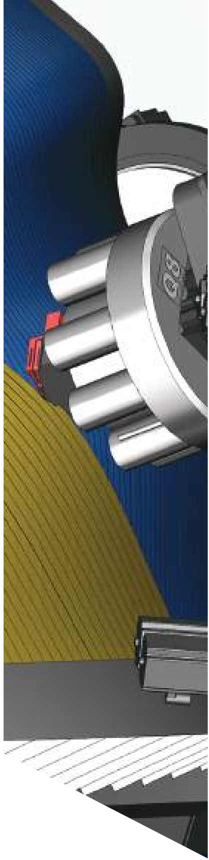

CHALLENGES AND BENEFITS OF IMPLEMENTING A DIGITAL TWIN IN COMPOSITES MANUFACTURING

White Paper

Vericut

vericut.com

Challenges and Benefits of Implementing a Digital Twin in Composites Manufacturing

White Paper

Vericut
9000 Research Dr.
Irvine, California 92618

1. INTRODUCTION

The phrase "digital twin" has proliferated marketing campaigns and manufacturing terminology for years. Too often, the term is misconstrued or devoid of any real meaning, instead reduced to buzzword status. Further, for many firms that understand the meaning at a conceptual level, their knowledge does not include implementation strategies or other means by which to realize a benefit from a digital twin. This paper explores the concept of a digital twin through a discussion of its benefits, explanation of challenges that often accompany such a model, and steps laid out toward implementation.

IBM (Mikell & Clark, 2018) defines a digital twin as:

> "… the virtual representation of a physical object or system across its lifecycle. It uses real-time data and other sources to enable learning, reasoning, and dynamically recalibrating for improved decision making."

While broad, several critical elements in this definition help guide our discussion. First, a digital twin is a "virtual representation." The phrase means that one must obtain a sufficient amount of data to represent reality accurately. Secondly, there is a "real-time" nature to the data that allows for dynamic decision making. The system relies on accurate, up-to-date information to work productively. Lastly, the digital twin embodies an entire product or system's lifecycle; it is not a snapshot of the product at a given time. Explicitly stating these three qualities helps to understand the source for the challenges and benefits discussed later in this paper.

Most manufacturing firms today operate in both the digital and real space, in terms of data and record keeping. Part design information is usually kept electronically (model-based), but different functional groups all too often use different models with little internal communication and collaboration.

Figure 1 shows the traditional flow of data through functional groups. Physical and digital barriers prevent seamless exchange of data and, in some cases, contribute to loss of data through inefficient communication. The design engineers work with one set of models while the manufacturing engineers work with a different set. Typically by the time a manufacturing engineer sees a model, the design is already set in stone. Manufacturing thus struggles to influence the design and to push needed revisions upstream to design engineers. If a manufacturing engineer succeeds in convincing the designer that the product needs altering, companies often fail to catalog useful information related to the design iteration.

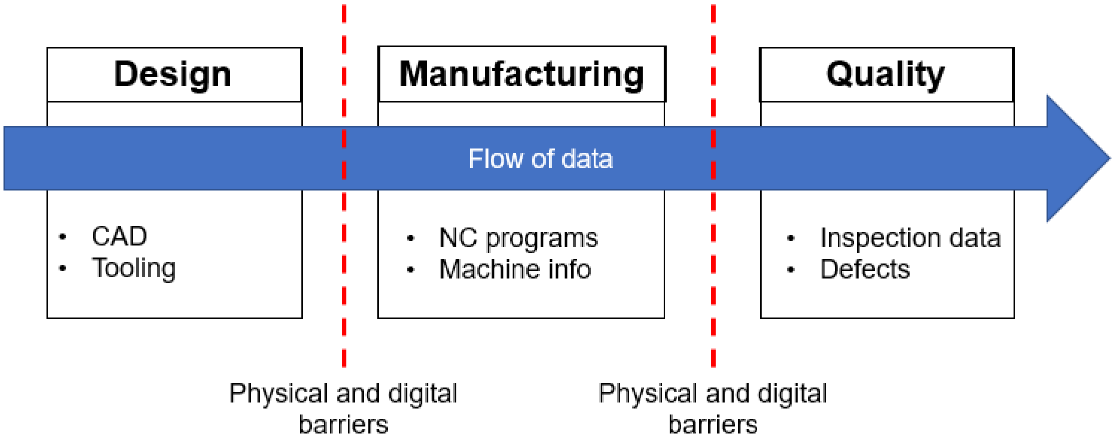

Figure 1 Traditional flow of manufacturing data

Having data that is all digital is not, on its own, wholly sufficient to produce a digital twin. Out-of-date data is just as useless as data that is unavailable from a decision-making standpoint. An apt example of this fact involves calculating the remaining shelf life for pre-impregnated carbon fiber material. Pre-impregnated material features resin that slowly cures at room temperature to the point of unusability. A typical material has up to thirty days at room temperature to be used before it becomes unusable. Because some rolls of material are removed from cold storage (a process that severely extends the shelf life from thirty days to approximately one year), thawed, and re-stored multiple times, the process of keeping up with remaining shelf life is not always straightforward. Nor are records always up-to-date. It is easy for shop-floor technicians to misgauge at what time they thawed material or to forget to note the relevant times entirely. These out-of-date material shelf life records jeopardize part quality by risking the use of expired material.

Non-destructive testing and final part inspection can catch quality issues before they reach the customer. Catching issues this far downstream prove costlier than eliminating the root cause of the problem. Still, unless consistent failings appear (those that could jeopardize the project as a whole), firms are tempted to treat systematic quality issues as individual problems. Even if firms invest time for an investigation, many processes lack insight into quality data across the part's entire lifecycle or actionable data to investigate the root cause.

2. THE DIGITAL TWIN IN INDUSTRY

It is straightforward to find industrial applications for creating and managing manufacturing digital twins. Companies such as Siemens, GE, IBM, and others market their digital twin solutions (Siemens, n.d.) (General Electric, n.d.) (IBM, n.d.). There are commonalities throughout each of these provider's explanations of their digital twins such as accurate representations of products and processes as they currently exist, the ability to forecast and predict future states such as needed maintenance, break-down of components, and areas of cost savings. These firms depict the necessary technology, information, and infrastructure from an already-installed, operational, and successful perspective. From this high-level perspective, the general concept is easy to grasp, as seen in Siemen's depiction in Figure 2 (Siemens, n.d.).

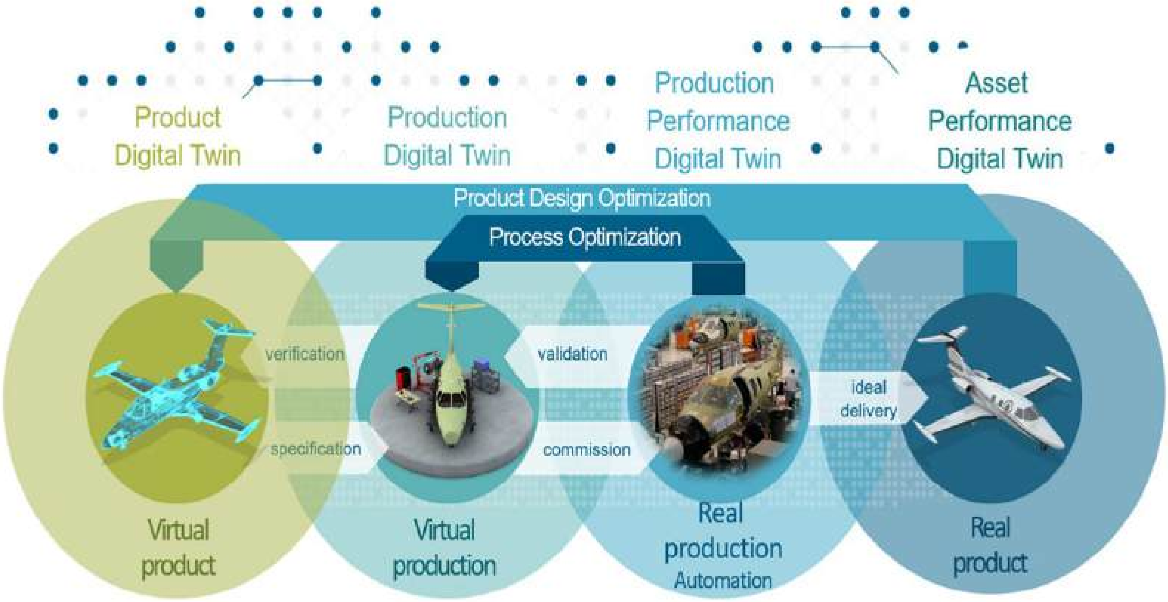

Figure 2 Siemens Digital Twin Model

A virtual product combines individual component designs into a nominal, complete, digital product. The virtual product allows for a simulation of production (i.e., "virtual production") by digitally representing production aspects such as work cell layout, machine positions, and design tolerances. The simulated production mimics real production through the use of accurate machine and tool models, along with knowledge of machine controllers and the use of programmed NC code. The virtual product and virtual production work hand in hand by exchanging design specifications and design verifications back and forth to improve the product design. This feedback loop enhances the virtual product and, in turn, improves the virtual production.

Next, the ideal virtual production connects with real production, through leveraged process automation, to facilitate a process optimization feedback loop. The real product, an output of real production, is finally analyzed to pass maintenance data back to the virtual product. This data helps predict needed maintenance, estimate costs, and further optimize product design.

A digital twin can address the three manufacturing issues brought up thus far: digitalization of data, timeliness of data, and scope (i.e., across a product's full lifecycle) of data. Service providers of digital twin platforms market the concept as a means of achieving "increased reliability and availability, reduced risk, lower maintenance costs, improved production, faster-time-to-value" (General Electric, n.d.). Obtaining specific, comprehensive benefits or quantified results is not as easy. For instance, IBM's Watson’s IoT (which includes digital twin functionality) marketing contains generic phrases including "intelligent innovation," "speed and agility," and "value creation" (Introduction to Digital Twin: Simple, but detailed). These are hardly concrete-enough to build a capital expense project budget around and reiterate the buzzword status mentioned previously.

Fortunately, General Electric (GE), one early adopter of digitals twins in the energy and aerospace industries and an extensive user and promoter of the technology, has provided greater detail in results and real-world use cases. In a whitepaper discussing GE's involvement in the digital twin realm, GE highlights the scenario of a combined-cycle power plant featuring a "natural gas-powered turbine as its primary electricity generator, and a steam turbine that uses the byproduct of gas-fired production (i.e., steam) as its secondary generator" (Stephanie, 2018).

Due to the extreme complexity of the system and the vast quantity of components which each vary in their recommended maintenance frequency, durability, environment, and other factors, traditional methods of managing the process are not sufficient. Because it is "impossible to pinpoint the proper time to take a turbine offline for maintenance using the traditional mean time between failures (MTBF) estimates," plant managers have historically relied on expensive scheduled maintenance. This disruptive process relies more on best-guesses of a few expert employees rather than any quantifiable means (Stephanie, 2018). By installing individual sensors on critical components and assemblies, GE can build a digital twin to monitor factors like system load, ambient temperature, and air quality in real-time. In this way, monitoring of the overall process's health is possible, and forecasts are feasible using advanced statistical tools to schedule maintenance predictively and eliminate unnecessary, disruptive downtime.

Real benefits exist for companies that implement a digital twin. For example, and shown in Figure 2, assuming physical and virtual costs of implementation are the same today and forecasting them over time, virtual costs "diverge with physical costs increasing at the rate of inflation and virtual cost decreasing on an exponential basis," (Grieves & Vickers, 2017).

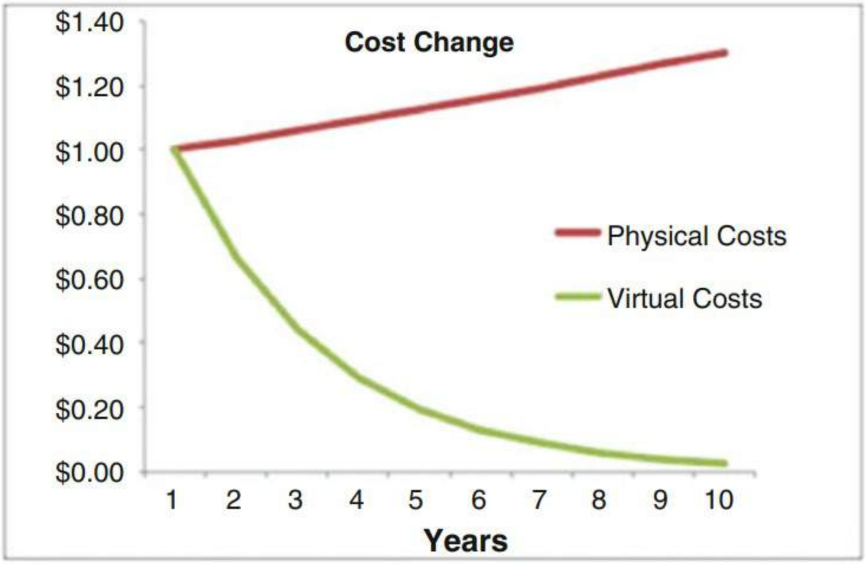

Figure 3 Real versus virtual costs (Grieves & Vickers, 2017)

Furthermore, using digital twin patterns, GE has realized these specific benefits: "93-99.49" increased reliability in less than 2 years, 40% reduced reactive maintenance in less than 1 year, 75% reduced time to achieve outcomes, $11M avoidance in lost production by detecting and preventing failures" (General Electric, n.d.).

The concept and use of digital twin methodologies have proliferated many industries. A 2018 article on digital twin use among enterprises predicts, "In 10 years, digital replicas of industrial equipment in industries ranging from food and beverage to manufacturing and health care will be widespread," (Castellanos, 2018). The digital twin market as a whole is growing significantly, "worth US$3.8 billion in 2019—is projected to reach US$35.8 billion in value by 2025," (Mussomeli, Parrott, Umbenhauer, & Warshaw, 2020).

Boeing's adaptation of the concept and reaping of the ensuing benefits highlights applications within the aerospace industry. A 2018-article on the subject highlights some details, which states, "Boeing has been able to achieve up to a 40% improvement in first-time quality of the parts and systems it uses to manufacture commercial and military airplanes by using the digital twin asset development model." The same article quotes an investor briefing from September 12th, 2018, made by then-Boeing-CEO Dennis Muilenburg, "The use of the digital twin is changing how Boeing designs its airplanes," (Bellamy III, 2018). It is clear that the concept of a digital twin has become vital and will become essential for all suppliers of these OEM's.

3. CHALLENGES TO THE DIGITAL TWIN

Many firms have not yet adopted a digital twin model for their production environment despite its apparent benefits. This fact is partly because digital twins are still "midway between discovery and adoption," according to a Gartner latest Emerging Tech report (Castellanos, 2018). Some firms simply have not been exposed to the idea yet. Other firms are aware of the idea but don't have the infrastructure in place to implement the model.

Automatic gathering of processes and assets information is a component of the required infrastructure, which relies heavily on the "Internet of Things" (IoT). "A system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction," defines the IoT (IoT Definitions, n.d.). Therefore, the ability to update process data in real-time without human interaction is one required milestone toward creating a digital twin. For companies that have not yet done this, the idea of implementing a digital twin seems nebulous at best.

Because total life-cycle visibility is a critical feature of the digital twin concept, individual asset data must represent its total life-cycle too. Asset data must include information about its production, not just its use. For example, the asset record for carbon fiber material must include not only the environment data during manufacturing processes but also the environment data during its production.

Obtaining the asset data from its supplier, historically considered to be out of the scope of manufacturing usefulness, requires close collaboration with multiple tiers of the supply chain. General Electric, with their competence in digital twin use, states that "…industrial companies have amassed decades of physical science about their products, equipment assets, manufacturing processes, and operator control systems," (Stephanie, 2018). Establishing the level of communication in a supply chain to retrieve this information is not easy, nor is it straightforward to maintain. However, it is vital to model real-world conditions to predict future outcomes accurately.

Another consideration is the cost of implementation. According to Gartner Group's Marc Halpern, "There's a naïveté about the possibility of bringing together digital twin concepts in terms of cost and time. It will take longer and will be more resource-consuming than anyone can imagine getting these solutions in place" (Oleksiuk, 2019). Some estimates place the minimum threshold for a digital twin implementation at approximately US$50,000 (What is the value of a Digital Twin?, 2018). More-complex processes will require a significant investment to model with a non-trivial implementation period.

In addition to this direct implementation cost, there are costs associated with disruption and change. Because the model of a digital twin is virtually all-encompassing, its implementation affects the processes and thinking of multiple functional groups. A Deloitte (provider of digital twin services) white paper highlights, "Adopting digital twins, therefore, calls for considerable investment, collaboration, and sustained commitment on the part of leaders from all of the business functions affected." Specifics of leader obligations include "Operations leaders will need to reimagine workflows…" and "Technology leaders will need to establish the required technology infrastructure – robust IoT deployments, simulation platforms, and integrated data sources – across departments and across IoT contextual systems," (Mussomeli, Meeker, Shepley, & Schatsky, 2018).

These challenges do not diminish the returns described previously, but they do impose requirements of careful planning and consideration before implementing a digital twin. Delicate navigation around the challenges and diligent planning will result in a return on investment through leveraging the benefits of a digital twin.

4. STEPS TOWARD DIGITAL TWIN IMPLEMENTATION

The discussion thus far has been in ideal terms. Ideally, a digital twin should encompass all data from asset manufacturing conditions to ongoing lifecycle monitoring for performance and maintenance. However, a firm cannot expect to navigate the process from no real-time modeling to complete automation and a fully-fledged digital twin immediately. This process is tedious and incremental, but one that rewards adopters considerably. Composites manufacturing represents a specific set of challenges to overcome if a firm wants to realize the benefits of a digital twin. The discuss hereafter seeks to address the uniqueness of the composites manufacturing industry.

The first step to take towards implementation is to take stock of where you, your firm, your processes, and your leadership stands. How much data is collected right now? Are processes automated or manual? Does executive leadership understand the concept and importance of a digital representation of the real world? The answers to these questions guide your initial steps. The magnitude of change required to implement a digital twin requires an internal champion and change agent with significant influence and budget.

With leadership open to change, the next step is to ensure processes are at a level of automation that facilitates human-free data gathering. Automation of critical manual processes identified in the previous step is required to capture their information within the digital twin. Although automating composites manufacturing processes is, in its own right, complicated, there is a business case for it, and it can increase reliability and reduce costs (Anderton, 2017).

Middle River Aerostructure Systems (MRAS; Baltimore, MD, US) recently embarked on the process of automating their manufacturing processes for its nacelles and thrust reversers (Mason, 2019). Initially, MRAS "…was using mostly hand layup," and wanted to "…eliminate the variability that comes with hand layup and reduce labor costs at the same time." Due to budget restrictions, however, existing hand layup tooling needed to be used for any automated processes.

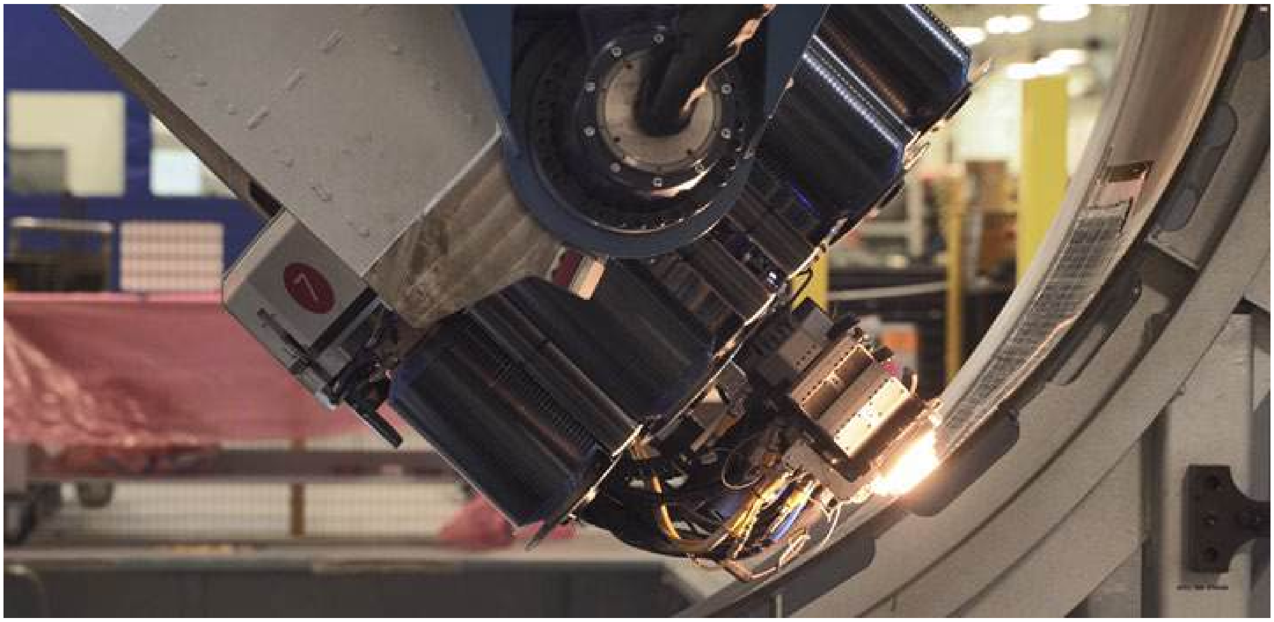

Figure 4 Complex curvature of MRAS part tooling (Mason, 2019)

Without the ability to contract new tooling, MRAS turned to digitizing their process through the help of machine-builder Electroimpact (Mukilteo, WA, US) and software-supplier Vericut (Irvine, CA, US). "The companies digitally modeled and simulated the manufacture of each of the candidate parts," which enabled a deep understanding of both costs and savings. Accurate simulation of the physical world was paramount to avoid potential collisions with "…the U-shaped female tooling," shown in Figure 4. MRAS was able to reduce labor costs, increase throughput, and are reported to be at or above the planned business case. Additionally, the automation of existing processes did not result in a reduced workforce; instead, MRAS hired additional personnel to handle the growth (Mason, 2019).

One benefit of process automation above and beyond the increased reliability and reduced costs is that it often also allows for automated data collection. Not only are processes automated, but they are also enhanced. Envision an automated fiber placement (AFP) machine that produces nacelles for MRAS. A scanning profilometer could be attached to the AFP end effector to allow for simultaneous material placement and inspection.

Boeing is working with Electroimpact and Aligned Vision (Chelmsford, MA, US) to use this automated inspection and data collection process on the 777X wing skin project. In conjunction with a separate laser, and by measuring the height of more than 1,000 positions along the laser during material placement, the profilometer can create a 3D surface profile. A combination of this profile, data from a separate inspection camera, part programs, and operator input creates "a ply-by-ply 3D model of the part as production progresses," (Black, 2018). Tow end placement, overlaps, gaps, and other manufacturing defects are analyzed using in-house software from Electroimpact and the raw data generated by this automated inspection process.

The accuracy of the inspection and growing confidence from Boeing have supported this use of “big data.” Todd Rudberg, a senior engineer at Electroimpact, states:

> “This is a smart use of big data. We’re measuring every tow relative to the ply boundaries and creating a digital record of the results. These data improve part quality, and allow the client to make more informed decisions. Because we can prove part quality digitally, it ultimately will allow use of less restrictive design allowables,” (Black, 2018).

By automating processes with data collection and inspection in mind, a firm can make progress toward digital twin optimization, as Boeing did in this example. Critical manual processes that cannot be fully automated require other solutions that allow for real-time tracking. We must revisit the previous example of calculating the remaining shelf life for pre-impregnated carbon fiber material for an example of this. Instead of relying on the floor worker to manually log times that material changes location (within or out of the cold storage unit), radio-frequency identification (RFID) tags can automatically log this information.

RFID uses electromagnetic fields to identify and track items that have a tag (radio transponder). The tags can communicate inventory numbers or other digital data to RFID reading devices, which ping nearby tags. In this way, reading devices can log location changes for tags attached to material spools and automatically reduce or stop reducing shelf life as appropriate. This “ability to transfer data over a network without requiring human-to-human or human-to-computer interaction” is a component of a firm’s IoT system, and as previously highlighted, is a stepping stone toward digital twin implementation.

Digitized data must be consolidated and combined to fit our definition of a digital twin completely. One example of this is to combine process information from various processes. For example, a given AFP-composites part could have relevant data from CAD, composite design (e.g., Fibersim or CATIA’s Composites Workbench), programming, probing, inspection, trimming, pick-and-place, painting, and other sources. Centralizing all of this data is possible with software solutions from Vericut. The Vericut ecosystem combines composite part design with real-world work cell layouts, machine-specific parameters, and limitations, and empowers decision-makers with process data consolidation. Because the Vericut environment creates and simulates the process-specific machine code, designs can be validated for producibility at each step along the manufacturing process, rather than just structurally validated, which is usually the design engineer’s focus.

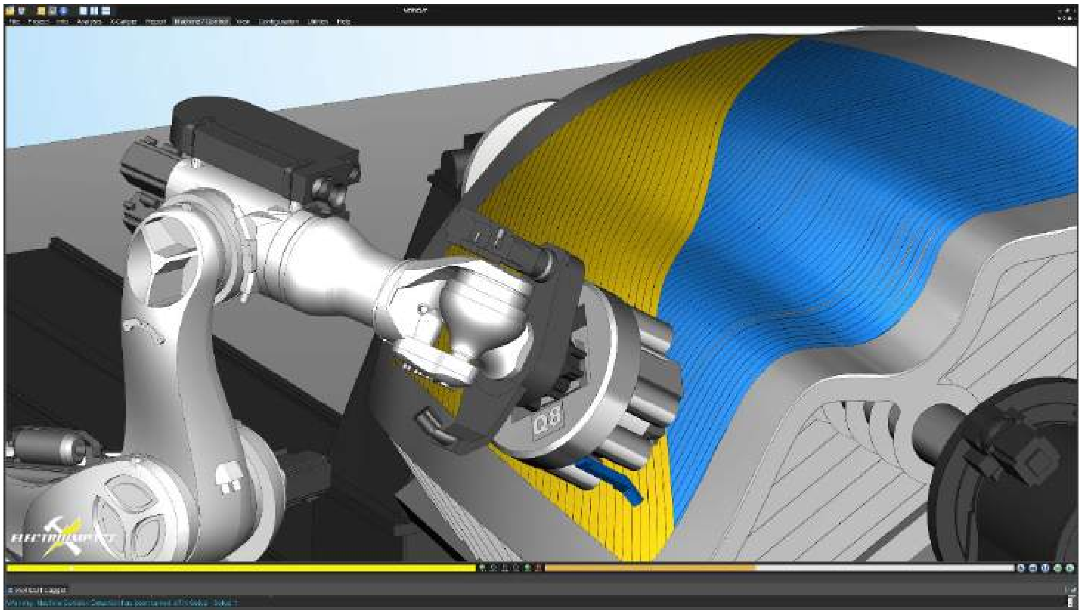

Figure 4 Complex curvature of MRAS part tooling (Mason, 2019)

Consolidated process information like this should is combined with non-automated process data (e.g., RFID tag data) across an entire lifecycle to produce the digital replicate that we require. Although the previous example of Boeing’s automated layup and inspection processes may seem sufficient, long-term analysis of the whole lifecycle is impossible without combining process and RFID-gathered data. It is this integration with the intent to monitor and forecast that represents, finally, digital twin implementation. Many firms have begun implementing IoT systems but have not yet made the transition to data consolidation that signifies a digital twin. “Thirteen percent of organizations implementing Internet of Things (IoT) projects already use digital twins, while 62 percent are either in the process of establishing digital twin use or plan to do so, according to a recent IoT implementation survey by Gartner, Inc,” (Castellanos, 2018). Another Gartner report found “that digital twins are slowly entering mainstream use,” and that “by 2022, over two-thirds of companies that have implemented IoT will have deployed at least one digital twin in production,” (Costello & Omale, Gartner Survey Reveals Digital Twins Are Entering Mainstream Use, 2019). It is clear that although many firms are in the process of completing the steps outlined above, few have accomplished the necessary groundwork to implement a full digital twin.

5. CONCLUSION

Managers at various firms and different organizational levels often misunderstand the definition and actuality of a digital twin. This white paper has shed light on the true definition of the term, along with considerations of its implementation. Visualizing the path toward implementation and the detailed planning required is not easy, despite real benefits existing for companies that implement digital twins.

Conceptually, the path would involve steps to automate critical processes when at all possible. The increased reliability associated with automation would help build a foundation for automated data acquisition necessary to represent the processes digitally. For critical processes that must still involve a manual component, implementing passive data collection through systems such as RFID tags would allow for the required data collection without human intervention.

Finally, the digitized data from all of these sources would need to be consolidated in an exact way to allow real-time management and future analysis. Success in implementation requires a deep understanding of both the difficulties and benefits of implementing a digital twin, even though this level of understanding is complicated, time-consuming and challenging to achieve.

6. ABOUT VERICUT

Headquartered in Irvine, California, Vericut specializes in numerical control (NC/CNC) simulation, verification, optimization, and analysis software technology for manufacturing. Vericut was founded in 1988. Since that time, our main software product, Vericut®, has become the industry standard. With offices worldwide, Vericut software is used by companies of all sizes, universities/trade schools, and government agencies.

For more information about Vericut, our products, or how we can support your unique process, contact us at:

Vericut

www.vericut.com

info@cgtech.com

949-753-1050

7. REFERENCES

Anderton, C. (2017). *A ROADMAP TO AUTOMATED COMPOSITES.* CompositesWorld.com.

Bellamy III, W. (2018, September 14). *Boeing CEO talks 'Digital Twin' Era of Aviation*. Retrieved from aviationtoday.com: https://www.aviationtoday.com/2018/09/14/boeing-ceo-talks-digital-twin-era-aviation/

Black, S. (2018, January 29). *Improving composites processing with automated inspection*. Retrieved April 29, 2020, from https://www.compositesworld.com/articles/improving-composites-processing-with-automated-inspection

Castellanos, S. (2018, September 12). *Digital Twins Concept Gains Traction Among Enterprises*. Retrieved from wsj.com: https://blogs.wsj.com/cio/2018/09/12/digital-twins-concept-gains-traction-among-enterprises/

Costello, K., & Omale, G. (2019, February 20). *Gartner Survey Reveals Digital Twins Are Entering Mainstream Use*. Retrieved from Gartner.com: https://www.gartner.com/en/newsroom/press-releases/2019-02-20-gartner-survey-reveals-digital-twins-are-entering-mai

Costello, K., & Omale, G. (2019, February 20). *Gartner Survey Reveals Digital Twins Are Entering Mainstream Use*. (Gartner Inc.) Retrieved April 30, 2020, from https://www.gartner.com/en/newsroom/press-releases/2019-02-20-gartner-survey-reveals-digital-twins-are-entering-mai

General Electric. (n.d.). *Digital Twin*. Retrieved from ge.com: https://www.ge.com/digital/applications/digital-twin

Grieves, M., & Vickers, J. (2017, August). Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. In F.-J. Kahlen, S. Flumerfelt, & A. C. Alves, *Transdisciplinary perspectives on complex systems: New findings and approaches* (pp. 85-113). doi:10.1007/978-3-319-38756-7_4

IBM. (n.d.). *Digital Twin*. Retrieved from ibm.com: https://www.ibm.com/internet-of-things/trending/digital-twin

Introduction to Digital Twin: Simple, but detailed (n.d.). [Motion Picture]. Retrieved from https://youtu.be/RaOejcczPas

IoT Definitions. (n.d.). Retrieved from techtarget.com: https://internetofthingsagenda.techtarget.com/definitions

Mason, H. (2019, September 6). *A digital approach to automation*. Retrieved from compositesworld.com: https://www.compositesworld.com/blog/post/a-digital-approach-to-automation

Mikell, M., & Clark, J. (2018, January 4). *Cheat sheet: What is Digital Twin?* Retrieved from ibm.com: https://www.ibm.com/blogs/internet-of-things/iot-cheat-sheet-digital-twin/

Mussomeli, A., Meeker, B., Shepley, S., & Schatsky, D. (2018). *Signals for Strategists: Expecting digital twins*. Retrieved from deloitte.com: https://www2.deloitte.com/content/dam/insights/us/articles/3773_Expecting-digital-twins/DI_Expecting-digital-twins.pdf

Mussomeli, A., Parrott, A., Umbenhauer, B., & Warshaw, L. (2020, January 15). *Digital twins: Bridging the physical and digital*. Retrieved from deloitte.com: https://www2.deloitte.com/us/en/insights/focus/tech-trends/2020/digital-twin-applications-bridging-the-physical-and-digital.html

Oleksiuk, A. (2019, April 22). *Digital Twin Technology: A Guide for 2019*. Retrieved from intellias.com: https://www.intellias.com/digital-twin-technology-a-guide-for-2019/

Siemens. (n.d.). *Webinar: Industry 4.0 for Composite Aerostructure Development*. Retrieved from siemens.com: https://www.plm.automation.siemens.com/global/en/webinar/composite-aerostructure-development/68931

Stephanie, R. (2018). *The Digital Twin.* Retrieved from ge.com: https://www.ge.com/digital/sites/default/files/download_assets/The-Digital-Twin_Compressing-Time-to-Value-for-Digital-Industrial-Companies.pdf

What is the value of a Digital Twin? (2018, 10 12). Retrieved from hightechsoftwarecluster.nl: https://hightechsoftwarecluster.nl/paper/what-is-a-digital-twin-and-what-value-does-it-deliver/