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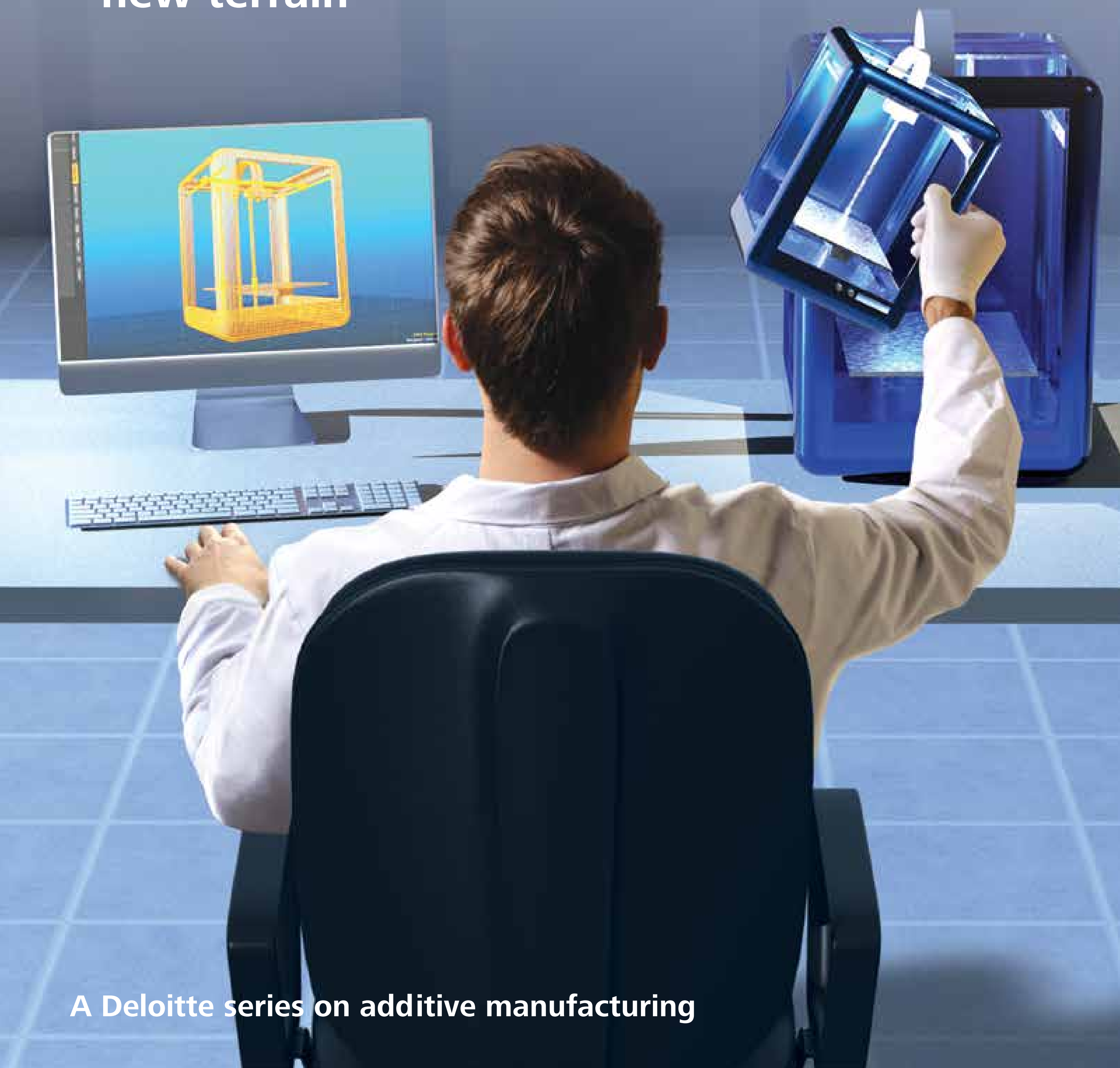
3D opportunity for technology, media, and telecommunications

Additive manufacturing explores new terrain



A Deloitte series on additive manufacturing

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Deloitte Consulting LLP's Supply Chain and Manufacturing Operations practice helps companies understand and address opportunities to apply advanced manufacturing technologies to impact their businesses' performance, innovation, and growth. Our insights into additive manufacturing allow us to help organizations reassess their people, process, technology, and innovation strategies in light of this emerging set of technologies. Contact the authors for more information, or read more about our alliance with 3D Systems and our 3D Printing Discovery Center on www.deloitte.com.

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Introduction

ADDITIVE manufacturing (AM), commonly referred to as 3D printing, plays an increasingly large role in many industries, including aerospace and defense,[1] automotive,[2] consumer products, industrial products, and medical devices.[3] The market for AM technologies is expected to continue to grow significantly from its current size of $4.1 billion in 2014.[4] Notwithstanding this growth, AM is still predominantly applied in rapid prototyping and tooling, rather than production of end-use products. Indeed, final-part manufacturing represents less than 35 percent of 3D printed objects,[5] a missed opportunity for value creation. When choosing to implement the technology, AM adopters have historically found themselves constrained to a relatively narrow set of choices regarding content, software, fabrication techniques and systems, materials, and services—particularly in comparison to conventional manufacturing, whose set of options is far wider.

However, backed by recent advances, AM solution providers within the technology, media, and telecommunications (TMT) sectors—companies that supply the materials, devices, software, content, and services used by manufacturers implementing AM—can meaningfully alter its adoption curve. These companies can provide an array of options to help manufacturers explore broader use beyond rapid prototyping and invest in the next generation of AM technologies, thereby introducing new solutions to foster greater movement toward innovative new products, mass customization, manufacturing at point-of-use, and supply chain innovation.

> TMT sector companies can provide an array of options to help manufacturers explore broader use beyond rapid prototyping and invest in the next generation of AM technologies.

The notion of a 3D printer as a "factory in a box" is a compelling one, bringing with it a breezy vision of the ability to print anything, anywhere, anytime, with simply the click of a button. While this particular outcome may not be suited for every company, realizing elements of it through broader adoption of AM can yield significant benefits. In this article, we examine how AM solution providers within TMT sectors can leverage advancements in content, software, fabrication techniques and systems, materials, and services to provide the next generation of AM solutions. Analysis of patents issued in the AM space in the last five years highlights interesting trends of how new inventions are addressing AM adoption challenges. Combining an exploration of ecosystem opportunities with patent analysis, we offer strategic recommendations to guide providers within TMT sectors in their approach to future growth and fostering strategic AM adoption.

THE ADDITIVE MANUFACTURING FRAMEWORK

Before outlining its impacts on the TMT sectors, it is important to understand the ways in which AM can help rewrite the playbook for manufacturing. AM is an important technological innovation that helps manufacturers break existing performance trade-offs in two fundamental ways. First, AM reduces the capital required to achieve economies of scale. Second, it increases flexibility and reduces the capital required to achieve scope.[6]

Capital versus scale: Considerations of minimum efficient scale can shape supply chains. AM has the potential to reduce the capital required to reach minimum efficient scale for production, thus lowering the manufacturing barriers to entry for a given location.

Capital versus scope: Economies of scope influence how and what products can be made. The flexibility of AM facilitates an increase in the variety of products a unit of capital can produce, reducing the costs associated with production changeovers and customization and, thus, the overall amount of required capital.

Changing the capital-versus-scale relationship has the potential to affect how supply chains are configured, and changing the capital-versus-scope relationship can affect product designs. These impacts present companies with choices on how to deploy AM across their businesses.

Companies pursuing AM capabilities choose between divergent paths:

Path I: Companies do not radically alter their supply chains or products, but they may explore AM technologies to help improve value delivery for current products within existing supply chains.

Path II: Companies take advantage of scale economics offered by AM to help transform supply chains for the products they offer. The aerospace and defense industry is increasingly using AM to improve the availability of parts at point-of-use.[7]

Path III: Companies take advantage of AM technologies' scope economics to enable new levels of performance in the products they offer. In the automotive industry, AM has opened up the potential for new designs and cleaner, lighter, and safer products.[8]

Path IV: Companies alter supply chains as well as products in pursuit of new business models. Food makers have been able to explore direct-to-consumer relationships using AM.[9]

The four tactical paths that companies can take are outlined in figure 1.

AM solution providers within TMT sectors can improve the ability to evolve the supply chain and better achieve product optimization—path IV—through the next generation of AM materials, fabrication techniques, software, content, and services. Through new, expanded offerings and a host of technological developments, AM solution providers can help manufacturers come further along in transforming both products and supply chains, manufacturing at point-of-use, mass customization, and more innovative products.

Figure 1. Framework for understanding AM paths and value

Graphic: Deloitte University Press | DUPress.com

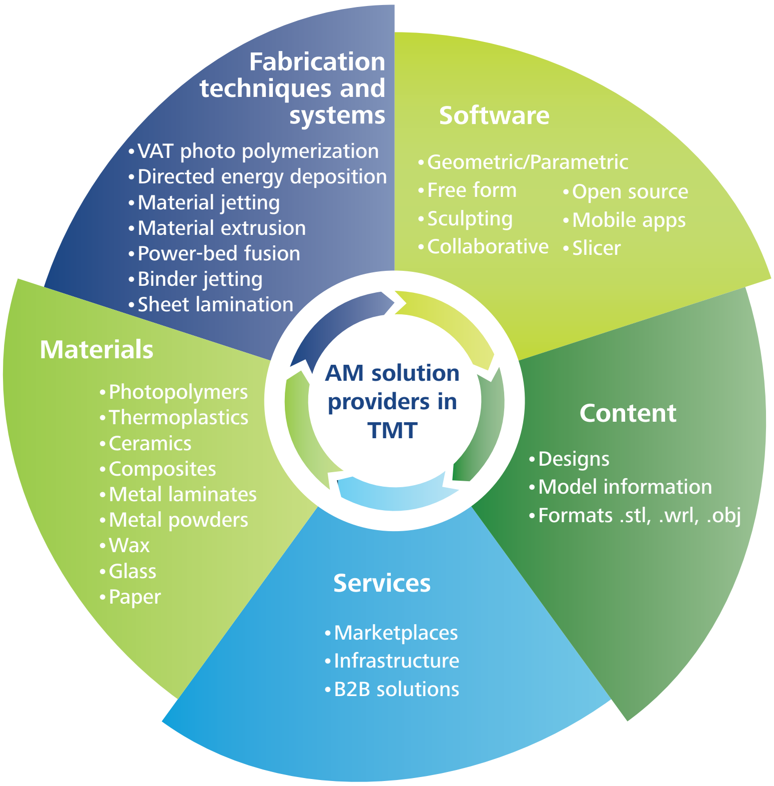
The AM solution provider ecosystem

THE impact of TMT companies can be found throughout the AM process; they are present each step of the way, from scanning of physical objects, to modeling, designing, and slicing software and finally to the materials and printers themselves. Figure 2 identifies several of the main categories of AM solution providers within TMT sectors, along with examples of some significant products or services they provide that drive AM from design to physical object. In this section, we examine each of these core groups and review some key issues, challenges, and new developments affecting them.

Content

In AM, content generally takes the form of designer- or user-generated models created using computer-aided design (CAD) or 3D scanners. There is no shortage of available file formats available, including STL, AMF, OBJ, and VRML. Standard tessellation language (STL) remains the most popular

Figure 2. AM solution provider ecosystem within TMT



Source: Deloitte Analysis.

Graphic: Deloitte University Press | DUPress.com

format among this crowded field of design programs, although it comes with its own set of challenges. STL historically lacks the robust model information (color, texture, material provisions) and the flexibility to be interoperable across diverse machines, platforms, and systems, creating difficulties in sharing designs across different platforms.[10] Developers are working on new formats to avoid STL's limitations and allow for more flexible and interoperable file formats having detailed model information, enabling files to be shared across different operating systems and programs.[11]

The inception of the 3MF file format—which locates the complete model attributes in a single file and is broadly interoperable across applications, platforms, services, and devices—is a step forward in developing such a standard. Many TMT companies are actively working to encourage its adoption via an industry consortium, which is focused on building and encouraging use of this standard format to improve interoperability.[12] In a related development, Autodesk launched an open professional 3D printing platform, Spark, in May 2014. Spark supports the 3MF format and is meant to enable collaboration and knowledge-sharing between model designers, software developers, material scientists, and hardware engineers working to develop products using 3D printing technology.[13]

Indeed, interoperability remains a big hurdle for 3D printing. In order to drive greater adoption, AM solution providers within TMT sectors will need to continue to work toward adopting shared processes, open platforms and standards, and interoperable and interchangeable files. As with any system that requires interoperability, standards are needed to increase ecosystem interoperability so that designs and data can be more easily shared.

> The impact of TMT companies can be found throughout the AM process; they are present each step of the way, from scanning of physical objects, to modeling, designing, and slicing software and finally to the materials and printers themselves.

Software

Design and slicing software are essential for proper execution of AM, and options continue to increase in this space. Sophisticated 3D scanning and imaging tools can be used alongside traditional CAD programs, and scanning techniques have evolved, widening design possibilities both from a creative and process standpoint. Additionally, cloud-based CAD programs increasingly enable collaboration among remote teams, allowing them to share project files across locations.

Design software continues to grow in other ways as well. While current software is still relatively limited in terms of accurately capturing the intricacies of an object's physical structure, texture, and color, each successive software iteration is making strides to improve these capabilities.[14] As design programs evolve, however, their complexity can increase in tandem, requiring expertise and experience on the part of the designer. They can also alter the design process itself, setting in motion changes for how designers and engineers work together and iterate through designs.[15]

Even as professional-level programs grow more sophisticated, still other new, more accessible design programs are helping to lower barriers, both in terms of cost and ease of use, making it easier for trained designers to experiment and hobbyists and designers without formal training to create new designs.[16] Free software tools such as Autodesk 123D Design include libraries of shapes and can be used on a tablet, making them accessible to the layman. Open-source software such as Blender™ also offers free 3D design tools for more experienced designers. At the same time, these options seem unlikely to provide the same level of design support as more industrial-scale tools that engineers use for parts and products requiring greater degrees of precision, high-performance physics-based modeling, and a more rigorous level of quality assurance.[17]

Beyond expanding the universe of designers, software can help expand the universe of AM applications. Holographic projections and virtual reality devices and applications are two such examples: Tools and programs that allow designers and engineers to leverage these technologies can enable enhanced object manipulation and greater designing capabilities.[18] These immersive or virtual reality solutions can allow designers to work on real-time scanned models of physical objects, and potentially update or revise models through actions as simple as gestures—streamlining the design process and potentially improving the quality of physical prototypes at the product development stage.[19]

Apart from designing, software is needed that enables the simulation, debugging, and verification of 3D models and their final output. These tools are essential for the dimensional, as well as material, accuracy of the end part. Indeed, quality assurance is a crucial issue affecting adoption of AM technologies.[20] Researchers at Massachusetts Institute of Technology, for example, have created a system that employs machine-learning algorithms to verify an object's dimensional accuracy by matching CAD data with the end part's real-time dimensions. The system stops the production process if it detects any defect in the object being manufactured.[21] TMT solutions providers can consider implementing these advancements in AM design software to enhance the process.

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Fabrication techniques and systems

3D printers range from affordable, consumer-friendly appliances costing several hundred dollars to large, advanced 3D production systems whose prices may reach into the millions.[22] These 3D printers perform primary AM processes such as vat photo polymerization, material jetting, material extrusion, power bed fusion, binder jetting, sheet lamination, and directed energy deposition.[23] Often, however, post-production finishing is required, printing can be slow and costly, and parts may be of uneven or unacceptable quality.

For their part, less expensive, consumer-directed printers have relatively few options in terms of materials, often produce end products of lower quality and finish, and are incapable of mass production. Likewise, mid-range 3D printers can run into similar issues; while of higher quality than consumer-oriented printers and open to a wider array of materials options, they are costlier and lack the capabilities of advanced systems. Printer providers may consider exploring new fabrication techniques that can address issues such as design complexity, surface finish, unit cost, and speed of operations. They can also consider launching inexpensive yet higher-quality printer models.

Indeed, TMT companies are continuing to address these challenges; HP Inc. has announced a forthcoming 3D commercial Multi Jet Fusion™ printer that it claims can print faster than others currently on the market, while at the same time producing stronger structures.[24] HP has noted that it believes the device can help increase AM adoption.[25] Likewise, Canon also recently announced its own 3D printer, which uses a resin-based material and which it expects to commercialize in two years.[26] Autodesk also has invested in several start-ups and advanced fabrication techniques such as continuous liquid interface production.[27] The company has announced plans to invest up to $100 million total in 3D printing-focused start-ups.[28]

Developments in materials and programs call for similar leaps forward in fabrication techniques. Hybrid processes combine the benefits of additive and subtractive manufacturing to help improve post-processing and dimensional and geometric accuracy while reducing production times, ultimately enhancing the quality of finished end-use products.[29] Hybrid systems include additional milling and cutting capabilities, making final AM-produced objects more accurate.[30] These combined capabilities improve the post-processing and surface-finish quality of the end part.[31] NASA is exploring hybrid systems through development of a multi-3D system based on combination of fused deposition modeling (FDM) and milling capabilities to compensate for FDM's deficiencies in dimensional accuracy.[32] Likewise, researchers at the University of Bath have created a hybrid process called iAtractive, combining additive and subtractive methods to produce parts with intricate structures and dimensions.[33] On the commercial side, companies such as DMG MORI offer hybrid solutions as well.[34]

More advanced multimaterial printing—an evolution in the current state of the technology—carries the added benefit of further reducing the time to manufacture a product. Drop-on-demand printing, which uses multiple nozzles to deposit different materials, is an alternative to build multimaterial objects. Printing is controlled via a microcontroller, enabling it to generate more complex finished products.[35] One or a combination of these fabrication techniques might become the norm for producing high-quality finished products using AM. Solution providers and design software companies can work to harness these fabrication techniques to enhance the finish quality, reliability, and durability of end-use parts, as well as lower overall costs.

Materials

Materials used in AM can take the form of granules, powder, filaments, and other physical forms. Unlike conventional manufacturing techniques, AM principally relies on a limited set of materials that include specific polymers, ceramics, metals, and composites.[36] Many newer materials are available but less tested, leaving their performance in various configurations and conditions uncertain—and creating barriers to more widespread adoption of AM.

In fact, manufacturers' hesitancy to adopt AM production is driven in part by a lack of qualification of materials properties.[37] Manufacturers are less likely to use materials for which they cannot be certain of strength, durability, reactions to manufacturing processes, or wear and tear in the real world.[38] Developers and designers require a platform that promotes knowledge sharing about materials and processes. Researchers continue to explore and experiment with innovative part materials and support materials that are suitable for use in AM applications. Organizations such as Senvol and NASA's MAPTIS program are working at varying levels of detail to build materials databases to catalog material properties and uses, as well as the AM systems that support them. Multimaterial printers, aforementioned, require not just the nozzles to deposit multiple materials but attention to the materials' thermal and other physical properties to be able to adhere and cohere to adjacent materials.[39]

Beyond traditional polymers and metals, companies are exploring new materials that can offer advanced functionality, such as integrated circuits. Nanomaterials such as graphene offer potential due to their elastic and conductive properties, opening up possibilities for flexible electronics.[40] AM providers can use these novel materials to embed distinctive functionalities in a broad range of products and applications, such as wearables and flexible displays.[41] Materials inks that can conduct electric current allow engineers to print sensors directly on complex-shaped objects with diverse geometries to perform increasingly sophisticated functions. For example, embedded electronics created via AM are expected to play a key role in the Internet of Things.[42] (For more information on Deloitte's perspectives on the Internet of Things, please see http://dupress.com/collection/internet-of-things/.)

Researchers from Harvard University have proposed embedded 3D printing, for manufacturing sensors using direct ink deposition of conductive material in the substrate.[43] The flexibility of the embedded electronics confers the advantage of incorporating sensors in real-life objects, regardless of geometries and textures. These sensors can then capture critical information about processes without interfering in core functions. AM solution providers can explore and work with new materials that lead to better structural strength and finish quality of end parts and have conductive and elastic properties to increase their functionality.

Hybrid processes combine the benefits of additive and subtractive manufacturing to help improve post-processing and dimensional and geometric accuracy while reducing production times, ultimately enhancing the quality of finished end-use products.

Services

3D printing service providers play a key role in making AM more accessible, efficient, and effective. These service providers include online communities and marketplaces, business-to-business AM solution providers, and companies that enable efficient data management and storage along with secure transmission of 3D content. 3D printing marketplaces are lowering the barriers to entry by allowing users to share and trade 3D files and designs.[44] Some of these platforms also act as service bureaus that accept user-submitted designs as input and deliver the final product at doorsteps on demand.

Some of these service providers operate in the B2B segment offering 3D printing as a service to suit client requirements; some can provide customized end-to-end solutions for a particular sector or industry as well.[45] 3D printing service providers are also pitching in to address issues related to intellectual property and security, data management, and certification and standards. The sharing of model design files through cloud technologies and distributed networks is vulnerable to threats such as counterfeiting, pilferage, and cyber-attacks.[46] Hence, secure systems backed by strong encryption techniques are crucial for digital rights management—and thus important for TMT AM solution providers to develop. Methods such as device fingerprinting and tokenization can enhance security and copyright protection of content.[47] For example, a US inventor has developed a way to trade digital rights to a remote 3D printer on a network through encryption[48]—the encrypted file contains the dimensional information of the object with copyright constraints to avoid counterfeiting.[49]

Data management has also emerged as one of the major barriers for network operators. 3D printing could add to network congestion due to the enormous data traffic generated while transferring 3D model files.[50] Upcoming software-defined networking (SDN) and network function virtualization (NFV) technologies are likely to play a key role in data management. AM solution providers can capitalize on such upcoming technologies and solutions for a more secure and efficient transfer of content across the various stakeholders.

As each of the provider categories within the TMT ecosystem continues to evolve, their growth will determine the path AM takes in the coming years. To begin envisioning the shape that path will take, it is important to examine innovations that may still be several years away, but whose trajectory is very much in motion.

Addressing adoption challenges through new inventions

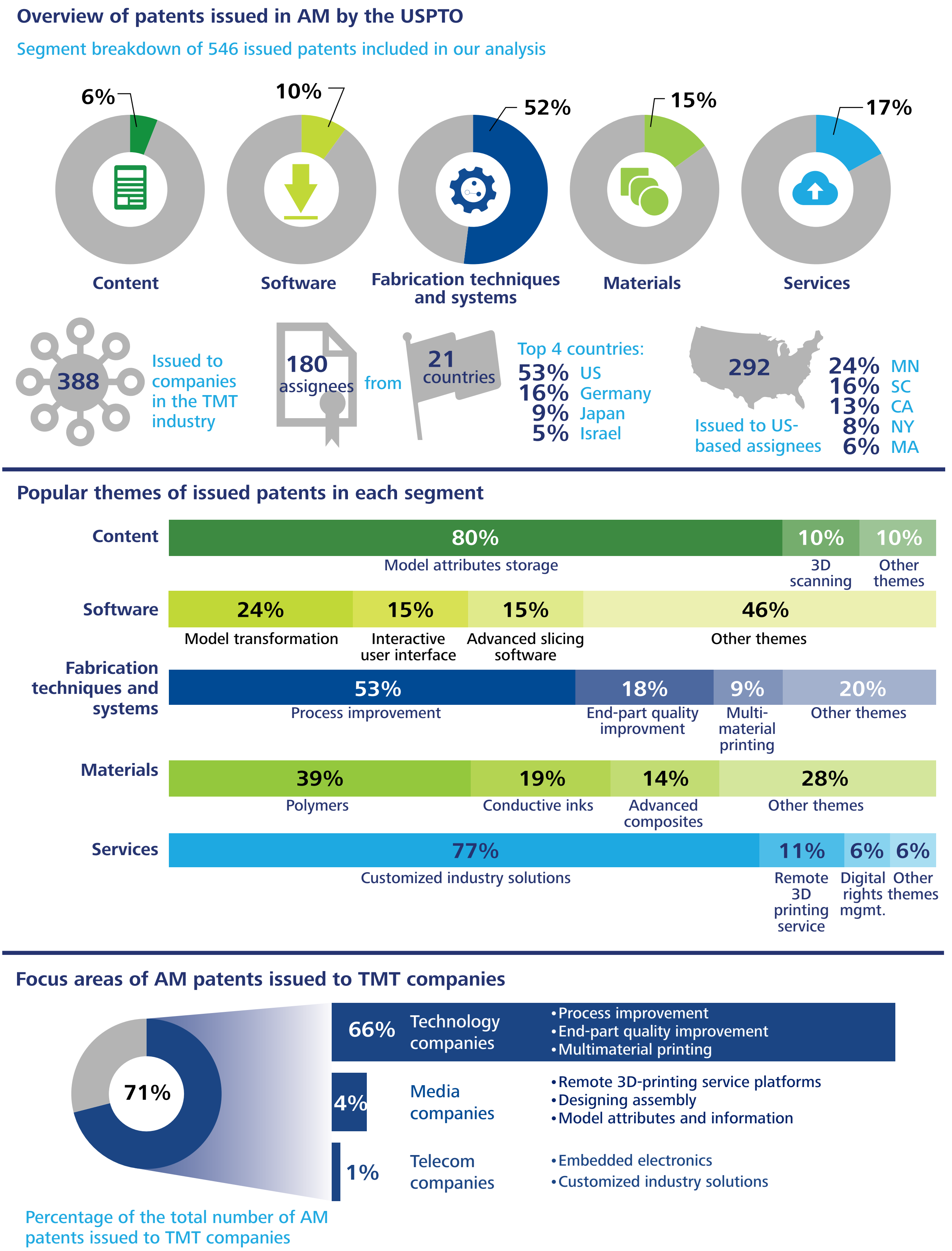
THE AM ecosystem—which goes beyond simply TMT providers to include research labs and universities—is working together to overcome the challenges inherent in the above segments: interoperability (content); complex design programs and model repairing (software); high cost of printers, low speed of printing, multimaterial printing, and component quality and repeatability (fabrication techniques and systems); limited set of materials and embedding functionality (materials) and security; and IP and data management issues (services). Advancements are being made to address many of these issues, leaving us optimistic about AM's future. In fact, the number of patents issued in the AM space has steadily grown during the past five years.[51] Evidence suggests an R&D focus on expanding printing capabilities and data management. Deloitte's analysis of patent data (see below for a description of our patent research methodology) finds that fabrication techniques dominated patent filings during the last five years (2011–15), accounting for half of the total.[52] Figure 3 depicts the recent landscape of patent filings related to AM technologies, services, and other intellectual property.

> The patents issued in this space have grown in the last three years, suggesting the development potential in printable electronics that may begin to emerge in the coming years.

A closer look at US Patent and Trade Office patent data filed in the AM space across the five groups within the TMT AM ecosystem (content, services, materials, fabrication techniques, and software) during 2011–15 sheds light on emerging developments in AM.

For their part, **content and software** collectively accounted for 16 percent of issued patents in the 2011–15 timeframe. Programs featuring greater interactivity and intuitive interfaces emerged as a key area of focus. Recent patents in this segment propose providing touch-based inputs and haptic interfaces, suggesting that future CAD programs will be more interactive and immersive, operable through virtual-reality devices. In the content segment, storing detailed model information including dimension, color, texture, and material composition in 3D printing file formats is a dominant theme. Growth in model debugging, editing, and repair will enable design software to better ensure models are ready for 3D printing.

Figure 3. Profile of patents issued in the AM space (2011–15)



Source: Deloitte analysis based on data from the United States Patent and Trademark Office.

Graphic: Deloitte University Press | DUPress.com

In the **fabrication techniques and systems segment**, improvement in processes and end-part quality are the predominant themes. These improvements are targeted toward enhancing existing processes' resolution, production time, temperature control, waste reduction, safety, material flow, and economic efficiency. Patents also focus on improving the quality of end parts, including surface finish, structural strength, and dimensional accuracy. Together, these two themes account for 71 percent of the patents issued in this segment. As a result, we expect to see more market advancements in the near future in the themes of advanced multimaterial printing using multiple nozzles, bio-printing, and hybrid printing, given the growth in patents focused on these themes over the last few years.

Patents issued in the **materials segment** constituted 15 percent of the total. The major topics in this segment related to polymers and photopolymers, with different compositions such as polyamides, polyesters, and other photocurable resin compositions. Furthermore, conductive inks that can enable embedding of minute circuits, sensors, and devices on substrates feature in the materials patent data. The patents issued in this space have grown in the last three years, suggesting the development potential in printable electronics that may begin to emerge in the coming years. Growth may also occur in expendable or soluble support materials, which can separate out seamlessly at the end of the AM process without requiring extra effort—improving finish quality while reducing production time.

The **services segment** accounts for 17 percent of patents filed during 2011–15. Patents related to customized industry solutions predominate, including end-to-end solutions targeted toward diverse industries such as aerospace, automotive, consumer products, medical technology, health care, defense, and industrial products. While not as prevalent, patents related to remote 3D printing service platforms that allow sharing and trading of designs over the Web and digital rights management and encryption services are noteworthy.

A deeper analysis of the assignee of these patents provides insight into TMT companies' depth of involvement in the development of new AM technologies. In fact, TMT companies accounted for 71 percent of the patents issued in the AM space, with the vast majority coming from the technology sector, at 66 percent of total patents. Geographically, companies and institutions from the United States filed the largest number of patents, accounting for 53 percent of the total, followed by Germany and Japan, with shares of 16 percent and 9 percent, respectively.

Despite the excitement that new patents and inventions may generate, AM solution providers within the TMT sectors still have hurdles to overcome as they work to see new offerings through to greater adoption. To be sure, AM is hardly unique in this regard—as new technologies move into the marketplace, they often encounter many of the same challenges: the ability to operate alongside other devices and within already-functioning, connected design-production ecosystems; concerns about ease of use, particularly compared with conventional manufacturing processes; and how to manage the legal and intellectual property issues that may arise.[53] Concurrently, unique intellectual-property opportunities also exist to partner across the ecosystem to create capabilities that can be licensed, and to develop operating parameters that can be adopted across the industry.

Looking forward

DESPITE the hype surrounding 3D printing, its use in end-part production is still far from achieving mass adoption. To encourage this process, AM solution providers within the technology, media, and telecommunications sectors should leverage recent advancements in material science, manufacturing technologies, and information technology, and also consider potential applications for those advancements currently in development. Likewise, partnering for growth may become increasingly important as TMT companies find that more talent and greater capabilities are necessary to scale development. Figure 4 links the overarching challenges and advancements detailed in the ecosystem and patent analysis sections to provide considerations for potential next steps. TMT companies can choose their strategic path based on their role in the AM solution provider ecosystem, as well as the capabilities they currently have and the strengths they would like to develop. AM solution providers that can leverage the advancements in materials, devices, processes, standards, and regulations can meaningfully alter the adoption curve of AM.

Figure 4. Potential next steps for TMT companies within the AM solution provider ecosystem

Challenges	Actions	Potential next steps
Need for interoperable and interchangeable formats	**Support interoperability of content**	• Develop and/or support formats that enhance interchange of content between the different stakeholders. • Consider shared processes, open platforms and standards, and interoperable and interchangeable file formats to drive widespread AM adoption.
Complex design programs and model verification	**Develop interactive and collaborative software**	• Make the end-user experience of CAD programs seamless through interactive and gesture-supported user interfaces. • Develop software that supports collaboration and provides simple toolkits to create designs. • Create programs that enable simulation, debugging, and verification of designs.
Cost and speed of printing; finish quality of end parts; multi-material printing	**Embrace emerging fabrication techniques**	• Transform existing additive fabrication processes, techniques, and systems to make them more accurate, effective, and efficient. • Explore new approaches such as hybrid manufacturing and drop-on-demand printing to help achieve scale while also addressing quality and reliability. • Focus on developing printers with advanced multimaterial printing abilities.
Limited set of materials and embedding functionality	**Explore and use new materials**	• Start by piloting new materials, such as graphene, including those with conductive and elastic properties, to increase functionality in 3D-printed objects. • Explore emerging compositions to increase the range of products that can be additively manufactured. • Deploy support materials that can be separated out quickly and easily at the end of the process.
Security, IP, and data management issues	**Manage digital rights and data traffic via relevant services**	• Leverage the infrastructure of 3D printing service bureaus and marketplaces to optimize storage requirements. • Use strong encryption techniques for securing design files. • Use new network technologies such as SDN and NFV to manage the explosion in data traffic.

Methodology

We selected USPTO Patent Full Text and Image Database as the reference database for patents. The USPTO houses full text for patents issued from 1976 to the present. The patents can be searched by keyword or terms. To get the set of relevant keywords and terms for running the search, we chose Deloitte's *The 3D opportunity primer: The basics of additive manufacturing* and *Wohlers Report 2015: Additive manufacturing and 3D printing state of the industry*. After analyzing these two reports, we selected the following keywords and terms.

"3D model, 3D object, 3D printer, 3D printing, 3D scanning, 3D structure, Additive fabrication, Additive manufacturing, Additive process, Additive technique, Agile manufacturing, Binder jetting, Bio-printing, CAD, Computer aided design, Continuous liquid interface production, Digital light processing, Digital manufacturing, Digital model, Direct deposition, Direct manufacturing, Direct metal laser sintering, Direct printing, Directed energy deposition, Electron beam melting, Freeform fabrication, Fused deposition modeling, Fused filament fabrication, Generative manufacturing, Generative production, Hybrid manufacturing, Inkjet printing, Laminated object manufacturing, Laser metal deposition, Laser sintering, Layer-by-layer process, Layered deposition, Layered manufacturing, Layering technique, Layerwise manufacturing, Layerwise production, Layerwise solidification, Material extrusion, Material jetting, Mesh Model, Multijet modeling, Multi-material printing, Photopolymerization, Plaster based 3D printing, Powder bed printing, Power bed fusion, Rapid manufacturing, Rapid prototype, Rapid prototyping, Selective deposition modeling, Selective heat sintering, Selective laser melting, Selective Laser sintering, Sheet lamination, Solid imaging, Stereolithography, Three dimensional fabrication, Three dimensional model, Three dimensional object, Three dimensional printer, Three dimensional printing, Three dimensional representation, Three dimensional scanning, Three dimensional structure, Ultrasonic consolidation"

The search query was then run on USPTO database using these keywords. Any patent that had one of these keywords in its "abstract" was extracted from the database. The search yielded more than 1,600 patents. We extracted the details of these patents, including description of patents, date of issue, name of assignee, geographic location of assignee. After validation and data cleaning and filtering by date (January 1, 2011–October 20, 2015), we finally arrived at 546 patents. These patents were used as our final data set. We then analyzed the description of these patents and tagged them based on the segment they belong, the key theme of patent, the profile of assignee and the industry/sector of the assignee. Once all fields for these patents were populated, we ran descriptive analysis to get the key insights. Although not exhaustive, this analysis gives key highlights of the trends and developments in additive manufacturing in the last few years.

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