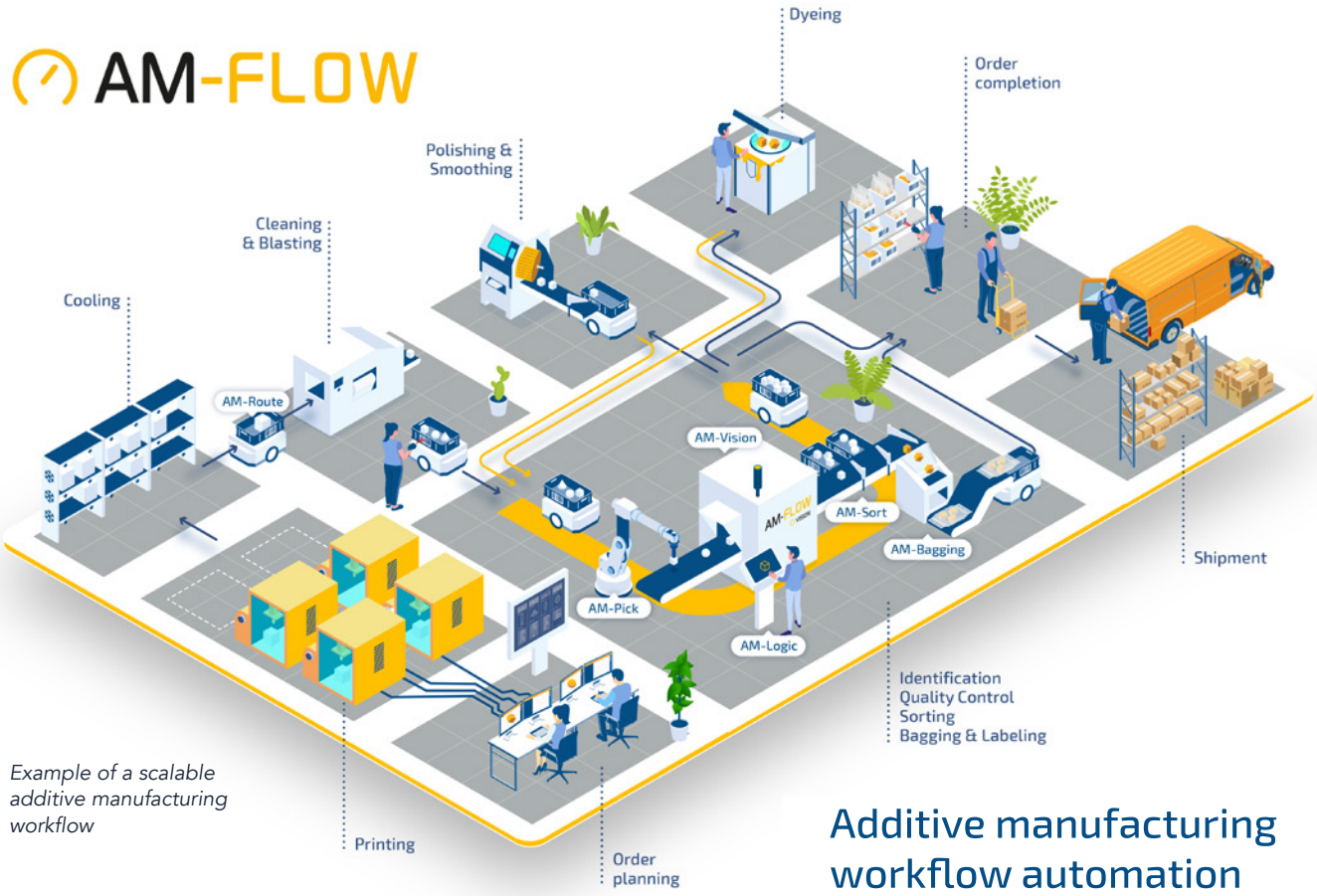
VoxelMatters × AM-FLOW

Moving AM towards full-scale automated AM-Factories

From single part to infinity and back: learn how AM-Flow helps additive manufacturing companies on their voyage of automation, from the first steps to massively scaled digital production.

The world has changed dramatically over the past few years. Global natural and socio- political events have altered a delicate balance that was driving business, supply chains and global commercial networks. Because of recent global events, many if not all manufacturing companies took a serious look at their way of doing things, transforming challenges into opportunities. McKinsey and Company have established that certain areas of industrial automation, including addi-tive manufacturing, can drive value potential in sever-al areas. For instance, inventory costs can be reduced by up to 20% and productivity increased up to 30%. These can be achieved through downtime reduction up to 50% and throughput increase up to 30%. In addition, forecasting accuracy can be improved by up to 85% and cost of quality reduced by up to 20%.

Additive manufacturing has matured significantly in terms of process and speed however it remains costly and limited in terms of overall output. The efficient scalability of AM is limited by factors such as repeatability, efficient quality assessment, part cost as well manual labor costs required in various phases of the workflow. Whereas parts produced by formative processes can be standardized, AM parts can be infinitely customized. AM-Flow, the only company addressing these challenges specifically for additive manufacturing, was built on these premises.



Example of a scalable additive manufacturing workflow

Additive manufacturing workflow automation

At the source of the flow

During his previous experience as VP of Manufacturing at a pioneering 3D printing service provider, AM-Flow CEO Stefan Rink observed that AM manufacturing was limited by the lack of automation and digitalization in post processing workflows. He learned that if he added one more printer upfront, he had to recruit two or three more people in the backend. During these years he saw that by adding new machines gross margin increased only up to a certain point and then it gradually declined. From his analysis he found out that the only element that made the gross margin drop was the labour cost of handling the different parts that were being produced. They were basically a victim of their own success: selling more, producing more led to lower gross margins."

Rink understood that to address these challenges, the company would need to automate production. The fully digital production of the largest EOS machines was in sharp contrast with the many manual operations required to remove the powder, clean, identify and sort the parts. Rink turned to giants like Siemens and Philips in search of answers, but there was no ready solution. That is until an accidental encounter with a startup in Amsterdam called Borges. Borges developed a software algorithm for the "democratization of design" which would address the issue Rink was facing from the opposite perspective. The Borges software enabled people to create their designs by parametric shifting. They proposed this software as a way for users to find just the right product, making new designs based on existing ones.

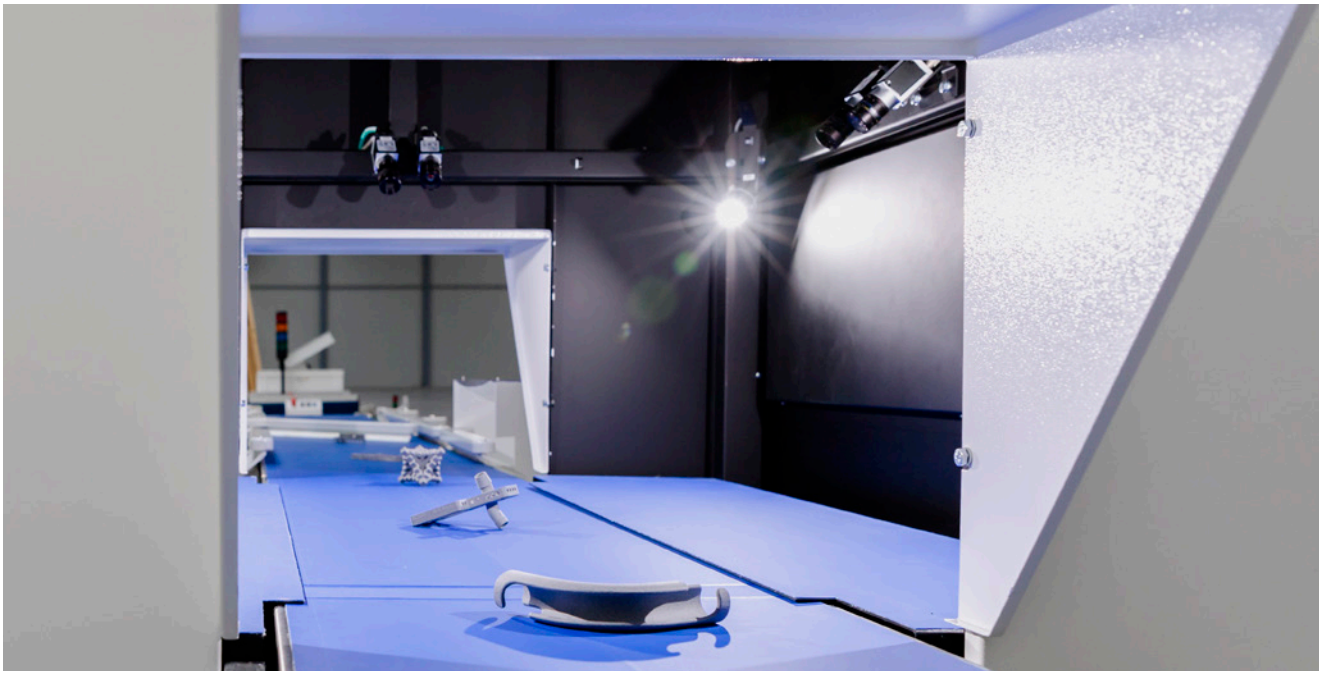
Rink realized he could use the Borges software to identify parts which would then be the basis for creating a fully end-to-end digital environment. Without identification, automation wouldn't be possible. After the company was founded in early 2018, AM-Flow built the first prototype of the AM-VISION in two months to present it at Formnext 2018.

Many manual post-processing steps will be automated

Understanding the business potential

Recognition alone is not a business, but it can be used to subsequently sort parts and initiate the first steps to workflow automation in the AM industry. There are loads of solutions for sorting, but not for additive manufacturing. A generalist 3D printing service provider could be printing something as hefty as an iPhone at one moment and something as thin as a business card the next. Existing sorting solutions are standardized and cannot cope with the variety of parts that need to be processed by an AM service provider or at the internal AM facility at an OEM.

So, AM-Flow introduced an MVP for sorting in 2019 at Formnext and subsequently launched the industrialized, ready-for-market version half a year later. AM-Flow has continued to keep this rhythm, with a new solution introduced on the market almost every year since. The company has become increasingly relevant as the global AM market grows. According to VoxelMatters' latest polymer AM report, the core polymer AM market alone (hardware, materials, and



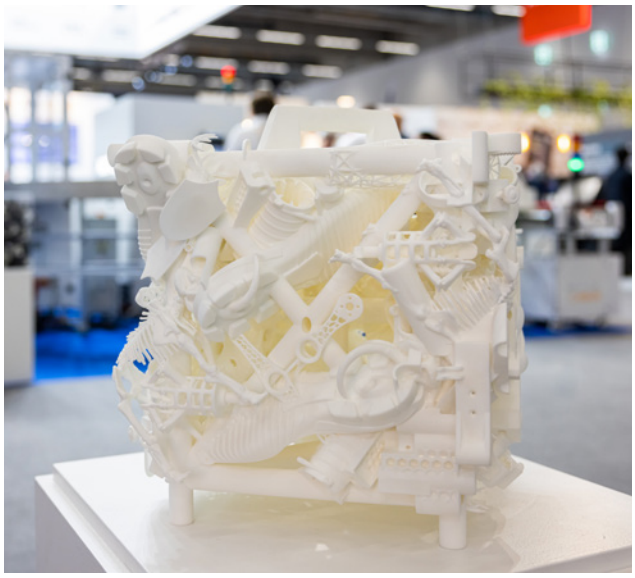
Identifying parts in a split of a second with vision technology based on their geometry only

services) generated $3.7 billion in 2020 and is going to grow to $11 billion by 2025 and to $34 billion by the end of the forecast period, in 2030. In 2020 AM services represented 38% of these revenues with $1.4 billion and are expected to grow to $9.6 billion in 2030. This exponential growth trend will see this particular segment of the AM market double in size roughly every four years, growing at 20.7% CAGR.

As of today, Power Bed Fusion (PBF) remains the most efficient production technology for AM service providers. This family of technologies was used by 3D printing service providers in 2021 to produce over 27 million parts globally, representing 64.8% of all units produced by AM service providers around the world. In this scenario AM-Flow has identified customers that have both high mix production output and high growth. These ideal customers include relatively small entities with just several printers that made the decision to grow their business fully automated, without the challenges of having to recruit people to deal with the consequences of producing a higher number of 3D printed parts. These companies target 40% year on year growth based on scalable automation.

"Those are our ideal types of customers," says AM-Flow CCO Carlos Zwikker, explaining that the company is in the meantime also initiating relationships with customers that have as many as fifty printers already installed. These companies generally have a legacy as they have grown incrementally over many years. "They bought five printers, put them in one area, then the next five, in a different area. And the next five are around the

Economics of 3D Printing I Optimal nesting of parts



corner. Their current way of working needs to be rationalized or at least reviewed and organized for a more streamlined, automated digital workflow. They understand that the way they are working today is not efficient, and that they need to increase that efficiency for additive manufacturing to be more competitive."

Workflow optimization is a major issue being addressed by AM-Flow, however it is not the only issue impacting growth of the AM industry. A big part of making AM more attractive depends on improving repeatability, quality, and predictability across different technologies. "Predictability is always going to be an issue," Zwikker admits, "but if we can resolve these quality aspects and provide repeatability, then it will be even more important to automate workflows, otherwise the price point of parts will never be attractive for scalable production. Our main

Bin handover from sorting station to Automated Guided Vehicle (AGV)

focus is to increase production efficiencies through automation. In addition, identification and sorting is a boring job. You don't want people doing that on a daily basis. We're eliminating mindless jobs that shouldn't be in the system in the first place because AM is a digital concept."

Revenues generated by AM service providers (by technology) Forecast through 2030

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total	1,348	1,605	2,116	2,867	3,407	4,026	4,772	5,763	6,739	8,025	9,651
	584	720	1,101	1,689	2,063	2,423	2,857	3,462	3,977	4,656	5,562
	461	539	624	741	854	1,006	1,206	1,438	1,695	1,954	2,269
	160	185	213	247	285	376	470	592	757	1,060	1,410
	144	161	178	191	205	221	240	272	310	355	409

Provided by VoxelMatters

In 2020 AM services generated $1.4 billion in part revenues and are expected to grow to $9.6 billion in 2030. PBF technologies represent will continue to represent more than half of all revenues through the end of the forecast period.

Basic set-up for identifying and sorting 3D printed parts with the AM-VISION and AM-SORT

From many to one

AM-Flow's long-term vision starts with the AM-VISION, which is the system used to identify parts. Using one-piece flow parts fed into the AM-SORT after which the AM-VISION recognizes parts based on their geometry. Once the parts have been identified, they are placed in bins for the next batch process. Each part has its own individual route through the factory, past various post-processing steps to shipping at the end. After the initial identification, all parts are sorted according to their respective next step in production.

One of the current challenges is to develop a system that can pick non-standardized objects with near-infinite shapes, to move them from a batch into a singular flow. Then the process can be repeated, as many times as necessary, for increasingly more complex, accurate and automated digital workflows.

"We're still working on several modules because, now that we can identify and sort parts, we need to transport them. We have to RFID the bin, the carrier, everything – Zwikker explains – and we have to set up that system. Then we need to be able to automatically place a singular part on a conveyor belt. It's a switch between batch process and singular flow and we need to develop a solution that will (re-) singularize the parts. This only exists today for standardized products; it could be as many as 100 different parts but still standard. There's noi system out there now that can face the challenge of the infinity of geometry of AM."

There are a few different ways that additive manufacturing (AM) companies are addressing high mix/high volume, small series in additive manufacturing production. However, the most economical approach depends on the technology used, such as photopolymerization, material jetting, or extrusion technologies.

For all these methods, a key strategy is to nest as many parts as possible in a 3D volume, as in most PBF processes. "The most economic environment that you can create – Zwikker argues – is by nesting in the most optimized way possible within the entire build box. This can be considered as a type of "3D Tetris" which will increase the variation among the different parts present in each build. This in turn generates a high-volume x high-mix output which is the most economical way of AM production."

From zero to automation hero

AM-Flow has visited numerous AM production facilities, each with its own level of automation and way of working. AM-Flow has created a model consisting of 5 stages of automation adoption. This descriptive model is by no means scientifically validated but does help understand the extent to which you can automate AM production facilities. An interesting element to keep in consideration is that scaling from one level to the next higher level is not necessarily a matter of increasing the number of printers as much as enabling those printers to be more productive. The first stage "Entry Level Automation", concerns service providers with a relatively small machine park of up to 3 systems and volumes under 400 parts per day. In this phase, post-processing workflows are generally manual. The next level is defined as "Emerging Automation Practice", where a company grows to between 5 and 10 systems and produces up to 1000 parts per day. In this stage, part identification and part sorting are automated and most other processes are manual. As the company grows, it goes through two other phases, defined as "Coordinated Automation Practice and "Automation Leadership", that see the service move beyond 10 machines installed, using multiple technologies, and producing up to 2,000 parts per day (approaching the 1 million parts per year threshold). At these stages, many more phases of the workflow are automated, including part routing and transport, part bagging and labeling, and quality assessment. No company has yet achieved this level of automation in AM, however, it is now within reach through AM-Flow's current and upcoming capabilities, including the newly introduced AM-QUALITY. The final stage "Industry Automation Leadership" represents the complete automation of an AM production line, all the way to automated order packaging.

Thus, automating the additive manufacturing workflow is a step-by-step process. Where an AM service provider or internal AM facility in the early stages of automation might devote its resources to the automation of order intake, quoting and nesting, part identification and sorting, a fully developed AM enterprise can automate the complete workflow end-to-end, from pre-print to production, and all post print workflow steps, part identification and sorting, routing, transport, bagging and labelling, post-processing tracking & tracing, quality assessment, and order packaging.

But how does a business or production facility level up from its entry-level automation practices to a full-scale automated production line? At what stage in its growth does it introduce new tools like picking robots and intelligent de-powdering stations? And

AM-Flow's vision of a Smart AM Factory

how does it maintain productivity while constantly introducing new areas of automation?

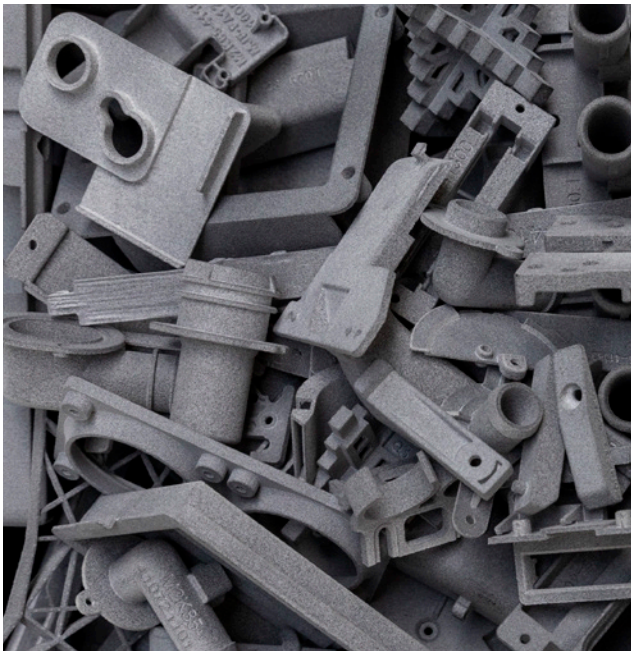
For AM service providers, automation can be introduced early on. Consider, for instance, an AM service provider operating between one and three SLS/MJF systems in addition to post-processing equipment and an order-processing system, like the example of the first stage of workflow automation at page 10. Though it does not yet have footing on the automation ladder, it has the foundation required for automation at later stages of its evolution: digital manufacturing technology, a basic order processing infrastructure, and a scalable business model. The essence at this stage is that those responsible for the future of the company start developing an automation vision and strategy. Instead of addressing short-term bottlenecks of production, it's now the right time to develop ideas and thoughts about what role automation should and could play in growing the production output. Why now? Because later, once the facility grows, you'll have no time to develop ideas or routes of action.

Customer satisfaction at the end of the workflow: automated bagging & labeling of 3D printed parts

A fledgling AM service provider does not introduce automation all at once. And also, internal AM facilities need to navigate their corporate IT system to find clear linkage with existing IT. However, once its productivity increases to 400–800 parts per day, with a staff of 20–40 people operating between five and 10 AM systems, one can identify bottlenecks in its workflow and suitable areas of automation that are attainable within its a still-moderate budget. In many cases, this will involve automation of part identification and sorting using tools like the AM-Flow's AM-VISION part identification solution and AM-SORT, a customizable conveyor system that will be capable of handling greater production volumes at later stages of the business's evolution. These systems are supported by AM-LOGIC, AM-Flow's middleware that feeds back all data of a part in the overall production process back to the customer's MES.

These highly efficient automation tools, thus, can facilitate further growth. And when an AM service provider or internal facility expands its print park to comprise at least 10 machines, it may end up producing more than 1,000 AM parts per day, qualified as high-volume X high-mix. At this point, it one must consider automation of other processes in order to keep up with production and processing the increasing throughput. So, what should be targeted after identification and sorting?

With such high volumes, manual bagging and labeling can be replaced by an automated solution like the AM-Flow's AM-BAGGING unit, capable of processing up to 25 bags per minute. Additionally, AM-PICK bin picking robots may be introduced to enable quick transitions between batch and



Typical High mix / High volume production batch

one-piece flows. Crucially, these more advanced automation solutions will integrate seamlessly with foundational solutions like such as the aforementioned AM-VISION, AM-SORT, and AM-LOGIC, meaning that businesses do not have to uproot their workflow each time they level up to their next stage of evolution. Automation is introduced gradually and painlessly.

An AM service provider or internal AM facility might grow further still, eventually producing over 2,000 parts per day. Although not yet operating a full-scale automated production line, it can introduce further elements of automation at this stage of its evolution. Such elements might include automated quality assessment (AM-QUALITY) and inspection solutions, in addition to automated routing and transportation via solutions like the AM-ROUTE, an autonomous vehicle developed by AM-Flow's partner company Omron, or other similar AGVs. Another key augmentation of the workflow is the introduction of automated de-powdering and cleaning stations, eliminating one of the more laborious of the remaining manual tasks.

The last step towards full automation of the AM enterprise, now producing more than 15,000 parts per day across its fleet of 15+ machines, is an automated fit-to-size boxing unit to replace the manual packaging process. Production may take place across multiple locations, but this can be managed using a solution like AM-Flow AM-LOGIC, the digital brain of the factory — accessible via a touch-screen console — that is connected to the company's ERP or MES software.

AM-Flow offers modular solutions that can be independently installed but seamlessly integrated at any point that suits the evolutionary nature of automation. The fully evolved AM service provider, using automation at every stage of its workflow, can now manage its huge operation with potentially just a single human operator supervising production. But at no stage of its evolution has the business had to significantly interrupt its workflow in order to accommodate new automation solutions.

User interface AM-LOGIC connecting with CAD/CAM, ERP, MES and PLM systems

The 5 stages of workflow automation

As illustrated in the previous section From Zero to Automation Hero, automating the additive manufacturing workflow is a step-by-tep process. This applies to an e-commerce front-end where customers can upload their print files and obtain quotes, to MES packages, nesting and warehousing software. Where an AM service provider in the early stages of automation might devote its resources to the automation of order intake, quoting and nesting, a fully developed AM enterprise can automate the complete workflow end-to-end, from pre-print to production, and all post-print workflow steps, part identification and sorting, routing, transport, bagging and labelling, tracking & tracing, quality assessment, and order packaging.

But how does a business or production facility level up from its entry-level automation practices to a full-scale automated production line? At what stage in its growth does it introduce new tools like picking robots and intelligent de-powdering stations? And how does it maintain productivity while constantly introducing new areas of automation?

Levels in automation

1 – Entry level automation

2 – Emerging automation practice

3 – Co-ordinated automation practice

4 – Automation leadership

5 – Industry automation leadership

1 - How it starts

For AM service providers, automation can be introduced early on. Consider, for instance, an AM service provider operating between one and three SLS/MJF systems in addition to post-processing equipment and an order processing system. With these resources and just two or three employees, such a business might produce 10–100 parts per day. Though it does not yet have footing on the automation ladder, it has the foundation required for automation at later stages of its evolution: digital manufacturing technology, a basic order processing infrastructure, and a scalable business model. The essence at this stage is that those responsible start developing an automation vision and strategy. Instead of addressing short-term bottlenecks of production, it's now the right time to develop ideas and thoughts about what role automation should and could play in growing the production output. Why now? Because later, once the facility grows, you'll have no time to develop ideas or routes of action. A fledgling AM service provider does not introduce automation all at once. And also, internal AM facilities need to navigate their corporate IT system to find clear linkage with existing IT.

2 - How it grows

Once productivity increases to 400–800 parts per day, with a staff of 20–40 people operating between five and 10 AM systems, one can identify bottlenecks in its workflow and suitable areas of automation that are attainable within a still-moderate budget. In many cases, this will involve automation of part identification and sorting using tools like AM-Flow's AM-VISION part identification solution and AM-SORT, a customizable conveyor system that will be capable of handling greater production volumes at later stages of the business's evolution. These systems are supported by AM-LOGIC, AM-Flow's middleware that feeds back where each individual part is in the overall production process.

AM Automation Levels

01 Entry Level Automation

- Printer Park small: 1-3 printers
- Volume: under 400 parts per day
- ERP – mostly proprietary
- Focus on getting things printed
- Post-processing manually

02 Emerging Automation Practice

- Printer Park midsize: 5-10 printers
- Volume: 400-1000 parts per day
- Recognized need for automation
- ERP next generation proprietary / switch to AM software source
- Multiple 3D print technologies
- Multiple Materials
- Part Identification automated
- Part sorting automated
- All other post-processing steps manual / standalone workstations

03 Coordinated Automation Practice

- Printer Park large: > 10 printers
- Volume: 1000-1500 parts per day
- Goal: Automated production
- Goal: Track & Trace
- ERP AM software supplier
- Multiple 3D print technologies
- Multiple Materials
- Part Identification automated
- Part sorting automated
- Automated part bagging & labelling
- Part routing & transport automated
- All other post-processing steps manual / standalone workstations

04 Automation Leadership

- Printer Park XL: >10 printers
- Volume: > 2000 parts per day
- Goal: Automated production
- Full Track & Trace in place
- ERP AM software supplier
- Multiple 3D print technologies
- Multiple Materials
- Part identification automated
- Part sorting automated
- Part routing & transport automated
- Part bagging & labelling automated
- QC automated
- De-powdering / cleaning automated
- DC still to be digitally connected to production line

05 Industry Automation Leadership

- Printer Park XL: > 10 printers
- Volume: > 2000 parts per day
- Full scale automated production line
- ERP-MES Industry Standard
- Multiple 3D print technologies
- Multiple materials
- Part identification automated
- Part sorting automated
- Part routing & transport automated
- Part bagging & labelling automated
- QC automated
- De-powdering / cleaning automated
- Order packaging automated

Provided by
AM-FLOW

3 - How it secures workflow efficiency

What is being addressed through automation is the continuous switch between one-piece flow and batch processes and the high mix output of printers. Regarding the latter, the economics of printing is driven by the optimal nesting of parts in the building box of the printer. Optimal nesting enables the printing of multiple geometries within a 3D space; optimizing nesting ensures a maximum high-quality output of the printer and the best use of virgin powder (powder bed fusion).
These highly efficient automation tools, thus, facilitate further growth. And when an AM service provider or internal facility expands its print park to comprise at least 10 machines, it may end up producing more than 1,000 AM parts per day, qualified as high-volume X high-mix. At this point, one must consider automation of other processes to keep up with the increasing throughput. So, what should be targeted after identification and sorting?

4 - How automation becomes seamless

With such high volumes, manual bagging and labeling can be replaced by an automated solution like AM-Flow's AM-BAGGING unit, capable of processing up to 25 bags per minute. Additionally, bin-picking robots may be introduced to enable quick transitions between batch and one-piece flows. Crucially, these more advanced automation solutions will integrate seamlessly with foundational solutions such as aforementioned AM-VISION, AM-SORT, and AM-LOGIC, meaning that businesses do not have to uproot their workflow each time they level up to their next stage of evolution. Automation is introduced gradually and painlessly.

An AM service provider or internal AM facility might grow further still, eventually producing over 2,000 parts per day. Although not yet operating a full-scale automated production line, it can introduce further elements of automation at this stage of its evolution. Such elements might include automated quality assessment and inspection solutions, in addition to automated routing and transportation via solutions like the AM-ROUTE, an autonomous vehicle developed by AM-Flow's partner company Omron, or other similar AGVs. Another key augmentation of the workflow is the introduction of automated de-powdering and cleaning stations, eliminating one of the more laborious of the remaining manual tasks.

5 - How industry automation leadership is reached

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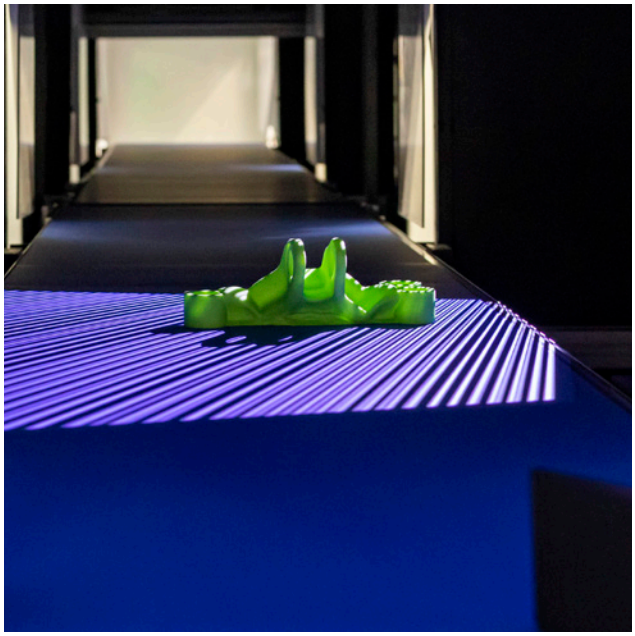
Quality, the next frontier

The latest addition to the AM-Flow family of products is the AM-QUALITY, the world's first AM In-Line Quality assessment solution. Stefan Rink, CEO AM-Flow, explained that the company's "perspective has always been to provide industrial solutions to the AM industry, setting industry standards, to help it scale and deliver on AM's core benefits." Together, part identification, sorting, bagging, transport, and bin-picking modules, the AM-QUALITY, was introduced to help further scale the AM industry.

AM-QUALITY: in-line quality assessment is seconds.



Partial scan of the full spherical point cloud data generation to assess the quality of 3D printed parts

Defect on 3D printed part?

Comparison of point cloud with the digital source files showing missing details on the parts in grey.

The AM-QUALITY production line enables quality assessment of each, and every part produced in 3D print factories, at an unprecedentedly high processing speed. 100% quality assessment, at a cycle time of 10 seconds per part, with a resolution of 50 Microns. The system identifies issues such as breakages, warping, surface defects, etc. thus enabling early detection and addressing of sub-quality prints, immediately during production.
Supported by AM-Flow's proprietary middleware software platform, AM-LOGIC, the AM-QUALITY feeds all generated data back to the MES system of clients, enabling immediate reprints when necessary and optimizing setting parameters of the 3D printers and post-production equipment, creating a true AM industry.

The time is now

"What happens is some larger companies don't feel the pain yet because their margins are still high," Zwikker says. "As margins become thinner, they decide they need to streamline through increased automation but that's when the competition kicks in. What happens is that even smaller companies that have already started using our technology are able to compete on price and can also scale in a much quicker way. So, via a highly automated AM workflow, smaller companies can produce at lower prices than larger companies leveraging scale economics on legacy production capabilities.

If the additive manufacturing market continues to show double-digit growth, volumes will continue to increase, and companies must be able to manage these highly diversified volumes. Even is these new production volumes will be created by new entry companies, they will be able to enter the market with a highly automated workflow and not have to go through the learning curve of companies that have been operating in the market for decades.

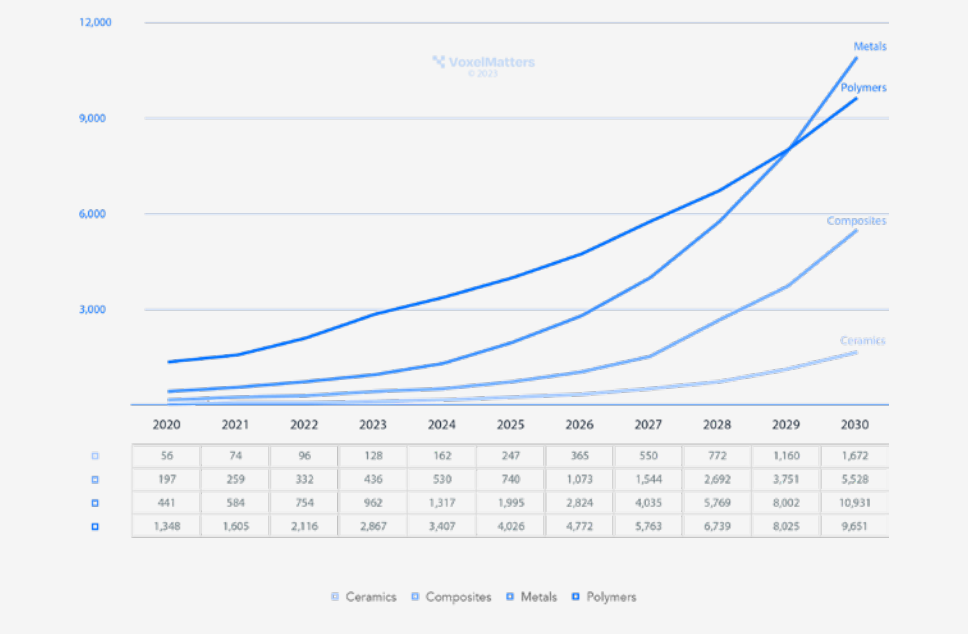
There also are all sustainability aspects to consider that will drive on demand or manufacturing as a

Forecast of all core additive manufacturing industry (hardware, materials and services) revenues through 2030

The core AM industry (hardware, materials and services), including all polymer, metal, ceramics and composites AM products, is expected to grow from $6 billion in 2020 to $80 billion in 2030, at an overall CAGR of 29.6%. From today's $9.5 billion, yearly revenues are expected to more than double to $20.6 billion by 2023.

Provided by VoxelMatters

Forecast of AM service revenues (in USD) in terms of parts produced by material segment - 2020 through 2030



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Ceramics	56	74	96	128	162	247	365	550	772	1,160	1,672
Composites	197	259	332	436	530	740	1,073	1,544	2,692	3,751	5,528
Metals	441	584	754	962	1,317	1,995	2,824	4,035	5,769	8,002	10,931
Polymers	1,348	1,605	2,116	2,867	3,407	4,026	4,772	5,763	6,739	8,025	9,651

AM services are a key segment of the Core AM market. The segment is ecpected to generate $7 billion by 2025 and nearly $28 billion by 2030. Polymer As more automated workflows are implemented, AM production will also increasingly become internalized by vertical adopters (vertical end-users, not included in this forecast), especially in the polymer segment.

Provided by VoxelMatters

service business, along with more iterative and faster innovation cycles. There are supply chain issues that are driving production re-shoring, along with high material prices that drive AM as a way to reduce material use.

"Automating end-to-end for a production line is going to happen. And it's happening already. And these are the things that people have been talking about for about 20-30 years, and we're now seeing those things happen. So going back to that question, it's not if, it's when. And it's happening now. The very fact that a company like AM-Flow exists, with a solid client base and increasing demand, shows just that", explains Zwikker.

Now, automation is needed, to enable double-digit growth, and maximize AM factory throughput, supported by end-to-end visibility. However, as AM is still a relatively young industry, there are many dots to connect to create a full automation value chain. As we saw in this document, automation in AM has many different definitions. Whether it be an e-commerce front-end where customers can upload their print files and obtain quotes, MES packages, nesting software, warehousing software, and workflow automation, In the coming years we will see the development of this new automation value chain. In the meantime, AM production facilities, internal and external, have already made their incremental steps toward end-to-end automation.

AM-VISION and AM-SORT combined with buffer stations expanding the capabilities for sorting of serial production

Case Study 1

The Creabis vision of AM production

Technologies and systems: 3 MJF, 7 SLS, post-processing

Immediate requirements

- Large batch production
- Packing hundreds of parts in a single print job
- Handling many different geometries in a single print job
- Tracking and tracing parts across different print jobs and systems
- Reducing paperwork
- Higher efficiency, lower cost per part
- Direct feedback into MES/ERP system

Long-term requirements

- Lights-out, fully automated factory integrating post-processing automation
- Re-singularize parts with complex and unique geometries
- Automatic storage systems connected to AM-Flow

System/s owned:

- AM-VISION, AM-SORT
- Systems planned:
- AM-QUALITY, AM-BAGGING

Founded in Munich by AM industry veteran Ralf Deuke in 2011, after his pioneering experience at Alphaform, Creabis was created first and foremost to provide production services through additive manufacturing. From the start the company targeted production runs which means that Creabis can now deliver batches of thousands of different parts, built on multiple powder bed fusion technologies. Along with its MJF machine park, Creabis offers laser PBF and – as part of the Prodways group since last year – it can do so via P1000 systems, along with EOS machines.

Multijet fusion systems in operation at Creabis

"We run seven SLS machines plus three HP machines and some Ultimakers as a side business," Deuke says, "Our core of our business is based on the large frame HP and SLS machines and the key for our business to be profitable is definitely the ability to get to a high density in nesting, which means handling many different parts, rapidly."

"Since the HP system entered the market the number of requests for batch production increased significantly," he reveals: "About 65% of all the parts we produce today are for serial manufacturing orders. On HP systems that percentage rises to about 80%."

Serial orders or small batch orders or even large number of parts of the same geometry will require filling up the build volume to get the highest value. or you must make sure that you will get a good fill of your job. "This means you always have a lot of parts in the print jobs," Deuke says, "sometimes we have jobs with more than 500 parts or even a thousand parts with as many as 40, 50 different geometries." This is what the AM-VISION system is used for.

The next automation challenge is relative to accurately tracking and tracing the parts. As the same kind of parts are produced for weeks, months, or even years the more difficult it gets to track and trace these parts across in different print jobs, different machines, and different follow-up processes like tumbling, dying, smoothing, and blasting. And so, if you must produce a batch of 100 parts, you need to know how many of these are complete, where they are, how many of them failed, and how many need to be rebuilt. "The challenge when scaling AM is to track and trace your parts while producing them," Deuke says, "It's about making sure that you know the planning for your machines over the next days or weeks to be able to coordinate with real demand and the sales team: we need more orders of small parts here, more big parts there..." Creabis uses AM-Flow's AM-SORT system to separate and count the parts, decide which ones go into dying, which go into tumbling, etc. The AM-SORT also provides direct feedback into the MES/ERP system. Automated quality inspection is also on the list.

Automation for Creabis is not just about making more parts as much as about making parts more efficiently, reducing paperwork and thus also reducing the cost per part. This is where the AM-SORT now, and the AM-QUALITY system in the near future, can offer a key contribution.

The big picture for the long term is a lights out factory, where the parts are automatically moved from the printer into de-powdering, then into the AM-SORT, onto follow-up processes, and then they are automatically moved into the dyeing and finishing. The biggest challenge to achieving this result is the ability to re-singularize infinitely different parts. That is having a robot able to pick and place parts where no geometries are alike, which is also one of the key USPs of digital manufacturing. That's something to think about for the future, today the most important thing in improving productivity is to reduce paperwork and even eliminate it. Here the AM-SORT system can already make a difference.

A battery of SLS systems at Creabis, including both Prodways and EOS technology

Case Study 2

3Faktur sets sights on production

Technologies and systems: 4 MJF, post-processing

Immediate requirements

- Quality assurance and control
- Repeatability
- Increasing productivity
- Tracking and tracing parts across to be sent out
- Reducing paperwork
- Higher efficiency, lower cost per part

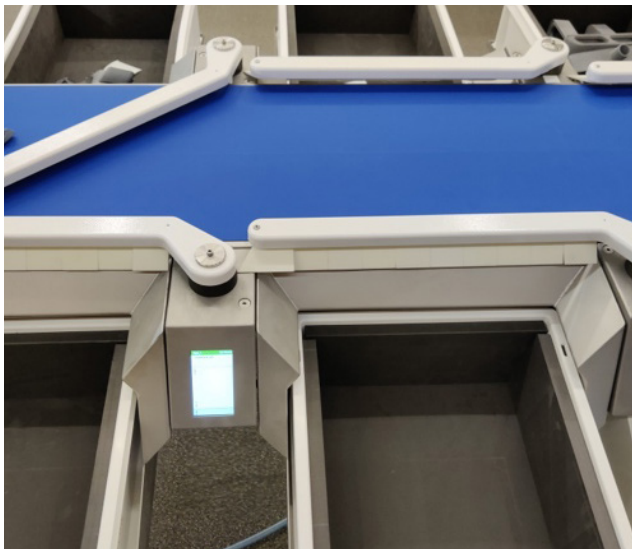
Long-term requirements

- Automated and integrated post-processing (dying) automation
- Automated picking of parts
- Automatic storage systems connected to AM-Flow

System/s owned:

- AM-VISION, AM-SORT, Return Conveyor, AM-BAGGING
- Systems planned:
- AM-QUALITY

AM-Flow Sorting



Based in Jena, in the German state of Thuringia, 3Faktur has built up a reputation as a reliable 3D printing service bureau within Europe. With a focus on high-throughput industrial plastic part production, the company currently services over 2,000 customers from across the continent and from a diversity of industries, including automotive, medical, aviation and engineering.

While many AM services tout the breadth of their services and capabilities, over the years 3Faktur has progressively sharpened its technological focus on high-throughput, highly automated PBF part production. In other words, you won't find its facility equipped with various 3D printing systems and processes. Rather, 3Faktur offers a high degree of specialization, using only powder AM processes (specifically, HP's Multi Jet Fusion) to fulfill end-use small-series production runs. 3Faktur's Co-founder Markus May explains how AM-Flow's systems are helping achieve this goal.

3Faktur's approach is to have just one technology and focus on the production of end-use parts. This involves making prototypes if they are high quality or complex, but mainly doing batch production. The company is running four HP machines: two MJF 4210 3D printers and two MJF 5210 systems, as well as two post-processing stations.

For the last five years (2016-2021), 3Faktur has grown as much as 58% in terms of revenue every year. "And this year we're also at 55% growth," May adds "By the next quarter, we expect to end up at about 30% to 35% growth. That is our goal. If you go back to 2016, we were still small and so it was easier to grow. Even this year, we have high growth because we added people and we added floor space. At some point, however, maintaining 50%

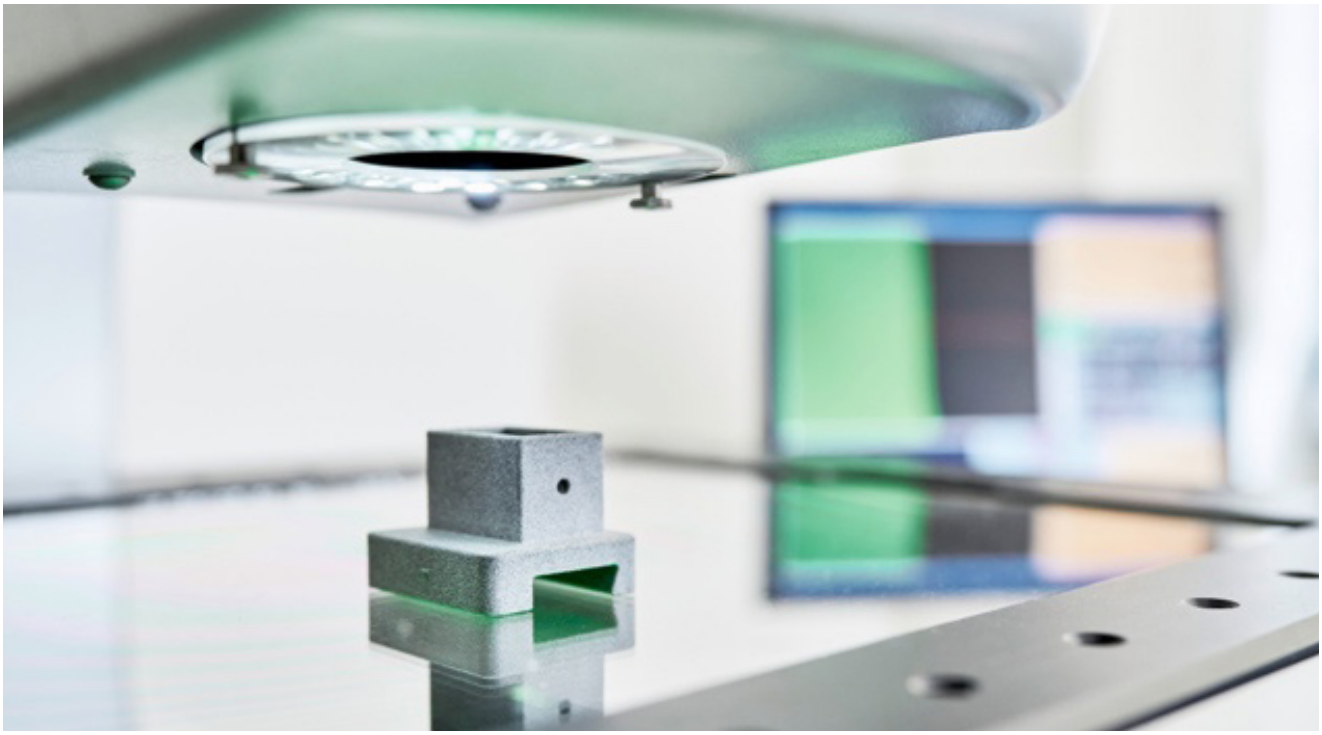
growth will be complicated. That's why for the next five years our growth expectations are around 35%."

The company's business today is based primarily on plastic components for machines, such as encasings, structural parts that screw into larger assemblies, parts for sensors, PCBs, etc. "Sometimes, we don't even know what the parts are," May admits. "The batches that we produce go up to 5,000 parts, and typically companies will not order these all at once. For example, they will order about 500 parts per month for several months or years. Presently, we have about 2,000 customers from various industries. For our specific use case – May adds – the biggest limitations are really scalability and productivity. In general, after 3,000 to 5,000 parts, 3D printing is rarely cost competitive—unless the parts are very complex."

3Faktur is running the AM-VISION and AM-SORT systems from AM-Flow while post-processing in-house includes dyeing, shot peening, and vapor smoothing. For the German service provider, increasing workflow automation is not only about reducing costs, but as much as about improving quality assessment and repeatability of the parts. "When you add one machine, the persons are stable, they know exactly what they're doing and things work extremely well," May explains. "With more people and more machines things are not as simple but workflow automation can bring a more streamlined environment with cost savings as a welcome side effect.

The idea is to implement what May describes as belt-logic to handle parts and with the AM-Flow systems anyone can do it. Even if the parts are placed on the belt manually after post-processing, it already results in a time reduction and, more importantly, there are more guarantees that the sorting is carried out correctly.

Now May is very much looking forward to implementing the new AM-QUALITY system to address what he describes as "by far the most time-consuming and complex step". Manually, the 3Faktur production team can check up to 20% of each batch but if a customer requires higher accuracy this rate needs to be higher. The AM-QUALITY is going to address this specific need.



Inline quality is needed for fast assessment of qualitative elements of any 3D printed part.

Case Study 3

Ziggzagg-ing through thousands of AM parts

Technologies and systems: 10 Multi-Jet Fusion (MJF), post-processing

Immediate requirements

- Enabling and supporting large batch production
- Repeatability
- Quality assessment (QC)
- Increasing productivity
- Paperless automation from order intake to shipment
- Direct feedback into MES/ERP system
- Lowering costs without moving production to low wage countries

Long-term requirements

- Running an AM factory of 50 production printers with a 30 people team
- High automation of workflow using automated vehicles
- Adding additional workflow modules into the workflow
- Implementing Industry 5.0, advanced human-robot collaboration

System/s owned:

- AM-VISION, AM-SORT
- Systems planned:
- AM-QUALITY, AM-ROUTE, AM-SORT, BAGGING

A set of parts at ZiggZagg undergoing recognition and sorting on the AM-Flow system.

With 10 Multi-Jet Fusion (MJF) systems running full-time, Belgium-based Ziggzagg is one of the most prolific and rapidly growing AM service providers in the world today. "We went through a drastic strategy shift about five years ago now," says Stijn Paridaens, CEO. "We decided to specialize in one technology. Now we have a very good relationship with HP, we know what is coming and what the technology will be able to do in a couple of months or a year from now. And it's all about production." Stijn believes that Multi-Jet Fusion (MJF) technology is the best suited for AM services today.

Ziggzagg's highly specialized, production-oriented strategy has led to 30% growth every year over the past five years, which is above the industry average. But this is still only the start. The company has a roadmap to triple its capacity over the next four to five years and this will be implemented through new contract manufacturing capabilities to cater to more aspects of production.

"We get orders for 10 to 50,000 thousand parts that need assembly or other subsequent process-es – he explains. This kind of productivity leads an

extreme mix of parts. Stijn reveals that the number of different designs of parts produced by Ziggzagg to data has just surpassed 10,000. An incredible figure if you think that this is sometimes applied to batches that total 15,000 to 50,000 parts on average, with the largest batch totaling 750,000 parts and counting.

"We are 15 people today and we want to grow adding 15 more people at most, which would mean tripling our business and machine park. We do not want to have 200 people whose entire job is taking care of 30 or 50 printers. That needs to be done through a small team of highly educated people with the help of automation systems, to ensure profitability and reduce human errors on large size production runs."

Ziggzagg started on its workflow automation journey by implementing the AM-VISION system to connect to the company's ERP and MES systems.

Now ZiggZagg is looking at the new AM-QUALITY to automated QC capabilities and is working directly with AM-Flow to integrate labeling and packaging capabilities as well. The company's stated goal is to automate the entire process from order intake to part shipping, however, Stijn intends to focus more on robotic transportation systems such as the AM-ROUTE, rather than belt-based connectors. "This – Stijn explains – would make it easier to scale and add new modules into the production workflow.

The endgame for Ziggzagg is to implement a Factory 5.0 strategy, leveraging advanced collaboration between humans and robots to contain costs rather than resorting to delocalizing operations to low-wage countries. "We want to stay in Belgium, Stijn says. "We have qualified people and want to support the local economy. We have knowledge and IPs here in Belgium. With a good supply chain, we can deliver tomorrow to the US."

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