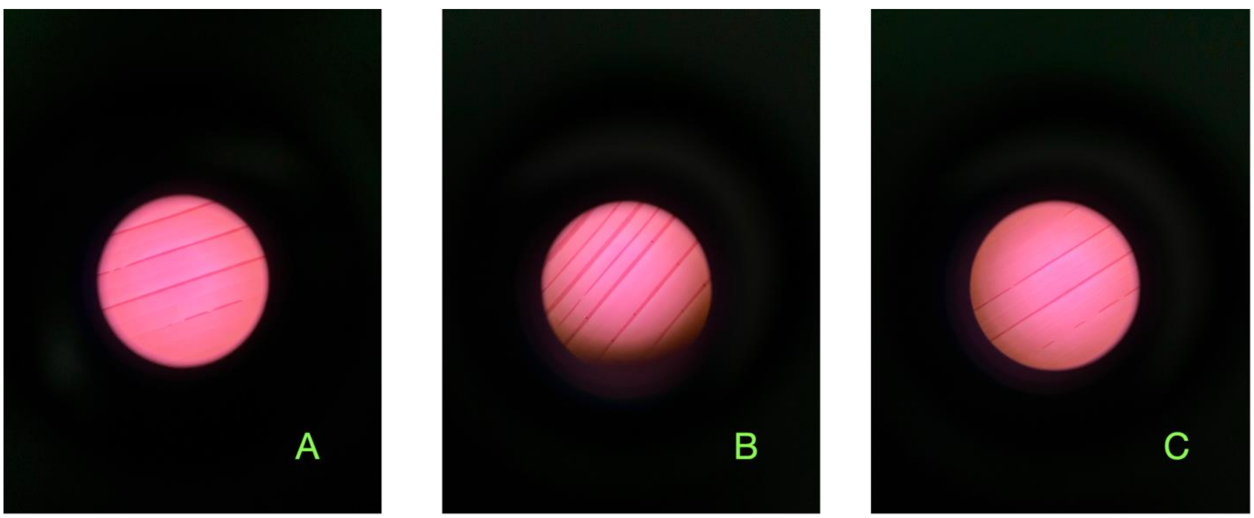

Figure 4. Photograph of the Top Cubes Pre-Fingerprint Development using the Pocket Micro™ 20x-60x LED Lit Zoom Lightweight Pocket Microscope

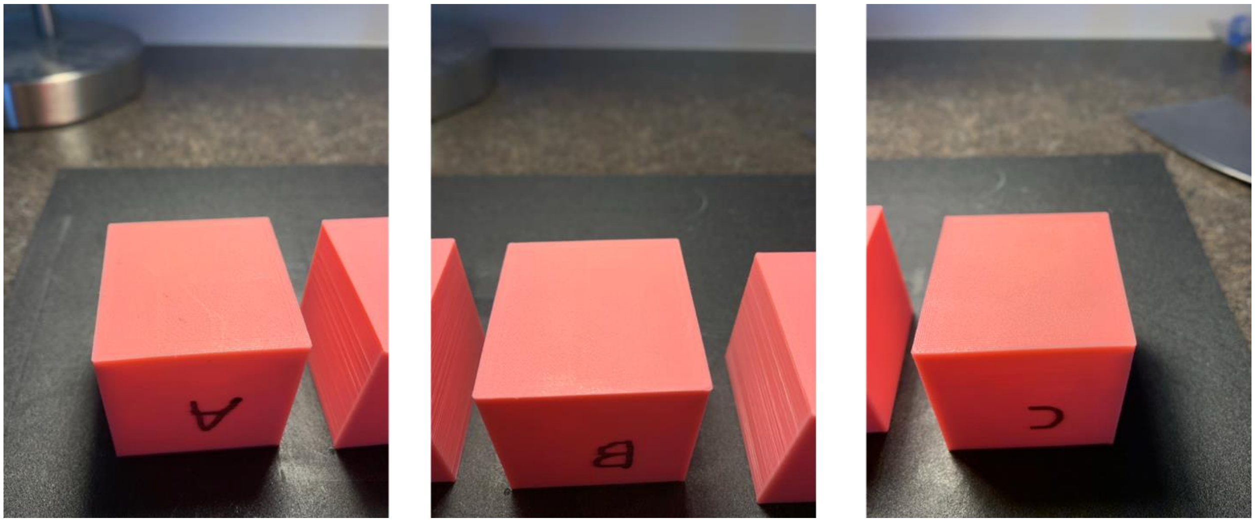

Figure 5. Photograph of the Bottom Cubes Pre-Fingerprint Development

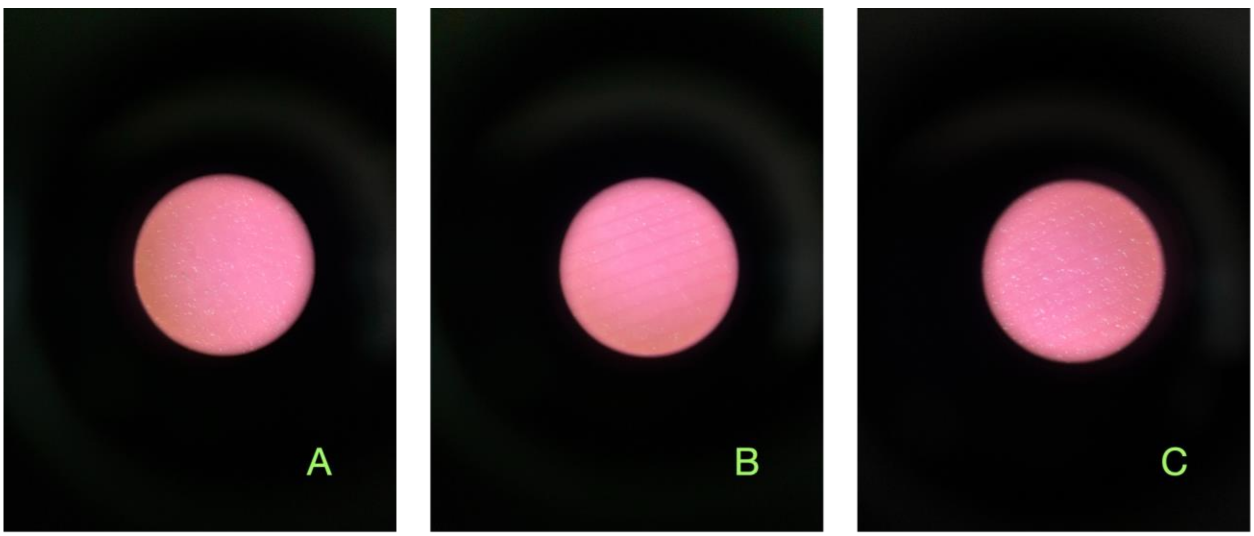

Figure 6. Photograph of the Top Cubes Pre-Fingerprint Development using the *Pocket Micro™ 20x-60x LED Lit Zoom Lightweight Pocket Microscope*

Figure 7. Photograph of the Top Cubes during Fingerprint Development

Figure 8. Photograph of the Bottom Cubes during Fingerprint Development

Novel Fingerprint Imaging Technique for 3D-printed Objects

Due to the poor image development of the Fingerprint, a novel method was employed to produce higher-quality fingerprint imaging. This method uses a stand clamp to hold the 3D-printed object while a *Sylvania 8.5W LED light bulb* is directed into the object, and a camera is pointed on the opposite end. Due to the physical property that allows light to pass through the 3D-printed object, fingerprint imaging is improved, allowing for increased detail development on the surface of all three cubes. Due to the brightness of each image, every image is edited by reducing the brightness on the iPhone photo app by -100.

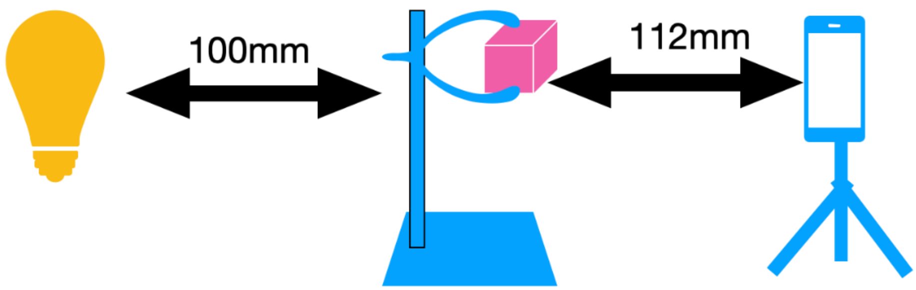

Figure 9. Illustration of Novel Fingerprint Imaging Technique

Results of Fingerprint Development on the Top and Bottom Layers of a 3D-Printed Object

When comparing images in (Figure 10 and Figure 11), it is apparent that fingerprint development on the surface with contact to the build plate provided greater fingerprint detail than the final top layers of the 3D-printed object. This study completes its original objective of providing further data on fingerprint development related to the location where the prints are deposited on the 3D-printed object.

Furthermore, this study also provides an affordable and novel technique to increase the clarity of fingerprint imaging when using bichromatic fingerprint powder. This method is easy to replicate and cost-effective with limited equipment.

During the pre-fingerprint stage, microscopic images from (Figure 4) show notable gaps on the top layers of the three cubes, whereas (Figure 6) shows a smoother and even surface. The different textured surfaces may explain why fingerprint imaging is better developed on the surface with contact with the build plate rather than the top surface layer of the Object.

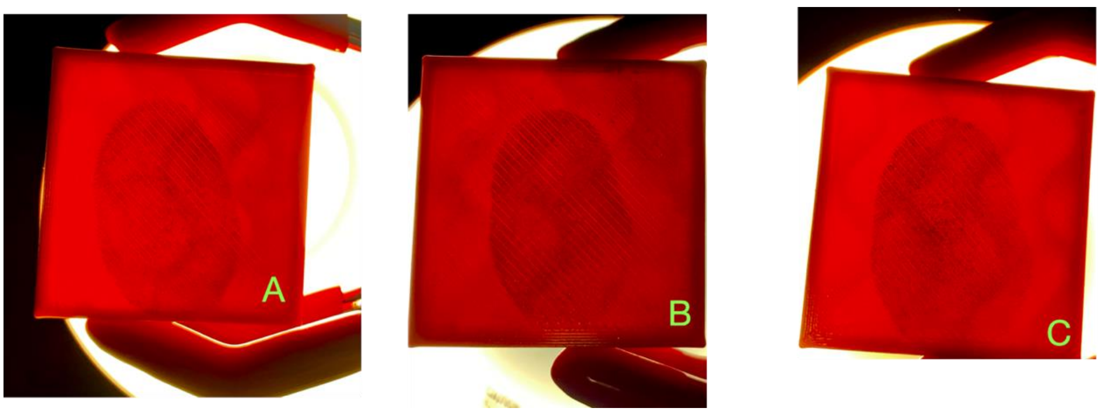

Figure 10. Photograph of the Top Cubes After Novel Fingerprint Imaging Technique

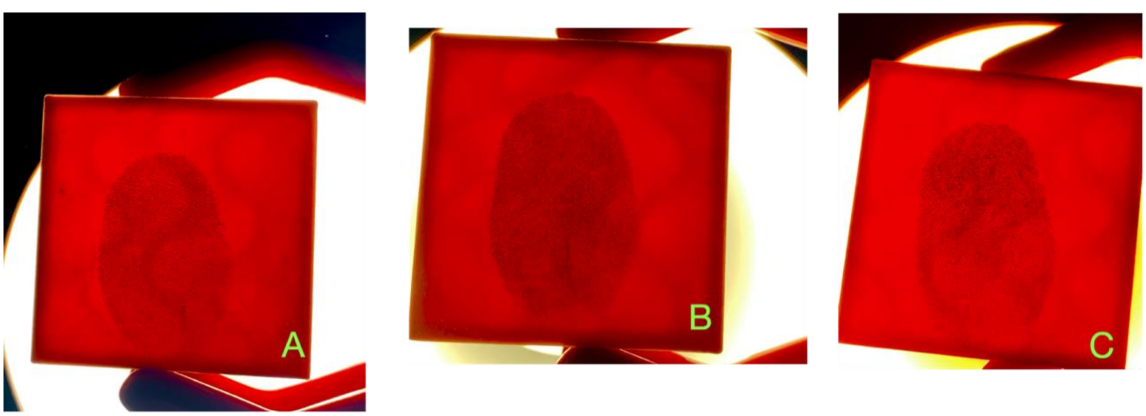

Figure 11. Photograph of the Bottom Cubes After Novel Fingerprint Imaging Technique

Limitations

This thesis only investigates PLA plastic; no other plastic polymers were used in this study. The use of bichromatic fingerprint powder may not be standard practice for forensic investigators. Additionally, the study only utilized polymer cubes that are unrepresentative of physical firearms. However, the concept that one side of a 3D-printed object must always form contact with the build plate leads to a credible opinion that every 3D-printed firearm must have one flat side when produced by an FDM 3D printer.

Experiment 2: Tool Mark Evidence from Improperly Calibrated 3D-Printers and Linkage to Physical 3D-Printed Firearms

There are some limitations to the study by Aronson and colleagues (2021). The first limitation is using a glass build plate; researchers admitted that the glass build plate used in their study may not be provided by the original manufacturer but that the glass replacement is an affordable alternative. The researchers' argument does not consider the long lifespan of 3D-printer build-plates, nor does the researchers consider research conducted by Gao and colleagues (2021). Gao and colleagues argued that some parts of a 3D printer are not consumable, and some distinct parts are not frequently replaced during the printer's lifespan. The second criticism is that a single artificial scratch mark on a glass 3D printer build plate is not representative of how other tool marks may appear on a 3D printer build plate. This study attempts to explain a novel mechanism of tool marks on an original build plate and how this discovery may potentially assist in tracing a 3D-printed firearm operation to a specific printer.

Hypothesis

Unique tool markings on an FDM 3D-printer build plate caused by nozzle wear to transfer onto the 3D-printed firearms as the filament deposits onto the build plate; imperfections or unique markings will transfer onto the 3D-printed objects. As the plastic polymer cools, these markings will solidify, forming a permanent mould of the impressions on the build plate. This study will build on the current research by printing a mock firearm lower receiver.

Method for Experiment 2

Using an *Ender-3* 3D printer, Ultimaker Cura as the slicer software, and one sheet of PLA plastic polymer measuring 20mm x 20mm x 0.5mm, the sheet of plastic polymer is produced using PLA plastic under the label of *ERYONE PLA Filament for 3D Printer 1.75mm +/- 0.03mm, 1kg (2.2LBS) PLA Cardboard Spool, Black.* After the sheet of plastic is produced, two mock replica firearms are produced using the same black polymer material, and only one mock firearm is produced using the *eSUN 1.75mm Pink PLA PRO* polymer filament. The mock firearms are produced as a trace from an original file downloaded from *Thingiverse; the* original file is labelled *glock lower airsoft.*

After all items are produced, a picture of both the build plate and the plastic sheet will be taken, and each mock firearm will be labelled A, B, and C. The surface area where each mock firearm has contacted the build plate will be photographed. After the initial photograph, another photograph will be taken of all 3D-printed items with a microscope labelled as *Pocket Micro™ 20x-60x LED Lit Zoom Lightweight Pocket Microscope* purchased under *Carson Optical, Inc*. The printer settings relevant to this study are listed below:

Table 2. Ender 3 3D-printer setting.

Quality Setting:	Retraction Distance:	Infill Setting:	Build Plate Adhesion:	Top/Bottom Setting:
Layer height: 0.2mm	5mm	Infill Density: 5%	Build Plate Adhesion Type: None	Top Surface Skin Layer: 1
Initial layer height: 0.2mm		Infill Line Distance: 8.0mm		Top/Bottom Thickness: 0.8mm
Line width: 0.4mm				Top thickness: 0.8mm
				Top Layers: 4
				Bottom Thickness: 0.8mm
				Bottom Layers: 4
				Initial Bottom Layers: 4
				Top/Bottom Pattern: lines

Bottom Pattern

Initial Layer:

Lines

Build plate properties

A catalogue of every item produced by this 3D printer has been stored in an Excel document for 2580 hours and 7275 minutes. The build plate was provided by the original manufacturer. Throughout the operation of this 3D printer, prior to this current study, the build plate has withstood over two thousand hours of printing; over this time, unique tool markings appeared on the build plate due to slight calibration caused by human error. The basic method of calibrating a 3D printer is placing a piece of standard A4 paper between the nozzle and the build plate, but such a method may cause errors due to the thin properties of A4 paper. According to *Action Press standard* (2018), standard printing paper is approximately 0.1mm thick. Another source for calibration error is the slight manufacturing defect causing slight height differences. Such slight differences may cause the nozzle of the 3D printer to gouge into the build plate, causing unique tool markings. Such markings are documented in the following images.

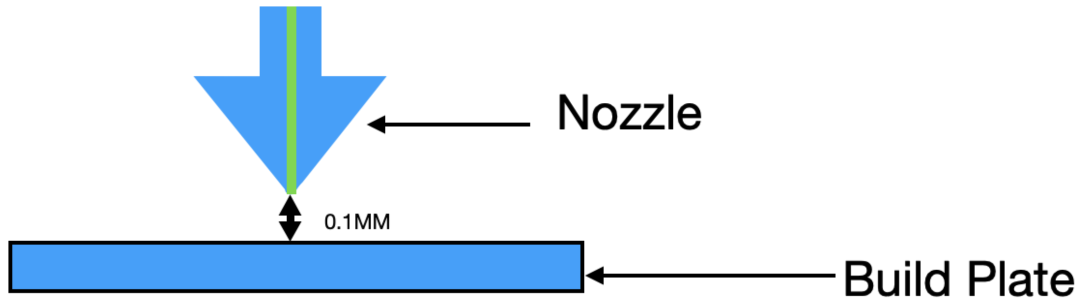

Figure 12. *Properly Calibrated Distance Between Nozzle Build Plate*

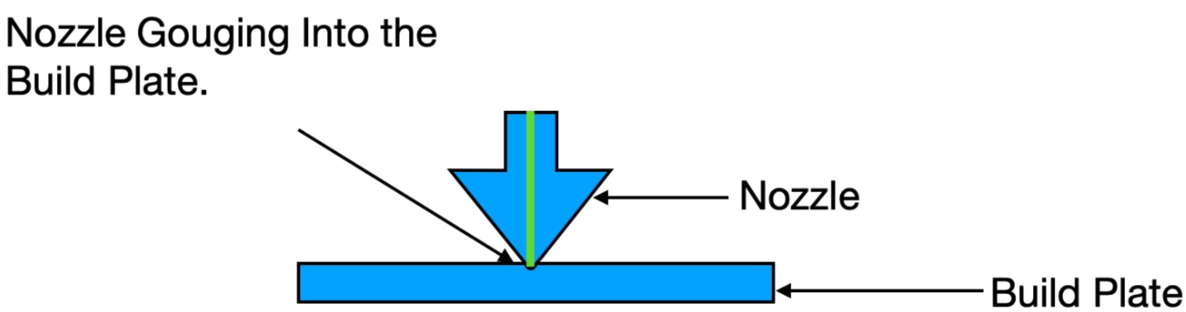

Figure 13. Improperly Calibrated Distance Between Nozzle Build Plate

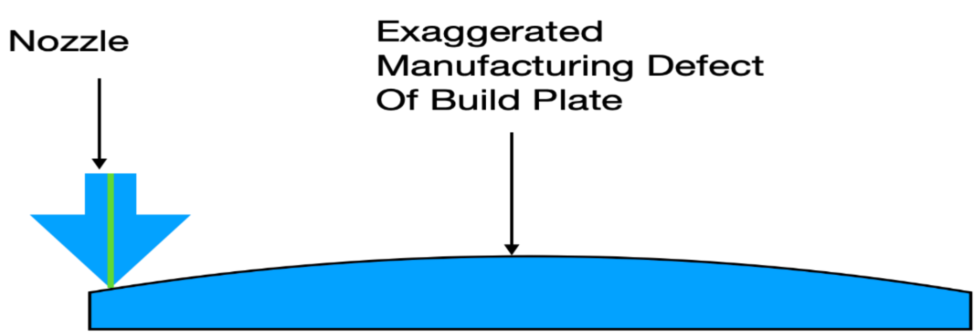

Figure 14. Exaggerated Manufacturing Defects on a Build Plate

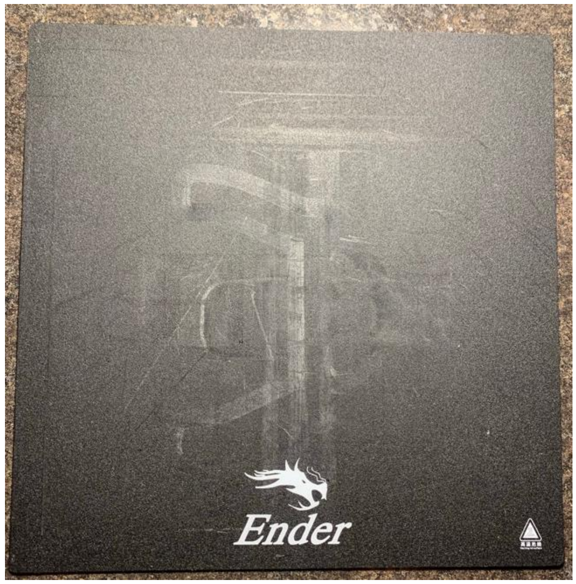

Figure 15. Original Build Plate Provided by the Manufacturer with Over 2500 Hours of Operating Time

Figure 16. 20mm x 20mm x 0.5mm Polymer sheet printed build plate

Assumptions

Four main assumptions were made for this study. The first assumption is that criminals printing Glock lower receivers will print the firearms in the orientation where the grip faces upwards. The second assumption is that a single G-code file can be used to print the exact firearm multiple times; the underlying assumption is that criminals would not be required to constantly change the orientation of the file for every firearm produced**.** The third assumption is that a malicious individual would not constantly change the build plate for every firearm component due to the time it would take to re-calibrate the nozzle height between the build plate. The fourth assumption is that different PLA polymers manufactured by different brands will have similar physical traits, allowing tool mark-on patterns to be consistent among different firearms.

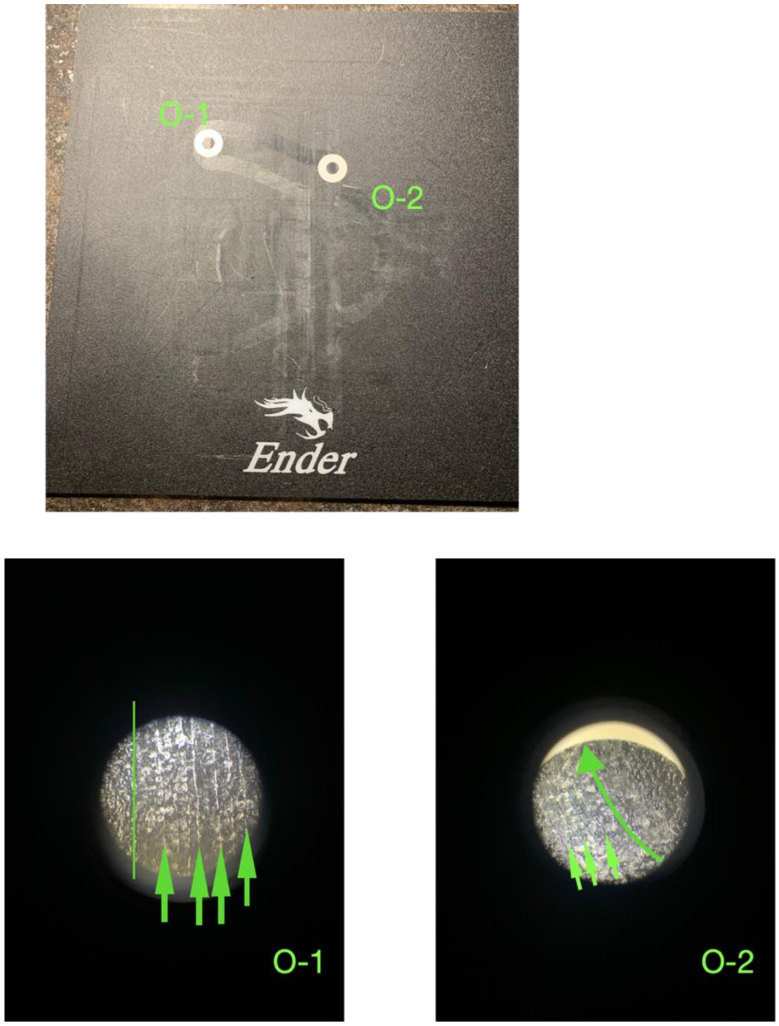

Figure 17. Each Area of Interest on the Original Build plate has a ¼ Diameter Reinforcement Sticker Placed on the Surface to Record where it was Photographed

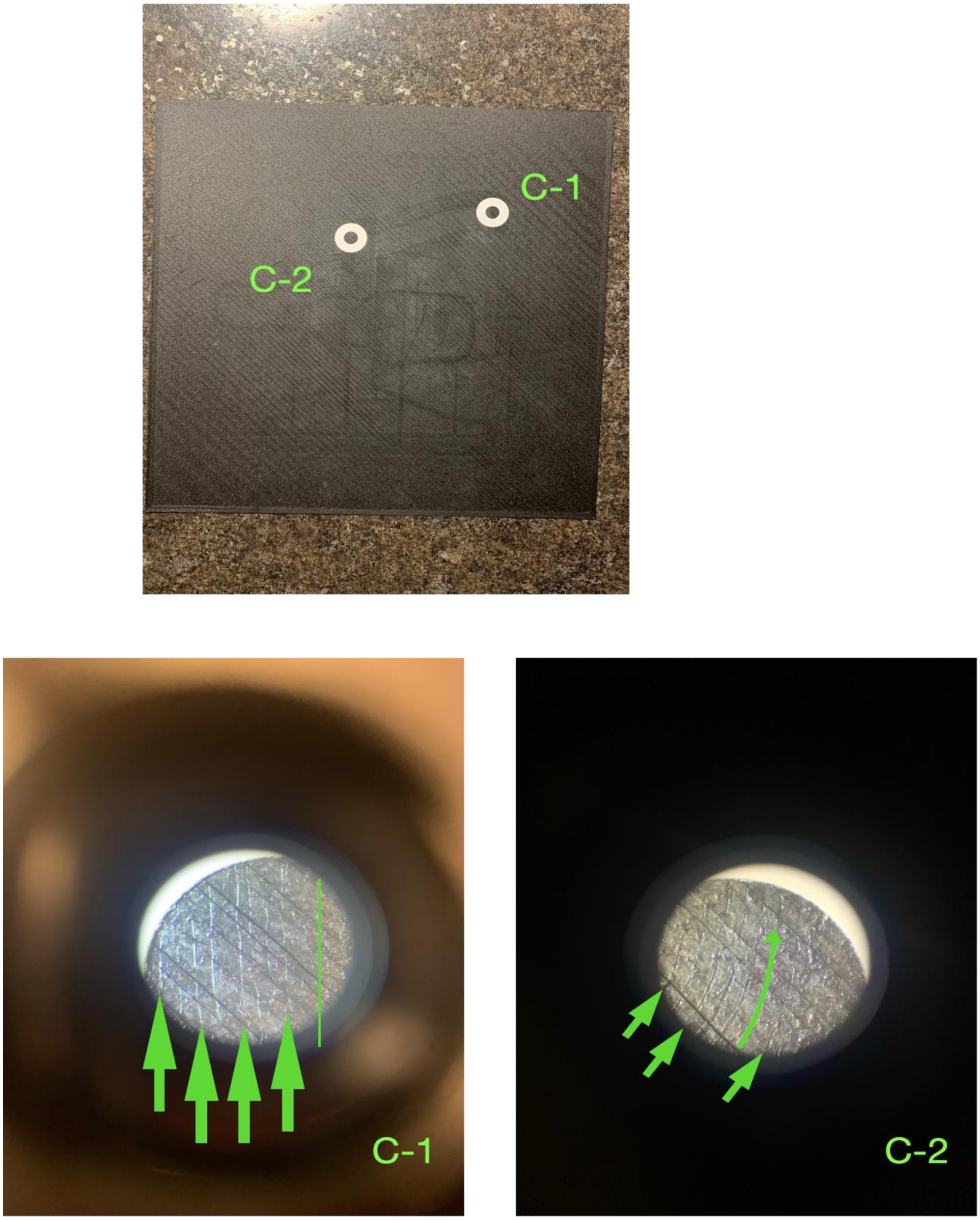

Figure 18. Areas of Interest on the PLA Plastic Polymer Sheet Measuring 20mm x 20mm x 0.5mm

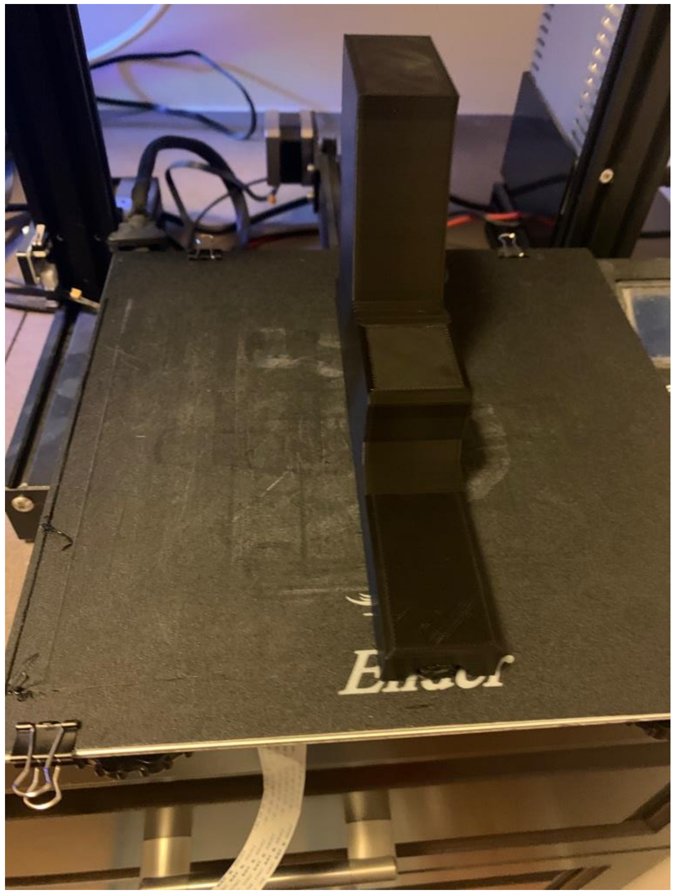

Figure 19. A Mock Firearm Printed on Top of a Build Plate, all three Mock firearms are Printed in the Same Orientation and Position from One G-code File

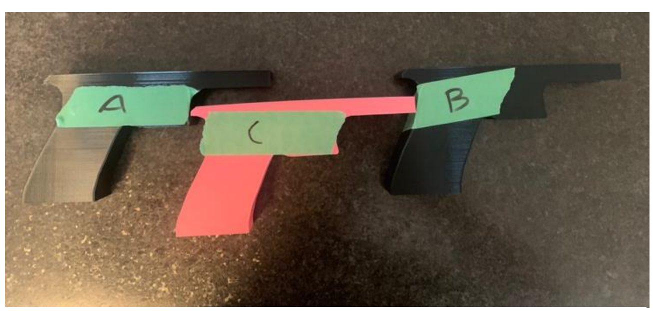

Figure 20. All three Mock firearms are labelled A, B, and C

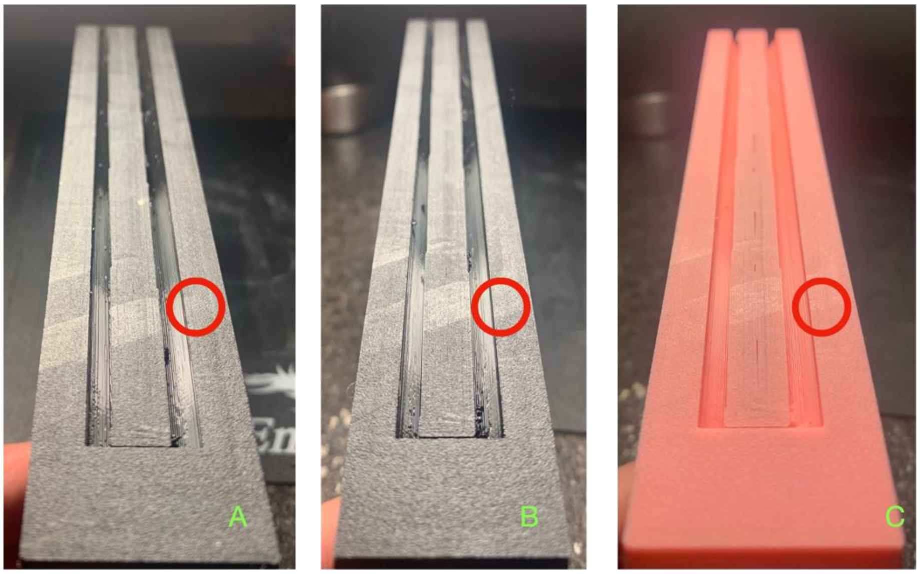

Figure 21. Areas of Interest on the Mock Glocks

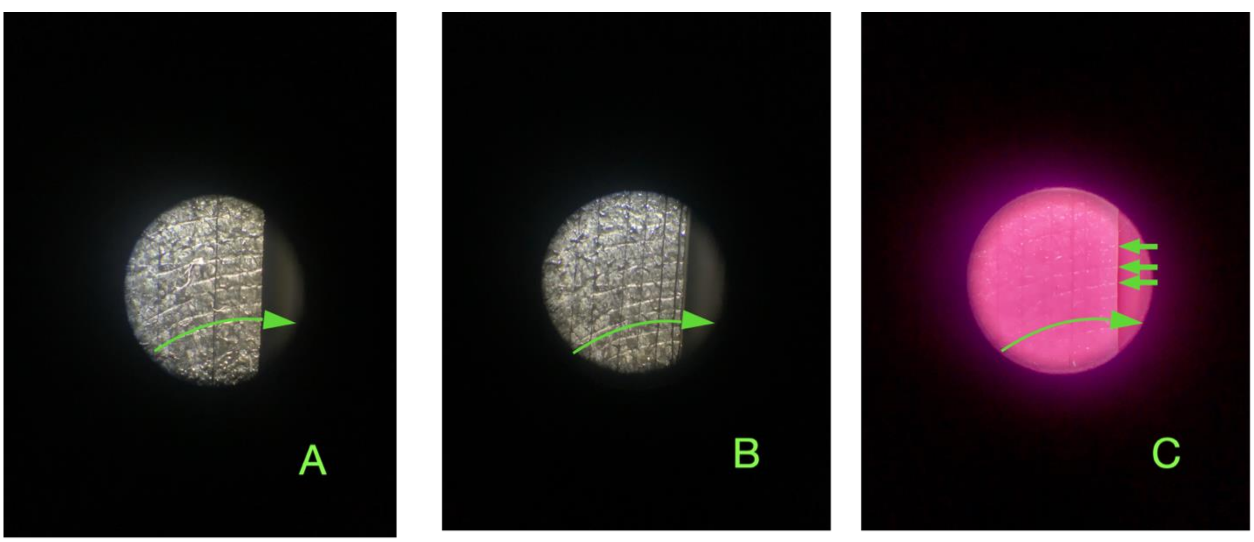

Figure 22. Areas of Interest on the Three Mock Glocks Under a Microscope

Figure 23. Mirroring Between the Build Plate and the PLA Polymer Sheet

Results of Build Plate Tool Markings Transferring to Mock Firearms

Results from images of O-1 and 0-2 showed distinct striation lines caused by nozzle calibration issues; images from C-1 and C-2 also showed the same striation lines found on O-1 and 0-2. The evidence confirms the initial hypothesis that unique nozzle striation patterns on build plates can transfer on objects. The second component of the hypothesis is confirmed by printing three exact mock firearms. Microscopic imaging shows all three firearms share the same striation pattern, and the assumption that other types of PLA will share similar characteristics is validated with the Firearm labelled as C. Despite firearm C being produced with a different coloured PLA polymer, firearm C has striation patterns matching both A and B. All microscopic imaging of the three firearms was printed on the area designated as O-2, resulting in the same striation patterns found on all three mock firearms.

The data provided in this study expands on the limited understanding of tool-marking evidence on 3D-printed firearms, while the previous study researchers modified their 3D printer with a glass build plate. This experiment is novel because it uses a build plate provided by the original manufacturer and the unique tool markings caused by nozzle calibration errors. Additionally, this study adds to the limited data on tracing a 3D-printed firearm to the 3D printer that produced the firearm. The original aim of this experiment was to generate data for forensic firearm investigators to assist in investigations involving the production of illicit 3D-printed firearms. This experiment demonstrates the transferability of tool mark evidence to multiple 3D-printed firearms regardless of different PLA materials used. Additionally, investigators should consider storing build plates of confiscated 3D printers to build a catalogue of tool markings and match build plates to confiscated 3D-printed firearms.

Conclusion

As 3D printers become more common and accessible to the public, there is an expectation that criminals will find novel ways to use 3D printers to commit crimes; research must be up to date to investigate these emerging threats to public safety. This thesis provides more data to bridge forensic methods with 3D-printed weapons; more importantly, this thesis has the potential to assist in criminal investigations where 3D-printed weapons are used. The practical implication of this thesis can be applied to unique 3D-printed weapons, such as drone parts and homemade shells used for homemade explosives. Within the Canadian context, this thesis can enhance police investigations and increase public safety.

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