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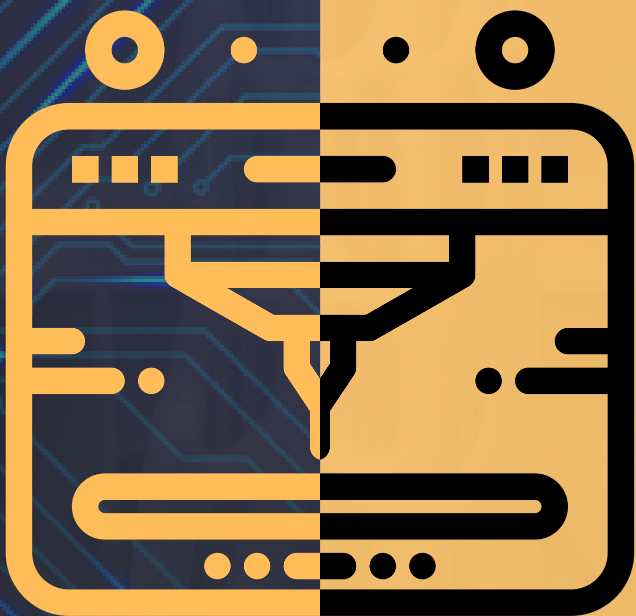
DIGITAL TWINS IN ADDITIVE MANUFACTURING:

A BUSINESS CASE FOR 3D PRINTER MANUFACTURERS



BY CHARLES ODADA

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Table of Contents

Executive Summary

3D printing companies are struggling to raise revenue amid the industry's slow growth and heavy competition. A lower-than-expected adoption rate has been a key symptom, but the core issues seem to be user doubts regarding process reliability and difficulties scaling existing additive manufacturing technologies.

Currently, there is a risk that many companies relying on machine sales for the bulk of their revenue will cease to exist. Proprietary consumables and software may help but these are, at best, temporary solutions and could have the opposite effect unless they result in a markedly superior printing experience.

Digital twins (DTs) have the potential to improve the quality of 3D printed products and the reliability of additive manufacturing processes. They can also lower the expertise needed to get good manufacturing outcomes on the user end, simplifying adoption, integration, and scaling.

This shift would change user perceptions and expectations, allowing machine makers to better price their 3D printers. Additionally, DTs would enable them to play an ongoing role in maintaining and improving the lifetime value of their machines, creating an opportunity to establish a new revenue stream.

The Challenge: An Unsustainable Revenue Model

In the past few months, a major player in the 3D printing industry declared bankruptcy[1] and another was acquired for 2.4% of its peak valuation.[2]

These two events may have made the headlines, but it's common knowledge that the whole 3D printing industry is going through a turbulent period, and has been for a while.[3]

A wider post-pandemic economic slowdown may have worsened the situation, but the history of negative reports goes further back than 2019.[4]

"In 3D printing over 150 companies compete with each other for the same amount of revenue ($7B) — the result is pretty disastrous." - David Lakatos, Formlabs.

High Competition, Low Revenue

The current statistics of 3D printing paint a picture of an industry that is too competitive in its infancy; or perhaps one that overpromised stakeholders.

More than 100 companies manufacture and sell 3D printers globally, but the industry, including publicly listed companies, contract manufacturing, consumables, and software, just crossed the $20 billion mark in 2023.[5]

Many publicly traded 3D printing companies are also trading at or near historic lows, a sign of waning investor confidence in the sector.[6] Despite many positives, the 3D printing market isn't growing fast enough to sustain the level of competition. So, why has the market growth been so slow?

The Core Problem

3D printing currently lacks the automaticity* that would make it simple and reliable and this continues to limit adoption.

A 2024 survey by 3DPI revealed that the top two concerns regarding 3D printing were process and machine reliability and the quality of the parts produced. A connected issue, ranked fifth, was the difficulty in qualifying and certifying parts.[7]

The Paradox of Quality

The fact that part quality is still raised as an issue may seem strange given what the technology is already used for. 3D printed parts can be found in demanding fields including the aerospace industry.[8]

However, the crucial factor often overlooked is that the results in these industries are often not achieved through a process that is automated and repeatable. They require a high level of expertise and sustained effort. Many other industries cannot afford to approach every 3D print as a custom solution requiring the same level of problem-solving.

This high demand for expertise also came up in a survey by Materialise.[9] Although training more personnel can help, it's not a solution that scales well.

An ideal and scalable solution would be one that made it simpler for users to consistently get good results, i.e., one that reduces the effort and expertise needed per print.

Unsustainable Situation

100+ companies fighting for more revenue amid low adoption levels is not sustainable.

Many have stated that 3D printer manufacturers must reassess the entire process so they can offer users the products they need.

Different solutions have been proposed including a greater adoption internally so machine makers can be at the forefront of solving automation and scaling problems[10] and revisiting basic ideas, e.g., replacing filaments with pellets and using nozzles with variable diameters in FDM.[11]

A recurring theme in these proposals is the need for automation but automating 3D printing at scale will be expensive and risky. A digital twin-centered automation initiative can allow machine makers to improve the process while simplifying the user experience. This increases the incentive for adoption and creates a new revenue stream for machine makers.

**Can be performed with minimal user intervention especially on low-level details*

Alternative Revenue Solutions

The revenue problem in 3D printing is not new. It has existed since the 2010s but common alternative solutions don't seem to be the industry's best bet.

Higher Printer Costs

The cost of 3D printers plummeted in the 2010s after key patents expired and new machine makers entered the fray.[12]

This led to a lot of hype but also resulted in an oversupply of similar machines and rock-bottom pricing.[13]

Higher prices industrywide would mean more revenue per printer sold but this is unlikely given the level of competition. Even if existing companies consolidated, the inherent simplicity of an acceptable printer by current consumer standards means that raising prices could just encourage the entry of new low-cost machine makers.

Proprietary Consumables and Software

Some machines only work with in-house materials, spares, and software. This approach has had mixed results and many consumers dislike it because it usually means paying more for functionally similar products and limited access to good 3rd party options.[14]

When a proprietary product doesn't offer significantly better results, it's easy for consumers to see it as an attempt to lock them in an expensive ecosystem leading to poor sales.

Third-Party Digital Twins

Before discussing first-party digital twins, it's important to acknowledge that third-party digital twins are already under development and could help grow the market by improving the functionality of some machines.[15]

These digital twins are often intended to be compatible with different companies' machines, but the question can be asked of how much fidelity they can achieve.

Third parties don't have all the product information OEMs have. The printers may also not be designed to prioritize automation and digital twinning, limiting the achievable fidelity by default.

This arrangement is also not ideal for 3D printer manufacturers if they must pay to have their systems on this platform. Not to mention the opportunity lost by not creating a new revenue stream using their own digital twin ecosystem.

Solution: A Digital Twin-Centric Business Model

What Are Digital Twins (DTs)

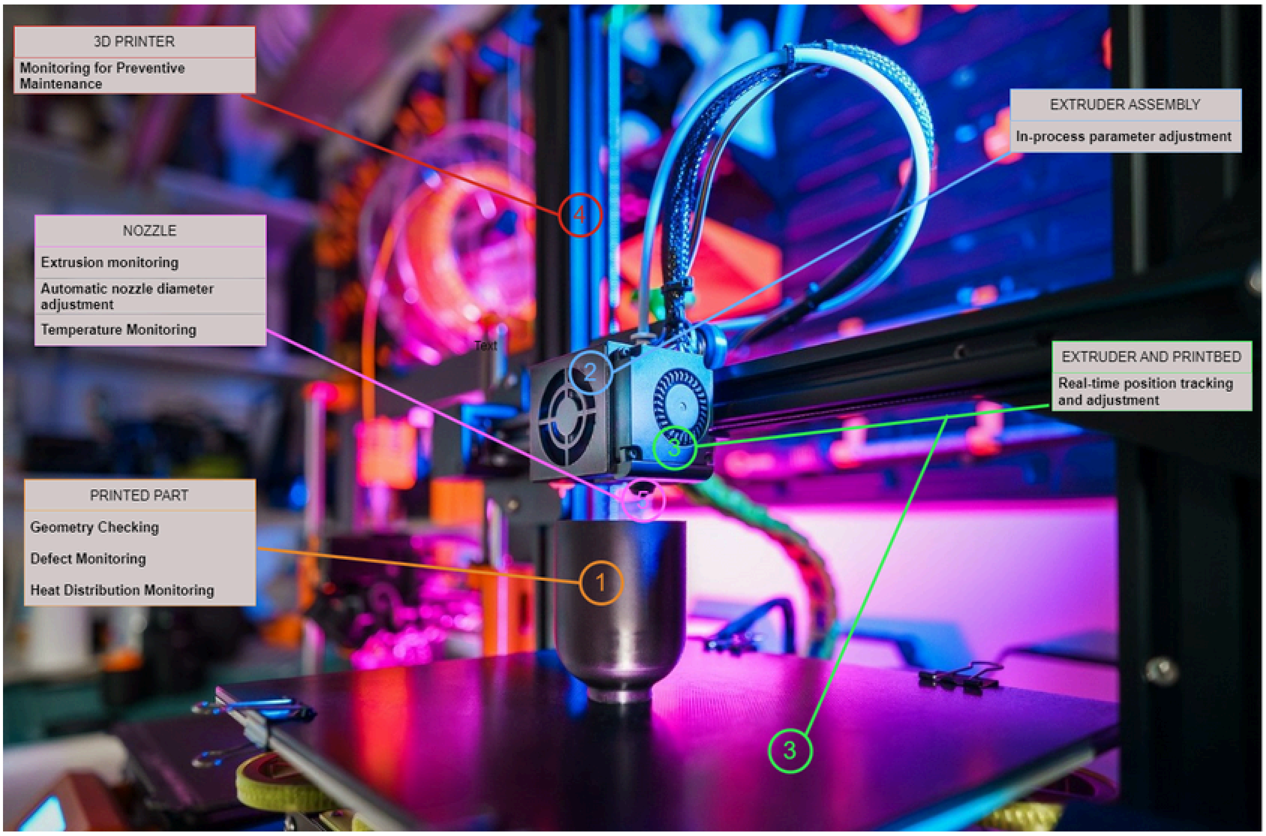
Digital twins are models of real-world entities that can replicate their actions and simulate their behavior in a computerized environment.[16]

Unlike regular simulations, these systems allow for data exchange between the digital and physical asset, resulting in accurate simulations and improved implementation of solutions in a continuous loop.

Digital Twins in 3D Printing

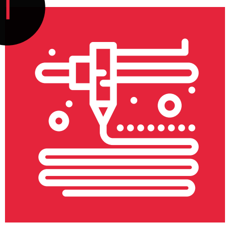
Digital twins can be used in 3D printing as a platform for:

- Accurate process monitoring - Part geometries, motion, heat distribution, errors, defects, etc.
- Process simulation to identify ideal printing parameters and conditions
- Virtual part testing
- In-process parameter updates
- Maintenance scheduling
- Quality Control, etc.



DTs Impact On 3D Printing Outcomes & Experiences

1



ENHANCED PROCESS MONITORING

Need for physical process monitoring is eliminated. Automated Systems can monitor part geometries, process parameters, positions of moving parts, vibrations, etc. on multiple machines and provide more information about the printing process in real-time.

2

OPTIMIZED PRINT SETTINGS

Automatic parameter selection for different prints and features based on analysis of past print data. The quality of successive prints is improved while errors and defects are lowered. Settings can also be updated mid-print based on real-time data.

3

ACCURATE PROCESS SIMULATION

Printing process can be accurately simulated using physics-based and data-driven modeling. Potential points of failure can be identified and print settings such as speed optimized without trial and error testing.

4

QUALITY CONTROL (QC)

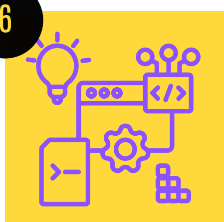
Consistent monitoring of the printing process and automated checking of printed parts against designs ensure they meet specific criteria, making it easier to predict part performance and creating a framework for reliable quality control procedures.

5

MAINTENANCE

Consistent monitoring of machine behavior can help identify patterns preceding failure or decreased performance allowing for timely preventive maintenance.

6



INTEGRATION

Real-time data from printed parts and the printer can improve integration with other systems such as automatic part removal, cleaning, material swapping, and in-situ post-processing systems.

For users, the above boils down to higher part quality, a faster, consistent, and reliable manufacturing process, predictable performance from printed parts, easier integration with other systems, longer machine life, and fewer manual processes.

Cost Management

Developing and implementing commercial digital twins is not cheap. Machines could become very expensive, limiting the impact of DTs on adoption.

To manage these costs, machine makers must make strategic decisions on which features to develop first. This will require working closely with customers to identify key challenges that, if addressed, will greatly increase the potential for adoption. Machines and their twins should also be designed for easy addition of features in the future.

If properly implemented, the revenue from greater adoption alone could make up for the initial cost of DT development.

Low User Complexity

Part of this proper implementation is for machine makers to elegantly shoulder the burden of complexity.

The intricacies of optimal parameter selection, in-process adjustments, data analysis for quality control, design optimization, etc. should not be left to users.

There should be limited user interaction or intervention required to get good manufacturing outcomes.

Whether their goal is producing quality parts with predictable performance or to have manufacturing equipment that easily integrates with other processes, current challenges show that many potential users favor simplified solutions regardless of what the technology can achieve in the hands of an expert.

The option to interact with the DT to implement expert customizations can still be made available to power users.

It's also by taking on this burden of complexity, that machine makers can exploit the long-term revenue potential of digital twins.

Improved Revenue Potential

The sale of machines is the most reliable source of revenue for many manufacturers today. This is not ideal given the level of competition.

However, digital twinning can turn a printer into a superior product with a better lifetime value. If this value is high enough, price will no longer be a barrier, just the cost of doing business.

This creates an opportunity to raise prices to match the expected value.

Digital Twins As A Service

Having a reliable long-term revenue source may be of more interest to machine makers and the running demands of digital twins favor this.

High-fidelity simulations and complex machine learning tasks require high-performance processors and other hardware many users don't have.

Data must also be gathered centrally to perform the analysis used to improve the twin and the 3D printing process. This translates to a need for data management resources.

These running demands can be turned into services that the ideally placed machine makers are paid to provide.

This isn’t the only way to implement digital twins. A company with enough resources and printer utilization could set up its digital twin locally and get enough value from it.

However, regular customers who just want a manufacturing system minus the complex infrastructure needed to get good results may prefer to pay a regular fee to avoid the inconveniences of setting up locally and hiring experts to run and maintain the system.

Using the digital-twin-as-a-service model, thousands of users can share costs, making printing less expensive for all and a consistent source of revenue for machine makers.

Intrinsic Competitive Advantage

The introduction of digital twins has the potential to significantly improve the adoption of 3D printing technology. However, it can also change the industry's competitive landscape due to:

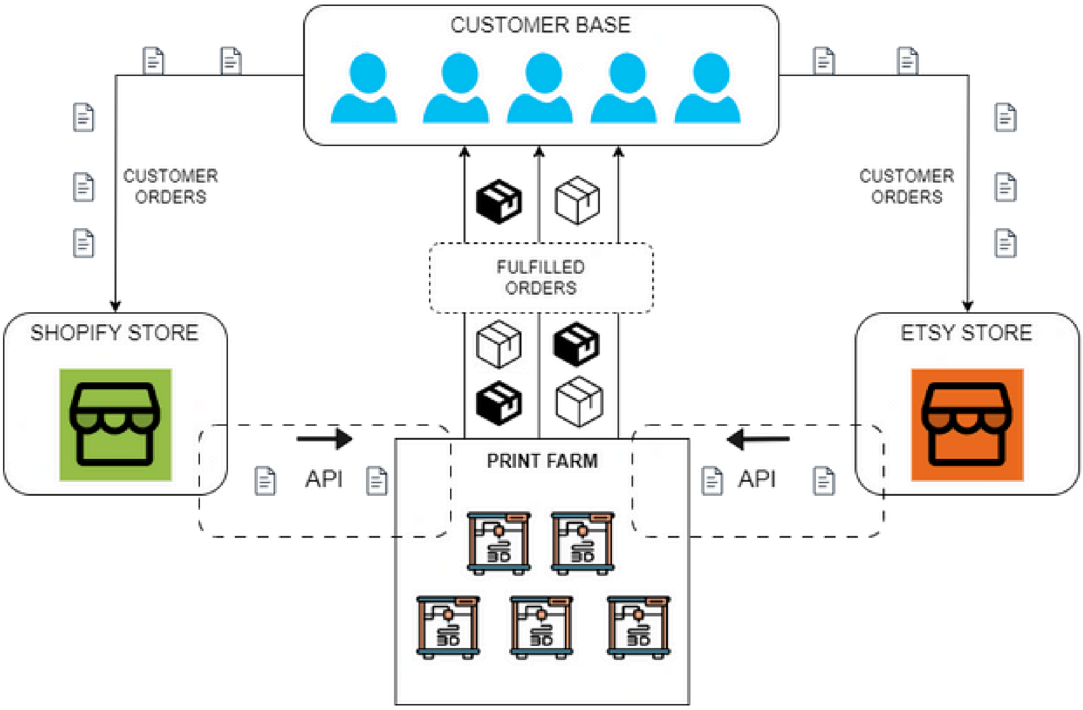
- **High development costs:** Many companies lack the resources to finance a project as costly as developing and implementing a digital twin.
- **Skills gap:** Digital twinning is relatively new but is getting attention in many industries. There aren't enough skilled personnel to help each company research and develop a digital twin.
- **First-mover advantage:** The nature of high-functioning digital twins can tie users to a company for the lifetime of a product. Companies that create a popular product early will have this advantage plus access to more data to improve their machines and digital twins.
- **Patents:** Digital twinning is an emerging field with opportunities to patent novel solutions and restrict who can implement them.

These factors will limit the number of companies capable of producing the next generation of 3D printers. This may help prevent an oversaturated market similar to what we have today. On the other hand, without regulatory intervention, some companies could end up with monopoly power.

Hypothetical Case Study: 3D Printing In a Fulfillment Role

Background

The concept of 3D printing as a fulfillment service is not new. It's currently championed by several companies operating print farms.[17] It allows other businesses to fulfill orders sent to their Etsy and Shopify stores through the fulfillment companies' print farms. The model works something like this:



Customers send orders to a Shopify or Etsy store. The stores are linked to a 3D printing service provider by an API which allows specific orders to be routed to the print farm. The parts are produced and packaged at the print farm and delivered directly to customers.

In this setup, business owners are product designers. They are not required to maintain inventory since items are manufactured on demand. Manufacturing is also done at a print farm (fulfillment center) near the customer, reducing shipping costs and order fulfillment cycle time.

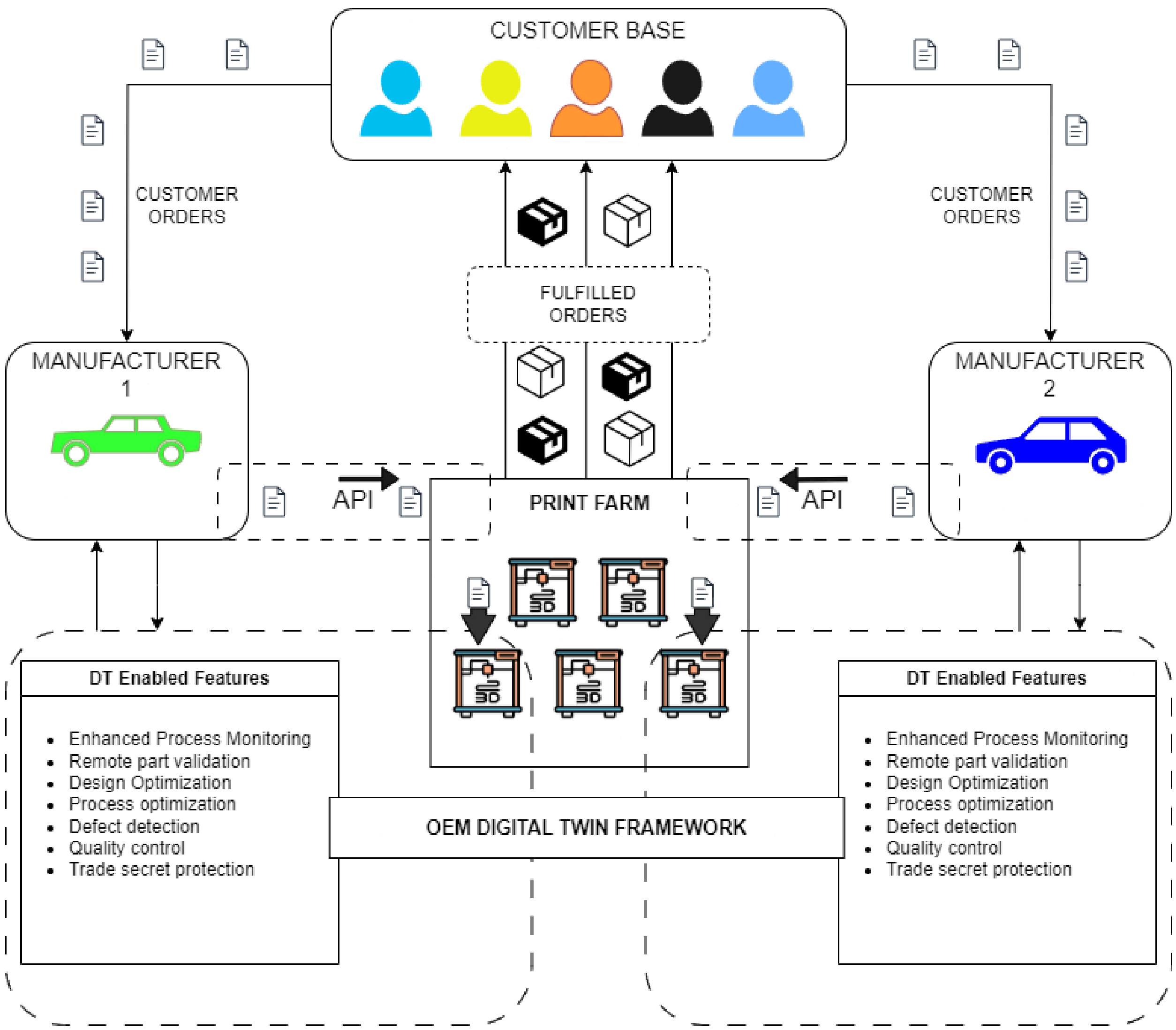
The printing company provides a service for which they can charge a fee. Business owners benefit from fewer storage expenses, faster order processing, and 3rd party manufacturing.

End users also enjoy benefits such as faster deliveries, lower shipping costs, no import fees*, etc.

A key challenge in this model is the brand owner has limited oversight over the manufacturing process and QC of the final product. This is fine for simple toys and decorative items but not for critical industrial machine parts, car engine components, etc. For such items, brand owners, customers, and regulators expect more assurances.

Digital Twin-Centered Fulfillment Model

A digital twin-centered fulfillment model can offer brands the oversight they need to reassure customers and regulators. This would work as follows:



*Depending on current and future regulations

In this scenario, the fulfillment system is used by customers to request automotive spares for different vehicles. From their end, this system is no different from the first. However, carmakers (brand owners) must ensure each part meets specific design and performance criteria.

When the customer makes an order, it's sent to a print farm near them. When it's time to print, the farm operator gives the carmaker remote access to the machine handling their order via the digital twin. This allows the carmaker to monitor process variables, make adjustments, collect data, and perform remote tests for quality control purposes.

The print farm company can also set up a tiered system so only customers who require certain DT features have to pay for them. For example:

- **Level 1 (No Access):** Brand owners enjoy higher print quality and process reliability due to the digital twin but without direct access. Ideal for clients who only want a simple manufacturing experience and consistent results.

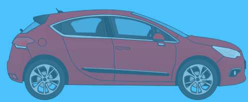
- **Level 2 (Monitoring and QC):** All level 1 benefits plus real-time monitoring of the printing process and conditions and data collection for quality control. Part validation e.g. comparison of design and actual dimensions can be another feature.

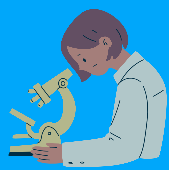
- **Level 3 (Process Control):** Levels 1 and 2 benefits plus direct process control for result optimization. Brand owners can utilize trade secrets and other knowledge from internal research e.g. unique material formulations. Automation is key to ensuring clients have optimal remote control.

Even at level 1, the digital twin improves the base quality of parts and process reliability. At higher levels, manufacturers who must validate the quality of manufactured parts or those designing parts for novel or critical applications can choose to closely monitor the process or control it directly.

Print Farm Access Levels

	Level 1	Level 2	Level 3
Features	Digital twin-enabled higher print quality and manufacturing consistency.	Level 1 benefits plus real-time monitoring, data collection for QC, and part validation	Level 1 and 2 benefits plus direct process control and optimization
Products	• Arts and Crafts • Toys • Non-critical parts	• Standard automotive and industrial spares	• Aircraft spare parts • High-performance automotive parts. • Medical Equipment • Critical prototypes
Probable Clients	• Hobbyists • Parents • Kindergartens	• Carmakers • Appliance makers • General manufacturers	• Aerospace companies • Universities • Private research labs • Startups

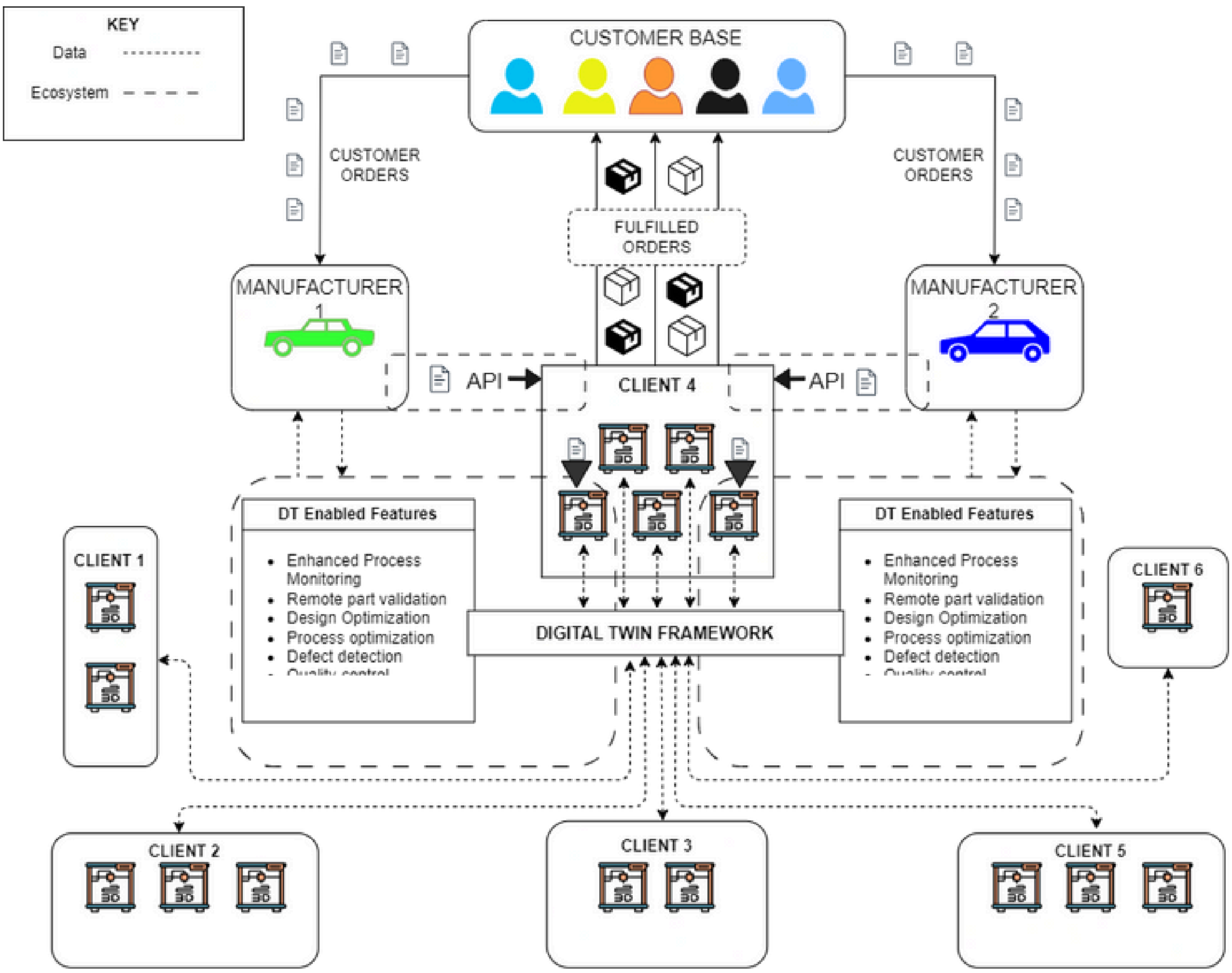




Carmakers enjoy benefits like faster order fulfillment, lower inventory costs, predictable quality and performance of 3D printed parts, and higher customer satisfaction. Their customers enjoy lower costs and faster order fulfillment.

In servicing overseas orders, this model can reduce shipping, storage, customs fees, and other non-manufacturing costs. These savings could outweigh any extra costs incurred by using additive manufacturing. The system's main concern would be to consistently produce reliable parts hence the digital twin.

In this example, the machine maker's business model is improved because the farm buys machines and pays a regular fee to have them in the DT ecosystem. The print farm's model is also improved because it can offer better services and attract more clients. It can also be run by a less skilled operator because there are fewer manual or technical demands placed on them to ensure good manufacturing outcomes. The DT is managed by the machine maker who will have other clients, e.g., schools, other print farms, hobbyists, manufacturers, research companies, etc. in an ecosystem like the one shown below.



Conclusions

The 3D printing revolution has not gone as planned. Although some are already reaping the rewards of the technology, adoption has been slow leaving machine makers fighting for revenue in a small market.

Digital twins have the potential to make additive manufacturing simpler for users while improving the quality of products and the reliability of the printing process. With proper implementation, this technology can make 3D printing more convincing for commercial clients. It can also serve as a new, long-term revenue channel for machine makers.

Developing a digital twin is a significant undertaking. 3D printing companies will need time, money, and expertise to achieve this vision. However, if the value proposition makes sense to users, the companies that can deliver this next generation of machines will have a big advantage in a larger market.

Recommendations

Machine Makers: Shift to a long-term vision for additive manufacturing by rethinking the entire 3D printing process from commercial users' perspectives. Invest in digital twins and automation to improve process reliability and scalability and minimize technical demands on end users.

Researchers: Develop the frameworks, hardware, and software needed to implement digital twins in additive manufacturing in a meaningful way.

Policy Makers: Anticipate the likelihood of digital twins and 3D printing disrupting manufacturing and trade in manufactured goods and implement policies to improve all stakeholder benefits.

Investors: Recognize the gains made in additive manufacturing and the inevitable success of the technology in the future. Invest in the research needed to reach this future.

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Contact

The Printed Future
www.theprintedfuture.com
charles@theprintedfuture.com

For White Papers and Other Content Writing Services:
charles@thecontentengineer.pro

The Content Engineer