What limits the greater adoption of 3D printing in Canada?

Identifying the Barriers to the Adoption of 3D printing in Canadian Industry

Nicholas Di Scipio

A Thesis Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the
Requirements for the Degree of Master of Applied Science

Graduate Program in Mechanical Engineering,
York University,
Toronto, Ontario
December, 2025

Abstract

3D printing is a manufacturing technology that builds objects layer by layer and was once forecasted to revolutionize the sector through enhanced design flexibility, production efficiency, and decentralized manufacturing; however, its adoption within Canadian industry still remains limited. This thesis investigates the barriers hindering its widespread adoption and develops a framework explaining how economic, technical, and organizational factors influence the integration of 3D printing into existing manufacturing systems. Drawing on the Technology Acceptance Model (TAM), Diffusion of Innovation (DOI) theory, and the Product Adoption Process, and through semi-structured interviews with Canadian industry experts, researchers, and policymakers, this study seeks to understand the barriers impacting 3D printing adoption and to develop a novel technology adoption model. Findings reveal that 3D printing adoption depends not only on traditional technology acceptance factors such as perceived usefulness and ease of implementation but also on innovation culture, organizational readiness, and collaboration among industry, academia, and government.

Acknowledgments

The author is greatly indebted to all those who offered their guidance, insights, support, and feedback, which proved invaluable to the creation of this thesis. The author would like to especially acknowledge the mentorship and encouragement of their supervisors, Dr. Andrew Maxwell and Dr. Reza Rizvi, and committee member Dr. Solomon Boakye-Yiadom whose guidance and continued support were instrumental throughout this research journey.

The author also wishes to extend sincere gratitude to their parents, family, and friends for their unwavering support and encouragement throughout the trials and tribulations of graduate study. Their belief in the author’s goals provided the foundation for perseverance and focus.

Finally, a special acknowledgment is extended to Hideo Kodama and Chuck Hull, the pioneering minds behind the early innovations in 3D printing. Their groundbreaking work laid the foundation for the field that inspired this research and continues to drive technological progress in 3D printing today.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Overview of 3D Printing

3D printing is the process of creating three-dimensional objects by forming layers of material into a specific profile based on a digital file created in a computer aided design software. [1] Unlike traditional subtractive manufacturing, where material is removed from a solid block to make a part, 3D printing manufactures objects layer by layer, significantly reducing waste and allowing for intricate geometries unattainable through conventional methods. Since its conception in the 1980s, 3D printing has evolved from a tool created to quickly manufacture prototypes into a sophisticated manufacturing technology with applications across aerospace, healthcare, automotive, construction, and consumer goods. [2] The field has undergone multiple waves of innovation: beginning with early polymer-based stereolithography (SLA) and fused deposition modeling (FDM) systems, which enabled engineers to rapidly test and iterate product designs. Subsequent developments in selective laser sintering (SLS), direct metal laser melting (DMLS), and binder jetting have extended 3D printing into metals, ceramics, and composites, allowing for the production of end-use, high-performance parts. [3] In recent years, progress in multi-material printing has enabled the creation of components with integrated mechanical, electrical, or thermal functionalities, while advances in design software such as generative design, topology optimization, and simulation tools have allowed engineers to exploit the full geometric freedom of additive processes. Automation, robotics, and distributed digital workflows have also played a transformative role, connecting multiple printers through networked manufacturing platforms that support remote monitoring, predictive maintenance, and on-demand production. [3]

Despite significant technological advancements over several decades, 3D printing has not achieved the widespread adoption forecasted by industry leaders and market projections.Early projections in the 2010s predicted that 3D printing would disrupt global manufacturing, replacing traditional mass-production models and reshaping supply chains by the mid-2020s. [3] However, the technology still represents less than one percent of global manufacturing output, with Canada's adoption rate trailing behind leading nations such as the United States, Germany, and China. [3] This thesis seeks to investigate the underlying factors contributing to Canada's slower adoption of 3D printing and to identify opportunities to accelerate its integration within the national manufacturing landscape.

1.2 Research Problem

Although 3D printing has evolved into a technically mature and commercially viable production method, its integration into mainstream manufacturing remains limited. Despite major advancements in material science, process reliability, and design software that have positioned 3D printing as a cornerstone of sustainable, localized, and flexible production, adoption across Canadian industry continues to lag behind leading nations such as the United States, Germany, and China. Most Canadian firms continue to employ 3D printing primarily for prototyping rather than for large-scale or end-use production, reflecting a persistent gap between technological potential and practical implementation.

This gap cannot be attributed solely to technological readiness. Instead, it stems from a mixture of technical, economic, and psychological barriers that shape how organizations perceive and implement 3D printing within their operations. Technical challenges include issues of material performance, process standardization, and production scalability. Economic barriers involve high equipment costs, uncertain return on investment, and limited market access, while psychological and organizational factors such as risk aversion, lack of awareness, and resistance to change further constrain adoption. Within the Canadian context, these issues are intensified by regional disparities in manufacturing infrastructure, fragmented policy frameworks, and insufficient workforce training in advanced manufacturing technologies.

Therefore, the central problem this research seeks to address is *why 3D printing adoption in Canada remains limited despite demonstrated technological capability and strategic national interest in digital and advanced manufacturing transformation.* By examining the barriers influencing adoption across technical, economic, and behavioral dimensions, this study aims to uncover the systemic causes of Canada's slow progress in 3D printing integration and identify actionable strategies to accelerate its diffusion across industrial sectors.

1.3 Research Objectives

The primary objective of this research is to investigate the key factors limiting the widespread adoption of 3D printing in Canada and to understand how these factors influence the use of 3D printing as a viable method for mainstream production. By examining the technical, economic, and behavioral dimensions of adoption, this study aims to provide a holistic view of the challenges facing Canadian manufacturers and identify actionable strategies to accelerate 3D printing integration within the broader manufacturing ecosystem.

To achieve this goal, the research pursues the following specific objectives:

1. Identify and categorize the barriers to 3D printing adoption across technical, economic, and organizational dimensions within the Canadian manufacturing landscape. This

includes examining issues such as equipment and material costs, standardization, certification, and workforce capability.

2. Assess the influence of organizational behavior and perception on 3D printing adoption decisions, with a particular focus on managerial awareness, perceived risks, and the cultural readiness of firms to embrace digital transformation.
3. Evaluate how external factors such as policy frameworks, regional infrastructure, and industrial networks shape the diffusion of 3D printing technologies across Canada.
4. Apply established technology adoption frameworks, including the Technology Acceptance Model, Diffusion of Innovation, and Product Adoption Process to analyze how technology adoption principles and frameworks apply to the decision-making in 3D printing implementation.

1.4 Research Questions

Building upon these objectives, this study is guided by a series of research questions designed to uncover the underlying mechanisms influencing 3D printing adoption in Canada. While the objectives define what this study seeks to achieve, the following questions clarify how the investigation will address the complex interplay between technological capability, organizational behaviour, and external context. The central research question driving this study is:

What are the key factors preventing the widespread adoption of 3D printing within Canadian industry, and how do these factors influence its transition from prototyping to mainstream production?

To explore this overarching question, the research is structured around three interrelated lines of inquiry. First, what technical, economic, and psychological barriers constrain the scalability of 3D printing in Canada? This question aims to identify the tangible and intangible obstacles, ranging from high equipment costs and material limitations to risk aversion and lack of standardization that ultimately inhibit wider industrial implementation. Second, how do organizational perceptions, leadership attitudes, and workforce readiness shape adoption decisions within Canadian firms? This focuses on the internal dynamics of decision-making, examining how managerial awareness, perceived usefulness, and cultural readiness align with the constructs of the Technology Acceptance Model and Diffusion of Innovation theory, which are further discussed in Chapters 3 and 4. Collectively, these questions provide the framework for understanding not only the barriers that persist but also the systemic enablers that could accelerate adoption. Addressing them will contribute to a clearer picture of how Canada can strengthen its 3D printing ecosystem, bridge the gap between research and commercialization, and position itself as a competitive player in the global transition toward advanced, digitally enabled manufacturing.

1.5 Thesis Structure

This thesis investigates the factors influencing 3D printing adoption in Canada, focusing on how geographical, economic, and policy conditions create both challenges and opportunities for integration.

Chapter 1 introduces the background, evolution, and current state of 3D printing, outlines the research problem, and defines the objectives guiding this study.

Chapter 2 provides a technical overview of 3D printing processes and their applications across key sectors such as aerospace, healthcare, automotive, and construction. This chapter establishes the technological foundation necessary to contextualize the barriers and enablers discussed in later sections.

Chapters 3 and 4 present the theoretical framework underpinning this research. Chapter 3 applies the Technology Acceptance Model to explore how perceived usefulness and ease of use influence adoption decisions, while Chapter 4 draws on the Diffusion of Innovation theory to examine how innovation characteristics, social systems, and communication channels affect the spread of 3D printing technologies within Canadian industry.

Chapter 5 details the research methodology, including the design, participant selection, and data collection methods used to gather insights from industry professionals, academic experts, and policymakers. This chapter also explains the analytical approach used to interpret findings within the context of TAM and DOI frameworks.

Chapter 6 presents the research findings and discusses their implications for Canadian industry and government policy. It highlights the key barriers to adoption, identifies potential pathways for improvement, and concludes with strategic recommendations aimed at fostering greater integration of 3D printing into Canada’s manufacturing ecosystem. By examining both the technological evolution and the persistent barriers to adoption, this thesis seeks to identify actionable strategies to unlock 3D printing’s full potential as a driver of innovation, sustainability, and industrial resilience in Canada.

Chapter 7 concludes the thesis by summarizing the key insights drawn from the analysis and reflecting on their broader significance for Canada’s manufacturing sector. It revisits the research objectives and questions to evaluate how each has been addressed through the findings presented in earlier chapters.

Chapter 2: How 3D printing is Currently Used in Industry

2.1 Cross-Sector Comparison of 3D printing Applications in Canada

While 3D printing is often associated with prototyping and is sometimes mistakenly seen as limited to it, the technology has evolved significantly, expanding into a wide range of applications across diverse sectors and industries. This chapter provides an overview of how 3D printing is being adopted across key Canadian industries, emphasizing the distinct drivers, applications, and barriers present in each sector.

Throughout the chapter, evidence is drawn from academic literature, industry reports, and case studies to provide a comprehensive and context-specific understanding of 3D printing's role within Canada's industrial landscape. The discussion distinguishes between high-adoption sectors where 3D printing has achieved production-level integration, and low-adoption sectors where progress remains slow and fragmented. By mapping these sectoral variations, the chapter establishes the foundation for the theoretical exploration in Chapters 3 and 4, which examine the behavioral and organizational factors influencing technology adoption using the Technology Acceptance Model and the Diffusion of Innovation frameworks.

To better compare how 3D printing is being applied across industries in Canada, Table 1 summarizes below the key use cases, the benefits driving adoption, and the barriers that persist.

The table distinguishes between technical, economic, and regulatory challenges, highlighting where obstacles have already been addressed and where they continue to limit wider use.

Table 1: Applications of 3D printing in Canada: Cross-Sector Comparison

Domain / Sub-Segment	How 3D printing is Used	Benefits Driving Adoption	Technical Barriers	Economic Barriers	Regulatory Barriers
Healthcare Applications					
Healthcare - Dental (aligners, guides, crowns)	Patient-specific aligners, crowns, abutments, surgical guides	Customization; digital workflow integration; reduced chair time	Limited certified biocompatible resins; printer/material compatibility	Cost of medical-grade systems and resins	Health Canada Class II device approvals (sterility, biocompatibility)
Healthcare - Hearing Aids	Custom shells using SLA/SLS from ear scans	Near 100% adoption; reduced waste; rapid turnaround	Surface finish and acoustic optimization	Low now (mature tech), but requires specialized labs	Compliance with CSA/ISO for medical devices
Healthcare - Orthopedic & Craniofacial Implants	Titanium implants, cranial plates, hip stems, joint replacements	Complex lattices for osseointegration; lighter, stronger implants	Qualification and repeatability for load-bearing parts	Expensive titanium powders and LPBF machines	Health Canada Class III/IV device certification; long approval cycles
Healthcare - Bioprinting (experimental)	Tracheal splints, tissue scaffolds	Medical breakthroughs; personalized implants	Cell-material integration; reproducibility	Prohibitive research costs	Unclear/ evolving Health Canada bioprinting framework
Aerospace & Automotive					
Automotive OEMs (Original Equipment Manufacturer)	Prototyping dashboards, jigs/fixtures, low-volume EV parts	Faster design cycles; reduced tooling costs; lightweighting	3D printing part durability for exterior/structural use	High per-part costs; integration with legacy lines	Must meet Transport Canada road safety standards
Automotive Aftermarket	Obsolete/replacement parts; interior upgrades	Digital inventory; mass customization; on-demand availability	QA and certification not standardized	IP/design file restrictions; variable demand	CSA/ISO testing for consumer parts
Racing & Motorsports	Aerodynamic ducts, cooling	Speed of iteration;	Material fatigue under extreme	High costs vs. performance	Homologation rules in racing

	parts, on-track redesigns	performance optimization	stress	trade-offs	leagues
Custom & Luxury Vehicles	Personalized trims, collector edition parts	Mass personalization; brand differentiation	Limited surface finishing	High costs; limited throughput	General consumer product compliance
Automotive Tooling & Fixtures	Welding jigs, assembly guides, end effectors	Ergonomic; rapid in-house production; less downtime	Durability for repeated use	Training & resistance from traditional toolmakers	Workplace safety standards (CSA)
Automotive Supply Chain	Virtual inventories; spare parts at remote sites	Resilience; localized production	File security; qualification of critical parts	IP risks; maturity gaps	Traceability requirements
Automotive R&D Labs	New materials, generative design prototypes	Design freedom; experimentation	Scalability to production	ROI uncertain	None beyond lab safety standards
Aerospace Engine Components	Fuel nozzles, turbine blades	Lightweight; fuel efficiency	Process repeatability; high-temp alloys	Cost of aerospace powders	Transport Canada certification, traceability
Aerospace Structural Components	Brackets, UAV structures	Weight reduction; part consolidation	Fatigue validation	High machine/powder cost	Same as above
Industrial & Consumer Products	On-demand printing near point-of-use	Reduced downtime; distributed supply	Qualification for certified use	Licensing/IP	Certification for flight parts
Industrial Tooling, Jigs & Fixtures	Assembly jigs, mold inserts, fixtures	Lower tooling costs; faster iteration	Wear resistance of printed tooling	Low for SMEs, high for industrial	Workplace safety standards
Industrial Spare Parts	Mining equipment, heavy machinery	Reduced downtime; local production	Lack of qualification standards	Licensing/IP for proprietary parts	CSA certification for hazardous equipment
Consumer Goods	Eyewear, electronics housings, sports gear	Personalization; rapid design iteration	Durability & finish limits	Weak economies of scale	Consumer product safety & labeling (Hazardous Products Act)
Fashion & Footwear	Insoles, midsoles, niche apparel	Lightweight; mass customization	Comfort & durability inconsistent	High unit cost vs. molding	Textile/chemical labeling standards

Emerging Applications					
Construction & Infrastructure	Concrete printing, infrastructure molds	Reduced labor; fast builds; remote sites	Structural validation; durability	High capex	Building code approvals; municipal permitting
Electronics & Photonics	Printed circuits, antenna housings	Miniaturization; integration	Precision & conductivity limits	Not competitive with PCB fabs	EMC compliance; wireless certification
Education & Research	University labs, training programs	Skills pipeline; innovation	Limited technical challenges	Budget constraints	Regulatory only if parts enter certified domains
Frontier Bio/Materials	Bioprinting tissues, multi-material 3D printing	Medical/sustainability breakthroughs	Scalability; reproducibility	High research costs	Evolving frameworks; unclear approvals

[4], [5], [6], [7], [8]

2.2 Sector-by-Sector Adoption Patterns and Barriers

While the applications of 3D printing vary widely across industries, several patterns emerge when comparing sector adoption in Canada. The Canadian 3D printing market was valued at 329.0 million CAD in 2023 and is projected to more than quadruple to 1.43 billion CAD by 2030, with a compound annual growth rate (CAGR) of 21.9% [9][10]. Canada accounts for only about 2% of the global 3D printing ecosystem, with its activity highly concentrated in a few strategic sectors such as aerospace, healthcare, and automotive [11]. Within healthcare, applications like dental aligners, hearing aids, and surgical guides have reached near-total adoption, as 3D printing's ability to deliver customized, patient-specific products directly matches industry needs and has already navigated regulatory approval pathways. Aerospace has also seen strong uptake, particularly in tooling, prototyping, and low-volume, high-value components, where weight reduction and design flexibility provide tangible performance and cost benefits. By contrast, industries such as automotive OEMs (Original Equipment

Manufacturers), construction, and consumer products remain at earlier stages, where 3D printing is mostly limited to prototyping or niche runs because per-part costs, certification hurdles, and integration with existing production systems outweigh the current benefits.

Between these high and low adoption sectors lie industries like orthopedics and industrial spare parts, where adoption is moderately present but not yet widespread. As highlighted in a recent Canadian industry analysis, this uneven adoption reflects a system at a crossroads: 3D printing in Canada has moved beyond hype into practical use, but scaling more broadly will require addressing cost competitiveness, workforce readiness, and regulatory clarity [11]. To better understand how 3D printing is being adopted across Canada, this section organizes industries into three tiers: high adoption, where 3D printing has already become a standard practice; moderate adoption, where promising applications exist but remain unevenly implemented; and emerging adoption, where use is still experimental or limited to research pilots. This structure allows us to compare sectors not just by where 3D printing is being used, but by the mix of technical, economic, and regulatory factors that either enable or constrain growth. By grouping industries in this way, common patterns become clearer, highlighting where 3D printing has already delivered value, where barriers still prevent scaling, and where Canada is only beginning to explore its potential.

2.2.1 Analysis of High Adoption Sectors

Dental & Hearing Aids

Among all industries, dentistry and hearing aids are widely regarded as among the most established industries leveraging 3D printing in Canada. [6] With almost every custom hearing aid shell and orthodontic aligner now being produced using 3D printing this transformation has replaced labor-intensive mold-based manufacturing with streamlined digital workflows that leverage the customization at scale that 3D printing offers. [6] In orthodontics, aligner manufacturers rely on 3D scanning and printing to deliver millions of patient-specific devices each year, drastically cutting turnaround times from weeks to days while maintaining consistent quality. These sectors highlight the conditions where 3D printing adoption thrives: a strong need for customization, well-defined certification frameworks for biocompatible materials, and an economic case where efficiency and reduced waste outweigh the cost of equipment. Additionally, the increased adoption of 3D printing for these applications reflects a combination of technical, regulatory, and economic enablers that make 3D printing uniquely suited for the task. On the technical side, 3D printing's ability to replicate complex geometries with micron-level precision enables the production of shells and aligners that perfectly match patient anatomy. Economically, the shift to digital workflows has minimized waste, reduced skilled labor requirements, and allowed manufacturers to scale production while cutting costs per unit. From a regulatory perspective, these devices generally fall under Health Canada's Class II medical device category, which covers products like dental appliances, hearing aids, and surgical guides. For Class II devices, the approval process is more straightforward than for higher-risk categories (Class III and IV), because regulators primarily assess factors such as material safety, biocompatibility, and patient fit, rather than demanding extensive clinical trials or long-term performance testing under structural loads. [6] This means manufacturers can introduce new 3D printing-produced dental and hearing products more quickly, provided they use approved biocompatible resins or polymers and demonstrate that the end product meets established safety and hygiene standards. In contrast, devices like orthopedic implants or spinal cages, which are Class III or IV, face much more stringent testing and certification requirements. [12] This creates a relatively predictable and accessible certification environment compared to more complex devices like orthopedic implants or aerospace components.

Aerospace Tooling & Prototyping

The Canadian aerospace industry has emerged as one of the strongest areas for 3D printing adoption in the country, specifically with regards to producing tooling, prototypes, maintenance repair and overhaul (MRO), and low-volume non-critical parts. Major industry players, including Bombardier and Pratt & Whitney Canada, have integrated 3D printing into their design and production workflows for jigs, fixtures, and prototype components [7]. By leveraging 3D printing, these firms are able to reduce tooling and repair costs, shorten design validation cycles, and accelerate iteration, enabling more agile development processes. For example, 3D-printed jigs and fixtures not only cost a fraction of traditionally machined tools but can also be redesigned and replaced in days rather than weeks, minimizing downtime and increasing efficiency on production lines. [13] Additionally, these tools as well as other parts can potentially be produced in-house using industrial printers or outsourced to Canadian 3D printing service providers, reducing dependence on overseas machining and strengthening local supply chains.

One of the key reasons aerospace has reached a higher level of adoption compared to other Canadian sectors is its alignment with 3D printing's economic and technical advantages. Aerospace manufacturing is characterized by low production volumes, high part complexity, and high material costs, conditions where the unique advantages of 3D printing align very strongly with the manufacturing characteristics of the Aerospace industry. Lightweight brackets, housings, and heat exchangers produced through 3D printing demonstrate performance improvements that translate directly into measurable fuel efficiency savings and reduced emissions. Furthermore, these benefits also support broader industry commitments to sustainability and carbon reduction, giving 3D printing an additional strategic value proposition. [28]

From a regulatory standpoint, non-flight-critical parts and tooling applications face relatively few certification hurdles. Unlike structural or flight-ready components, which require extensive validation under Transport Canada Civil Aviation (TCCA) and international standards (e.g., FAA, EASA), jigs, fixtures, and test parts can be certified internally at the company level. This regulatory flexibility has allowed aerospace firms to deploy 3D printing widely in support applications, building organizational familiarity and confidence with the technology. As a result, the Canadian aerospace ecosystem has gained practical experience with 3D printing while sidestepping the steep regulatory costs associated with certifying flight-critical components [29].

Looking ahead, aerospace adoption in Canada is expected to deepen, particularly as firms expand beyond tooling into certified part production. Globally, aerospace leaders such as GE and Airbus have already certified flight-critical 3D printing components, such as fuel nozzles and cabin brackets. [30] Canadian firms are beginning to follow this trajectory, with pilot projects exploring powder-bed fusion of titanium and nickel superalloys for critical applications. While certification remains a bottleneck, these initiatives highlight the long-term potential for 3D printing to reshape aerospace manufacturing in Canada. Overall, aerospace provides one of the clearest illustrations of how 3D printing delivers ongoing, measurable value in Canadian industry. Adoption here is not driven by market hype, but by concrete performance gains, cost savings, and a regulatory environment that allows innovation to flourish in tooling and prototyping before scaling into higher-risk domains.

Analysis

Based on the industry reports, case studies, and other research conducted, sectors that have achieved the highest levels of 3D printing adoption in Canada are those where the technology's unique strengths directly align with the most important market needs. In hearing aids and orthodontics, the technology enables mass customization, transforming what was once a slow, manual process into a fully digital workflow. Dental aligners, for example, are now routinely designed from 3D scans and produced using resin printing, cutting production time from weeks to days while ensuring consistent fit and quality. In the hearing aid sector, an estimated 99% of custom in-ear devices are now 3D printed, including those manufactured for the Canadian market. This reflects a rare case of near-universal adoption, achieved because 3D printing directly solves the industry's fundamental problem: the need for patient-specific devices delivered quickly at scale. The regulatory framework also reinforces adoption, as these products typically fall under Health Canada's Class II medical device category, which emphasizes biocompatibility and fit rather than requiring costly long-term trials.

In aerospace tooling and prototyping, the adoption story is similarly compelling but shaped by different drivers. Aerospace is inherently a low-volume, high-value industry, where even marginal efficiency gains translate into significant cost savings. 3D printing enables the rapid production of jigs, fixtures, housings, and non-flight-critical components, which can be fabricated in-house or outsourced to Canadian service providers such as Solaxis or Burloak.

These parts can be redesigned and manufactured in days rather than weeks, dramatically reducing downtime and enabling agile design iteration. Unlike flight-critical components, which face stringent Transport Canada certification, tooling and prototyping applications operate under less restrictive regulatory frameworks. This flexibility allows firms like Bombardier and Pratt & Whitney Canada to embed 3D printing in everyday operations while gradually building expertise toward more complex certified applications. Beyond cost savings, aerospace adoption is also supported by the unique capabilities of 3D printing: lattice-optimized brackets and heat exchanger, not manufacturable with other technologies, that reduce weight and improve fuel efficiency, aligning with global industry goals for sustainability and emissions reduction.

The common trend across these high adoption sectors is that 3D printing is not competing against well-optimized mass production on economy of scale alone, but addressing use cases where traditional methods fall short. For healthcare, the demand is for one-off, personalized devices where speed and precision matter more than volume. For aerospace, the value lies in tooling flexibility and performance-driven parts where lead time and design agility outweigh the higher cost per unit. In both cases, adoption has been accelerated by relatively clear regulatory pathways that reduce uncertainty for firms investing in 3D printing.

By meeting these needs directly and within manageable regulatory frameworks, 3D printing has moved past strictly experimentation and into production for these industries. These high adoption sectors, therefore, provide a blueprint for how Canada might accelerate 3D printing use elsewhere: by focusing on applications where its unique value proposition is unrivalled, rather than trying to compete head-on with high-volume conventional manufacturing on cost. In mass production, traditional methods like injection molding or stamping will almost always be cheaper per unit, but in low-volume, fast turnaround, or highly customized contexts 3D printing delivers value that conventional processes cannot match.

2.2.2 Analysis of Moderate Adoption Sectors

Orthopedic Implants & Surgical Devices

In Canada, orthopedic implants and surgical devices have emerged as a leading area of medical 3D printing, driven by the country's advanced hospital networks, research collaborations, and growing expertise in patient-specific treatments. Hospitals and service bureaus use 3D printing for cranial plates, spinal cages, and joint replacement implants, where patient-specific geometries and porous lattice structures eliminate stress-shielding effects, improve biocompatibility, bone growth, and have other benefits according to a review by Meng et al. [8]

While adoption is growing, high material and machine costs limit access outside major hospitals and institutions. Only a limited number of large research hospitals and specialty centers, such as the University Health Network in Toronto and service providers like Precision ADM in Winnipeg, have the resources and expertise to integrate 3D printing implants into patient care pathways. [14] The adoption across the entire national healthcare system faces various structural barriers: high material and machine costs make LPBF systems prohibitively expensive for most institutions, while maintaining validated workflows and quality management systems requires significant ongoing investment. This cost challenge is compounded by Canada's decentralized healthcare model, where procurement decisions vary by province and institution, resulting in inconsistent investment in the technology that slows nationwide adoption of 3D printing in the healthcare sector. Additionally, the rigorous standards of Health Canada's Class III and IV medical device categories result in lengthy approval processes that often slow commercial adoption. As a result, mass adoption in Canada is presently limited to pilot programs and specialty centers, rather than broad hospital-wide integration with the first ever Canadian-made, 3D-printed implant being approved in 2021. [14]

Automotive (Tooling, Aftermarket, Motorsports)

In Canada's automotive sector, over the last 5-7 years 3D printing has begun to establish a foothold in tooling, aftermarket replacement parts, and motorsports applications. [15] The strongest adoption has been in tooling, jigs, and fixtures, where 3D printing's ability to produce ergonomic, lightweight, and custom tools provides measurable operational benefits. Assembly guides, welding fixtures, and robotic end-effectors can be fabricated in-house or sourced from Canadian 3D printing service bureaus, often at a fraction of the cost and lead time of machined tools [15]. This capability reduces downtime on the production line, allows for faster design iteration, and supports just-in-time manufacturing practices.

Beyond tooling, 3D printing has opened opportunities in the aftermarket and custom parts segment, particularly for discontinued or low-demand components that are no longer supported by OEM supply chains. Canadian firms have experimented with using 3D printing to reproduce vintage and specialty parts, maintaining legacy vehicles such as classic Porsche and GM models [15]. The digital inventory model, in which CAD files are stored and reproduced on demand, offers a long-term solution to the challenges of stocking rare or obsolete components such as in the previously mentioned cases. However, broader use in aftermarket parts is limited by IP ownership issues, variability in demand, and the absence of universal certification standards for critical automotive parts ultimately slowing the transition from pilot projects to regular industry practice.

Motorsports and performance-focused applications represent another promising but niche area. Teams and research hubs in Canada have experimented with lightweight aerodynamic brackets, ducts, and cooling components, using 3D printing to achieve complex geometries and rapid part redesigns between races. While adoption is growing in these high-performance contexts, Canada lags behind European counterparts, where Formula 1 and other racing leagues have embraced 3D printing more extensively [16]. The limited adoption is partly due to the smaller scale of Canada's motorsport industry and the high cost of developing performance-validated 3D printing parts. For OEMs, the barriers to wider 3D printing adoption remain quite steep, especially around cost. Large-batch production economics still overwhelmingly favour stamping, casting, and injection molding, where per-part costs are significantly lower. 3D printing continues to face challenges with durability under heat, vibration, and stress, all critical conditions for exterior or load-bearing parts. In addition, integrating 3D printing into existing supply chains is complex, requiring digital file management, operator training, and quality assurance protocols that are not yet standardized across the industry [17]. On the regulatory side, Transport Canada requires certification for any safety-critical automotive parts, and global OEMs demand compliance with their own rigorous standards before 3D printing components can enter production vehicles. These requirements add time, cost, and risk to scaling 3D printing beyond prototyping and tooling.

Overall, the Canadian automotive sector demonstrates a pattern of partial adoption. Tooling and fixtures are widely used, aftermarket and motorsports applications show targeted promise, but OEM integration remains limited due to cost, durability, and certification hurdles. This reflects the broader dynamic of 3D printing adoption in Canada: it succeeds in niches where its unique strengths such as customization, rapid iteration, and localized production outweigh the costs, but still struggle to be leveraged in high-volume production environments where traditional methods still have a stronger economic advantage.

Industrial Spare Parts

In Canada, the use of 3D printing for spare parts is gaining traction as companies look for solutions to the high costs of downtime and the logistical challenges of supplying remote operations. Within the resource extraction and energy sectors, where equipment downtime can cost millions of dollars per day, remote and hard-to-access operations face persistent challenges in securing spare parts because of long supply chains and dependence on foreign OEM suppliers. By leveraging the on-demand production capabilities of 3D printing, sectors like the mining industry can produce spare parts directly at or near work sites, significantly reducing costly downtime, lowering dependence on traditional supply chains, and minimizing the need to maintain large physical inventories that tie up capital and storage space. [18]

A growing trend in this sector is the move toward digital inventories, a strategy in which part designs are stored as digital CAD files and reproduced on-demand, only when required. This approach eliminates the need for extensive warehousing of rarely used spares while providing operators with immediate access to critical components. A recent Select3D printing analysis highlights that digital part libraries, combined with localized 3D printing production, can reduce both lead times and lifecycle costs, particularly for industries where excess downtime has steep financial consequences [19]. The ability to print a replacement impeller, bracket, or pump housing on-site in a matter of hours rather than waiting weeks for delivery underscores the practical value of this model in Canada's remote industrial regions.

Beyond simply producing spare parts, AM also enables part consolidation and performance improvements by combining multiple components into a single, optimized design, reducing assembly time and incorporating advanced geometries such as lattices that provide additional benefits such as improving strength-to-weight ratios. This is especially significant for heavy equipment in mining and oil extraction, where operating conditions demand both robustness and reliability. Canadian service bureaus such as Burloak Technologies and Precision ADM have already begun supporting industrial clients by redesigning spares for 3D printing, leveraging lattice structures and weight reduction strategies to enhance performance [20].

Despite its promise, widespread adoption of AM for spare parts in Canada has yet to be achieved. Several systemic barriers continue to slow diffusion with IP ownership being a primary concern, as most spare parts remain under the control of OEMs, and reproducing them without licensing agreements raises legal and contractual challenges. Qualification and certification standards are also underdeveloped; without universally accepted testing protocols for AM produced parts, operators are reluctant to trust AM-produced spares for safety-critical systems [21]. To bridge these gaps, Canadian firms are increasingly adopting hybrid strategies, outsourcing production to local service bureaus or working with consortia to test AM spares in pilot programs. This outsourcing approach reduces the need for in-house investment while still allowing operators to test the benefits of AM. For example, the Canadian Mining Journal reports that mining firms are exploring partnerships with AM providers to shorten supply chains, with early results suggesting significant reductions in downtime when digital part libraries are paired with regional print hubs [19]. However, scaling beyond these pilots will require industry-wide progress in standardization, licensing models, and workforce training.

Analysis

The sectors reviewed above illustrate both the promise and the limitations of 3D printing Canada as well as what moderate adoption of AM looks like sector to sector. Industries such as orthopedic implants, automotive applications, and industrial spare parts demonstrate clear technical feasibility and market potential, yet their integration and adoption remains somewhat limited. Unlike high adoption sectors, where AM's value proposition is irreplaceable and the technology is widely adopted, these industries face structural barriers that continue to slow scaling. By analyzing these sectors as a whole, Canada's moderate adoption cases reveal that technical success does not automatically translate into widespread adoption. Each sector demonstrates AM's clear strengths such as customization in healthcare, agility in automotive tooling, and resilience in spare parts supply chains, yet all three sectors remain constrained by economic challenges at scale, regulatory hurdles, and organizational inertia. In healthcare, the challenge lies less in proving clinical efficacy than in navigating lengthy approval pathways and the high costs of titanium powders and LPBF machines. In automotive, AM is proven for tooling and niche aftermarket applications, but it struggles to scale into OEM production, where cost-per-part and material durability remain decisive. In industrial spares, the economic case is strong in principle, but unresolved issues around IP, qualification, and fluctuating demand prevent adoption from moving beyond pilots.

Unlike high adoption cases, the moderate sectors reflect a transitional phase where AM competes with existing solutions that are already reliable, certified, and deeply embedded in supply chains. For adoption to progress, these industries require not only clearer certification standards and cost-reduction strategies, but also more streamlined pathways for integration such as digital inventory platforms, joint OEM–supplier partnerships, and standardized qualification frameworks. Workforce readiness is another critical factor: Canadian firms often cite the lack of engineers trained in AM-specific design and validation as a bottleneck. [39]

Ultimately, until these gaps are bridged, AM in Canada's moderate adoption sectors will remain defined by promising pilots and localized successes rather than mass adoption across these industries. The opportunity, however, is significant: if barriers around certification, cost, and integration can be addressed, these industries are well positioned to replicate the adoption trajectory of dental aligners or aerospace tooling.

2.2.3 Analysis of Low Adoption Sectors

Construction & Infrastructure

Unlike other sectors where 3D printing has been used and widely adopted for years such as aerospace, automotive, and healthcare, the Canadian construction industry is only beginning to explore the potential of AM for large-scale infrastructure and housing. While international projects have demonstrated the potential of concrete 3D printing to reduce material waste, accelerate construction timelines, and deliver cost-effective housing, Canadian adoption remains confined to demonstrations, research pilots, and academic collaborations. [22] Unlike dental devices or aerospace tooling, where regulatory frameworks and supply chain integration are clearer, construction in Canada is constrained by a more complex set of barriers, with regulatory uncertainty being the biggest challenge to adoption in the construction sector. Canada's building codes do not yet include explicit provisions for additively manufactured structures, creating ambiguity for municipalities and permitting authorities. [23] Without formal recognition in national or provincial codes, 3D-printed buildings cannot be certified for occupancy, making most current efforts experimental rather than commercial. [23]

The economic investment required to adopt 3D printing in the construction industry is also a large barrier. Unlike other sectors where 3D printers can range from a mere hundred to thousands of dollars, large-format concrete printers represent a significant capital investment, often costing several hundred thousand dollars, with additional expenses for proprietary printing materials and software. For an industry already facing productivity pressures, the business case for AM is not yet compelling in Canada, especially when conventional concrete construction methods are cheaper and better understood [24]. Moreover, construction firms are typically risk-averse and operate on thin margins, which reduces their willingness to experiment with unproven technologies without clear financial incentives.

On the technical side, AM for construction faces challenges related to material performance, durability, and scalability. Concrete mixes must be carefully engineered to be extrudable, quick-setting, and structurally sound, and Canadian climates add another layer of complexity, with extreme temperatures and freeze thaw cycles demanding rigorous material validation. [25]

Workforce readiness is also a barrier: Canadian builders, engineers, and regulators currently lack widespread training in AM-based construction processes, which further slows adoption. Unlike traditional skills in construction trades, there are very few standardized curricula, certifications, or apprenticeships focused on using 3D printing for construction, leaving a gap in technical expertise. Training tends to be provided directly by equipment suppliers or through short-term pilot projects, which does not offer the scale and distribution of training needed to build a competent workforce capable of supporting widespread adoption. Moreover, regulatory bodies often lack the in-house expertise to evaluate AM-based structures, creating uncertainty around code compliance, permitting, and inspection. [26] This lack of workforce preparedness at multiple levels across the sector greatly contributes to slower adoption and the cautious investment that has been observed so far across the sector. [26]

Consumer Goods

Unlike other sectors where 3D printing has demonstrated clear pathways to commercialization, the Canadian consumer goods industry has been slow to adopt AM beyond prototyping and niche customization. AM is often promoted as a means to deliver personalized products and shorten design cycles, but adoption in this sector has remained limited to design studios, early-stage ventures, and premium brands experimenting with customized accessories, eyewear, or small home goods [27]. For most consumer product manufacturers producing hundreds of thousands or even millions of identical units, 3D printing currently cannot match the cost efficiency of established high-volume methods like injection molding, extrusion, or die casting, which achieve dramatically lower per-part costs once tooling is amortized. [27] This contrasts with sectors like healthcare or aerospace, where the unique benefits of AM such as customization, weight reduction, or supply chain resilience directly align with performance-critical needs. However, cost efficiency, scalability, and consistency of finish tend to be the most sought after criteria in mass produced consumer goods, leaving AM to only only make financial sense in low volume or customized production runs. [27]

Even as printer costs have declined, consumable materials remain several times more expensive per unit than plastics or metals used in injection molding, creating an immediate price disadvantage. In a highly competitive retail environment where consumers are price sensitive, this cost differential makes AM-produced goods commercially unviable except in cases where personalization or exclusivity can justify a premium [47]. On the technical side, AM also struggles to meet the durability, safety, and aesthetic standards required for consumer products. Many AM polymers lack the consistency and certification needed for items that must endure repeated handling, stress, or exposure to environmental factors Surface finish remains another limitation. While some 3D printing processes can deliver smooth detail, most processes such as FDM 3D printing require significant post-processing to meet consumer expectations for polish and consistency. For goods like toys, housewares, or personal devices, where regulatory approval and safety testing are stringent, AM introduces additional uncertainty. These factors reinforce an industry perception that AM is better suited for ideation and limited-run prototyping than for end-use consumer products.

Workforce readiness and consumer awareness also shape the adoption gap. Canadian designers and engineers are generally familiar with AM as a design tool, but few consumer goods firms possess in-house expertise to integrate AM into their production strategies [29]. Training opportunities specific to consumer product applications are scarce, and AM literacy among product managers and executives is limited. As a result, AM adoption in consumer goods in Canada remains largely symbolic, demonstrated through pilot projects, small-batch runs, or marketing campaigns, rather than integrated into mainstream production.

Analysis

3D printing adoption in Canada remains slowest in construction and consumer goods, two industries where the technology's potential benefits are often overshadowed by structural, economic, and regulatory barriers. For both construction and consumer goods, adoption has largely been limited to pilot projects, niche customization, and academic research, with commercialization mostly constrained by the economics of implementing 3D printing at scale but also in part due to regulations, and workforce capacity.

In construction and infrastructure, Canadian firms are constrained by the absence of clear regulatory frameworks. Building codes do not yet recognize 3D-printed structures, making municipal approval and certification for occupancy impossible. This has confined activity to demonstration projects rather than scalable business models. Large-format printers also demand substantial capital investment, often hundreds of thousands of dollars, which is difficult to justify in an industry operating on thin margins. Technical barriers add another layer of complexity: engineered mixes must withstand Canada's freeze–thaw cycles, and there is little established workforce training in AM construction processes.

In consumer goods, the challenge is fundamentally economic. For firms producing hundreds of thousands or millions of units, AM cannot yet compete with the per-unit cost of injection molding, extrusion, or die casting, where tooling amortization drives prices down dramatically. While AM offers agility in prototyping and opportunities for personalization, these advantages are only commercially viable in low-volume or premium niches. Technical limitations further slow adoption: AM polymers often lack durability certifications, surface finishes require costly post-processing, and safety testing introduces additional compliance burdens. At the organizational level, most consumer goods firms lack in-house expertise in Design for 3D printing (DFAM), and Canada faces an ongoing skills shortage in advanced manufacturing roles. As a result, adoption in this sector remains largely symbolic, with AM showcased in small batches, design studios, or marketing pilots, rather than scaled production.

In order to improve adoption across both sectors as well as other low adoption sectors, a few key changes need to be made. First, regulatory modernization is essential: national and provincial bodies should develop explicit provisions for AM in building codes and expand product certification frameworks to include AM materials and processes. Second, economic incentives and pilot funding can reduce the risk aversion of firms facing high capital costs, especially in construction. Third, technical research and standardization could reduce uncertainty and encourage industrial uptake. Finally, closing the training gap in DFAM is critical: investments in workforce development, standardized curricula, and cross-industry training programs would equip Canadian firms with the skills to translate AM from prototyping into production. Without these structural changes, AM in low adoption sectors is likely to remain that way, leaving Canada behind countries that are already integrating AM more fully into these challenging but high-potential sectors. Having established these sectoral patterns of adoption, the next chapter applies theoretical frameworks to explain why these disparities persist. By examining the behavioral and organizational factors influencing decision-making through the Technology Acceptance Model and the Diffusion of Innovation, Chapter 3 provides a theoretical lens for understanding why the adoption of AM varies so widely across sectors. These models were selected because they capture both the individual-level drivers of technology acceptance, such as perceived usefulness, ease of use, and attitudes toward innovation, and the organizational and social dynamics that determine how innovations diffuse across industries. Together, they offer a comprehensive framework for interpreting how perceptions, institutional readiness, and communication networks influence the pace and pattern of AM adoption within the Canadian manufacturing landscape.

Chapter 3: Technology Adoption Theory and the Adoption of 3D printing

3.1 Introduction to Technology Acceptance Models (TAM)

The Technology Acceptance Model (TAM), developed by Fred Davis in 1989, is a foundational framework used to understand how individuals come to accept and use new technologies, otherwise known as technology adoption. [30] Originally developed to explain user acceptance of information systems, TAM has since been adapted and applied across a wide range of sectors such as healthcare, mobile technologies, and more recently, manufacturing and advanced production technologies such as 3D printing.

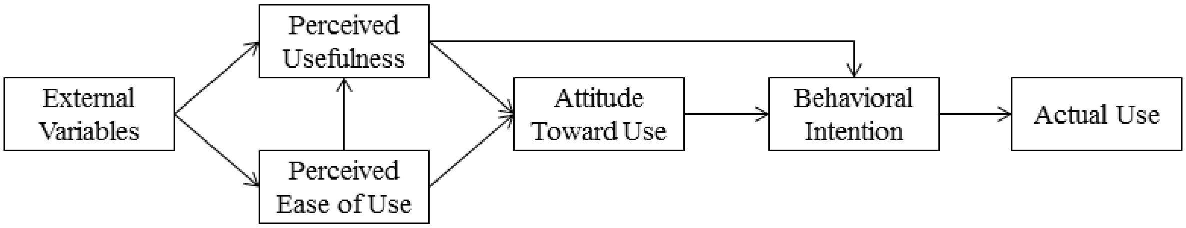

Figure 1: A visual representation of the original Technology Acceptance Model by Davis

The Technology Acceptance Model centers around two key factors that shape a user's acceptance of a given technology: perceived usefulness (PU) and perceived ease of use (PEOU). [30] Perceived usefulness refers to the degree to which a person believes that using a technology will enhance their quality of life or other more specific aspects such as job performance, while perceived ease of use reflects the belief that using the system will require minimal effort or change. [30] These factors influence the user's perception of a technology, which in turn affects their motivation to use the technology, ultimately determining user behaviour of a given technology. TAM provides a structured way to assess why some technologies are embraced while others are resisted, making it especially valuable in contexts like 3D printing where adoption depends on both technical benefits and user perceptions. [31] While TAM's original scope focused on individual users, later models such as TAM2, TAM3, and the Unified Theory of Acceptance and Use of Technology (UTAUT) have introduced additional variables like social influence, facilitating conditions, job relevance, and perceived behavioral control to reflect the role of organizational dynamics in shaping adoption decisions. [31] In the context of advanced manufacturing technologies like 3D printing, these newer models are especially relevant as adoption decisions are rarely made by single users. [32] Instead, they involve multiple stakeholders such as engineers, procurement officers, and executives, who all bring various levels of expertise, perceived risk, and professional incentives to the decision-making process. In this environment, a purely cognitive model such as TAM may overlook deeper cultural and structural factors that inhibit or enable adoption. This chapter uses TAM as a foundation to explore the specific barriers and enablers of 3D printing adoption. It begins by outlining the theoretical roots of TAM and how it has evolved since its inception. It then reviews the literature applying TAM to manufacturing environments and identifies common limitations of the model when applied to complex industrial technologies. The chapter concludes by proposing a modified conceptual framework tailored to AM, incorporating additional variables identified through interviews and existing research. This framework sets the stage for a deeper empirical analysis in the following chapters, where interview data is used to test and refine the model in practice.

By grounding the discussion in TAM, this chapter aims to clarify how internal perceptions, organizational support, and contextual alignment work together to shape adoption behavior. It also highlights where gaps in understanding remain, pointing toward areas where theory can be expanded to better reflect the real-world challenges faced by firms considering the transition to 3D printing.

3.2 Literature Review of TAM in Manufacturing Contexts

Since its introduction in the late 1980s, the Technology Acceptance Model has become one of the most influential frameworks for understanding individual-level adoption of technology. [30] While the foundational structure of the Technology Acceptance Model is widely cited, its continued relevance depends on how well it can be adapted to emerging technologies and complex organizational environments. In manufacturing contexts like 3D printing, adoption is shaped not only by user perceptions, but also by how well those perceptions align with operational demands, strategic priorities, and institutional norms. This section reviews the theoretical extensions of TAM and synthesizes key findings from the manufacturing literature to identify where the model succeeds, where it falls short, and how it must be adapted to reflect the real-world challenges faced by firms evaluating AM adoption. As the pace and complexity of technological innovation have increased, so too has the need to adapt TAM for more nuanced and sector-specific analyses.

To address the limitations of the original Technology Acceptance Model, researchers have extended TAM in several ways. TAM2, developed by Venkatesh and Davis, introduced variables like subjective norms, job relevance, and output quality, which were designed to capture the influence of organizational expectations and peer behavior on technology adoption. [33] These constructs acknowledge that individuals do not evaluate new systems in isolation, but rather within the context of workplace culture, managerial influence, and the perceived relevance of the technology to their specific roles.

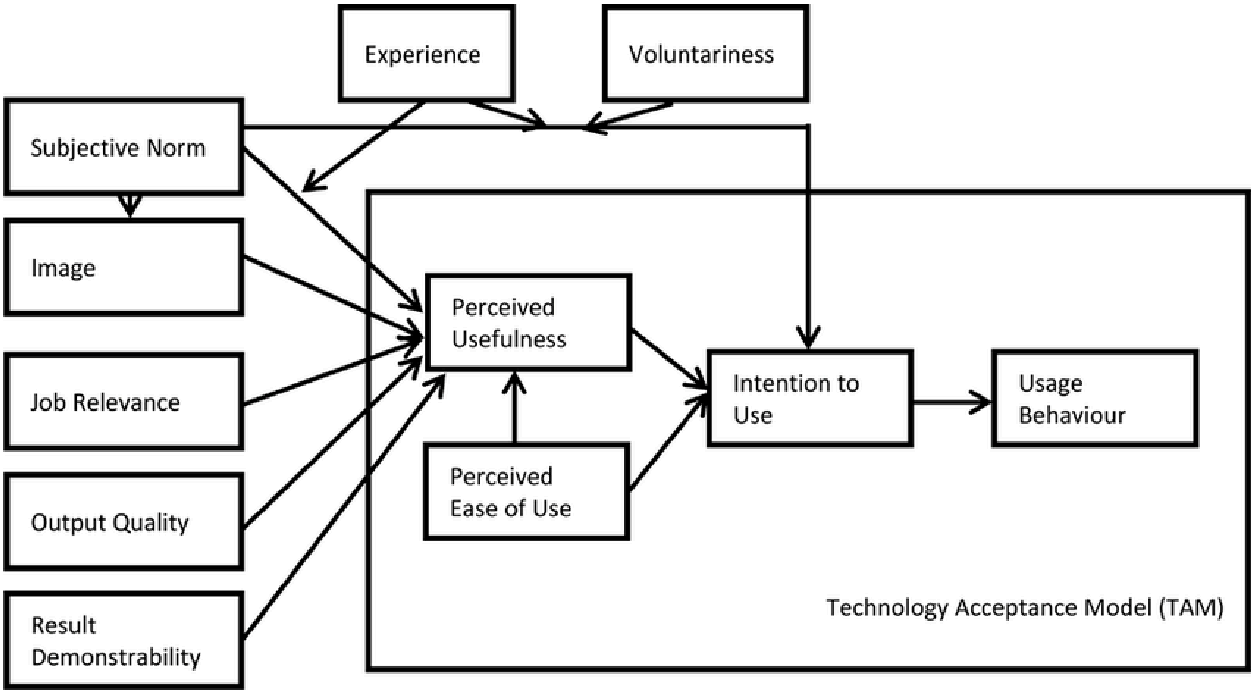

Figure 2: A visual representation of the Technology Acceptance Model 2 by Venkatesh and Davis [33]

Building on this, TAM3 further enhanced the model by introducing computer self-efficacy, perceived external control, computer anxiety, and perceived enjoyment. [34] These variables recognize that emotional and psychological responses such as confidence in one's ability to use a system, or discomfort when faced with new interfaces can profoundly shape perceptions of ease of use and ultimately impact adoption behavior. This is particularly present in manufacturing, where advanced technologies like AM often require operators and engineers to adopt entirely new digital workflows that contrast quite significantly to the more traditional interfaces and workflows they are accustomed to, sometimes with limited support or training.

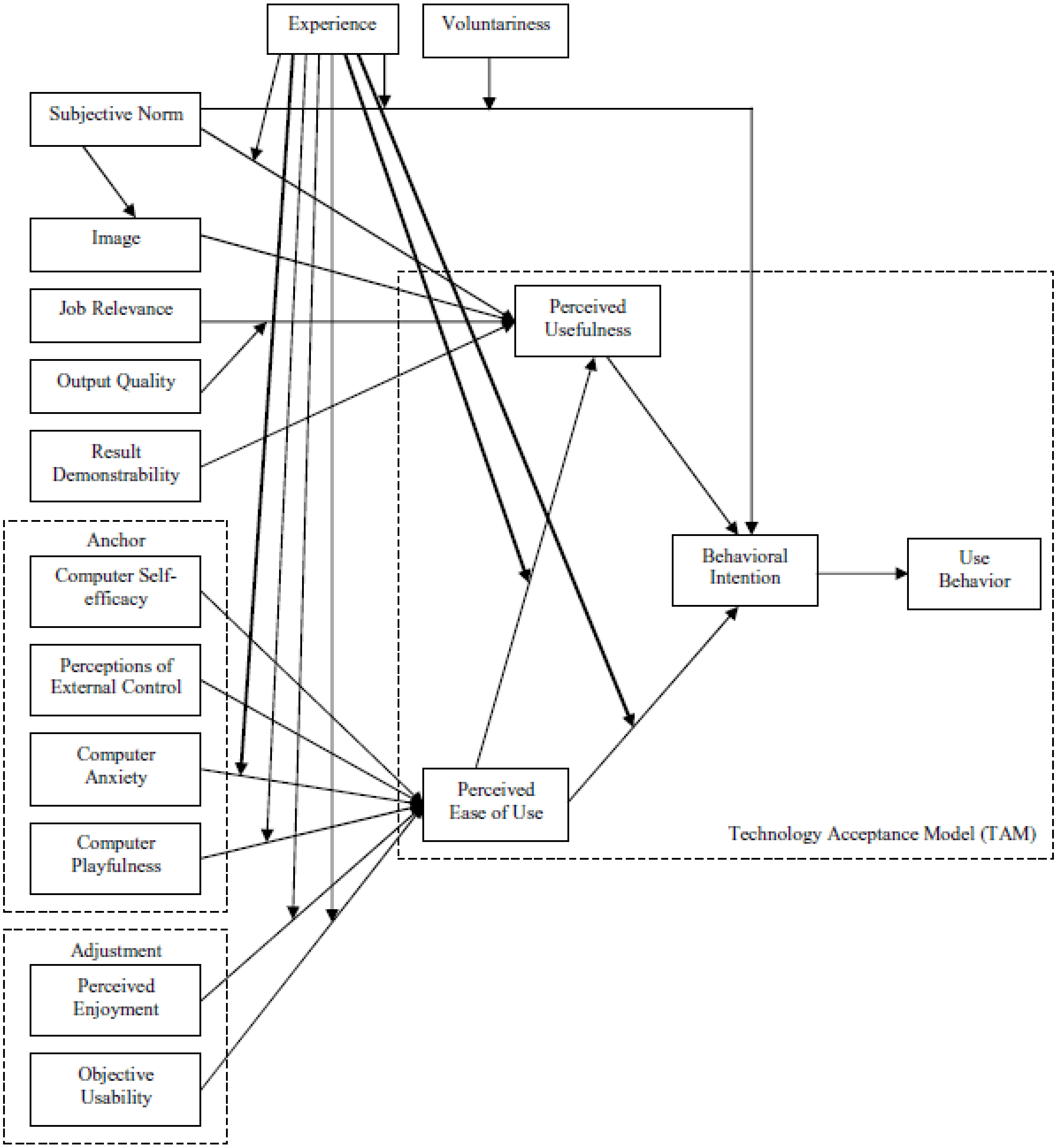

Figure 3: A visual representation of the Technology Acceptance Model 3 by Venkatesh, Viswanath, and Hillol Bala [34]

In response to the growing number of technology adoption models, the Unified Theory of Acceptance and Use of Technology (UTAUT) was developed as a comprehensive framework that synthesizes key elements from TAM, the Theory of Planned Behavior, Innovation Diffusion Theory, and other foundational models. [34] Additionally, variables such as age, gender, experience, and voluntariness of use have been incorporated as moderators that influence how users interpret and respond to new technologies, shaping both their behavioral intentions and actual usage patterns across different organizational contexts.

UTAUT introduced four core constructs:

1. **Performance expectancy**

   The degree to which an individual believes that using a technology will lead to gains in job performance or productivity.

2. **Effort expectancy**

   The degree of ease associated with the use of the technology; similar to perceived ease of use in TAM.

3. **Social influence**

   The extent to which an individual perceives that important others (e.g., peers, supervisors) believe they should use the new technology.

4. **Facilitating conditions**

   The degree to which an individual believes that the organizational and technical infrastructure exists to support the use of the system.

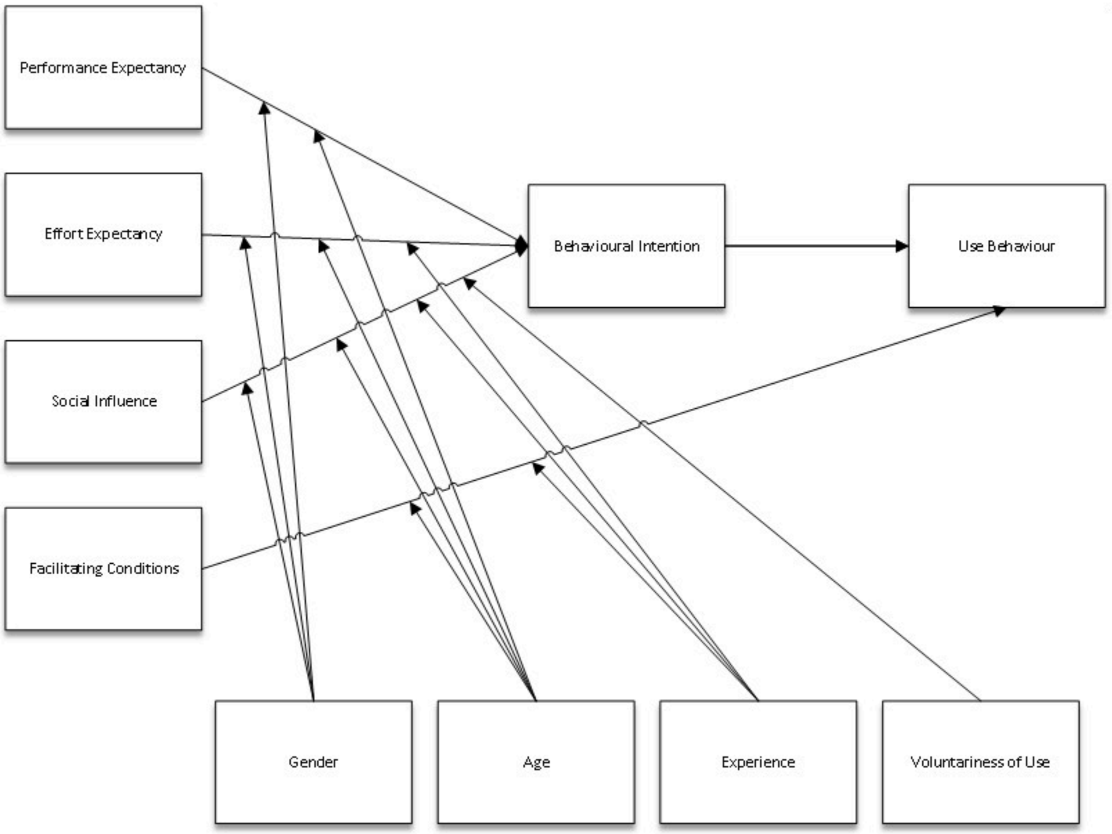

Figure 4: A visual representation of the Unified Theory of Acceptance and Use of Technology by Venkatesh, Viswanath [35]

In the context of manufacturing, this model allows for a more comprehensive understanding of how user perceptions are shaped by access to infrastructure, leadership support, peer adoption, and organizational culture. While UTAUT extends the cognitive framing of technology adoption by incorporating social influence, behavioral control, and user affect, it still underrepresents the structural and institutional factors that influence real-world decision-making. Adoption requires alignment with organizational systems, professional norms, and long-term strategic objectives. In manufacturing contexts, especially, successful implementation depends on how well the technology aligns with existing workflows, organizational systems, and strategic priorities. It also demands cultural compatibility with the professional norms and identities of those expected to use or support it. Similarly, Wallin, Nokelainen, and Kira (2022) demonstrate that digitalization can induce identity misalignment as when professionals feel their skillset or role is threatened, their adoption behavior may be constrained even if the technology is objectively beneficial. [36] In their study, identity misalignment arises when individuals feel that their existing skillsets or established roles are being devalued or replaced. Even in situations where digital tools offer clear functional or organizational benefits, adoption may be constrained because professionals act to protect their sense of competence, legitimacy, and belonging within the workplace. This dynamic reveals that resistance is not always a matter of misunderstanding or lack of technical knowledge, but rather a rational response to perceived threats to identity and status.

From this perspective, digitalization is more than an operational shift, it is also a cultural change that can redefine what it means to be a professional in a given context. When workers interpret new technologies as incompatible with their expertise or as eroding the value of their contributions, adoption is likely to be negatively impacted or even actively opposed. Within the 3D printing domain, Haug (2022, 2023) highlights the importance of knowledge networks and organizational maturity in enabling firms to align technological capability with broader business strategy. [37] His research shows that AM adoption is rarely a matter of acquiring machines alone; instead, it requires the development of organizational structures, collaborative ties, and knowledge flows that integrate technical expertise into decision-making. Firms that cultivate strong networks, whether through partnerships with suppliers, universities, industry consortia, or customers, are better able to access the specialized knowledge needed to deploy AM effectively. These connections not only accelerate learning but also provide benchmarks and shared practices that reduce uncertainty in the face of disruptive technologies. [37]

At the same time, maturity levels play a critical role in shaping how well AM technologies are embedded into organizational routines. Organizations with higher maturity demonstrate a clearer ability to translate technical potential into business value, ensuring that AM investments are aligned with strategic objectives rather than isolated experiments. This maturity reflects both technical competencies (such as design for AM or process optimization) and organizational readiness (such as leadership support, change management, and cross-functional collaboration). [37] By bridging technical knowledge with strategic alignment, mature firms are more successful in addressing common barriers, including role misalignment, inertia in established workflows, and skepticism from professionals who may view AM as disruptive to existing practices.

Haug's findings suggest that successful adoption depends not only on the technological capability of AM systems but also on the firm's ability to embed that capability within a broader network of knowledge and strategy. When organizations achieve this alignment, AM can move beyond pilot projects toward scaled applications that generate sustained competitive advantage. [37]

3.3 Developing a TAM-Based Conceptual Framework for 3D printing

While the core principles of the Technology Acceptance Model remain relevant, applying TAM to the context of 3D printing requires a more specific adaptation. Unlike many consumer-facing or administrative technologies, AM is not a plug-and-play solution, but instead requires changes in workflows, technical training, digital design integration, and even organizational mindset. These challenges go beyond the basic notions of perceived usefulness and ease of use originally outlined by Davis (1989), requiring a broader framework that accounts for the industrial complexity and cultural inertia often associated with new manufacturing tools. The conceptual framework developed in this study builds on TAM's foundational logic but introduces a set of new variables that reflect both the technical realities of AM and the organizational environment in which adoption decisions are made. This model has been shaped by a synthesis of existing literature and the preliminary findings from interviews with professionals engaged in manufacturing, product development, and industrial innovation. In particular, research on identity and digitalization demonstrates that technology adoption is not purely a rational evaluation of utility and usability, but is also tied to how technologies intersect with professional roles, organizational identity, and strategic alignment.

In the AM context, perceived usefulness refers to how the technology is expected to improve product development, reduce lead times, or enhance customization capabilities. For example, design engineers may value the ability to iterate quickly on part geometry without incurring tooling costs. However, perceived usefulness can be undermined if AM is viewed as less capable in terms of mechanical performance, surface finish, or scalability. This variability means usefulness is highly context-specific and must be evaluated in light of existing manufacturing processes and business priorities.

Perceived ease of use similarly takes on new meaning in AM environments. It no longer refers to basic interface usability, but instead encompasses the entire technical and procedural workflow, ranging from CAD modeling and print preparation to machine operation, post-processing, and quality assurance. When users are unfamiliar with the digital tools required or when integration with legacy systems proves difficult, ease of use is naturally rated low.

To enhance the model's realism and relevance, four additional variables are introduced in this conceptual framework:

1. **Organizational Support:** The extent to which leadership, budget, and personnel are allocated to support adoption. If AM is viewed as an isolated experiment rather than a strategic initiative, it is less likely to be integrated successfully.

2. **Workflow Compatibility:** The degree to which AM fits into existing production and design workflows. Technologies that require major changes to procurement, quality control, or product lifecycle planning are often perceived as burdensome.

3. **Perceived Complexity:** A counterpoint to ease of use, this construct captures the broader sense of technical difficulty, maintenance demands, and learning curve associated with AM. High perceived complexity can override perceived usefulness, especially when organizational risk tolerance is low.

4. **Cultural Factors:** The shared values, norms, and attitudes within an organization or industry that shape perceptions of innovation, authority, and change. Cultural context influences how individuals interpret core elements of TAM such as usefulness, ease of use, and social influence, and how communication channels and opinion leadership function within the DOI framework. In organizations with open, collaborative, and learning-oriented cultures, AM is more likely to be embraced as a tool for innovation. Conversely, in hierarchical or risk-averse environments, adoption may be slowed by resistance to experimentation or deviation from established practices.

A visual representation of the model is provided in Figure 5 on the next page. It captures the relationships between core TAM constructs and the extended variables relevant to 3D printing adoption. This model will be tested and refined in the next section using qualitative data collected from industry interviews. The goal is to determine whether the relationships proposed here are supported by real-world experience and to identify where further adjustments may be needed to better reflect practice.

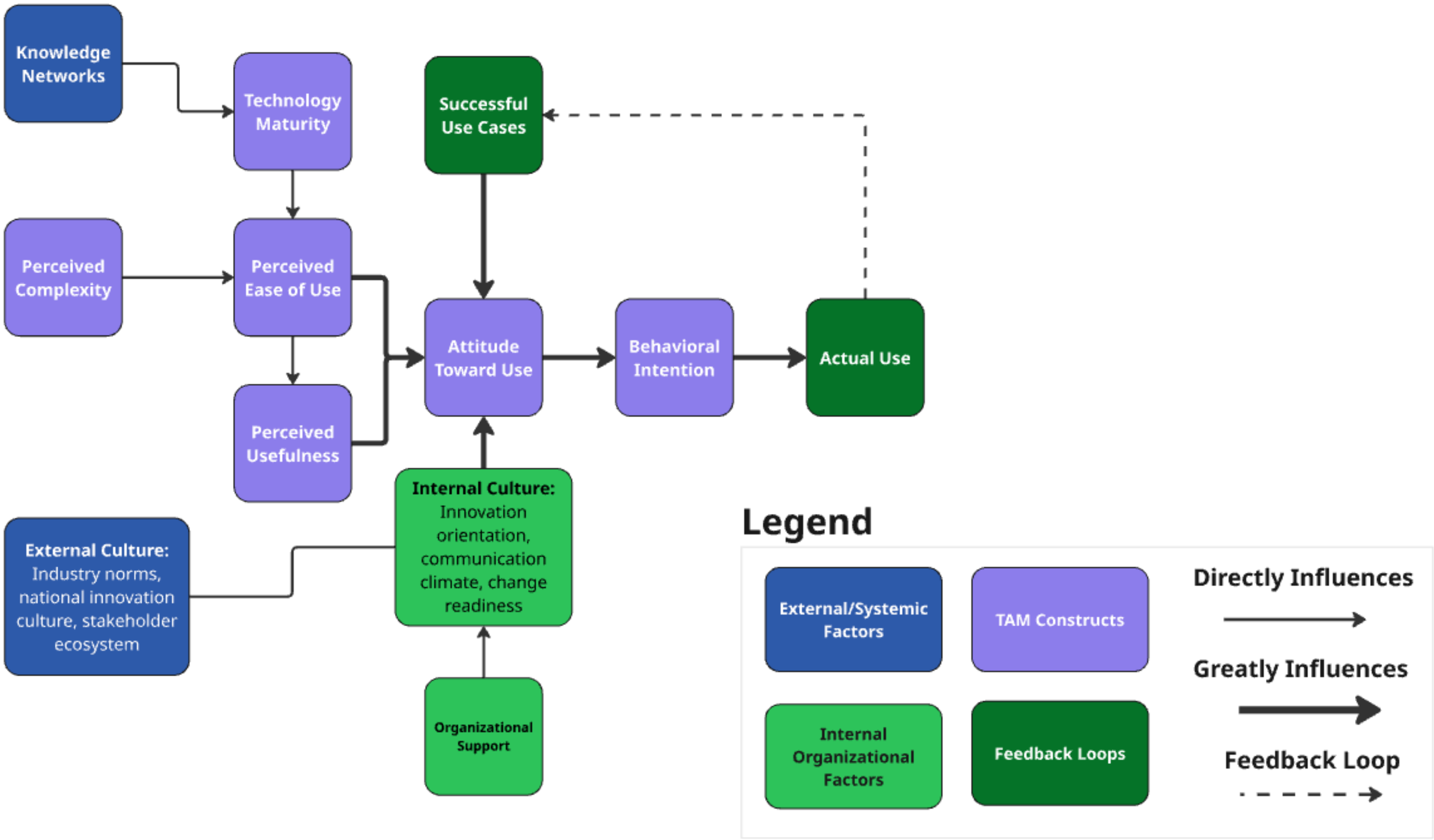

Figure 5: TAM-Based Conceptual Framework for 3D printing

Each of the factors within the framework interacts dynamically with the core constructs of the Technology Acceptance Model (TAM) to shape an individual's overall attitude toward additive manufacturing (AM) and their behavioral intention to adopt it. As shown in Figure 5, the model illustrates that AM adoption does not follow a strictly linear path but is instead influenced by multiple feedback loops and contextual factors. For example, increased organizational support can reduce perceived complexity, which in turn strengthens both perceived ease of use and perceived usefulness. Conversely, a lack of role clarity or alignment between the technology and professional identity can suppress positive attitudes even when perceived usefulness is objectively high. The interaction of these elements determines not only whether a user forms a favorable attitude toward AM, but also whether that attitude translates into actual use within the organization.

Internal and external culture plays a significant role on how decisions around technology adoption are made. As defined by Edgar Schein, organizational culture comprises shared assumptions, values, and behavioral norms that shape how employees perceive, think about, and respond to technological innovation. [37] Factors such as innovation orientation, communication climate, and readiness for change influence how individuals make sense of new technologies and evaluate their potential benefits. [37] Organizations characterized by openness, collaboration, and experimentation are more likely to frame 3D printing as a tool for creativity and problem-solving, reinforcing positive perceptions of both perceived usefulness and perceived ease of use. In contrast, hierarchical, highly formalized, or risk-averse cultures tend to amplify perceived complexity and reduce enthusiasm for adoption, even when technological maturity or institutional support is high. [38]

External culture such as including industry norms, sector-specific innovation traditions, national attitudes toward technological experimentation, and stakeholder expectations also plays a critical moderating role. Industries with strong innovation cultures and active knowledge-sharing ecosystems create social reinforcement that accelerates acceptance of emerging technologies, whereas industries with conservative norms or rigid regulatory structures experience slower diffusion. Thus, culture operates as a bridge between individual cognition and systemic forces, determining how readily organizations move from awareness to trial, adoption, and sustained implementation. This aligns with longstanding findings that organizational culture is a central determinant of innovation adoption, influencing not only whether individuals perceive a technology as useful or usable, but also whether the broader organizational environment supports or suppresses the behavioural changes required for successful diffusion.

The model also incorporates a feedback loop that influences adoption over time. Early implementation failures can elevate perceived complexity, reduce confidence, and stall momentum. In contrast, successful use cases such as a well-communicated pilot project or a visible production win can reinforce perceived usefulness, enhance organizational confidence, and generate social proof that encourages wider diffusion.

Overall, this conceptual model serves as both an interpretive and diagnostic framework. It provides a structured lens through which to analyze qualitative data and assess how theoretical constructs manifest in practice. By organizing internal, external, and perceptual variables into a cohesive system, it clarifies how AM adoption is shaped by interactions among technical maturity, user perceptions, and cultural readiness. Practically, this framework enables organizations to identify friction points and prioritize interventions that enhance adoption success. From a research standpoint, it forms the analytical foundation guiding the interview design and coding strategy described in Chapter 5, ensuring that each construct is systematically examined through empirical data.

While the Technology Acceptance Model provides valuable insight into the cognitive and organizational determinants of technology adoption, it does not fully capture the broader social, institutional, and systemic forces that shape diffusion. Cultural norms, communication networks, and collective learning processes influence how innovations spread beyond individual organizations.. The following chapter therefore extends this analysis by applying DOI to examine how innovation attributes, communication channels, and social system factors contribute to the pace and breadth of additive manufacturing adoption across Canada's manufacturing ecosystem.

Chapter 4: Diffusion of Innovation (DOI) and The Product Adoption Process

4.1 Introduction to Diffusion of Innovation

The Diffusion of Innovation theory, developed by Everett Rogers, provides a broad and influential framework for understanding how new technologies spread through social systems over time. [37] While the Technology Acceptance Model, discussed in Chapter 3 focuses on explaining why individual users or organizations decide to adopt or reject a technology, DOI examines how adoption expands across populations, industries, and interconnected networks. In the context of 3D printing, this distinction is essential: while individual firms may recognize specific advantages, the broader question is how adoption advances across the Canadian manufacturing ecosystem as a whole. [37] Rogers' model illustrates that adoption rarely occurs uniformly. Instead, it follows a predictable distribution of adopter categories, depicted in Figure 4.1, where populations move through stages of uptake at different rates. The model divides adopters into innovators, early adopters, early majority, late majority, and laggards, representing varying levels of openness to new technologies and risk tolerance.

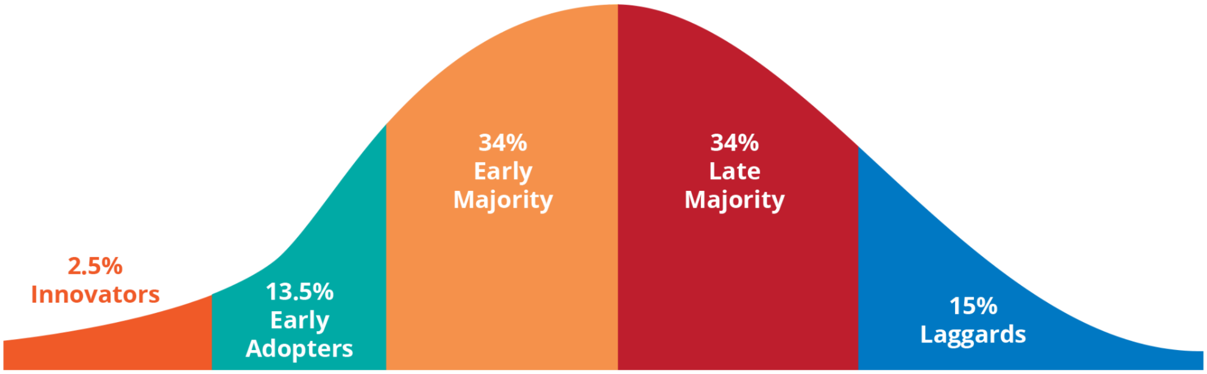

Figure 6: The Diffusion of Innovation Adoption Curve (Diffusion of Innovations, 5th Edition) [37]

Innovators tend to adopt early due to resource availability, experimentation, and curiosity. Early adopters often serve as opinion leaders seeking strategic advantage. The early majority adopt once the technology's benefits are validated by peers, while the late majority follow as adoption becomes standard practice or competitively necessary. Laggards are the last to adopt, typically constrained by structural, cultural, or financial barriers. Understanding where Canadian manufacturing sectors fall within this curve is critical to analyzing why AM diffusion remains uneven, often concentrated in advanced sectors such as aerospace and healthcare, yet limited in traditional manufacturing domains.

Beyond categorizing adopters, Rogers conceptualizes diffusion as a process progressing through five stages: knowledge, persuasion, decision, implementation, and confirmation. [37] These stages trace how potential adopters move from awareness of a technology to sustained use. Progression through these stages depends on multiple contextual factors, including the characteristics of the innovation, the social systems in which it is embedded, the communication channels that transfer information, and the time over which adoption decisions are made.

To explain why some innovations spread more rapidly than others, DOI identifies five key attributes that influence adoption rates: relative advantage, compatibility, complexity, trialability, and observability.

1. Relative advantage refers to the perceived improvement of the innovation over existing alternatives.
2. Compatibility concerns how well the innovation fits within established workflows, practices, and systems.
3. Complexity captures how difficult it is to understand and apply.
4. Trialability measures the extent to which organizations can test or pilot the innovation before full-scale adoption.
5. Observability relates to the visibility of the innovation's benefits to others.

In the context of AM, these attributes highlight the friction between its technical potential and practical integration. AM exhibits strong relative advantages in prototyping, tooling, and design iteration, and several studies identify this attribute as a primary driver of adoption. [38] However, adoption remains hindered by challenges of compatibility with legacy production systems, the complexity of digital workflows, limited trialability due to cost and equipment access, and low observability when applications occur internally rather than in visible end-use products. [39]

One of DOI's central contributions is its emphasis on communication networks and knowledge ecosystems. Innovations spread more effectively within systems that foster active information exchange through industry associations, research institutions, supply chain partnerships, and peer networks. Conversely, fragmented or isolated systems inhibit diffusion by limiting visibility and reducing opportunities for shared learning. In the Canadian context, where manufacturing hubs are geographically dispersed and collaboration across sectors remains inconsistent, these dynamics play a defining role in the speed and scope of AM adoption. Empirical research on AM knowledge networks indicates that firms embedded in stronger information-sharing ecosystems experience faster and more effective adoption outcomes. [40]

Overall, DOI complements TAM by expanding the analytical lens from individual decision-making to the collective mechanisms of technological diffusion. TAM explains why organizations perceive value in AM, whereas DOI reveals how those perceptions aggregate into broader adoption patterns across the industrial landscape. Together, these frameworks form a comprehensive foundation for examining both micro-level drivers and macro-level barriers to AM adoption in Canada. Overall, DOI complements TAM by shifting the analytical lens from individual perceptions to the broader mechanisms through which technologies spread across industrial systems. Yet understanding diffusion alone is insufficient without examining how individual firms progress through the internal decision steps that lead to adoption. The next section introduces the Product Adoption Process (PAP), a firm-level model inspired by the Diffusion of Innovation framework that outlines the sequential stages organizations move through from initial awareness of a given technology such as 3D printing to full implementation. Together, DOI and PAP provide a multi-level foundation for analysing 3D printing adoption in Canadian manufacturing.

4.2 Introduction to the Product Adoption Process

While the Diffusion of Innovation framework explains how technologies spread across populations and industries, understanding adoption at the firm level requires a more granular model of how organizations progress from initial exposure to full implementation. The Product Adoption Process (PAP) provides this micro-level perspective by outlining the sequential stages that shape how individual firms learn about, evaluate, test, and ultimately integrate a new technology. In manufacturing environments where adoption decisions are often capital-intensive and dependent on organizational readiness, PAP offers a practical framework for analyzing the specific decision points at which firms advance, hesitate, or disengage. The structure of PAP is illustrated in Figure 7 below, which presents the sequential stages of organizational adoption and their role in shaping decision progression.

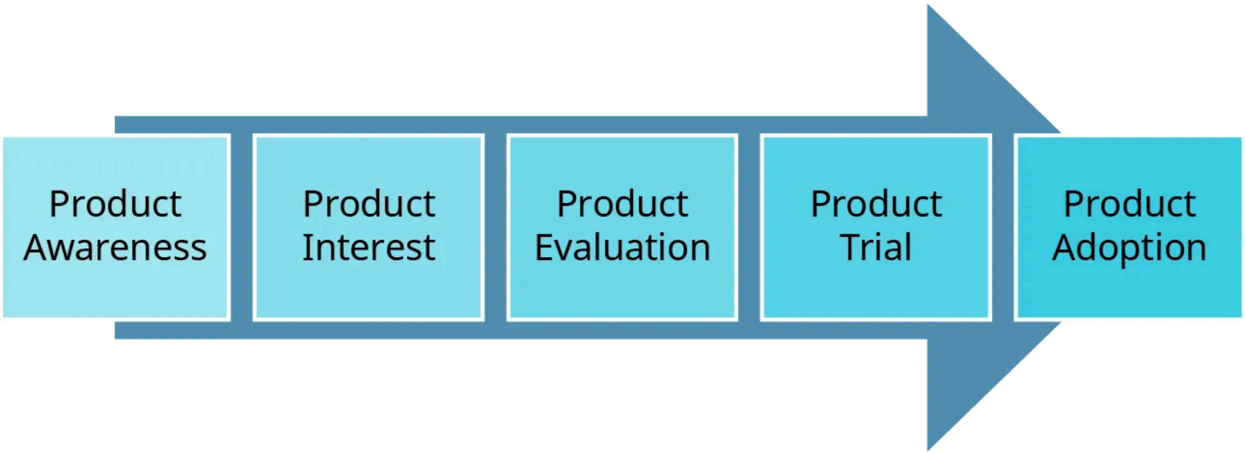

Figure 7: The Product Adoption Process

PAP is commonly represented as a five-stage sequence consisting of awareness, interest, evaluation, trial, and adoption. Unlike DOI, which categorizes where a firm sits relative to others on the diffusion curve, PAP focuses on internal decision-making progression, capturing the behaviours, information needs, uncertainties, and constraints that shape each step of the adoption journey. This distinction is critical for 3D printing, where many Canadian manufacturers express early curiosity yet struggle to advance past the evaluation or trial stages due to concerns over cost, technical complexity, certification requirements, or workforce capabilities. Following this sequence offers a useful lens for understanding technology adoption behaviours which can be used to understand the adoption process for 3D printing. When looking at the product adoption process for 3D printing, the awareness stage involves initial exposure to 3D printing through media, trade shows, vendor outreach, or academic collaboration. Awareness may be superficial and often reflects general curiosity rather than concrete technological understanding. As firms transition into the interest stage, decision-makers seek additional information, examining case studies, exploring potential applications, and assessing early perceptions of relative advantage or compatibility. These early judgments strongly influence whether interest deepens or stalls.

The evaluation stage marks a pivotal point in the process, where firms compare 3D printing against existing workflows, costs, and performance standards. Continuing to explore this process under the lens of 3D printing, many adoption efforts become stuck here due to uncertainties around design-for-additive-manufacturing capabilities, material reliability, certification pathways, or ROI. When firms do advance, they enter the trial stage, running pilot projects, outsourcing prototypes, or leveraging demonstration centres, university labs, and government-supported testbeds. Trialability reduces uncertainty by allowing firms to learn through experimentation, hands-on testing, and controlled implementation. Finally, successful trials can lead to adoption, where the technology is integrated into standard workflows and supported through resource allocation, staff training, quality assurance frameworks, and process redesign. In 3D printing, this stage often requires cultural readiness, interdisciplinary collaboration, and alignment with regulatory or customer expectations.

Understanding PAP is essential for interpreting AM adoption patterns in Canada. Many firms remain early in the process, not because they reject the technology but because barriers arise at distinct stages, preventing progression from evaluation to trial or from trial to full adoption. By identifying where and why firms stall, PAP helps clarify the mechanisms behind the broader diffusion gaps observed in DOI analyses. When combined, DOI and PAP offer a multi-level understanding of adoption: DOI describes how far adoption has spread across the ecosystem, while PAP clarifies how and why individual organizations progress through the adoption journey. The next section reviews literature applying both DOI and PAP in manufacturing settings and examines how these frameworks have been used to analyze the adoption of 3D printing and other advanced production technologies.

4.3 Literature Review of DOI and PAP in Manufacturing Contexts

Building on the frameworks introduced in Sections 4.1 and 4.2, this section reviews how the Diffusion of Innovation and Production Adoption Process frameworks have been applied within manufacturing contexts, with particular emphasis on 3D printing adoption. While DOI has proven effective in explaining adoption patterns across various fields such as agriculture, healthcare, and information technology, its application to manufacturing reveals distinctive structural and organizational challenges. Manufacturing systems are capital-intensive, risk-averse, and highly interdependent, often involving complex supply chains and regulated production environments. As a result, the diffusion of manufacturing technologies tends to follow a slower, more incremental trajectory than that observed in consumer or digital markets, where barriers to experimentation and adoption are comparatively low. [41]

In the case of 3D printing, diffusion patterns reflect these broader industrial dynamics. Studies have shown that AM adoption has been most pronounced in aerospace, automotive, and medical device sectors, where production volumes are relatively low and performance demands justify the investment in advanced technologies. These industries represent the innovators and early adopters stages of Rogers' diffusion curve, as they leverage AM for specialized applications such as lightweight structural components, patient-specific implants, and high-performance tooling. These uses illustrate the strong relative advantage of AM in enabling complex geometries, reducing lead times, and supporting mass customization. [42]

Conversely, sectors such as construction, heavy manufacturing, and energy remain situated within the late majority or laggard stages. Here, AM adoption has been hindered by compatibility issues with established workflows, complexity in scaling production, and limited observability of commercial success. Construction firms, for example, face material certification challenges and inconsistent quality standards for large-scale printing, while general manufacturing often lacks validated design rules and post-processing frameworks. These barriers reinforce Rogers' observation that diffusion is rarely uniform; innovations with clear technical potential may still fail to progress beyond early adoption if ecosystem conditions are unfavorable. [43] Within advanced manufacturing research, scholars have emphasized that communication networks and ecosystem maturity are critical determinants of diffusion speed. Knowledge transfer and collaboration, particularly across academia, industry, and government, serve as key drivers in overcoming uncertainty and building trust in emerging technologies. Boundary organizations such as industry consortia, superclusters, and government innovation agencies play an important intermediary role in translating technical advancements into accessible knowledge and shared standards. [44]

Beyond system-level analyses, several studies have applied stage-based adoption models closely aligned with the Product Adoption Process (PAP) to understand how individual firms move from awareness to implementation of 3D printing. Mellor, Hao, and Zhang (2014), for example, propose a multi-stage AM adoption framework in which firms progress through awareness, evaluation, trial, and deployment, noting that many manufacturers stagnate in the evaluation or pilot stage due to uncertainty around cost, quality assurance, and process integration. [45] Similarly, Schniederjans and Yalcin (2018) find that AM adoption often follows a stepwise decision path shaped by organizational readiness, perceived benefits, and internal capability development, mirroring PAP's emphasis on sequential decision-making. [46] Khanzadeh and Tulu (2021) further observe that firms rarely advance directly to full-scale adoption; instead, 3D printing is first explored through low-risk, exploratory trials that act as a bridge between interest and commitment, consistent with the trial stage of PAP. [47]

These studies collectively highlight that AM adoption is not a binary decision but a process of gradual progression, where firms accumulate knowledge, reduce uncertainty, and build internal capability over time. This stage-based behaviour aligns closely with PAP and provides empirical support for integrating PAP alongside DOI in this thesis. In particular, the repeated observation that firms stall at evaluation or trial underscores that the obstacles to AM adoption occur at specific points in the decision journey, not uniformly across all stages.

In Canada, this dynamic is reflected in initiatives such as Next Generation Manufacturing Canada (NGen), NRC-IRAP, and regional Advanced Manufacturing Superclusters, which promote collaborative AM projects and encourage cross-sector learning. These programs aim to reduce perceived risks through shared infrastructure, funding support, and pilot projects, helping to increase trialability and by extension, adoption. Collectively, the existing literature underscores that AM adoption is influenced by a complex interplay of technological, organizational, and systemic factors. While AM offers clear relative advantages, its broader diffusion is constrained by compatibility challenges, high perceived complexity, limited trialability, and low observability of proven success cases. At the same time, PAP-aligned studies demonstrate that adoption is a multi-stage organizational process, where barriers arise at specific decision points rather than uniformly across the diffusion curve. These insights reinforce the value of developing an integrated DOI–PAP conceptual framework that captures both the macro diffusion patterns and the micro-level pathways governing AM adoption. Building on these insights, the next section develops a DOI–PAP conceptual framework tailored to Canada's AM diffusion landscape.

4.4 Developing a DOI/PAP-Based Conceptual Framework for 3D printing

The literature reviewed in the preceding sections demonstrates that the adoption of 3D printing in manufacturing is shaped by a complex interplay of technological, organizational, and ecosystem-level factors. While Rogers' Diffusion of Innovation theory offers a valuable macro-level perspective on how new technologies spread across populations over time, and the Technology Acceptance Model explains how individuals cognitively assess technological usefulness and ease of use, neither framework fully accounts for the step-by-step progression firms undertake when deciding whether to adopt a new production technology. To address this gap, the Product Adoption Process (PAP) is integrated into this framework as a micro-level model that captures the sequential stages through which firms traverse adoption: awareness, interest, evaluation, trial, and adoption.

Incorporating PAP into the conceptual model provides a structured way to understand how firms advance through the adoption journey, while DOI explains why adoption diffuses unevenly across sectors and what factors accelerate or hinder the pace of that diffusion. Together, DOI and PAP allow for a more comprehensive and process-oriented understanding of how 3D printing adoption unfolds within Canadian manufacturing. PAP highlights the internal decision-making mechanisms inside each organization, while DOI identifies the innovation attributes and ecosystem supports that shape progression at each stage.

The resulting DOI/PAP-based conceptual framework is illustrated in Figure 8 on the following page, which maps Rogers' innovation attributes and diffusion enablers onto the five PAP stages. By aligning innovation characteristics (e.g., relative advantage, compatibility, complexity, trialability, and observability) with the specific decision points within PAP, the framework demonstrates how perceptions of 3D printing evolve as firms move from initial exposure to full integration.

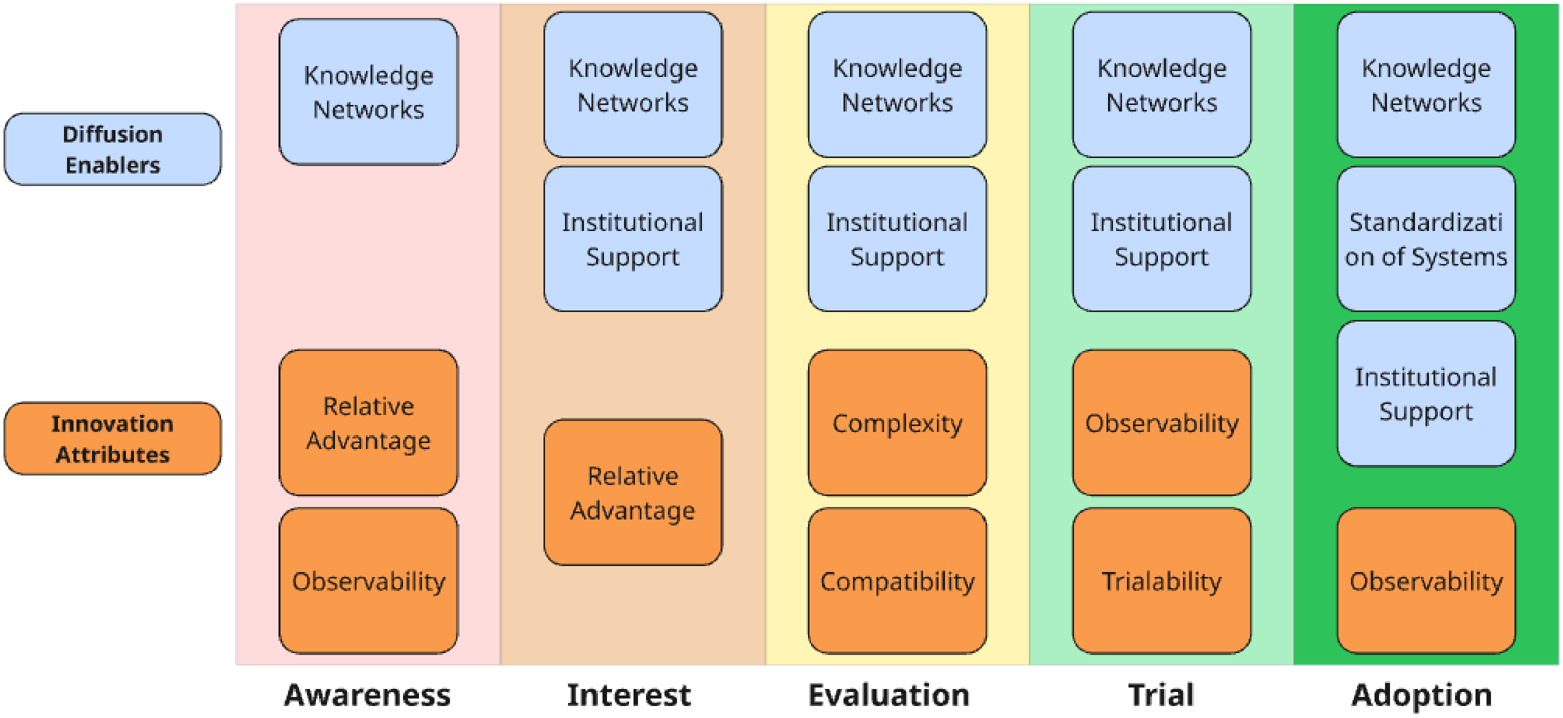

Figure 8: DOI/PAP-Based Conceptual Framework for Additive Manufacturing Adoption

A breakdown of how the various elements of the Diffusion of Innovation model fit into each stage of the Product Adoption Process has been provided below:

1. Awareness

In the awareness stage, firms first encounter 3D printing through broad information channels and industry exposure. At this early point, adoption decisions are not yet being weighed; rather, organizations are learning that AM exists and may hold potential relevance to their operations.

1a. Relevant Diffusion Enablers

Knowledge Networks: Industry associations, peer manufacturers, conferences, trade shows, and academic partnerships introduce firms to AM by circulating information, demonstrations, and early use cases.

1b. Relevant Innovation Attributes

Relative Advantage: Firms become aware that AM may offer improvements such as faster prototyping, design flexibility, or reduced tooling time.

Observability: Exposure to visible examples of AM in use, such as publicized case studies or physical demonstrations, helps firms recognize that the technology is actively deployed elsewhere.

Together, these elements shape initial awareness by highlighting both the existence of AM and its potential benefits, often through visible demonstrations and information-sharing networks.

2. Interest

The interest stage is characterized by organizations beginning to explore 3D printing more deliberately, motivated by curiosity and supported by early evidence of potential value. Firms actively seek further information to determine whether AM merits deeper investigation.

2a. Relevant Diffusion Enablers

Knowledge Networks: Provide more detailed insights into AM capabilities, use cases, and industry experiences.

Institutional Support: Signals strategic importance through grants, pilot programs, or innovation funding that encourages exploration.

2b. Relevant Innovation Attributes

Relative Advantage: Firms begin assessing AM benefits in a more concrete way, considering whether its advantages align with their needs or product portfolios.

These factors foster an active interest in AM by demonstrating its strategic relevance and encouraging organizations to envision possible internal applications.

3. Evaluation

In the evaluation stage, firms critically analyze whether AM is technically feasible, economically viable, and organizationally compatible. This stage involves comparing AM to existing processes and determining whether barriers can be overcome.

3a. Relevant Diffusion Enablers

Knowledge Networks: Offer benchmarks, lessons learned, and examples that inform evaluations of feasibility and ROI.

Institutional Support: Reduces risk through funding, training, and technical assistance, enabling firms to investigate AM more thoroughly.

3b. Relevant Innovation Attributes

Complexity: Firms assess the technical difficulty of adopting AM, including training requirements and process reliability.

Compatibility: They evaluate how well AM fits within established workflows, production systems, and digital infrastructure.

Evaluation is often where organizations encounter the most significant barriers, as technical and operational challenges become more apparent.

4. Trial

The trial stage involves hands-on experimentation, typically through pilot projects, prototype runs, or collaborations with service bureaus or academic labs. Firms gain direct experience using AM with their own parts, materials, and quality requirements.

4a. Relevant Diffusion Enablers

Knowledge Networks: Provide access to expertise, testing facilities, and peer support during pilots.

Institutional Support: Lowers financial and technical barriers to experimentation by supporting demonstration projects and pilot programs.

4b. Relevant Innovation Attributes

Observability: Firms generate internal evidence of how AM performs in their specific context.

Trialability: The ability to test AM on a limited scale without significant investment is central to this stage.

Trial activities allow organizations to validate performance, uncover practical constraints, and build internal capability before committing to full adoption.

5. Adoption

In the adoption stage, firms transition from experimentation to regular use of AM in production, tooling, prototyping, or other established workflows. Adoption involves formal integration, resource allocation, workforce training, and alignment with quality requirements.

5a. Relevant Diffusion Enablers

Standardization of Systems: Provides essential quality, regulatory, and material benchmarks that support reliable, certifiable use of AM.

Institutional Support: Facilitates scaling through training, infrastructure support, and long-term funding mechanisms.

5b. Relevant Innovation Attributes

Observability:Continued visibility of successful internal outcomes reinforces the decision to adopt and strengthens organizational confidence in AM.

At this stage, AM becomes part of normal operations, supported by standards and institutional mechanisms that ensure reliability, compliance, and scalability.

By aligning DOI constructs with the sequential stages of the Product Adoption Process, this framework bridges theoretical perspectives on innovation with the practical realities of organizational decision-making. The following chapter describes the research design employed to evaluate these relationships empirically within the Canadian manufacturing sector.

Chapter 5: Research Methodology

5.1 Introduction

This chapter presents the research methodology employed to examine the barriers and enablers shaping the adoption of 3D printing in Canadian industry. The study adopts a qualitative, exploratory approach, selected to capture the depth and complexity of economic, technological, and cultural factors influencing adoption decisions. The reasoning behind why this approach was selected is because qualitative inquiry is better suited than survey-based or purely quantitative methods for revealing nuanced perceptions, lived experience, and context-specific insights. [48] While survey-based and quantitative methods can yield broad generalizations, they are less able to probe the subjective meanings and organizational dynamics underlying adoption decisions.

Thus, such approaches were omitted in favor of interview-based data collection, which allows greater reflexivity and depth. [49]

The semi-structured interviews served as the primary data collection method with this format allowing a balance between consistency in addressing core research questions and openness to deeper exploration of participant experiences, organizational constraints, and sectoral differences. [50] A total of 30 participants were interviewed, representing a diverse mix of industry leaders, academics, policymakers, suppliers, and manufacturing organizations either using or considering AM. The sample was purposely selected to capture a range of diverse perspectives across industries, professional backgrounds, and organizational roles. Deliberate sampling strategies of this nature are common in qualitative research to ensure diversity of insight rather than statistical representativeness. [51]

To ensure validity, reliability, and ethical integrity, multiple procedures were embedded throughout the research process. Triangulation was achieved by including participants from different stakeholder groups and sectors, providing cross-verification of key themes. Member checking was conducted by sharing summaries of participant contributions to confirm accuracy and interpretation. Anonymization procedures were applied during transcription to protect participant confidentiality, with all identifying details removed. Ethical approval for the study was obtained through York University's Research Ethics Board in accordance with the Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2).

Finally, interview transcripts were analyzed using a hybrid coding approach, which combined deductive coding based on TAM and DOI constructs such as perceived usefulness, compatibility, and relative advantage with inductive coding that allowed new, unanticipated themes to emerge from participant narratives. This dual strategy ensured both theoretical grounding and openness to discovery. [52] The following sections elaborate on the research design, participant recruitment, interview procedures, and data analysis techniques, detailing how methodological rigor was maintained throughout the study.

5.2 Data Gathering Structure

5.2.1 Recruitment

A total of thirty participants contributed to the study, representing a cross-section of the Canadian AM ecosystem. Approximately sixty percent (n = 18) were industry professionals, including manufacturers currently using or considering AM technologies and suppliers specializing in AM materials, systems, or services. Thirty-five percent (n = 10) were academics engaged in AM-related research, providing perspectives on scientific, technical, and educational dimensions of adoption. The remaining five percent (n = 2) were policymakers and representatives of industry associations whose insights reflected national innovation priorities and policy-level considerations. This diverse participant composition ensured that findings captured viewpoints across technical, organizational, and institutional boundaries. The table below provides an anonymized overview of the interview participants categorized by stakeholder group and sector.

Table 2: Anonymized Interview Participant Overview

Participant ID	Stakeholder Group	Sector / Organization Type
P01	Industry	3D Printer Manufacturer
P02	Industry	Aerospace Manufacturing SME
P03	Industry	Automotive Supplier

P04	Industry	Medical Devices Manufacturer
P05	Industry	Tooling & Mold Production
P06	Industry	Product Design Studio
P07	Industry	3D Printing Service Bureau
P08	Industry	3D Printing Materials Supplier
P09	Industry	Automotive Supplier
P10	Industry	Aerospace Manufacturing SME
P11	Industry	Hardware/Hardtech
P12	Industry	Tooling & Mold Production
P13	Industry	3D Printing Service Bureau
P14	Industry	Aerospace Manufacturing SME
P15	Industry	Metal Fabrication SME
P16	Industry	3D Printing Materials Supplier
P17	Industry	3D Printer Manufacturer
P18	Industry	Product Design Studio
P19	Academic	University - Engineering Faculty
P20	Academic	University - Engineering Faculty
P21	Academic	University - Engineering Faculty
P22	Academic	College - Applied Research Centre
P23	Academic	University - Engineering Faculty

P24	Academic	University - Engineering Faculty
P25	Academic	University - Engineering Faculty
P26	Academic	University - Design Department
P27	Academic	University - Design Department
P28	Academic	University - Makerspace Coordinator
P29	Policymakers	Non-Profit Global Innovation Center
P30	Policymakers	Automotive Part Manufacturer Association

Participants were recruited using a purposive sampling strategy, which was selected to ensure that the study captured perspectives from across the Canadian 3D printing ecosystem. Purposive sampling is widely used in qualitative research to generate information-rich cases, prioritizing depth and diversity of insight over statistical representativeness. Given the exploratory focus of this research, the objective was not to produce generalizable findings, but to capture the varied experiences and perceptions of stakeholders positioned at different points within the AM value chain. Recruitment drew upon a combination of professional networks, industry associations, and targeted outreach to individuals and organizations known to be engaged in, or considering, AM adoption. This approach aligned with the study's ethics approval under York University's Human Participants, Minimum Risk category, as outlined in the TD1 proposal. All participants were invited through direct communication, provided with an information sheet describing the study, and asked to give informed consent prior to participation.

The sample was designed to include participants from four primary groups: industry leaders, AM suppliers, academics, and manufacturing organizations either currently using or considering AM. This diversity ensured that both strategic and operational perspectives were represented. Industry leaders contributed insights on competitiveness, policy, and long-term vision, while suppliers provided accounts of technological development and client adoption challenges. Academics offered perspectives rooted in ongoing research across materials, applications, and process development, while manufacturing organizations grounded the dataset in the practical realities of integrating AM into production workflows.

This recruitment strategy ultimately secured interviews with a balanced mix of stakeholders from across these categories, strengthening the validity of the study by incorporating voices from multiple sectors and professional roles. By capturing perspectives from those advancing AM technologies, those supporting their diffusion, and those making adoption decisions, the study was able to assemble a holistic dataset. This diversity not only reflected the technical and strategic considerations relevant to AM adoption but also created a foundation for analyzing how barriers and enablers operate at multiple levels of the Canadian manufacturing ecosystem.

5.2.2 Interview Procedures

Interviews were the primary method of data collection and were conducted to balance flexibility with methodological rigor. Each interview lasted approximately 30 to 40 minutes and was carried out either virtually or in person, depending on participant preference and logistical considerations. The semi-structured format ensured consistency in addressing the core topics outlined in the interview guide while allowing flexibility to explore emergent themes in greater depth as they arose. This approach enabled the discussions to address the study's research objectives while also capturing unanticipated, context-specific insights.

All interviews were audio-recorded with explicit participant consent to ensure data accuracy. Recordings were transcribed verbatim to preserve both content and phrasing, and the resulting transcripts were anonymized by removing names, organizational identifiers, and other potentially identifying information. Each transcript was assigned a participant code used throughout the analysis process. Access to recordings and transcripts was restricted to the researcher and stored securely in accordance with institutional data management protocols and ethical requirements. This process established a systematic and ethically sound method of data collection, producing a rich dataset of interview transcripts suitable for thematic analysis. By combining a semi-structured design with strict adherence to ethical standards, the study captured nuanced perspectives on 3D printing adoption in Canada while safeguarding participant confidentiality and research integrity. Building on these procedures, the following section outlines the development of the interview guide and the data gathering techniques used to collect insights from diverse stakeholder groups across Canada's 3D printing ecosystem.

5.3 Data Gathering Techniques

To ensure coverage of the diverse factors influencing adoption, a structured interview guide was developed and tailored to each stakeholder group (Appendix A). The interview guide was grounded in the Technology Acceptance Model and the Diffusion of Innovation theory, integrating constructs such as perceived usefulness, ease of use, compatibility, and trialability. These theoretical dimensions were complemented by insights from existing literature on AM adoption barriers and industry readiness. Together, these sources informed a balanced structure that was both theory-driven and responsive to participant experience. Questions were organized around five central themes:

1. Barriers to adoption
2. Drivers and perceived benefits
3. Collaboration and ecosystem support
4. Policy and institutional influence
5. Future trends and technological readiness

To capture the multifaceted nature of 3D printing adoption, tailored question sets were developed for five primary stakeholder groups representing. Industry leaders were included as senior executives and decision-makers providing strategic perspectives on AM's role in Canadian manufacturing relative to global trends and industrial competitiveness. 3D printing suppliers represented technology providers and service firms offering insights into client experiences, technical challenges, and innovations in materials and equipment. Academics encompassed researchers engaged in diverse AM and 3D printing disciplines, contributing perspectives on material challenges, emerging research directions, and the broader role of universities in advancing the field. Policymakers and industry association representatives were included to provide institutional perspectives on how policies, funding programs, and collaborative frameworks influence the national adoption landscape. Finally, manufacturing organizations, both current users and potential adopters, offered ground-level insights into implementation, integration challenges, and the operational realities of scaling AM within production environments.

This structure ensured that interviews captured perspectives across the full innovation ecosystem, providing a comprehensive view of the barriers and enablers shaping AM adoption in Canada from policy formation and technological development to research, commercialization, and industrial applications.

The following subsections summarize the interview focus for each stakeholder group, highlighting the thematic areas explored and how these perspectives contributed to understanding the barriers, enablers, and broader dynamics of AM adoption in the Canadian context.

5.3.1 Industry Leader Questions

Industry leaders were interviewed to capture high-level strategic perspectives on the current and future role of 3D printing in Canada. These participants, positioned as senior executives and decision-makers, offered insights into how AM aligns with broader industrial strategies, how it compares to global trends, and what value it may contribute to Canadian competitiveness. The questions posed to this group were intended to move beyond technical considerations and examine AM adoption as a matter of industrial strategy, policy alignment, and long-term vision.

A central focus of the interview guide for this group was on barriers to adoption, which were organized into three primary dimensions - economic, technical, and psychological/organizational. The first, economic barriers, asked leaders to reflect on the cost–benefit analysis of AM investments, including capital costs, uncertain returns on investment, and financial risks that deter adoption. The second, technical barriers, explored material limitations, equipment capabilities, skill shortages, and the integration of AM processes into established production systems. The third, psychological and organizational barriers, addressed cultural readiness, workforce acceptance, and regulatory or standards-related issues that create uncertainty for firms considering adoption. Together, these categories ensured that the inquiry captured not only tangible constraints but also the softer, yet equally important, factors influencing decision-making.

Beyond barriers, industry leaders were asked to comment on the role of collaboration and ecosystems in driving adoption. These questions probed how manufacturers, universities, suppliers, and government agencies could work together to reduce barriers, share knowledge, and accelerate the diffusion of AM technologies. Leaders were also asked to evaluate the effectiveness of current government policies and incentives, including funding mechanisms, tax incentives, and strategic programs, and to suggest improvements that might encourage broader industrial uptake. The interviews concluded with a forward-looking discussion of broader trends and future trajectories. Industry leaders were invited to share their views on the innovations, market developments, and policy changes most likely to shape AM adoption in the next five to ten years. These reflections provided valuable insight into how Canadian manufacturers might position themselves relative to global competitors, as well as how national policies and industrial ecosystems could support long-term competitiveness.

Collectively, the perspectives of industry leaders contributed a strategic dimension to the study’s dataset. Their responses shed light on how adoption decisions are framed at the organizational and national levels, and how systemic enablers such as policy, collaboration, and innovation ecosystems interact with firm-level barriers. These insights are particularly important in understanding how Canada might accelerate AM adoption in ways that reinforce industrial resilience and competitiveness.

5.3.2 3D printing Supplier Questions

3D printing suppliers were interviewed to capture the perspectives of technology providers who work directly with manufacturers in Canada. These participants occupy a critical position in the adoption process, as they not only develop and sell AM technologies but also support clients through training, design expertise, and technical assistance. The questions directed to this group were intended to reveal both the practical challenges encountered by end users and the strategies suppliers employ to enable successful adoption.

A primary line of inquiry focused on success stories and key ingredients that contributed to effective AM integration. Suppliers were asked to provide examples of industries or companies where adoption had been most successful and to identify the factors that made these cases possible. This included elements such as close collaboration, robust training programs, or the availability of design support services. These accounts were particularly valuable in highlighting not only where adoption had worked, but why it had worked, offering lessons transferable to other sectors.

The interviews also examined barriers to adoption as observed from the supplier side. Suppliers were asked to identify the most common challenges their clients faced when attempting to implement AM. These included technical hurdles, such as difficulties with materials or equipment compatibility, as well as organizational resistance rooted in cultural or psychological factors. In many cases, suppliers reported encountering firms hesitant to adopt due to concerns about disrupting established processes or doubts about the reliability of AM technologies.

Building on this, suppliers were asked to discuss strategies for overcoming barriers. These questions explored how suppliers collaborate with manufacturers, particularly small and medium-sized enterprises (SMEs) to make AM more accessible. Responses often highlighted the importance of offering flexible support services, scalable solutions, and affordable entry points that lower the risks of adoption. This perspective shed light on the enabling role suppliers play in bridging the gap between technical capability and user readiness.

Finally, the interviews addressed market trends and ecosystems from the suppliers' viewpoint. Participants were asked about innovations or breakthroughs they believed would accelerate adoption in the near future, such as advances in materials, faster or more affordable printers, and improved post-processing technologies. They were also invited to comment on the role of governments, industry groups, and academic institutions in creating a supportive ecosystem, particularly through policy initiatives, workforce development, and collaborative partnerships.

Collectively, the perspectives of AM suppliers provided insight into both the challenges and opportunities associated with scaling the technology. Their accounts emphasized the dual role of suppliers as both technology providers and ecosystem partners, responsible not only for delivering products but also for building the knowledge, trust, and confidence necessary for widespread adoption. These findings enriched the dataset by illustrating how adoption is shaped not only within individual firms but also through the networks of support and innovation surrounding them.

5.3.3 Academic Questions

Academics engaged in 3D printing and 3D printing research were interviewed to provide perspectives rooted in scientific inquiry, technological development, and the broader research environment. Unlike industry leaders or suppliers, academics often approach AM from an exploratory and developmental standpoint, focusing on advancing materials, processes, and applications. Their contributions were essential to understanding the current state of knowledge, identifying unresolved technical challenges, and assessing how research institutions contribute to the diffusion of AM.

The questions directed to academics were designed to capture insights into the critical scientific and technical issues that need to be addressed before AM can achieve widespread adoption. This included discussions of performance limitations, cost-related challenges, and knowledge gaps in materials such as metals, resins, and polymers. Particular emphasis was placed on the material-specific challenges associated with different classes of AM technologies, such as the mechanical reliability of polymers, the cost and complexity of metal printing, and the post-processing requirements of both. Academics were asked to evaluate how these material limitations constrain adoption in high-performance industries such as aerospace, medical devices, and advanced manufacturing.

In addition to technical considerations, academics were asked about the applications and deployment of AM across industries. These questions explored which sectors were currently best positioned to adopt AM and why, as well as where the technology continued to face barriers. In many cases, responses highlighted the mismatch between AM's technical potential and the readiness of industry workflows to integrate such innovations, underscoring the importance of collaboration between research and practice.

Another line of inquiry addressed the role of academic institutions in ecosystems and policy. Academics were invited to reflect on how universities contribute to filling skills gaps through education and training, as well as how research partnerships with industry and government can accelerate innovation. They were also asked to comment on the effectiveness of current funding programs, policies, and incentives aimed at supporting AM research and commercialization, and to suggest changes that could foster a more enabling environment for both research and industrial adoption.

Together, the interviews with academics added an essential research-focused dimension to the dataset. Their perspectives highlighted not only the technical and material frontiers of AM but also the systemic role of universities in developing talent, advancing innovation, and shaping policy discourse. This academic lens complemented the more commercially oriented views of industry leaders and suppliers, offering a broader understanding of how scientific progress and institutional collaboration intersect with the realities of adoption in Canadian manufacturing.

5.3.4 Manufacturing Organization Questions

Manufacturing organizations currently using or considering 3D printing were interviewed to capture practical, ground-level perspectives on adoption. These participants provided firsthand accounts of how adoption of AM is evaluated, implemented, and integrated within production environments. Unlike industry leaders or suppliers, who often operate at a strategic or ecosystem level, these organizations offer a view from within firms navigating the realities of adoption including technical, organizational, and cultural challenges.

The interview questions began with the current use and perceived benefits of AM. Organizations already employing the technology were asked to describe the applications in which it was being deployed and the advantages they had observed, such as design flexibility, faster prototyping, or reduced lead times. For those still considering adoption, the discussion centered on the perceived opportunities that AM could bring relative to traditional methods. These questions established a baseline understanding of how AM was positioned within different sectors of Canadian manufacturing.

A substantial portion of the interviews focused on barriers to adoption. Participants were asked to identify the main challenges preventing them from adopting AM more extensively. Responses highlighted issues such as the difficulty of identifying suitable applications, the absence of robust testing and validation protocols, and the limited availability of mechanical data and standards. Organizations also pointed to the shortcomings of simulation software, which often fails to accurately capture the performance of AM-produced components. These challenges underscored the risks and uncertainties that firms face when deciding whether to invest further in AM.

Organizations were also asked about material-specific and application challenges, including the relative costs and limitations of metals, polymers, and resins. Many firms reported that the complexity of post-processing requirements, particularly for metal printing, constrained scalability. Participants reflected on where AM excelled such as in producing lightweight or custom parts and where it fell short, especially in high-volume or safety-critical applications.

The interviews concluded with questions about the ecosystem of support available to manufacturing organizations. Participants discussed the types of resources that would make AM adoption easier, ranging from technical training and workforce development to stronger partnerships with suppliers, universities, and government agencies. They were also invited to share their broader vision for AM if key barriers were removed, describing how their industries might transform if the technology became more accessible and reliable.

The perspectives of manufacturing organizations enriched the dataset by grounding the research in practical realities. Their accounts revealed the complexities of integrating AM into established workflows, highlighted the disconnect between technological promise and industrial readiness, and emphasized the need for coordinated support across the ecosystem. These findings provided a critical complement to the more strategic insights offered by industry leaders, the technical innovations described by suppliers, and the research contributions highlighted by academics.

5.4 Data Analysis Techniques

The interview data were analyzed using a hybrid thematic analysis that combined both deductive (theory-driven) and inductive (data-driven) strategies. This approach allowed the analysis to remain anchored in the Technology Acceptance Model and Diffusion of Innovation frameworks, while remaining open to emergent, context-specific insights. Following Braun and Clarke (2006), the analysis was iterative and interpretive, progressing from initial familiarization to the development of abstract, integrative themes that captured both expected and novel dimensions of 3D printing adoption in Canada.

5.4.1 Data Preparation

All interview recordings were transcribed verbatim and verified against the audio to ensure accuracy. Each transcript was anonymized, with identifying information replaced by a sector-based tag (e.g., [Industry], [Academia], [Policy]). Verified transcripts were then imported into a structured Excel analysis workbook specifically designed for this study.

The workbook contained three core components: (1) a Codebook integrating TAM, DOI, and inductive categories; (2) a Raw Data sheet used to code individual quotes; and (3) an automated Pivot Summary that aggregated theme frequencies across stakeholder groups. This system provided a transparent, auditable process for coding and cross-comparison without reliance on proprietary software.

5.4.2 Coding Process

The coding process followed a three-stage hybrid sequence - open, axial, and selective coding, to move systematically from raw text to conceptual themes. [53]

Open Coding

Each transcript was reviewed line-by-line to identify significant ideas, perceptions, and actions related to AM adoption. [53] Codes were initially generated inductively to reflect the participants' own language and context. Early codes included phrases such as "risk aversion," "policy fragmentation," "training gap," and "material limitations." At this stage, the emphasis was on inclusivity, capturing the full range of viewpoints rather than imposing pre-determined categories.

Axial Coding

In the second stage, related open codes were clustered into higher-order categories that described patterns across the data. [53] For instance, "training gap" and "skills shortage" were combined under Skills & Education Gap, while "simulation limits" and "QA uncertainty" were merged under Complexity. Relationships between categories were examined to reveal underlying linkages. For example, how organizational resource constraints (organizational factor) reinforced perceived technical difficulty (technological factor). This process began bridging the empirical data with the theoretical constructs of TAM and DOI.

Selective Coding

Selective coding refined and integrated the categories into overarching themes aligned with the study's theoretical framework. Deductive mapping ensured each theme corresponded to at least one TAM or DOI construct such as Perceived Usefulness, Ease of Use, Compatibility, Relative Advantage, or Observability. Inductive analysis captured emergent insights not anticipated by either model. New, data-driven themes such as Risk Aversion, Policy Fragmentation, and Automation & Scale extended existing theory to better reflect Canada's manufacturing ecosystem. The result was a balanced, theory-grounded yet empirically responsive thematic structure. [53]

Thematic Integration and Cross-Group Comparison

Following coding, themes were compared across stakeholder sectors industry, academia, and policy using the pivot summaries embedded in the Excel workbook. This facilitated both convergent analysis (themes shared across groups) and divergent analysis (themes unique to particular sectors). For example, Industry participants emphasized economic and operational benefits such as speed and cost efficiency (Perceived Usefulness, Relative Advantage), whereas Academia underscored knowledge and infrastructure constraints (Organizational Support, Complexity), and Policy respondents highlighted systemic and funding barriers (Policy Fragmentation, Observability). This cross-group comparison strengthened interpretive depth and clarified how theoretical constructs manifested differently across Canada's AM ecosystem.

Validity, Reliability, and Trustworthiness

Several strategies were embedded to ensure analytic rigor:

1. Triangulation: Perspectives were cross-checked across the three stakeholder groups to confirm that major themes were not sector-specific artefacts but reflected broader systemic patterns.

2. Member Validation: Key summaries of interpreted findings were shared with select participants to verify that interpretations accurately represented their views.

The following chapter presents the results and discussion derived from this analytical process, detailing how the identified themes illustrate both the drivers and barriers influencing 3D printing adoption in Canada and interpreting these findings through the combined lens of TAM and DOI.

Chapter 6: Results and Analysis

6.1 Introduction

This chapter presents the results of the qualitative interviews conducted to examine the barriers, drivers, and enabling factors influencing the adoption of 3D printing within Canada's manufacturing ecosystem. Building on the methodological procedures outlined in Chapter 5, the analysis interprets participant perspectives through the theoretical lenses of the Technology Acceptance Model and the Diffusion of Innovation theory. These frameworks provided the conceptual foundation and served as analytical benchmarks for comparing theoretical expectations with the practical insights offered by interview participants. More specifically, the frameworks guided the analysis of how perceptions of usefulness, ease of use, innovation characteristics, and social and institutional influences collectively shape the pace and nature of AM adoption in Canada. The integration of these theoretical constructs with empirical evidence also supports the refinement of the TAM and DOI frameworks developed in Chapters 3 and 4.

6.2 Findings by Theoretical Constructs

The following section presents the empirical findings organized according to the key theoretical constructs of the Technology Acceptance Model and the Diffusion of Innovation theory. This structure enables a systematic comparison between theoretical expectations and participants' lived experiences, illustrating how perceptions of usefulness, ease of use, compatibility, observability, and social influence collectively shape the adoption of 3D printing within Canada's manufacturing ecosystem.

Across the participant pool, there was strong agreement that 3D printing offers a series of unique advantages that make it an attractive tool for Canadian manufacturers seeking greater agility, innovation, and competitiveness. However, the nature and strength of these perceived benefits varied by stakeholder group, reflecting differences in organizational priorities, technological readiness, and exposure to AM applications. The dominant drivers identified throughout the interviews include design flexibility and rapid prototyping, cost and efficiency gains, sustainability and supply-chain resilience, and innovation leadership and market differentiation. Collectively, these factors correspond closely to TAM's construct of perceived usefulness and DOI's dimension of relative advantage, both of which play a decisive role in shaping technology acceptance and diffusion.

A central theme across industry and academic participants was the transformative potential of AM for rapid iteration and design freedom. Many interviewees described the technology as enabling a level of creative flexibility and responsiveness that traditional subtractive or tooling-based methods could not easily match. As one industry leader noted, "AM allows us to fail faster and cheaper. Our product development timelines have been cut by months." This perception reflects the TAM principle that when a technology demonstrably improves performance or simplifies workflows, users are more inclined to adopt it. This perception reflects the TAM principle that when a technology demonstrably improves performance or simplifies workflows, users are more inclined to adopt it. In this context, AM's ability to shorten design cycles, reduce dependency on tooling, and enable immediate iteration directly enhances users' sense of operational control and efficiency, two psychological drivers that Davis identifies as core to perceived usefulness. [30] Participants described this improvement not merely as a marginal gain but as a paradigm shift in how manufacturing tasks are conceptualized and executed. By converting design intent into physical reality without the bottlenecks of machining or external suppliers, AM provides a visible and quantifiable enhancement in productivity, reinforcing confidence in its utility and accelerating acceptance within both technical and managerial domains.

Academics echoed these observations, emphasizing how AM enables simultaneous consideration of both functionality and manufacturability, allowing designs to be optimized for performance without the traditional constraints of tooling or assembly. Several participants also noted that academic research and industry practice increasingly demonstrate that designing for 3D printing is becoming more intuitive as software, materials, and process knowledge advance. The growing accessibility of design-for-AM tools and simulation platforms is gradually reducing the technical barriers once associated with the technology, reinforcing perceptions of improved usability and accelerating confidence in adoption across engineering disciplines. The ability to fabricate geometrically complex or customized components without extensive retooling was viewed as a major enabler for research and product innovation. Several respondents also connected this benefit to the democratization of design, arguing that AM allows smaller firms to compete in specialized markets by enabling low-volume, high-value production. This aligns closely with DOI's concept of relative advantage, as the capability to innovate quickly and affordably enhances the perceived superiority of AM over conventional manufacturing methods.

While cost was more commonly discussed as a barrier (see Section 6.2.2), participants also emphasized that when properly implemented, AM can deliver significant efficiency and cost benefits. Manufacturers with established AM workflows cited reduced waste, lower inventory requirements, and shorter supply chains as tangible economic advantages. The shift from centralized mass production toward localized, on-demand fabrication was highlighted as a cost-containment strategy that simultaneously improved responsiveness to customer needs.

Suppliers further elaborated that as printer reliability and material utilization improve, cost per part continues to decrease, especially for prototyping and small-batch production. Several respondents noted that "the economics of AM make sense when you print smarter, not more" a reflection of the growing sophistication of users in optimizing build orientation, material choice, and print scheduling. This operational efficiency aligns with TAM's perceived usefulness and DOI's compatibility, as firms recognize that AM can integrate into existing workflows to complement, rather than replace, traditional manufacturing systems.

Sustainability emerged as both a moral and strategic driver of AM adoption. Participants across academia, industry, and policymaking emphasized the environmental efficiencies inherent to additive processes, including material conservation, energy reduction, and the potential to decentralize production closer to end-users. Academic participants described AM as a “critical enabler of circular manufacturing,” capable of reducing transport emissions and facilitating product life-cycle repair or reprinting of components. These observations align closely with Canada’s broader sustainability agenda, including federal commitments to achieving net-zero emissions by 2050 and advancing clean technology innovation within the manufacturing sector. [54] By minimizing waste and supporting localized, on-demand production, AM was perceived to complement national efforts toward reducing industrial carbon intensity and fostering green growth. Several policymakers highlighted that the integration of AM into Canada’s clean manufacturing and innovation strategies could play a key role in balancing economic competitiveness with environmental stewardship, positioning the technology as both a sustainability tool and an industrial modernization mechanism.

In the post-pandemic context, many industry professionals and policymakers also framed AM as a tool for supply-chain resilience. Disruptions in global logistics and increased shipping costs have motivated firms to explore AM for replacement parts, tooling, and small-scale production that can be conducted domestically. Policymakers viewed this as aligning with Canada’s national innovation and manufacturing sovereignty objectives, noting that “AM offers a pathway for Canada to produce more, faster, and closer to home.” From a DOI perspective, this reflects observability, the visible success of AM in mitigating supply disruptions reinforces its perceived utility and accelerates its diffusion among peer organizations. During the COVID-19 pandemic, for instance, AM was widely deployed across Canada and internationally to produce critical components such as personal protective equipment (PPE), ventilator parts, and medical testing swabs when conventional supply chains were strained. [54] These highly publicized efforts, led by both private manufacturers and collaborative university/industry networks, demonstrated AM's capacity for rapid response and localized production. Beyond healthcare, participants also referenced applications within aerospace and automotive sectors, where Canadian firms successfully leveraged AM to fabricate replacement tooling and low-volume components to maintain operations amid global material shortages. The visibility of these successes has had a demonstrable signaling effect, showcasing that AM can provide immediate, tangible benefits under real-world pressures, and in turn has strengthened the perception of AM as a resilient and future-ready manufacturing technology.

For academic and research institutions, AM was viewed as an important vehicle for maintaining global competitiveness and talent development. By integrating AM capabilities into laboratories and curricula, universities not only advance research but also cultivate a workforce capable of driving industrial adoption. Several academic respondents stressed that student exposure to AM technologies fosters familiarity and confidence, directly addressing the perceived ease of use dimension of TAM at a societal scale.

Finally, participants frequently highlighted the synergy between AM and other emerging technologies such as artificial intelligence, robotics, and digital twins. These integrations were seen as accelerators of adoption, enhancing automation, real-time monitoring, and production optimization. Suppliers in particular emphasized that AM should be understood not as a standalone tool but as a pillar of Industry 4.0 transformation. This aligns with the DOI notion of compatibility adoption increases when new technologies align with existing systems and strategic trajectories. Industry participants also discussed the shift toward data-driven production environments, where AM's digital nature supports traceability, predictive maintenance, and design iteration without physical prototyping. This intersection between digital and physical innovation ecosystems reinforces the perception of AM as a cornerstone of advanced manufacturing, deepening its perceived usefulness and reinforcing its role within broader innovation strategies.

Several industry participants emphasized that adopting AM aligns with broader strategic objectives such as digital transformation, innovation leadership, and export competitiveness. This strategic framing reinforces the perception that AM is not merely a production tool but a catalyst for modernization within Canada's manufacturing base. It also positions early adopters as leaders in the transition toward advanced and sustainable production systems, supporting both firm-level competitiveness and the nation's ambition to expand its high-value manufacturing capacity. Participants further noted that AM adoption benefits from knowledge spillover through professional networks, trade associations, and collaborative research programs. As organizations witness successful implementations showcased by peers, the credibility and perceived achievability of adoption are reinforced. This "demonstration effect," consistent with DOI's emphasis on communication channels and social influence, has played a vital role in accelerating AM diffusion within Canada's tight-knit manufacturing ecosystem.

The growing availability of training programs, online design resources, and university–industry partnerships was cited as an emerging enabler of AM adoption. Participants observed that as workforce readiness improves and the learning curve shortens, organizations feel more confident investing in the technology. This directly supports TAM's perceived ease of use construct, as skill accessibility and design literacy significantly reduce perceived complexity, increasing both managerial and operator willingness to engage with AM.

Overall, the interviews revealed that AM adoption is propelled by a convergence of technical, strategic, and environmental motivations. The interaction between these drivers suggests that firms rarely adopt AM for a single reason; instead, adoption arises where perceived usefulness intersects with organizational strategy, ecosystem readiness, and the broader policy environment. This convergence underscores the multi-dimensional nature of AM adoption in Canada, rooted not only in technological capability but also in institutional alignment, collaboration, and the evolving maturity of the national innovation system. Overall, AM adoption is propelled by a convergence of technical, strategic, and environmental motivations. Firms rarely adopt AM for a single reason; rather, adoption arises where perceived usefulness intersects with organizational strategy, ecosystem readiness, and policy support. Within the TAM and DOI frameworks, perceived usefulness, relative advantage, and observability emerge as dominant constructs explaining early adoption behaviour. Yet, as subsequent sections demonstrate, these advantages coexist with persistent concerns about technical complexity, workflow compatibility, and organizational inertia.

6.2.1 Perceived Ease of Use / Complexity

While participants widely recognized the strategic advantages of 3D printing, they also identified several interrelated factors that complicate its practical implementation. These challenges reflect the constructs of perceived ease of use in the Technology Acceptance Model and complexity within the Diffusion of Innovation framework - both of which influence users’ willingness to engage with new technologies. Across interviews, participants emphasized technical limitations, design and process complexity, material variability, and skill and knowledge gaps as persistent deterrents to wider adoption. Despite growing optimism about improvements in printer technology and workflow integration, these concerns collectively illustrate that ease of use remains one of the most critical determinants of adoption readiness.

Across sectors, respondents consistently described AM as a technology that demands a high degree of technical literacy and process control. Industry practitioners noted that while newer machines are more user-friendly, calibration, slicing parameters, and support optimization still require substantial expertise. One manufacturer explained, “It’s not a plug-and-play system. Every material and geometry behaves differently, and one wrong setting can ruin the entire build.” Such variability contributes to a perception of fragility and uncertainty, which Davis characterizes as diminishing perceived ease of use. [30] Participants also highlighted post-processing demands including curing, surface finishing, and dimensional inspection as significant barriers to workflow efficiency. Academics echoed this view, emphasizing that AM involves “multiple technologies stacked together printing, curing, testing, and finishing each with its own learning curve.” From a DOI standpoint, these accounts reinforce the construct of complexity, where a higher number of interdependent tasks reduces the likelihood of widespread diffusion. [37] Material performance emerged as one of the most commonly cited sources of technical complexity. Participants emphasized that while polymer-based AM has achieved acceptable consistency for prototyping, variability in mechanical properties, anisotropic strength, and limited data on long-term durability continue to hinder confidence in end-use applications. One academic participant summarized this challenge succinctly: “The technology is evolving faster than the standards.”

Industry representatives similarly noted that a lack of standardized testing protocols and limited interoperability between printers and materials make qualification and certification processes difficult. For sectors such as aerospace and medical manufacturing where safety and reliability are paramount, this uncertainty translates into hesitation to scale production. While traditional processes such as machining, casting, or injection molding are governed by long-established ASTM, ISO, and CSA standards that define material properties, tolerances, and inspection procedures, equivalent frameworks for 3D printing remain relatively fragmented. Although organizations such as ASTM International's F42 Committee on 3D printing Technologies and ISO/TC 261 have developed foundational standards (e.g., ISO/ASTM 52900, 52921, and 52910), participants noted that these primarily focus on terminology, testing methods, and design guidelines rather than comprehensive material certification and process validation comparable to conventional manufacturing. [55] Suppliers, while more optimistic, acknowledged that material qualification remains a slow and resource-intensive process, particularly for metal AM systems where powder composition, machine calibration, and post-processing have interdependent effects on part quality. As one supplier observed, "We can meet performance targets, but proving it to certification bodies is the uphill battle." These findings align with DOI's concept of trialability: many organizations continue to experiment with AM in controlled environments, but refrain from full adoption until its material performance can be proven consistent, certifiable, and supported by standards on par with other established manufacturing processes.

Several participants described the difficulty of integrating AM into existing design and production workflows. Many firms lack established design-for-AM (DFAM) expertise, resulting in models that are either suboptimal or unprintable. One industry engineer noted, “Our CAD team can design beautiful parts, but that doesn’t mean they’ll print successfully.” This gap between digital design and physical output reinforces the TAM perception that AM requires significant learning investment before ease of use can be realized. Workflow complexity was also discussed in relation to digital infrastructure compatibility. Integrating AM data into legacy manufacturing systems such as ERP, MES, or quality control databases, was reported as cumbersome and often unsupported by current software ecosystems. Suppliers and academics stressed the need for better software interoperability and automated feedback loops between design, simulation, and production. This aligns with DOI’s compatibility dimension: the easier a new technology integrates with existing workflows, the lower its perceived complexity and resistance to adoption.

A recurring barrier identified across nearly all interviews was the shortage of trained personnel capable of operating, maintaining, and optimizing AM systems. Even among firms with AM experience, respondents described a dependence on “champions”- individuals with deep technical understanding of 3D printing who drive adoption internally. As one policy participant observed, “When that person like this leaves, the initiative often stalls.” Academic participants linked this issue to broader workforce readiness, emphasizing that Canadian education and training programs have not yet scaled to meet industrial demand. While many universities and technical colleges have introduced AM coursework, it remains concentrated in research environments rather than production-focused and practical curriculum. Industry respondents expressed a desire for more applied training programs, micro-credentials, and accessible design-for-AM modules for technicians. These findings highlight that perceived complexity is not only technological but also human rooted in the difficulty of building and sustaining AM expertise within organizations.

Another factor affecting perceived ease of use was trust in process repeatability. Several manufacturers described AM as inherently less predictable than conventional manufacturing, noting that even small variations in temperature, humidity, or material batch can impact print quality. “We don’t yet have the same sense of control that we do with CNC,” one respondent commented. This uncertainty leads to conservative adoption patterns where AM is confined to non-critical components or prototyping applications.

Suppliers countered that machine learning and in-situ monitoring are beginning to reduce this uncertainty by allowing real-time error detection and adaptive control. However, participants agreed that these features are not yet universally accessible or affordable. As such, AM’s perceived ease of use remains constrained by a tension between technical potential and operational reliability, consistent with Davis’s view that ease of use must be both experienced and demonstrable to influence long-term adoption intent.

Despite these challenges, participants recognized that ease of use is improving as hardware and software evolve. Newer AM systems offer automated calibration, integrated slicing tools, and intuitive user interfaces, lowering entry barriers for small and medium enterprises (SMEs). Several participants suggested that improvements in process standardization, user training, and vendor support are gradually shifting perceptions from experimental to practical. This sentiment aligns with the DOI concept of re-invention, where technologies evolve through iterative improvements informed by user feedback. As AM tools become more modular and guided, perceived complexity decreases, expanding the pool of potential adopters. Nonetheless, widespread diffusion will depend on sustained progress in education, standardization, and interoperability, areas where policy and industry collaboration will be essential. The following section examines this dimension of compatibility and workflow integration, exploring how well AM aligns with existing manufacturing infrastructures, digital, and organizational practices.

6.2.2 Compatibility and Workflow Integration

Through the insights provided from the participants interviewed, production systems, workflows, and organizational norms emerged as a defining factor influencing the adoption of 3D printing in Canadian industry. Within the Diffusion of Innovation framework, compatibility refers to how well an innovation fits within the adopter's current values, operational infrastructure, and experience base. Similarly, within the Technology Acceptance Model, compatibility reinforces perceived usefulness, since technologies that integrate smoothly into established systems are more likely to be embraced. Across the interviews, participants consistently emphasized that AM's integration challenges are as significant as its technical limitations, shaping perceptions of feasibility, efficiency, and organizational readiness. A recurring theme across industry and supplier interviews was the difficulty of embedding AM within established production environments. Many firms reported that AM remains a peripheral or standalone process, often disconnected from machining, assembly, and inspection workflows. As one participant observed, "3D printing still sits off to the side. It's useful, but it doesn't plug into how we normally build things."

This separation stems largely from differences in data structures, process parameters, and quality assurance practices between AM and legacy systems. Traditional manufacturing relies on deterministic, well-documented workflows with predictable tolerances, while AM introduces a new paradigm built on probabilistic layer-by-layer fabrication and extensive process monitoring. Several participants highlighted that AM generates large volumes of digital data such as build parameters, environmental readings, and post-processing metrics that many firms are not equipped to manage or interpret effectively. This lack of digital interoperability reinforces DOI's assertion that incompatibility between new and existing systems can slow or even stall diffusion, regardless of technical maturity. Some organizations are addressing these gaps through digital workflow integration platforms that unify computer-aided design (CAD), build preparation, and post-processing management. Such systems improve traceability and quality documentation across the production chain, yet adoption remains uneven. Smaller firms cited cost and infrastructure barriers, while larger manufacturers described challenges in synchronizing AM data across multiple divisions and enterprise systems. As one policy participant summarized, "The technology is ready, what's missing is the connective tissue."

Several respondents pointed out that incompatibility is not only technical but also conceptual. Traditional manufacturing workflows prioritize design for manufacture, focusing on minimizing machining time, reducing part count, and ensuring dimensional accuracy. AM, by contrast, emphasizes design for additive manufacturing (DFAM), a design logic that prioritizes topology optimization, lightweight structures, and geometric complexity. One engineer explained, "Our designers are brilliant, but they're still designing as if they have to machine everything." This cognitive and procedural misalignment means that even firms with advanced AM capabilities often fail to exploit its full potential. Instead, they tend to replicate conventional geometries using AM, achieving only limited gains in efficiency or performance. Academic participants emphasized that DFAM literacy remains uneven across the Canadian manufacturing sector and is a major determinant of whether AM is perceived as compatible or disruptive. Cross-disciplinary education where mechanical design, materials science, and digital fabrication is integrated together to create a holistic understanding of the entire 3D printing process was cited as critical to building this competency by both industry leaders and academic participants interviewed.

Participants also underscored the importance of software and data interoperability as a key determinant of AM's integration success. In many firms, AM operations function as data silos, with information on material batches, print parameters, and inspection results managed manually and separately from enterprise resource planning (ERP) systems. This disconnection limits AM's scalability and its contribution to broader digital transformation initiatives. Suppliers and industry experts noted that integrating AM into Industry 4.0 frameworks such as machine connectivity, digital twins, and real-time process monitoring, enhances traceability and efficiency. Connecting AM build data directly to ERP and quality management systems allows automated documentation and certification, particularly valuable for regulated sectors such as aerospace and medical manufacturing. However, achieving this integration requires standardized data protocols and collaboration among software vendors, equipment manufacturers, and end users. From a DOI perspective, such interoperability directly increases compatibility by embedding AM within existing digital ecosystems. It also reinforces TAM's notion of perceived usefulness where once AM data flows seamlessly across an organization, the technology transcends its role as a production tool and becomes a driver of operational intelligence, product lifecycle management, and supply chain transparency.

Beyond digital systems, organizational culture and management structures significantly influence AM’s integration trajectory. Many participants noted that AM often resides within innovation departments or R&D teams, rather than on the production floor. One respondent commented, “We treat additive like an experiment, not a process.” This separation reinforces a persistent perception of AM as a process only good for prototyping and experimentation rather than production-oriented technology, a mindset that often impedes its integration into established manufacturing operations. Academics and policymakers observed that firms with cross-functional AM teams where engineers, technicians, designers, and quality specialists are brought there are more successful in embedding additive processes into daily operations. These teams foster knowledge transfer and process standardization, reducing organizational friction. In contrast, firms with rigid departmental divisions or hierarchical decision-making structures often struggle to implement AM beyond isolated projects. As Rogers (2003) notes, diffusion is accelerated when innovations align with an organization’s existing values and internal communication networks. Participants further noted that compatibility challenges extend beyond individual organizations to the broader industrial and policy environment. Many small and medium-sized enterprises (SMEs) lack access to shared infrastructure, standardized software, or experienced integration partners. Several participants praised the role of regional innovation hubs, such as those operated by the National Research Council (NRC) and Next Generation Manufacturing Canada (NGen), which provide access to printers, training, and technical expertise. These programs were viewed as essential intermediaries for helping firms pilot AM technologies and integrate them into conventional workflows without excessive upfront investment; however participants also pointed out that these resources remain geographically concentrated, limiting access for firms outside major urban regions. Policymakers acknowledged this gap, emphasizing the need for nationwide digital infrastructure and knowledge transfer programs to make AM integration scalable and equitable across Canada's manufacturing landscape.

Overall, the findings indicate that compatibility and workflow integration are multidimensional challenges encompassing technical, cultural, and institutional elements. While advances in digital interoperability and hybrid manufacturing are improving compatibility, AM's broader diffusion will depend on firms' ability to trial and validate new applications in controlled, collaborative settings. The next section examines how organizations are responding to these compatibility challenges through pilot projects, demonstration programs, and iterative experimentation, highlighting the role of trialability and observability in building confidence and accelerating the adoption of 3D printing.

6.2.3 Trialability and Observability

Across all participant groups, the ability to test, validate, and witness the outcomes of 3D printing before committing to full-scale implementation emerged as a crucial determinant of adoption intent. Within the Diffusion of Innovation framework, trialability refers to the degree to which an innovation can be experimented with on a limited basis, while observability reflects the extent to which the results of that experimentation are visible to others. Together, these constructs help explain how confidence in AM builds through incremental exposure, peer observation, and demonstrable success. Participants consistently described pilot projects, industry showcases, and collaborative research initiatives as essential mechanisms for lowering perceived risk and translating theoretical potential into practical credibility. Many organizations reported that their entry into AM began with small-scale pilot projects, typically focused on non-critical components, tooling, or prototyping. These projects allowed firms to evaluate the technology's capabilities while minimizing financial and operational risk. As one manufacturer explained, "We started with jigs and fixtures because failure there is cheap. Once we saw the consistency, we got bolder." Such pilot efforts serve a dual purpose: they allow internal teams to gain hands-on experience with process parameters, post-processing requirements, and quality control procedures, while also generating data to justify further investment. Several participants highlighted that early pilots often reveal organizational bottlenecks such as skill shortages or digital infrastructure limitations that had to be addressed before scaling. This iterative approach reflects Rogers' (2003) view that trialability reduces uncertainty by enabling potential adopters to accumulate experiential knowledge prior to full diffusion.

Academic and supplier participants described how applied research partnerships with universities and technology centers function as a form of external trialability, giving firms access to equipment, materials, and expertise without immediate capital expenditure. Programs hosted by organizations such as the National Research Council (NRC) and NGen were frequently cited as pivotal in helping small and medium-sized enterprises (SMEs) de-risk adoption through shared pilot environments. These initiatives effectively extend the trial phase across an ecosystem level, accelerating learning and fostering collaborative problem-solving. However, respondents cautioned that such support must be sustained beyond initial pilots to translate experimentation into scalable adoption. Several participants noted that short-term demonstration projects often "prove the concept but stop short of integration." Policymakers acknowledged this challenge, emphasizing the need for longitudinal follow-up and standardization pathways to ensure that successful trials lead to permanent capability development rather than isolated showcases.

Participants also emphasized the importance of demonstration projects that showcase AM's effectiveness in real-world contexts. Industry associations, equipment suppliers, and research institutions often organize proof-of-concept (PoC) builds to illustrate practical applications, ranging from customized medical implants to lightweight aerospace components and tooling inserts. These visible successes not only demonstrate feasibility but also serve as persuasive communication channels that shape perceptions of AM's maturity. One supplier remarked, "When people see a working part in their hands, something that looks and feels production-ready, the conversation changes." This tangible validation transforms abstract concepts into concrete outcomes, satisfying both trialability through experimentation and observability through visibility of results. Policymakers added that government-supported demonstration programs often act as policy levers for diffusion, bridging the gap between research and commercialization by showcasing proven use cases that inspire confidence across the manufacturing sector.

Peer networks were repeatedly cited as influential in shaping perceptions of AM's credibility. Participants described how knowledge transfer occurs informally through conferences, consortiums, and digital communities where companies share lessons learned from their pilots and implementations. One industry respondent noted, "Seeing what another firm did with the same printer makes it real. It's no longer just a brochure claim." This process of vicarious learning reinforces DOI's construct of observability, as visible evidence of success within peer networks significantly reduces uncertainty. Academic respondents observed that these social learning mechanisms create a “multiplier effect,” where one firm’s trial indirectly informs and influences others within its supply chain or region. Over time, repeated exposure to successful demonstrations establishes social proof, normalizing AM as a credible and attainable technology.

Suppliers also reported that customer referrals and user communities have become major diffusion channels. Online repositories and forums where designers share printable files, machine settings, and troubleshooting guides have expanded the accessibility of AM knowledge. These collaborative platforms enhance observability by making expertise and best practices highly visible and replicable, thereby accelerating diffusion across both professional and hobbyist domains. The findings underscore that trialability and observability are critical enablers in the diffusion of 3D printing. Pilot projects and demonstration programs allow firms to experiment safely, validate performance, and build internal expertise, while visible success stories within and across sectors amplify legitimacy and reduce perceived risk. Together, these processes form a feedback loop: as firms test and share results, visibility increases; as visibility increases, new firms are motivated to trial the technology themselves. Within the DOI framework, these constructs serve as accelerators of diffusion, transforming uncertainty into confidence and perception into practice.

The following section examines how social systems and diffusion channels further influence AM adoption through the construct of social influence and communication networks.

6.2.4 Social Influence, Networks, and Diffusion Channels

While trialability and observability enable organizations to gain direct experience with 3D printing, the social systems through which information circulates play an equally decisive role in shaping adoption behaviour. Within the Diffusion of Innovation framework, social influence refers to the impact of peer networks, opinion leaders, and communication channels on adoption decisions. Similarly, within the Technology Acceptance Model, external social cues such as endorsements, success stories, and professional norms reinforce perceived usefulness and reduce uncertainty. Across interviews, participants emphasized that industry networks, supplier relationships, and collaborative ecosystems are central to how AM knowledge spreads and legitimacy forms within Canada's manufacturing community. Industry associations were repeatedly identified as primary conduits for AM knowledge transfer. Organizations such as NGen, Canadian Manufacturers and Exporters (CME), and regional innovation hubs were viewed as essential in convening stakeholders, disseminating case studies, and connecting firms with technical experts. One industry participant remarked, "We learned more from one NGen roundtable than from six months of vendor demos. It's where you hear what really works." These venues create trust-based learning environments that accelerate diffusion by framing AM adoption as a collective movement rather than an isolated experiment. Academics noted that cross-sector networks that connect universities, startups, and established manufacturers, facilitate interdisciplinary collaboration and strengthen social credibility. In DOI terms, these groups act as change agents who bridge communication gaps and promote shared understanding of the technology's benefits and risks.

Suppliers were frequently described as de facto educators within the Canadian AM ecosystem. Beyond selling equipment, they provide technical guidance, design consultation, and ongoing support that help customers build competence and confidence. One participant explained, “Our supplier isn’t just a vendor, they’re also our training department for using AM technologies.” This intermediary role expands DOI’s concept of communication channels, as suppliers actively mediate between technological innovation and user experience. Their demonstrations, webinars, and on-site trials serve as informal diffusion mechanisms that complement formal training programs. However, participants cautioned that supplier-driven information can sometimes be overly optimistic or fragmented, underscoring the need for neutral, evidence-based standards and comparative benchmarking to sustain long-term credibility.

A strong theme across interviews was the influence of peer-to-peer communication in normalizing AM. Participants described how informal exchanges at trade shows, online forums, and local maker or engineering communities provide practical, experience-based insights unavailable in marketing materials. This process exemplifies DOI’s observability interacting with social influence: visible peer success reduces uncertainty and validates the technology’s practicality. Academic respondents added that community-driven diffusion extends beyond industrial networks to educational institutions and open-source repositories, where students and independent makers contribute design files, process data, and troubleshooting advice. Such horizontal knowledge flows create a self-reinforcing cycle of experimentation and shared learning, broadening the technology’s reach beyond formal industrial channels. Within the DOI and TAM frameworks, social influence operates as a reinforcing mechanism that magnifies trialability and observability: as more organizations publicly share results and best practices, the perceived usefulness and normative acceptance of AM grow accordingly. While social networks and professional communities play a vital role in shaping perceptions and accelerating knowledge diffusion, participants also emphasized that broader institutional, policy, and ecosystem-level factors strongly influence how and where 3D printing adoption takes root. The following section examines these structural influences, focusing on how government programs, regulatory frameworks, and national innovation systems enable or constrain AM diffusion across Canada's manufacturing landscape.

6.2.5 Ecosystem and Policy Influences (Institutional and Social System Factors)

In addition to the ability to trial and understand how to leverage AM, the degree to which 3D printing aligns with existing production systems and organizational workflows emerged as a decisive factor in determining adoption readiness. Within the Diffusion of Innovation framework, compatibility refers to the extent to which an innovation fits with potential adopters' current values, experiences, and operational infrastructure. Similarly, in the context of the Technology Acceptance Model, compatibility can be viewed as an extension of perceived usefulness as a technology is more likely to be adopted when it can be seamlessly incorporated into existing processes without significant disruption. Across interviews, participants consistently emphasized that AM's integration challenges are as influential as its technical ones, affecting everything from digital infrastructure to supply chain coordination and organizational structure. A recurring theme across industry and supplier interviews was the difficulty of incorporating AM into conventional manufacturing workflows. Many firms reported that AM still operates as a standalone process, disconnected from traditional machining, assembly, and inspection operations. One participant noted, "Right now, 3D printing feels like a separate island in our production chain, it doesn't speak the same language as our other machines." This fragmentation stems largely from differences in data formats, process parameters, and quality assurance protocols between AM and legacy systems. Academics and policymakers echoed this sentiment, observing that many organizations lack the digital infrastructure or interoperability frameworks necessary to manage hybrid production environments effectively. This issue reinforces DOI’s notion that incompatibility between an innovation and existing systems can significantly slow diffusion, regardless of its technical merit.

Beyond technical integration, participants discussed the philosophical and procedural misalignment between AM and conventional design methodologies. Traditional manufacturing workflows often prioritize designing for traditional manufacturing processes, optimizing parts for casting, molding, or machining. By contrast, AM requires design-for-additive, which emphasizes lightweighting, topology optimization, understanding the impact of overhangs, and layer orientation. Several engineers described the challenge of adjusting their design process from designing for traditional manufacturing to designing for 3D printing: “Our designers are still thinking in terms of what limits a CNC machine has and not what a 3D printer can make.” This disconnect limits AM’s perceived compatibility with established design cultures and toolchains. Even when firms acquire AM capabilities, many fail to redesign parts specifically for additive processes, resulting in suboptimal designs that often contribute to the higher cost of a 3D printed part vs a traditionally manufactured counterpart. Academic participants noted that cross-disciplinary training where design for 3D printing, AM materials science, and digital fabrication knowledge is taught is crucial for bridging this gap. This supports TAM’s principle that ease of adoption increases when users can integrate new tools into familiar cognitive and procedural frameworks.

At the same time, several respondents described successful efforts to align AM with existing workflows by introducing hybrid manufacturing strategies, where printed components are post-machined or assembled alongside conventionally produced parts. These approaches increase process flexibility and allow firms to leverage AM's advantages without abandoning existing infrastructure.

Participants consistently highlighted the importance of interoperability between AM software, design systems, and enterprise resource planning (ERP) platforms. In many firms, AM-generated data is managed manually, often in isolation from quality management and production scheduling systems. This siloed approach hinders scalability and limits AM's ability to contribute to broader digital transformation initiatives.

Suppliers noted that integrating AM into Industry 4.0 frameworks such as through digital twins, machine connectivity, and real-time monitoring enhances both traceability and productivity. For example, linking AM build data directly to ERP systems enables automated documentation of material batches, printer parameters, and inspection results, streamlining certification and compliance. Yet participants acknowledged that these integrations are resource-intensive and require collaboration between software vendors, OEMs, and end users to establish common data standards. From a DOI perspective, improved interoperability directly enhances perceived compatibility by embedding AM within existing digital ecosystems. This also intersects with the TAM construct of perceived usefulness: when AM data flows smoothly across the enterprise, the technology becomes not just a manufacturing tool but a driver of organizational efficiency and data-driven decision-making.

Several interviewees pointed out that even when technical integration is achieved, organizational culture and structure often lag behind. In many cases, AM is confined to innovation departments or prototyping labs, isolated from mainstream production teams. One industry leader commented, “We treat additive like R&D, not manufacturing.” This compartmentalization reinforces the perception that AM is incompatible with day-to-day operations, particularly in firms driven by lean production metrics and just-in-time principles. Academics and policymakers stressed that achieving compatibility requires not only technical adjustments but also organizational realignment, where AM is embedded within procurement, quality assurance, and maintenance functions. Companies that have established cross-functional AM teams or 3D printing champions reported greater success in scaling from prototype to production. This aligns with Rogers’ (2003) argument that diffusion is accelerated when innovations are compatible with an organization’s existing values and workflows. Policymakers and industry association representatives underscored that compatibility extends beyond the firm level to the institutional and infrastructural environment. Many small and medium-sized enterprises (SMEs) lack access to shared facilities or standardized software environments that could facilitate smoother adoption. Several participants pointed to regional innovation hubs and 3D printing centers, such as those supported by the National Research Council (NRC) and Next Generation Manufacturing Canada (NGen), as critical intermediaries in improving ecosystem-level compatibility. These programs enable firms to access equipment, expertise, and validation tools without incurring the full cost of integration, effectively lowering the barrier to entry for AM adoption.

The findings reveal that compatibility and workflow integration are as much social and organizational challenges as they are technical ones. AM's success depends on its ability to coexist with and provide a clear improvement to established systems rather than replace them outright. Within the DOI and TAM frameworks, compatibility emerges as a critical determinant of sustained adoption: when AM is aligned with both existing technical infrastructures and organizational cultures, it transitions from a novel capability to an embedded component of modern manufacturing practice.

6.3 Synthesis and Revised Conceptual Model

The results presented in Section 6.2 emphasize that 3D printing adoption decisions are developed from a combination of individual perceptions and broader ecosystem conditions. While the Technology Acceptance Model captures the key factors driving users' willingness to adopt AM, for example, perceived usefulness, ease of use, and attitude toward use, the Diffusion of Innovation framework contextualizes these perceptions within external environmental factors such as institutional support, knowledge networks, and standardization systems. Empirical evidence from interviews demonstrates that these dimensions are not sequential but reciprocal. For instance, organizational support (a DOI enabler) directly enhances perceived ease of use by reducing implementation complexity, while knowledge networks increase perceived usefulness by providing tangible success stories and benchmarks. Conversely, limited ecosystem maturity constrains diffusion, even when perceived usefulness is high. Examining the intersections between DOI and TAM uncovers how individual and systemic drivers of adoption interact, with the primary linkages and moderating influences introduced in the following section.

The integration of DOI and TAM constructs revealed several important linkages that explain how individual, organizational, and ecosystem-level factors converge to shape 3D printing adoption. Rather than considering these factors in isolation, these factors interact dynamically, reinforcing or constraining one another depending on contextual conditions. The following linkages synthesize the primary relationships found between factors from both TAM and DOI, illustrating how ecosystem readiness, knowledge exchange networks, and experiential feedback collectively influence cognitive perceptions of usefulness and ease of use.

1. Ecosystem Readiness → Cognitive Perception

Institutional and policy enablers were consistently described by participants as shaping how 3D printing is perceived within their organizations. Several industry respondents emphasized that targeted funding programs and collaborative initiatives reduced the cognitive barrier to entry by making experimentation more attainable. One manufacturer explained that “without the support from NGEN, we may have not considered using AM. This initiative signaled to management that this was something the government believed in.” Similarly, a policy representative noted that federal pilot programs “create low-risk environments where firms can see success before committing,” directly enhancing TAM’s constructs of perceived usefulness and ease of use. These institutions mirror DOI’s attributes of compatibility and trialability, framing AM as a legitimate and strategically aligned technology rather than an isolated R&D activity.

Ecosystem readiness also manifested through softer forms of legitimacy and information flow. Academic participants observed that regions with active innovation hubs and industry–research partnerships “normalize AM talk” exposing firms to peer examples and shared learning that strengthen confidence in the technology’s relevance. A tooling executive echoed this, explaining that “once we saw another shop in our network printing fixtures successfully, our team believed we could, too.” Such visibility and social proof translate ecosystem maturity into cognitive trust, lowering perceived complexity and reinforcing the sense that AM can integrate with existing workflows. Conversely, interviewees from less connected sectors described uncertainty and hesitation, noting that “without clear standards or local expertise, it still feels like a black box at times.” Collectively, these insights show that readiness at the ecosystem level is not merely structural but also psychological with external support, policy signaling, and peer validation collectively enhance cognitive perceptions that drive adoption.

2. Feedback from Successful Use Cases

Observable benefits of 3D printing emerged as one of the most powerful drivers of adoption across all participant groups. Interviewees repeatedly emphasized that witnessing tangible results whether through internal pilot projects or external demonstrations transformed 3D printing from an abstract concept into a validated solution that showcased firsthand how it could meet their unique needs. One industry participant explained that “once we printed our first production jig and saw it hold up on the floor, that’s when the attitude changed, it suddenly felt real.” This process aligns with DOI’s attribute of observability, where visible success accelerates diffusion by validating perceived usefulness. Similarly, a policy representative noted that “showcasing real-world applications does more to convert skeptics than any marketing campaign,” reinforcing how practical evidence feeds into TAM’s behavioral intention construct. These experiences demonstrate that successful use cases act as credibility anchors, bridging the gap between theoretical potential and operational confidence.

The reinforcing nature of these experiences was particularly evident in organizations that engaged in peer learning or shared demonstration programs. Participants described a feedback loop in which early wins not only increased management support but also encouraged new experimentation. Over time, this collective momentum strengthened perceived usefulness and reduced the psychological distance between adopters and non-adopters. Conversely, firms that lacked exposure to visible success stories tended to perceive AM as risky or immature, echoing DOI's notion that limited observability suppresses diffusion. Across cases, feedback from successful use catalyzed a cycle of validation, learning, and motivation that transformed individual perceptions into sustained organizational commitment to AM adoption.

3. Knowledge Exchange Networks → Perceived Usefulness and Ease of Use

Collaborative knowledge-sharing environments such as industry consortia, applied research hubs, and peer manufacturing networks were consistently cited by participants as instrumental in shaping how AM is understood and evaluated. These settings serve as trust-based spaces where firms can observe practical demonstrations, share technical insights, and compare outcomes without the commercial pressures typically associated with vendor-driven information. One manufacturer emphasized the influence of national programs, explaining that "NGen brought structure to what used to be informal networking, it gave us a reason to collaborate and the resources to actually act on those ideas," illustrating how coordinated initiatives transform informal peer exchange into organized, outcome-oriented collaboration that accelerates collective learning and adoption. Similarly, academic participants noted that inter-organizational workshops and training sessions often "demystify the technology" by translating complex design or material concepts into applied examples. Such exchanges directly reinforce TAM's constructs of perceived usefulness and ease of use by providing credible, experience-based evidence that AM can be successfully implemented across diverse contexts.

The influence of these networks extends beyond information sharing to the co-construction of collective confidence in AM adoption. Firms that participate actively in collaborative ecosystems described a faster progression from experimentation to integration, supported by recurring exposure to peer success stories and technical validation from trusted collaborators. One policy interviewee remarked that "companies involved in cluster projects rarely stay at the pilot stage, they see what's possible and start scaling." Conversely, participants operating in isolation or without access to these networks expressed persistent uncertainty, perceiving AM as overly complex or unproven. This dynamic underscores DOI's emphasis on communication channels and the social system as central diffusion mechanisms. In essence, knowledge exchange networks act as accelerators of adoption by transforming scattered expertise into shared understanding, strengthening both the perceived value and usability of AM technologies within the Canadian manufacturing ecosystem.

6.3.3 Synthesized Adoption Model based on DOI and TAM Empirical Findings

The empirical findings from the interviews conducted supported the conceptual models created for TAM and DOI but also revealed additional linkages between both adoption frameworks discussed in the previous section. To capture these interactions, the revised framework shown on the next page in Figure 8 integrates constructs from the Technology Acceptance Model and Diffusion of Innovation theory, incorporating emergent variables identified in the data such as

AM maturity, and feedback from successful use cases. The model positions TAM as the core through which ecosystem enablers such as knowledge networks, institutional support, and standardization systems shape perceptions of usefulness and ease of use. Concurrently, DOI attributes such as relative advantage, compatibility, trialability, and observability provide the structural context that conditions these perceptions. This integrated framework illustrates adoption as an iterative, multi-level process in which cognitive acceptance, organizational alignment, and systemic readiness collectively determine the pace and sustainability of AM diffusion across the Canadian manufacturing landscape.

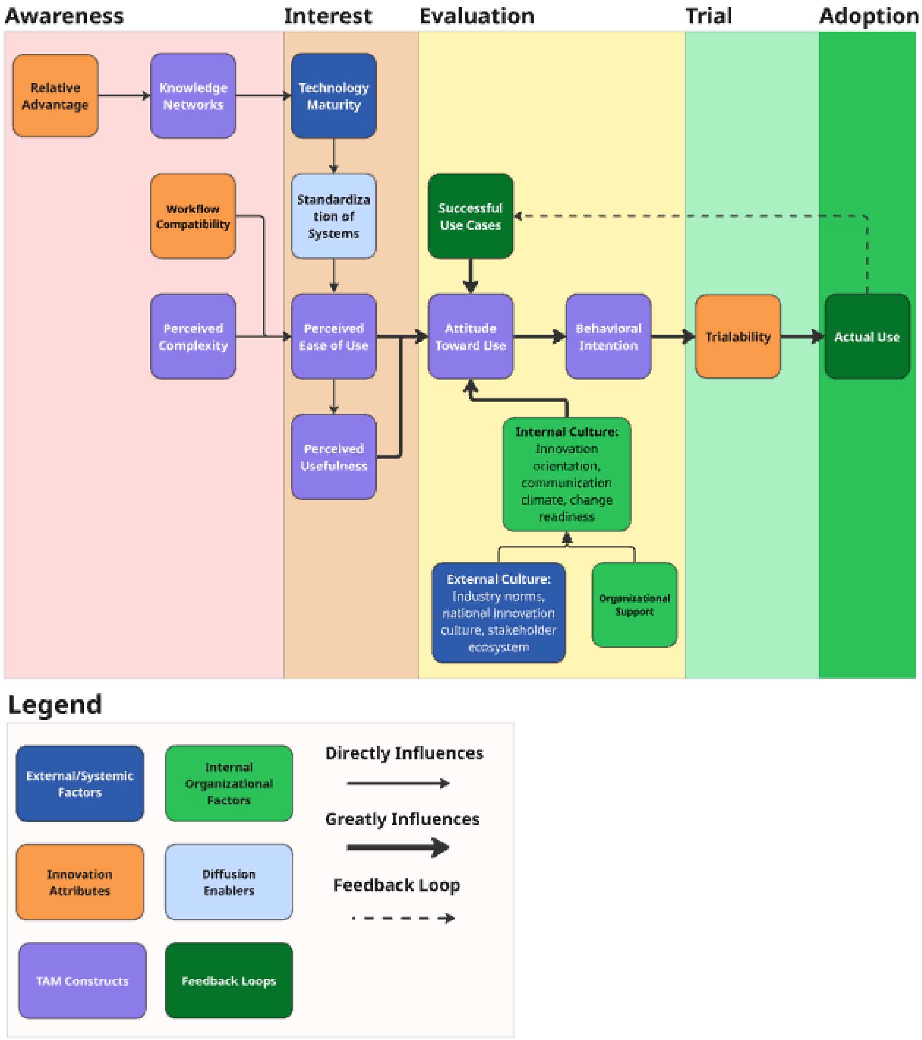

Figure 9: Synthesized TAM-DOI Framework for 3D printing Adoption in the Canadian Manufacturing Ecosystem

The framework begins with diffusion enablers and innovation attributes that define the surrounding ecosystem, establishing the foundation for AM maturity and user perception. Knowledge networks, institutional support, and standardization systems collectively foster readiness by reducing uncertainty, facilitating knowledge transfer, and legitimizing AM as an industrial practice. These enablers, alongside innovation attributes such as relative advantage, compatibility, trialability, and observability, directly shape organizational and individual perceptions captured within TAM. As ecosystem maturity increases, participants perceive AM as easier to implement (perceived ease of use) and more beneficial to productivity and competitiveness (perceived usefulness). The model also incorporates feedback mechanisms through which successful implementations enhance perceived usefulness and expand knowledge networks, reinforcing diffusion throughout the ecosystem. This cyclical process illustrates that AM adoption is not a one-time decision but a continuous learning loop shaped by technological experience, peer validation, and evolving institutional support. Overall, the synthesized TAM–DOI framework advances understanding of AM adoption by demonstrating that technology acceptance cannot be isolated from the institutional and cultural contexts in which it occurs. By embedding TAM's cognitive constructs within DOI's multi-level diffusion structure, the model reframes adoption as both a psychological and systemic process driven by perceptions of ease and usefulness but sustained through ecosystem readiness, and peer validation. This integration not only strengthens the explanatory power of both models but also grounds them in the lived realities of Canadian manufacturers navigating digital transformation. The resulting framework provides a foundation for future research and policy design aimed at accelerating AM diffusion through coordinated technological, organizational, and social interventions.

Chapter 7: Contributions

The research conducted makes a clear contribution to the understanding of technology adoption by developing a synthesized adoption model grounded in established theoretical frameworks and supported by empirical data drawn from the context of industrial 3D printing. While this study uses 3D printing as its primary application, the structure of the model is intentionally not technology-specific. Prior adoption frameworks such as the Technology Acceptance Model, Diffusion of Innovation, and the Process Adoption Perspective provided valuable insights in their own right, but they do not fully capture the dynamic, multi-level, and iterative nature of adoption observed in practice. This study addresses this gap by integrating theoretical constructs from these models with qualitative evidence drawn directly from industry interviews, resulting in a framework that can be adapted to examine the adoption of other emerging technologies.

The synthesized adoption framework conceptualizes adoption as an ongoing process rather than a single decision point. The model reflects how individual perceptions, organizational capabilities, and external ecosystem conditions interact and evolve over time. Interview data revealed that adoption is shaped by feedback loops, where early experimentation, pilot projects, and peer validation influence perceptions of value and feasibility, which in turn affect subsequent adoption decisions. Importantly, while the core structure of the framework remains consistent, the relative weighting, sequencing, and relevance of these factors can be adjusted based on the specific technology and organizational context being examined.

In addition to its conceptual contribution, this research provides empirical insight into the barriers that limit effective adoption. The findings demonstrate that adoption challenges extend beyond technical performance and include economic considerations, organizational learning, professional identity, and access to trusted knowledge sources. By situating these barriers within a unified framework, the study offers a structured explanation for why adoption often stalls despite clear technical potential. Although these findings are grounded in manufacturing, the identified mechanisms are broadly applicable to other complex technologies that require organizational change, experimentation, and risk tolerance.

Overall, this research contributes to adoption theory by offering a process-oriented, multi-level framework grounded in empirical evidence that extends beyond a single technological domain. The synthesized model provides a flexible foundation that future researchers can adapt and test across different technologies and sectors by tailoring factor emphasis and sequencing, while also offering practical relevance for stakeholders seeking to design, evaluate, and accelerate technology adoption in real-world settings.

Chapter 8: Future Work

While this study succeeds in achieving the research goals established at the beginning of the study, several opportunities remain for future work to extend and strengthen its contributions. Importantly, the findings and adoption model developed in this thesis suggest next steps that extend beyond follow-up academic research alone. From a strategic perspective, efforts to accelerate 3D printing adoption should focus less on further technology development and more on reducing perceived risk and strengthening organizational learning. This includes creating environments in which firms can experiment with low-risk use cases, build internal capability, and gain confidence through repeated exposure and observable success.

At a practical level, the model reinforces that adoption should be treated as a staged learning process rather than a single capital investment decision. Manufacturers may benefit from beginning with applications such as tooling, fixtures, or non-critical components, where integration costs and qualification requirements are lower, before progressing toward more complex or production-critical uses. In parallel, organizations can improve readiness through deliberate capability-building activities, such as establishing internal champions, developing repeatable workflows, tracking cost and quality outcomes from early projects, and investing in targeted training that reduces uncertainty around design and process constraints.

One important direction for future research is the continued testing and refinement of the synthesized adoption framework. Although the model was informed by interview data and existing adoption theories, further validation across a broader range of organizational and sectoral contexts would help assess its generalizability. Future studies could gather feedback from industry practitioners, suppliers, academics, and policymakers, including both previous participants and new stakeholders, to iteratively evaluate and adjust the framework as adoption conditions evolve. In addition, applying the framework through comparative case studies, quantitative adoption surveys, or policy-led pilot programs would help examine how organizational learning capacity, perceived risk, and ecosystem support shape adoption outcomes across different contexts.

Although this study focused on manufacturers and suppliers, the findings suggested that the end customers of manufacturing firms play an indirect but influential role in adoption decisions. Interviewees frequently referenced customer expectations around lead time, customization, cost, and reliability as drivers or constraints on adoption. In several cases, perceived customer skepticism around part quality or certification increased internal risk aversion, while customer demand for rapid iteration or customization accelerated experimentation. Future work that directly interviews customers could therefore strengthen understanding of the external pressures that shape perceived usefulness, organizational willingness, and trial behavior within the adoption process.

Future research could also apply the model to examine adoption challenges associated with different 3D printing technologies. For example, polymer-based printing often presents lower barriers to entry and allows for faster experimentation, whereas metal printing typically involves higher financial risk, stricter qualification requirements, and greater dependence on organizational readiness and ecosystem support. Using the synthesized framework as an analytical lens would allow researchers to compare how the relative importance of adoption factors shifts across technologies without altering the underlying structure of the model.

Another avenue for future work lies in expanding the practical implications of the framework for adoption planning and implementation. The model suggests that effective adoption strategies should account for learning over time and adapt to feedback from early use. Future work could investigate how organizations might use the framework diagnostically to identify where adoption efforts are stalling and to design staged interventions, such as targeted training, structured pilot projects, peer demonstrations, or external partnerships, to address specific barriers. Relatedly, support organizations, industry groups, and educational institutions could evaluate how shared learning infrastructure, such as open training modules, demonstration parts, and guidance on qualification expectations, might reduce uncertainty and accelerate capability-building across firms.

Finally, future studies could explore experimental or intervention-based approaches to examine whether actions informed by the model can influence adoption outcomes. Longitudinal research tracking organizations before and after targeted initiatives, such as peer demonstrations, mission-driven procurement efforts, or structured pilot programs, could provide insight into how perceptions of value and feasibility change over time. These approaches would help move adoption research beyond descriptive analysis toward a better understanding of how adoption rates can be actively influenced in practice.

Together, these directions for future work build directly on the contributions of this study while remaining consistent with its scope. By refining, applying, and testing the synthesized adoption framework, future work can further advance understanding of 3D printing adoption and support more effective integration of these technologies in manufacturing organizations.

Chapter 9: Conclusion

This thesis examined why the adoption of 3D printing in Canada remains limited, despite the technology having matured and demonstrated value across multiple industries. While 3D printing is widely recognized as a capable and commercially viable manufacturing method, many Canadian firms continue to use it primarily for prototyping rather than full-scale production. To investigate this gap, the research combined sector analysis, interviews with industry experts, and established technology adoption frameworks, including the Technology Acceptance Model, Diffusion of Innovation, and the Product Adoption Process.

The findings show that limited adoption is not driven by technical shortcomings alone. Instead, adoption decisions are shaped by a combination of economic, organizational, cultural, and ecosystem-level factors that influence how firms evaluate risk, value, and feasibility. High material and equipment costs, limited access to training, conservative organizational cultures, and uneven regional infrastructure all contribute to reduced confidence in the technology. These conditions weaken key adoption drivers such as perceived advantage, compatibility with existing workflows, and opportunities for experimentation. At the same time, the study highlights that adoption can succeed when enabling conditions are aligned. Sectors such as hearing aids, orthodontics, and aerospace tooling demonstrate that stronger uptake occurs when economic incentives, organizational readiness, and external support structures are present.

A recurring theme across interviews was regulatory uncertainty and the absence of clear standards. Participants expressed uncertainty around acceptable use cases, operator responsibility, and how to demonstrate part reliability to customers or regulators. In the absence of formal guidance, many organizations defaulted to conservative adoption strategies or restricted use to non-critical applications. These findings suggest that clearer standards related to machine operation, operator competency, and production quality could play an important role in reducing perceived risk and accelerating adoption. Potential approaches include operator certification or training requirements, standardized quality benchmarks for printed components, and clearer distinctions between prototyping and end-use production. Rather than mandating adoption, such mechanisms could help organizations better assess risk, justify investment decisions, and communicate credibility to customers.

From an adoption perspective, regulatory clarity functions as an ecosystem-level enabler by increasing confidence, legitimizing use cases, and supporting the transition from experimentation to sustained use. Incorporating regulatory and standards considerations into broader adoption strategies may therefore help address both internal organizational hesitation and external skepticism surrounding emerging manufacturing technologies.

A central contribution of this thesis is the development of a synthesized adoption model that integrates constructs from existing adoption theories while capturing the dynamic, multi-level nature of adoption observed in practice. Although the model is grounded in the context of 3D printing in Canada, its structure is intentionally not technology-specific. The framework connects individual perceptions of usefulness and ease of use with organizational capabilities and external ecosystem conditions, while emphasizing adoption as an iterative learning process shaped by experimentation, peer influence, and feedback. The relative weighting, sequencing, and emphasis of these factors can be adapted to examine the adoption of other emerging technologies across different organizational and sectoral contexts.

During the examination, the question arose as to whether the barriers identified in this thesis reflect a broader difference between 3D printing adoption in Canada and in the United States. While this research does not undertake a comparative empirical analysis, the adoption model developed here offers a useful lens for interpreting such differences. The findings suggest that slower adoption in Canada is not primarily the result of weaker technical capability or lack of awareness, but rather differences in how risk, learning, and incentives are structured within the manufacturing ecosystem.

In larger markets such as the United States, adoption is often supported by stronger demand-side pull from anchor firms, mission-driven procurement, and greater tolerance for early-stage experimentation. These conditions can reduce perceived risk for suppliers and manufacturers by increasing confidence that early investments in equipment, training, and qualification work will lead to real market opportunities. When firms have clearer pathways to repeatable demand, they are more willing to explore use cases beyond prototyping because the organizational effort required to integrate 3D printing into workflows has a higher likelihood of paying off. Similarly, when experimentation is culturally and operationally normalized, firms can build learning momentum through pilots, iteration, and internal capability growth, rather than treating 3D printing as a one-time purchase decision that must be justified immediately.

In contrast, Canadian firms often operate in smaller, more fragmented markets where adoption decisions are more sensitive to short-term justification, uncertainty around certification or qualification pathways, and the hidden integration costs associated with training, process control, and redesign. Even when the technology is understood and its potential value is recognized, the conditions that enable firms to confidently move from trial to sustained use may be weaker. This can result in a more conservative adoption posture, where 3D printing is kept in a limited role because expanding its use introduces risk that is difficult to offset through near-term revenue, clear standards, or strong external support.

Viewed through the synthesized TAM–DOI framework developed in this thesis, these ecosystem conditions shape adoption by influencing perceived usefulness and ease of integration (TAM) as well as trialability, observability, and perceived risk (DOI). When firms have fewer opportunities to observe successful peer implementations, fewer low-risk chances to experiment, and less confidence in downstream qualification pathways, the technology may be viewed as useful in principle but costly to adopt in practice. As a result, organizational learning slows, and the transition from experimentation to sustained use becomes more difficult. In this sense, the difference is not best interpreted as Canada having less capable firms or less mature technology, but as Canada having fewer reinforcing mechanisms that reduce uncertainty and accelerate learning at scale.

Importantly, this interpretation reinforces the central conclusion of the thesis: adoption outcomes are shaped less by the maturity of the technology itself and more by the organizational and ecosystem contexts in which adoption decisions are made.

Taken together, this interpretation underscores that the barriers identified in this thesis are not fixed constraints, but conditions that can be influenced through deliberate organizational, strategic, and policy choices.

Overall, the research highlights that improving 3D printing adoption in Canada requires more than acquiring new equipment. Strengthening the surrounding ecosystem is equally important. This includes developing a skilled workforce, improving access to qualification and certification resources, expanding regional manufacturing capabilities, and encouraging closer collaboration among universities, industry, and government. As Canada continues to pursue goals related to digital transformation, clean technology, and supply chain resilience, the insights from this thesis provide a foundation for strategies and policies aimed at enabling more effective and sustained technology adoption.

References

[1] “What is 3D printing? how does a 3D printer work? learn 3D printing,” 3D Printing, https://3dprinting.com/what-is-3d-printing/

[2] A. Chapman, “The Complete History of 3D printing,” UltiMaker, https://ultimaker.com/learn/the-complete-history-of-3d-printing/

[3] R. Aveni, “The 3-D printing revolution,” Harvard Business Review, https://hbr.org/2015/05/the-3-d-printing-revolution.

[4] C. Murray, “Common applications of 3D printing: From Aerospace to fashion,” Forbes, http://forbes.com/sites/conormurray/2023/04/21/common-applications-of-3d-printing-from-aerospace-to-fashion

[5] Inc, Opti-Tech Scientific. “2. A Deep Dive into Canadian 3D printing Applications.” *Opti*, 4 Mar. 2024, opti-tech.ca/explore-industrial-and-desktop-additive-manufacturing.

[6] “How Personalization Has Changed the Hearing Aid Industry.” *How Personalization Has Changed the Hearing Aid Industry*, www.materialise.com/en/inspiration/cases/phonak-3d-printed-hearing-aid.

[7] *RTX’s Pratt & Whitney Develops 3D printing to Reduce Engine Repair Time | Reuters*, www.reuters.com/business/aerospace-defense/rtxs-pratt-whitney-develops-additive-manufacturing-reduce-engine-repair-time-2025-04-08

[8] Meng, Meng, et al. "3D printing metal implants in orthopedic surgery: Methods, applications and future prospects." *Journal of Orthopaedic Translation*, vol. 42, Sept. 2023, pp. 94–112, https://doi.org/10.1016/j.jot.2023.08.004.

[9] MSC, Next. "Canada 3D printing Market Size, Share: 2030." *Canada 3D printing Market Size, Share | 2030*, www.nextmsc.com/news/canada-additive-manufacturing-market.

[10] 3D opportunity for the supply chain, https://www2.deloitte.com/content/dam/insights/us/articles/additive-manufacturing-3d-printing-supply-chain-transformation/DUP_1288-3D-opportunity-supply-chain_MASTER.pdf

[11] "3D printing trend report 2024," Protolabs, https://www.protolabs.com/resources/guides-and-trend-reports/3d-printing-trend-report

[12] Canada, Health. "Government of Canada." *Canada.Ca*, / Gouvernement du Canada, 17 Apr. 2023, www.canada.ca/en/health-canada/services/drugs-health-products/medical-devices/application-information/guidance-documents/clinical-evidence-requirements-medical-devices.html.

[13] Davies, Sam. "A Flying Start: GE Aerospace's 3D printing Journey." *TCT Magazine*, 4 July 2023, www.tctmagazine.com/additive-manufacturing-3d-printing-industry-insights/aerospace-insights/ge-aerospace-additive-manufacturing-journey.

[14] Tyrer-Jones, Alex, et al. "Health Canada Has Approved Its First Canadian-Made 3D Printed Medical Implant." *3D Printing Industry*, 9 Dec. 2021,

3dprintingindustry.com/news/health-canada-has-approved-its-first-canadian-made-3d-printed-medical-implant-201111.

[15] "Porsche Classic Supplies Classic Parts from a 3D Printer." *Porsche Newsroom*, 2 Dec. 2018,newsroom.porsche.com/en/company/porsche-classic-3d-printer-spare-parts-sls-printer-production-cars-innovative-14816.html

[16] Voulpiotis, Filippos. "What Role Does 3D Printing Play in Formula 1?" *3Dnatives*, 27 May 2025, www.3dnatives.com/en/formula-1-turning-to-3d-printing-281020194/.

[17] "How 3D Printing Could Drive the Factory of the Future" https://www.wsj.com/podcasts/wsj-the-future-of-everything/how-3d-printing-could-drive-the-factory-of-the-future/201981c8-9ef4-40ca-87b6-25cac6ca0832

[18] reporter, Staff. "3D Printing: Reshaping the Mining Landscape." *Mining Magazine*, 5 Sept. 2019, www.miningmagazine.com/environment/news/1263820/3d-printing-reshaping-mining-landscape

[19] "The Rise of 3D printing in Spare Parts Production: A Data-Driven Analysis: News." *SelectAM*, selectam.io/news/the-rise-of-additive-manufacturing-in-spare-parts-production-a-data-driven-analysis.

[20] "Burloak Technologies Inc.. Home: Advanced Manufacturing Solutions." *Burloak Technologies Inc. Home | Advanced Manufacturing Solutions*, www.burloaktech.com/

[21] S., Kety. “Qualification & Certification: Their Differences & Next Challenges for 3D printing.” *3D ADEPT MEDIA*, 22 July 2021, 3dadept.com/qualification-certification-their-differences-next-challenges-for-additive-manufacturing

[22] Sciach. “New Lassonde Partnership Leverages 3D Printing for Sustainable, Affordable Housing Solutions.” *Lassonde School of Engineering*, 29 July 2024, lassonde.yorku.ca/new-lassonde-partnership-leverages-3d-printing-for-sustainable-affordable-housing-solutions#:~:text=Typically%2C%20these%20mixtures%20contain%20significant,group%2C%E2%80%9D%20says%20Professor%20Butler

[23] “Building Forward to Address Canada’s Housing Crisis: Smith Engineering Researchers Working to Advance Commercialization of 3D Home Printing - Smith Engineering News: Queen’s University.” *Smith Engineering News | Queen’s University*, smithengineering.queensu.ca/news/2025/02/building-forward-to-address-canadas-housing-crisis-smith-engineering-researchers-working-to-advance-commercialization-of-3d-home-printing.html

[24] *Construction 3D Printing: Cost Analysis and Industry Challenges « fabbaloo*, www.fabbaloo.com/news/construction-3d-printing-cost-analysis-and-industry-challenges.

[25] Das, Arnesh, et al. “Freeze-thaw performance of 3D printed concrete: Influence of interfaces.” *RILEM Bookseries*, 2022, pp. 200–205, https://doi.org/10.1007/978-3-031-06116-5_30.

[26] “3D Printed Buildings and UL 3401.” *UL Solutions Code Authorities*, 19 Aug. 2024, code-authorities.ul.com/3d-printed-buildings.

[27] Amfg. “10 Exciting Ways 3D Printing Is Being Used in the Consumer Goods Industry.” *AMFG*, 30 Sept. 2020, amfg.ai/2019/03/12/10-exciting-ways-3d-printing-is-being-used-in-the-consumer-goods-industry/.

[28] Franchetti, Matthew, and Connor Kress. “An economic analysis comparing the cost feasibility of replacing injection molding processes with emerging 3D printing techniques.” *The International Journal of Advanced Manufacturing Technology*, vol. 88, no. 9–12, 3 June 2016, pp. 2573–2579, https://doi.org/10.1007/s00170-016-8968-7.

[29] Fianko, Samuel Koranteng, et al. “Mass customisation strategies in 3D printing: A systematic review and Implementation Framework.” *Processes*, vol. 13, no. 6, 12 June 2025, p. 1855, https://doi.org/10.3390/pr13061855.

[30] Davis, Fred D. *A Technology Acceptance Model for Empirically Testing New End-User Information Systems: Theory and Results*. 1989.

[31] Taherdoost, Hamed. “A review of technology acceptance and adoption models and theories.” *Procedia Manufacturing*, vol. 22, 2018, pp. 960–967, https://doi.org/10.1016/j.promfg.2018.03.137.

[32] Ballat, Gamal El. “Understanding the adoption of 3D printing in construction: A sociological perspective through a revised TAM model.” *Advances in Applied Sociology*, vol. 14, no. 10, 2024, pp. 517–536, https://doi.org/10.4236/aasoci.2024.1410035.

[33] Venkatesh, Viswanath, and Fred D. Davis. “A theoretical extension of the technology acceptance model: Four longitudinal field studies.” *Management Science*, vol. 46, no. 2, Feb. 2000, pp. 186–204, https://doi.org/10.1287/mnsc.46.2.186.11926.

[34] Venkatesh, Viswanath, and Hillol Bala. “Technology acceptance model 3 and a research agenda on interventions.” *Decision Sciences*, vol. 39, no. 2, May 2008, pp. 273–315, https://doi.org/10.1111/j.1540-5915.2008.00192.x

[35] Venkatesh, Viswanath. “Technology acceptance model and the unified theory of acceptance and use of Technology.” *Wiley Encyclopedia of Management*, 21 Jan. 2015, pp. 1–9, https://doi.org/10.1002/9781118785317.weom070047.

[36] Wallin, Anna, et al. “From thriving developers to stagnant self-doubters: An identity-centered approach to exploring the relationship between digitalization and professional development.” *Vocations and Learning*, vol. 15, no. 2, 25 Mar. 2022, pp. 285–316, https://doi.org/10.1007/s12186-022-09288-6.

[37] A. L. Wilkins, “Organizational culture and leadership: A dynamic view, by Edgar H. Schein. San Francisco, CA: Jossey‐bass, 1985, $21.95,” Human Resource Management, vol. 24, no. 3, pp. 370–375, Sep. 1985. doi:10.1002/hrm.3930240312

[38] [1] J. R. Detert, R. G. Schroeder, and J. J. Mauriel, “A framework for linking culture and improvement initiatives in organizations,” *The Academy of Management Review*, vol. 25, no. 4, p. 850, Oct. 2000. doi:10.2307/259210

[37] E. M. Rogers, Diffusion of Innovations, 5th Edition. Free Press, 2014.

[38] R. B. Handfield, J. Aitken, N. Turner, T. Boehme, and C. Bozarth, "Assessing adoption factors for additive manufacturing: Insights from case studies," *Logistics*, vol. 6, no. 2, p. 36, Jun. 2022. doi:10.3390/logistics6020036

[39] I. Tajuddin, "Challenges of new technology adoption in improving company growth and competitiveness," *Advances in Economics & Financial Studies*, vol. 3, no. 1, pp. 56–70, Jan. 2025. doi:10.60079/aefs.v3i1.458

[40] Haug, Anders, et al. "Adoption of 3D printing: A Survey of the role of knowledge networks and maturity in small and medium-sized Danish production firms." *International Journal of Production Economics*, vol. 255, Jan. 2023, p. 108714, https://doi.org/10.1016/j.ijpe.2022.108714.

[41] Dr. M. G. Albrecht, Dr. M. Green, and L. Hoffman, "10.5 stages in the consumer adoption process for new products - principles of marketing," OpenStax, https://openstax.org/books/principles-marketing/pages/10-5-stages-in-the-consumer-adoption-process-for-new-products

[42] L. Trieste and G. Turchetti, "The nature, causes, and effects of skepticism on technology diffusion," *Technological Forecasting and Social Change*, vol. 208, p. 123663, Nov. 2024. doi:10.1016/j.techfore.2024.123663

[43] M. Mehrpouya, A. Vosooghnia, A. Dehghanghadikolaei, and B. Fotovvati, "The benefits of additive manufacturing for sustainable design and production," *Sustainable Manufacturing*, pp. 29–59, 2021. doi:10.1016/b978-0-12-818115-7.00009-2

[44] N. Zimmermann, J. Lentes, and A. Werner, “Analysis of requirements, potentials and risks caused by using additive manufacturing,” *Procedia Manufacturing*, vol. 39, pp. 474–483, 2019. doi:10.1016/j.promfg.2020.01.404

[45] S. Mellor, L. Hao, and D. Zhang, “Additive manufacturing: A framework for implementation,” Int. J. Prod. Econ., vol. 149, pp. 194–201, 2014.

[46] D. Schniederjans and M. Yalcin, “Perceived benefits and barriers to the adoption of 3D printing in manufacturing,” Oper. Manag. Res., vol. 11, no. 3, pp. 135–148, 2018.

[47] M. Khanzadeh and B. Tulu, “Pathways to additive manufacturing adoption: A multi-stage decision model,” J. Manuf. Technol. Manag., vol. 33, no. 5, pp. 745–763, 2021.

[48] J. P. Hausberg and S. Korreck, “Business incubators and accelerators: A co-citation analysis-based, Systematic Literature Review,” *Handbook of Research on Business and Technology Incubation and Acceleration*, Apr. 2021. doi:10.4337/9781788974783.00009

[49] Lewis, Sarah. “Qualitative inquiry and research design: Choosing among five approaches.” *Health Promotion Practice*, vol. 16, no. 4, 2 Apr. 2015, pp. 473–475, https://doi.org/10.1177/1524839915580941.

[50] Ginn, Gina M., and Sunny L. Munn. “Book review: Interviews: Learning the craft of qualitative research interviewing interviews: Learning the craft of qualitative research interviewing, third edition, by Brinkmannsvend and Kvalesteinar. Thousand Oaks, ca: Sage, 2015. 405 pages, $60.00 (paperback).” *New Horizons in Adult Education and Human Resource Development*, vol. 31, no. 2, Mar. 2019, pp. 67–69, https://doi.org/10.1002/nha3.20251.

[51] Ruslin, Ruslin & Mashuri, Saepudin & Sarib, Muhammad & Alhabsyi, Firdiansyah & Syam, Hijrah. (2022). Semi-structured Interview: A Methodological Reflection on the Development of a Qualitative Research Instrument in Educational Studies Ruslin. Vol. 12. 22-29. 10.9790/7388-1201052229.

[52] Bell, Emma, et al. "Sampling in qualitative research." *Business Research Methods*, 30 Mar. 2022, https://doi.org/10.1093/hebz/9780198869443.003.0030.

[53] Williams, Bella. "Hybrid Coding in Qualitative Research: Combining Methods - INSIGHT7 - Call Analytics & AI Coaching for Customer Teams." *Insight7*, 11 Sept. 2024, insight7.io/hybrid-coding-in-qualitative-research-combining-methods/.

[54] "Government of Canada." Language Selection - Innovation, Science and Economic Development Canada Main Site / Sélection de La Langue - Site Principal d'Innovation, Sciences et Développement Économique Canada, / Gouvernement du Canada, 25 Mar. 2025, ised-isde.canada.ca/site/clean-growth-hub/en/cement-and-concrete-canada/roadmap-net-zero-carbon-concrete-2050.

[55] "ISO/TC 261 - additive manufacturing," ISO, https://www.iso.org/committee/629086.html

[56] E. Yardley, "Braun and Clarke Thematic Analysis - how to do the Six-step process in your qualitative research project," Degree Doctor®, https://www.thedegreedoctor.com/blog/braun-and-clarke-thematic-analysis-how-to-do-the-six-step-process-in-your-qualitative-research-project

Appendix

Appendix A: Interview Questions

Industry Leader Questions

1.What is your overall perspective on the adoption of 3D printing in Canada, and how does it compare to other countries or regions globally?

2.What strategic benefits do you believe 3D printing can offer to Canadian manufacturers, and how aligned is it with current industry needs?

Barriers to Adoption

Overview

3.What are the primary challenges or barriers that you see limiting the widespread adoption of 3D printing in Canadian industries?

Economic

4.How do you perceive the cost-benefit analysis for businesses considering 3D printing, and what specific economic hurdles do you believe are most difficult to overcome?

Technical

5.What technical challenges or gaps in knowledge (e.g., material limitations, lack of expertise, or compatibility with existing processes) do you think are most critical to address for wider adoption?

Other

6.Are there non-economic or non-technical factors, such as workforce readiness, organizational culture, or regulatory concerns, that you feel are playing a significant role in hindering adoption?

Role of Collaboration and Ecosystems

7.To what extent do you think collaboration between manufacturers, universities, and government agencies can help drive the adoption of 3D printing in Canada?

8.What role do you see for suppliers of 3D printing technologies in supporting manufacturers, especially small and medium-sized enterprises (SMEs), in overcoming adoption challenges?

Policy and Future Directions

9.Do you think current government policies and incentives are sufficient to encourage the adoption of 3D printing in Canada? What changes or initiatives would you recommend?

Broader Vision and Trends

10.Looking ahead, what trends or innovations in 3D printing do you think could make the technology more accessible or appealing to Canadian manufacturers in the next 5–10 years?

Impact of U.S. Tariffs (Specific for Flavio Volpe, APMA)

How do you anticipate the recent imposition of U.S. tariffs will impact Canadian manufacturers, for example in the automotive industry?

Given these tariffs, do you see 3D printing playing a larger strategic role in helping Canadian manufacturers remain competitive internationally?

What immediate and longer-term strategies would you advise Canadian manufacturers to adopt in response to these tariffs?

Do you see potential for increased collaboration or reshoring within Canadian manufacturing sectors as a result of the tariffs imposed by the U.S.?

What role should government policy play in supporting Canadian manufacturing, in light of the recent tariff actions by the U.S?

3D printing Supplier Questions

Success Stories and Key Ingredients

1.Can you share examples of industries or companies where 3D printing has been successfully adopted? What do you think were the key ingredients that contributed to their success?

2.What specific problems or challenges do you see 3D printing solving effectively for your clients, and how do these solutions differ from traditional manufacturing methods?

3.What role does collaboration with your company (e.g., technical support, design expertise, or training) play in ensuring successful adoption for your clients?

Barriers to Adoption

4.In your experience, what are the most common reasons companies struggle to adopt 3D printing?

5.How often do you encounter resistance to adopting 3D printing due to cultural or organizational factors? Explain the factors you’ve encountered

Overcoming Barriers

6.What strategies or solutions have you found effective in helping companies overcome the most significant barriers to adopting 3D printing?

7.How can suppliers like your company collaborate with manufacturers to make 3D printing more accessible, particularly for SMEs or those with limited budgets?

Insights on Market Trends and Ecosystems

8.Are there specific trends, innovations, or breakthroughs in 3D printing (e.g., new materials, faster printers, lower costs) that you believe will accelerate adoption in the near future?

9.What role do you think governments, industry groups, or academic institutions can play in removing barriers and driving wider adoption of 3D printing in Canada?

Questions for Academics working in relevant research fields

Widespread Adoption and Critical Issues

1.In your opinion, what are the most critical scientific and technical issues that need to be addressed before 3D printing can achieve widespread adoption?

2.What role do you think research and development in 3D printing play in making 3D printing more efficient and scalable?

3.How do you see academic institutions contributing to addressing the knowledge and skills gap in 3D printing among engineers and manufacturers?

Material-Specific Challenges

4.What are the biggest technical or cost-related challenges in using metals for 3D printing, and how do these compare to challenges with polymers like ABS or resins?

5.Can you discuss the challenges of post-processing and finishing for different materials, such as metals versus resins, and how these affect adoption decisions?

6.In your research, what advancements have shown the most promise for improving the performance, consistency, or affordability of materials like resin, ABS, or metals in 3D printing?

Applications and Deployment

7.Which industries or applications do you believe are best suited for 3D printing today, and what makes them more successful at integrating it into their processes?

8.What challenges do you see when deploying 3D printing for high-performance applications, such as aerospace or medical devices, particularly in terms of material properties?

Academic Perspective on Ecosystems and Policy

9.How can universities, government, and industry collaborate more effectively to drive innovation and reduce the barriers to adoption of 3D printing in Canada?

10.Are there any current policies, funding programs, or incentives that you believe are effective—or ineffective—in supporting research and adoption of 3D printing technologies? What changes would you recommend?

Questions for a manufacturing organization that is currently using/considering 3D printing

Current Use and Benefits

1.Can you describe your current use (or exploration) of 3D printing within your organization? What specific benefits have you experienced so far?

2.What unique opportunities or advantages do you believe 3D printing could offer your organization compared to traditional manufacturing methods?

Challenges to Adoption

3.What are the main challenges or concerns that have prevented your organization from adopting 3D printing more extensively?

- Takes time to find right applications
- Can’t do appropriate testing internally to validate new applications
- Mechanical data and standards is very limited
- Simulation software doesn’t accurately reflect 3D printed structures

4.For organizations like yours that have not yet adopted 3D printing, what specific factors (e.g., cost, expertise, or compatibility with current processes) make it difficult to take the first step?

5.If your organization is using 3D printing, what challenges have you faced in scaling up its use or expanding to more complex applications?

Material-Specific and Application Challenges

6.What challenges do you face when it comes to using specific materials like metals, resins, or polymers (e.g., ABS) in 3D printing? How do these impact your decisions to adopt or expand its use?

7.Are there particular applications or products where you see 3D printing excelling versus others where it falls short? What factors contribute to these differences?

Ecosystem and Support

8.What type of support or resources (e.g., training, partnerships, or government incentives) would make it easier for your organization to adopt or expand the use of 3D printing?

Perceived and Potential Benefits

9.Looking at your industry as a whole, where do you see the greatest potential for 3D printing to create value, and what would it take for your organization to realize similar benefits?

10.If the barriers to adoption were removed, what would be your organization's ideal vision for using 3D printing in your operations?