Additive manufacturing opportunities for Australia’s agriculture, fisheries and forestry sectors

By Dr Lee Clemon, Dr-Ing Matthias Guertler, Laura Tomidei and Rhys Edwards

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However, additive manufacturing – better known as 3D printing – offers a potential solution that could reduce productivity losses by improving product customisation and aiding new product development.

To help the sectors understand the opportunities 3D printing technology presents, AgriFutures Australia engaged the University of Technology Sydney to undertake a scoping study for possible use cases, benefits and pathways to market for this technology. This report aims to better inform primary producers, manufacturers and suppliers of the advantages 3D printing offers Australian agriculture.

Take, for example, international machinery company CNH Industrial, which owns a variety of agricultural machinery brands, including New Holland and Case IH. In 2019, the company revolutionised its production processes by producing components and spare parts using 3D printing. All products were printed locally and on-demand within 24 to 36 hours from when the order was placed, resulting in significant improvement in the time taken for machinery parts to be delivered to customers. This transformation of production processes cut warehousing costs for the company and reduced downtime costs for the producer.

But to fully realise the benefits of 3D printing, there are barriers that need to be overcome through suitable business models to enable this technology to be more readily used. These barriers include regulations covering the right to repair and intellectual property protections for equipment part designs. The report investigates the different ways that 3D printing can be used in a variety of agricultural production settings and further explores the use barriers, including regulation, that need to be resolved so producers can take full advantage of the technology.

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Michael Beer
General Manager, Business Development
AgriFutures Australia
Contents

Foreword 005
Executive summary 008

Section 1  Project overview 010

Section 2  Overview of Australian agriculture for technology suppliers 012

Section 3  Additive manufacturing in industrial contexts 014

Section 4  Additive manufacturing opportunities and business models 020

Section 5  Examples of successful industry adoption of additive manufacturing 028

Section 6  Considerations in adoption 040

Section 7  Empirical findings of additive manufacturing for agribusinesses 044

Section 8  Recommendations 050

Section 9  Conclusion and what next 054

Section 10 Appendix 055

References 058

Figure 1  Agriculture, fisheries and forestry value of production, by commodity, 2018-19 (Jackson et al, 2020) 013
Figure 2  Agricultural, fisheries and forestry production, 1999-2000 to 2018-19 (Jackson et al, 2020) 013
Figure 3  Production and pricing effects on value across agricultural sectors (Jackson et al, 2020) 013
Figure 4  Evolution of additive manufacturing technologies (Bartner, 2018) 014
Figure 5  Evolution of additive manufacturing use cases (Sisca et al, 2016) 018
Figure 6  Overview of a typical additive manufacturing process (Cottinate et al, 2016) 019
Figure 7  Centralised manufacturing (on-demand production, left) versus distributed rapid manufacturing (on-demand and in-situ production, right) (Holmström, Partanen, Sauk and Walter, 2010) 021
Figure 8  Additive manufacturing service provider supply chain (Rogers et al, 2016) 026
Figure 9  3D-printed tri-claw apple picker (A), components of the claws (B) (Pearce 2015) 029
Figure 10  3D-printable shovel handle (Pearce 2015) 029
Figure 11  Open-source mobile water quality testing platform (top), corn sheller (bottom) (Pearce 2015) 029
Figure 12  Plastic components printed by CNH Industrial (CNH Industrial, 2019a) 030
Figure 13  Foodini 3D printer (Natural Machines, 2021) 030
Figure 14  Process transitions for spare part printing (Montoro et al, 2019) 032
Figure 15  Original spare part (left), 3D scanned object (right) (Montoro et al, 2019) 033
Figure 16  Three prototypes of the spare part (Montoro et al, 2019) 033
Figure 17  Reverse engineering (Montoro et al, 2018) 034
Figure 18  Evolution of 3D design for a scanned component (Montoro et al, 2018) 034
Figure 19  Original component (left), re-manufactured component (right) (Montoro et al, 2018) 035
Figure 20  Digital inventory and on-site printing of spare parts (Kim et al, 2019) 035
Figure 21  Printed thermostat covers (Daimler, 2017) 037
Figure 22  A 3D printed workshop tool for mounting parts on an axle (Volvo Construction Equipment, 2018) 037
Figure 23  Turbine paddle wheel (left), fan wheel (centre); 27 kg component (right) (Deutsche Bahn, 2020) 038
Figure 24  Gravity concentrator (UTS, 2019; Image: Lewis Miles) 039
Figure 25  Model of AM supply chain in agriculture (adapted from Gupta et al, 2020) 040
Figure 26  Survey respondents demographics 045
Figure 27  Photos from the workshop at UTS ProtoSpace 049
Figure 28  Cost-quantity relationship in a laser sintering scenario (Baumers and Holwed, 2019) 052

Table 1  Classification of additive manufacturing processes (Arrieta-Escobar et al, 2020) 017
Table 2  Use cases of distributed manufacturing (Douric et al, 2016) 021
Table 3  Challenges for Australian agribusinesses and additive manufacturing opportunities 024
Table 4  Additive manufacturing business models 026
Table 5  Additive manufacturing business models 026
Table 6  3D printed tools for organic farming 028
Table 7  ASTM classification for food additive manufacturing (Pinna et al, 2016) 031
Table 8  Commercial 3D food printing technologies (Suter et al, 2019) 031
Table 9  Considerations for AM in Australian agriculture 043
Table 10  Organisations that received the survey 045
Table 11  Consideration for additive manufacturing deployment (Meisel et al, 2016) 051
Table 12  Example of production costs for laser sintering (Baumers and Holwed, 2019) 053
Executive summary

Agribusinesses across Australia have unique characteristics and challenges, which the increasing availability of new technologies may address in new and effective ways. In particular, additive manufacturing (AM; also called 3D printing) is a set of fabrication technologies that provide an effective response to many of these challenges.

Additive manufacturing uses and benefits

AM is a set of processes that build parts and assemblies by incrementally adding material where desired until the final product is complete. AM processes follow the same workflow of creating a digital design, preparing that design for fabrication, instructing a machine to construct the product, and post-processing the constructed object for final finishing. AM provides solutions within the three levels of technical sophistication: a) on-demand repair or replacement of components; b) customisation and reverse engineering; and c) creation of otherwise impossible product solutions. The suite of technologies can produce components on-demand at or near the end-use location starting only with the raw materials and design. In addition, each part is customisable with just a change in the digital design and without additional tooling or set-up. At the most advanced end of use, AM can create multi-material and multi-functional products in a single-step process that are impossible to make using other fabrication techniques.

Examples of adoption

We collected example use cases that demonstrate a variety of applications relevant for the various agricultural sectors in Australia. These referable examples can aid industry in adopting AM for their own unique needs. Current activities in the global agriculture sector that employ AM include fabricating hand tools, food processing, animal and water management, and hydroponics. Related industrial activities include remote site fabrication of replacement parts, rapid prototyping, rapid tooling, inventory reduction, ergonomic customisation, light-weighting, and product performance optimisation. These successful uses provide clear opportunities for Australian agribusinesses.

Success factors in adoption

Adoption of additive manufacturing occurs when a business need matches a feature or benefit of the technology, such as low-volume production, customisation, material minimisation, specialised or complex geometry, assembly reduction, or combinations of materials. In addition, adoption occurs when the current maturity level of the selected additive manufacturing process also matches the business need, providing a clear investment return. To identify this investment return, additional knowledge and understanding in the agribusiness is needed. Two of the common success factors for the adoption of additive manufacturing are a) a use case that suits the characteristics of additive manufacturing, like complex geometry, custom design, on-site and on-demand production, or composite of mixed materials; or functions; and b) access to relevant technical skills in design, fabrication and validation.

Opportunities and business models for sector change

Multiple business models exist for these production technologies. In particular, the opportunity for varying localisation of manufacturing. The most distributed model is where individual users have and operate one or more machines suited to their needs for on-site production. A more traditional production approach exists where a few large fabrication hubs provide a range of capabilities and distribute final products. In-between models are also promising, where fabrication is distributed to nearby coops, local hubs, or mobile units. These have short supply chains but with more targeted capabilities and enable quick turnaround. In addition to geographic and production-scale models, varying options exist for how parts are purchased and owned. For example, original equipment manufacturers (OEMs) could license the designs to be fabricated rather than the physical part(s) so users can create parts on demand through either pay-per-part or subscription models.

Recommendations

Australian agribusinesses can benefit from additive manufacturing in several areas. Remote and on-demand production of replacement components or no-longer-supported equipment offers near-term and direct opportunities. Tailoring of additive manufacturing processes and materials to specific agribusiness needs in bespoke or semi-bespoke application areas offers opportunities in the medium to long term, with appropriate investment and co-creation by suppliers and users.

The primary limitation for current adoption is knowledge and experience with the technology, partly because there are few, if any, suppliers in the agriculture sector. We recommend increased activities to educate and support agribusinesses and technology suppliers to bridge this gap. Targeted training and education around design thinking for additive manufacturing, and general training on the available machines and materials, is required. Adoption will happen when the technology features match the business needs. Consultation with technology experts and domain experts as part of planning prior to investment will greatly aid in progressing broader adoption and establishing supported market solutions.
Agribusinesses across Australia have unique characteristics and challenges, often related to Australia's unique geography. The increasing availability of new technologies offers opportunities to address these needs in new and effective ways. Additive manufacturing (AM; also called 3D printing) is a promising set of processes that can provide an effective response to many of the challenges faced by agribusinesses.

In the last decade, a new technological paradigm has transformed the industrial world by providing businesses across all industries the chance to seize new opportunities and address ongoing challenges. Industry 4.0 is defined as a new industrial stage in which emerging and disruptive technologies reshape several industrial fields by redefining patterns of value creation. As a result, traditional production/service systems are disrupted by the introduction of new digital solutions based on technologies such as Internet of Things (IoT), artificial intelligence (AI), robotics and additive manufacturing. The integration of these technologies in traditional systems enables greater efficiency, higher quality, shorter delivery times and more profitable and customised products (Bongomin et al, 2020).

In the context of agriculture and agribusiness, Industry 4.0 translates into the digital transformation of production infrastructure, and this idea is often referred to as ‘Agriculture 4.0’. Similar to manufacturing operations, Agriculture 4.0 is disrupting agricultural and food operations through the convergence of emerging technologies. The driving factors that push companies to reshape their processes include the need for higher productivity and efficiency, as well as the need to become more environmentally sustainable (Bongomin et al, 2020; Lammers et al, 2018). In particular, AM has the potential to address some of the challenges that distinguish Australian agribusinesses from general industrial production contexts, and thus it is expected to have very high impact for rural industries.

This report analyses aspects related to the integration of additive manufacturing solutions in agricultural processes by proposing a multi-pronged approach to investigating and documenting the potential for additive manufacturing in the agriculture, fisheries, and forestry industries in Australia. As current adoption of AM is quite limited in Australian agriculture, this project presents the current capabilities and practices while identifying the required capabilities and gaps. These are mapped against established and emerging additive manufacturing technologies, opportunities, success factors and use cases. Case studies in agricultural industries and other applicable industries illustrate the opportunities and success factors for additive manufacturing in Australian agribusiness.

1.1. Introduction

1.2. Objectives

The project objectives were:

1. Identify opportunities for adoption and use of additive manufacturing in agribusinesses.
2. Investigate enablers of, and success factors in, adoption of additive manufacturing in the agriculture, fisheries and forestry industries, and summarise successful adoption case studies from these and other applicable industries.
3. Present recommendations to enable additive manufacturing adoption by agribusiness and detailed areas of development needed by additive manufacturing suppliers.

1.3 Methodology

This project used a combination of in-depth insights, a general overview of the agriculture, fisheries and forestry industries, and a scan of global state-of-the-art and best practices in additive manufacturing.

A global systematic literature search was conducted using the Scopus database, which is a reliable source of scientific documents. The literature review was complemented by government reports, industry reports, statistical information and specific information about Australian rural industries. The purpose of the literature search was two-fold. First, it informed the design of the survey and semi-structured interviews. Second, examples of adoption and case studies were extracted from the global review and combined with the survey results to obtain a representative picture of the Australian additive manufacturing context.

The results identified in the literature review were validated through survey responses and explorative interviews. This enabled a more comprehensive understanding of current practices, needs and challenges across industries, as well as a clearer idea of what industry participants believe additive manufacturing is. The survey was distributed across the main industries and its goal was to validate the results that emerged from the literature search, as well as identify additional opportunity areas or challenges. The in-depths interviews were used to cover tacit or hidden needs and concerns. The semi-structured approach allowed for comparison between different organisations and exploration of interesting new aspects.

1.4. Report organisation

This report is organised in eight sections. Section 1 provides an overview of the project. Section 2 describes the current state of Australian agriculture and the challenges faced by the industry. This information provides context when identifying suitable opportunities for technology adoption and innovation. Section 3 introduces the range of additive manufacturing technologies and basic features. Section 4 highlights business models suitable for application to agriculture supply chains. Section 5 details use cases to make adoption opportunities more tangible to readers. Section 6 collects the implementation considerations for agribusinesses that are considering adoption. Section 7 reports the survey, interview, and workshop results of this study. Section 8 summarises our recommendations for how to increase or improve adoption of additive manufacturing in agribusiness.
This section provides an overview of the agriculture, fisheries and forestry industries. By identifying the characteristics and challenges of the industry, it is possible to define industry needs and ultimately how additive manufacturing can help address them. This description helps clarify the use cases that match agribusiness needs and thereby point suppliers of additive manufacturing services and production to opportunities in the agriculture sector.

Section 2.1 describes the main characteristics of the agriculture industry, highlighting the role of production value and its relationship with productivity levels, which can be supported by new technologies including additive manufacturing. Section 2.2 details the main challenges and risks that agribusinesses face, in order to define the needs that additive manufacturing can address and orient investment with consideration of market size.

2.1. Agribusinesses in Australia – an overview of the industry and supply chain

The Australian agriculture, fishery and forestry sectors are comprised of a range of crop and livestock products (Figure 1). Over the past decade, the value of production has increased by 19% (Figure 2) (Jackson et al., 2020) – 7% in consumer price inflation and then adjusted for increased efficiency and production volumes. These efficiencies and production increases come from adoption of new technologies. Sector-specific needs and financial flexibility will affect this adoption.

In livestock, high prices have been the main driver of growth, and these may provide an opportunity for moderate-to-long-term technology development. This extra revenue may offer opportunities to reinvest in technologies and improvements with a moderate development time. Whereas in cropping, a fall in prices has been compensated by productivity gains, enabled both by the adoption of new technologies and by an expansion of the land under crops. New technologies for crops may need a higher readiness level or a more established supply chain and market. Thus, technology suppliers should consider the specific sector when introducing new products. Increased prices indicate a potential to investigate and adopt new technologies while the market is strong, whereas a fall in prices and compensation with productivity gains in crops suggests new technologies will likely need to be revolutionary or have quicker returns for adoption. Thus, the consideration of which additive manufacturing processes and material are relevant to each segment of agriculture will vary depending on the current market state and the details of the intended use.

In all sectors, additional efficiencies and production increases are desired to maintain Australian competitiveness in export markets and ease increasing demands on producers.

Figure 1
Agriculture, fisheries and forestry value of production, by commodity, 2018-19 (Jackson et al., 2020).

Figure 2
Agriculture, fisheries and forestry production, 1999-2000 to 2018-19 (Jackson et al., 2020).

Figure 3
Production and pricing effects on value across agricultural sectors (Jackson et al., 2020).
Additive manufacturing in industrial contexts

The following sections present the basic concepts of additive manufacturing, by illustrating the maturity level, the main process types, the use cases and the operational steps required.

### 3.1 Additive manufacturing: State-of-the-art

Over the past four decades, additive manufacturing (AM) has evolved and improved tremendously. Initially, applications focused on the production of models and prototypes. In particular, AM for rapid prototyping has been mainly used for aerospace, automotive, machine tool production, and medical and dental care (Peng et al., 2018). However, as different AM technologies matured, AM was able to produce rapid and soft tooling and eventually end-use parts and products. As opposed to subtractive processes and formative processes, AM processes are realised by increasing workpiece mass piece-by-piece, line-by-line, surface-by-surface or layer-by-layer (Thompson et al., 2016). Therefore, the industry has moved toward maturing rapid manufacturing from the well-developed rapid prototyping foundation (Peng et al., 2018).

Figure 4 provides an overview of different AM technologies and their estimated level of maturity based on a systematic analysis by the research institution Gartner Inc. While technologies on the left side are still emerging and associated with usually exaggerated expectations, technologies on the right side are more mature and expectations for them are based on profound practical experience. These mature applications and processes exist in stable markets that support their delivery and growth and offer near-term direct adoption or use. The additional colour coding indicates when specific technologies are predicted to reach their maximum productivity.

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*In subtractive processes such as milling, the workpiece mass is reduced. In formative processes such as bending, the workpiece mass is conserved.*
3.1.1 Additive manufacturing technologies

AM includes a variety of different technologies. Almost all of these technologies build objects by adding material layer-by-layer. Different solutions represent different manufacturing techniques and can handle different types of material (Sisca et al., 2016). Table 1 summarises the main AM industrial categories as summarised by the F42 Committee on Additive Technologies of the American Society for Testing and Materials (ASTM) together with the International Organisation for Standardisation (ISO). For each, manufacturers can have multiple models corresponding to various fabrication envelopes (build size), fabrication speed, material selection, accuracy/resolution and layer thickness (Peng et al., 2018).

According to Shahrubudin et al. (2019), the most common AM technologies include:

- **Material extrusion.** Through fused filament fabrication (FFF), this process builds objects layer-by-layer by heating and extruding thermoplastic filament. It can build fully functional components characterised by multiple colours and materials, such as plastic, food or living cells.

- **Directed energy deposition.** This process is characterised by higher complexity and is used to repair or add additional material to existing objects. Metals and metal-based hybrids are often used as materials in the form of wire or powder for this process, although ceramics, polymers, composites, and a hybrid additive-subtractive process can also be used.

- **Material jetting.** Photosensitive materials are selectively deposited drop-by-drop, producing an object layer-by-layer under ultraviolet (UV) light.

- **Powder bed fusion.** This technique uses either an electron beam (EBM) or a laser (SLS) to fuse material powder together into layers. Possible materials include metals, ceramics, polymers, and composites.

- **VAT photopolymerisation.** This technique consists of the curing of photosensitive polymers by using a laser, light or UV. Materials in the form of liquid harden when exposed to ultraviolet light. The products are characterised by good details and premium quality surface.

- **Binder jetting.** This technique joins together powder particles from a variety of materials, including metals, sands, polymers, and composites.

- **Sheet lamination.** The final product is realised by bonding sheet materials together. This technology can create full-colour prints, and excess material can be recycled.

### Table 1: Classification of additive manufacturing processes (Arrieta-Escobar et al., 2020)

<table>
<thead>
<tr>
<th>Process category</th>
<th>Technology</th>
<th>Material type</th>
<th>Example materials</th>
<th>Strengths/weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material extrusion</strong></td>
<td>Fused deposition modelling (FDM)</td>
<td>Thermoplastic polymers</td>
<td>Polyamide, acrylonitrile butadiene, styrene, polylactic acid cellulose-based hydrogels</td>
<td>Inexpensive extrusion machine Multi-material printing Limited part resolution Poor surface roughness Ideal for biomaterials Maintaining structural integrity during drying</td>
</tr>
<tr>
<td><strong>Direct energy deposition</strong></td>
<td>Electron beam welding (EBW)</td>
<td>Molten metal powder</td>
<td>Steels, titanium, alloys, cobalt, chromium, Inconel, aluminium, copper</td>
<td>Repair of damaged/worn parts Functionality graded material printing Requires post-processing machine Can be combined with machining for on-board post-processing</td>
</tr>
<tr>
<td><strong>Material jetting</strong></td>
<td>Polyjet/inkjet printing (MJM)</td>
<td>Thermally stable or unstable plastics</td>
<td>Photopolymers Wax</td>
<td>Multi-material printing High-quality surface finish Low-strength material</td>
</tr>
<tr>
<td><strong>Powder bed fusion</strong></td>
<td>Selective laser sintering (SLS)</td>
<td>Polymide/ polylactic acid</td>
<td>Nylon, polystyrene Steel, titanium alloys, cobalt chromium, alumina, zirconia</td>
<td>High accuracy and details Fully dense parts High specific strength and stiffness Powder handling and recycling Support and structure</td>
</tr>
<tr>
<td><strong>VAT photopolymerisation</strong></td>
<td>Stereolithography (SLA)</td>
<td>Photopolymer ceramics</td>
<td>Epoxies and acrylates, alumina, zirconia</td>
<td>High building speed Good resolution Over-curing scanned line shape High cost for supplies and materials</td>
</tr>
<tr>
<td><strong>Binder jetting</strong></td>
<td>Indirect inkjet printing (IDP)</td>
<td>Polymer powder ceramics</td>
<td>Plaster Resin</td>
<td>Full-colour object printing Wide material selection High porosities on finishing parts Requires infiltration during post-processing</td>
</tr>
<tr>
<td><strong>Sheet lamination</strong></td>
<td>Laminated object manufacturing (LOM)</td>
<td>Thermoplastic polymers</td>
<td>Polyamide, acrylonitrile butadiene, styrene, paper, metallic sheet, ceramic materials</td>
<td>High-quality surface finish Low material, machine and process cost De-cubing issues</td>
</tr>
</tbody>
</table>
3.1.2 Additive manufacturing technologies

The large variety of AM techniques enables multiple intended uses. These can be classified into four broad categories (Sisca et al., 2016):

- **Rapid prototyping (RP).** AM was originally introduced to build conceptual prototypes, and those prototypes were only meant to “accelerate the development phase (time-to-market) of a product and under no circumstances are comparable to the end product regarding quality, material and durability” (Thymianidis, Achillas, Tzetzis and Iakovou, 2012). The original aim of AM was to create representative or functioning models to test different product functions and designs during research and development.

- **Rapid tooling (RT).** One of the main industrial applications consists of producing tools, moulds and master patterns or sacrificial shapes. Examples include jigs, fixtures, templates, gauges and drill guides.

- **Rapid manufacturing (RM).** Production of near-net-shape products. As the range of available materials increases, AM processes are capable of producing functional products and final components, which can be sold or used in market-ready products.

- **Maintenance and repair (M&R).** Repairing existing industrial products using AM can be convenient when it is difficult to supply or source spare parts, particularly if spare parts are no longer available for old machines or come with long lead times. For example, in the case of metal parts, metallurgical bonding replaces mechanical bonding.

3.1.3 The general additive manufacturing process

AM processes generally involve the following steps (Cotteleer et al., 2016; Haleem and Javaid, 2020), as illustrated in Figure 6:

1. **Creating a 3D CAD model through design software or 3D scanning technologies**

   The digital thread for additive manufacturing (DTAM) begins with the creation of a digital model of the product. This can be achieved by creating a model using computer-aided design (CAD) tools or by physically scanning an existing product. After the creation of the CAD model, iterations of analysis and design may occur in order to determine specific properties of the part (e.g., structural, thermal or fluid properties). For the creation of high-quality, consistent parts, advanced modelling and simulation may inform current and future design of the component using continuous improvement information. The CAD file is then translated into STL, AMF, or a similar file format. STL is the standard for most current machines. The transformation of the STL file into a toolpath plan for deposition is typically processed by software onboard the machine or supplied at purchase. Open source software exists for these functions for low-grade or custom-built equipment.

2. **Printing of the parts using appropriate AM technologies and customised post-processing**

   The model is translated into machine instructions that produce the component. Most processes require tuning or optimisation to balance the thermal and material transport phenomena and achieve a desired process consistency. When ordering from a printing bureau or service, the provider typically does this tuning. After its fabrication, the part must be post-processed, meaning it is removed from the build platform, cleaned and, in many cases, put through a surface preparation process. Examples include annealing, surface finishing, machining or coating. Post-processing may include adding threaded fasteners, as many processes cannot produce these natively.

3. **Part inspection and validation**

   Metallic components may be tested by using non-destructive evaluation (NDE) technologies such as x-ray or ultrasound to verify the quality and compare it with the design features. Some workflows adopt a sample or witness fabrication method where a separate piece is fabricated at the same time as the intended product to test the material properties of the build.

4. **Delivery**

   As with other industries, products are handled and shipped. In advanced setups that have adopted various other Industry 4.0 technologies, the part may be inspected through connected sensors that update a digital twin of the product. However, this digital twin is not necessary in many cases.
Additive manufacturing offers the opportunity to address some of the challenges unique to Australian agriculture. Long supply chains that extend for thousands of kilometres, and remote and harsh locations in which businesses often operate, require companies to be self-resilient and autonomous. In order to take advantage of these opportunities, businesses can adopt different business models that are based on different configurations of AM supply chains.

4.1 Opportunities provided by additive manufacturing

AM allows for new supply chain structures where objects can be produced closer to the point of use, thereby reducing or eliminating shipping constraints. AM also enables the production of complex and customised parts that can be tailored to specific needs. For example, out-of-stock or no-longer-supported spare parts can be manufactured locally using a digital design. Other words, AM provides a range of opportunities around where parts can be manufactured and what parts can be manufactured.

4.1.1 Centralised and distributed rapid manufacturing – where parts can be manufactured

As mentioned in section 3.1.2, rapid manufacturing systems produce parts from a 3D CAD file. In the last decade, there has been an increasing number of approaches that deploy rapid manufacturing in the context of spare part supply chains. The two main approaches are a) centralised manufacturing, in which parts are produced in regional distribution centres; and b) distributed manufacturing, in which the production of all parts occurs locally from centrally distributed digital models.

In a centralised manufacturing approach, parts that are not needed often are produced on demand through rapid manufacturing in regional distribution centres and then delivered to the service locations. However, as this approach still involves parts to be transported and delivered to users, it might still require them to hold inventory, depending on the maintenance policy of the user, as well as the criticality of the component (Holmström et al., 2010).

On the other hand, the concept of distributed manufacturing was introduced as a preferred solution for isolated systems, such as space stations in orbit or military equipment in the field, as it can produce parts both on demand and in situ (Figure 7). In these contexts, supplying parts from a centralised manufacturing hub is particularly difficult because of the characteristics of the environment in which the business operates (Péres and Noyes, 2006). Such constraints match the distributed and remote nature of many Australia agribusiness operations, and thus this model is similarly applicable to these businesses. For distributed manufacturing, the only requirements are digital data transfer and availability of the raw materials. Where there is no need for specific machines or knowledge, AM is able to bypass hurdles such as long distances. In addition, since AM processes add material only where needed, the required volume of basic materials is reduced to nearly the final volume of the product, and the process generates much less waste than subtractive manufacturing. This not only enables reduction in use and costs but also leads to smaller environmental footprints (Verboeket and Kirikco, 2019a).

Distributed manufacturing becomes particularly relevant in supplying spare parts as it allows a reduction in the risk of stock-outs of critical parts that can disrupt operations (Holmström et al., 2010). Thus, through AM, it is possible to produce an array of replacement parts from a single raw material source. As operations in remote and austere environments are characterised by limited access to materials, power and transport, AM can improve product service and availability while reducing supply chain costs associated with transportation and inventory (Meisel et al., 2016). Further, moving production close to the operations where the equipment is needed is particularly important for products that have long life cycles, such as agricultural machines. The geographical distribution of land-based agriculture highlights the potential for near-point-of-use production.

In the traditional configuration of distributed manufacturing, digital designs are centrally distributed to service locations (Holmström et al., 2010). However, different configurations have emerged in order to address the different nature of relationships between the central factory and the distributed site. Table 2 illustrates the use case evolution showing different levels of collaboration between supplier and user (Durão et al., 2016).

Table 2 Use cases of distributed manufacturing (Durão et al., 2016).

<table>
<thead>
<tr>
<th>Use case</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use case 1</td>
<td>The central factory has no influence on the process and only sends the part digital model to the site. Once the site has received the information, it sets up the machine and starts production.</td>
</tr>
<tr>
<td>Use case 2</td>
<td>The central factory remotely monitors process parameters but without having influence over the process; thus any deviation needs to be managed by the local site.</td>
</tr>
<tr>
<td>Use case 3</td>
<td>The central factory has full control over the process parameters and guides the quality control process as well.</td>
</tr>
<tr>
<td>Use case 4</td>
<td>The production is entirely controlled by the central factory via the internet. The digital file is sent directly to the machines or what is being produced.</td>
</tr>
</tbody>
</table>

Figure 7 Centralised manufacturing (on-demand production; left) versus distributed rapid manufacturing (on-demand and in-situ production; right) (Holmström, Partanen, Tuomi and Walter, 2010).
4.1.2 Complex and customised products – what parts can be manufactured

Additive manufacturing technologies allow manufacturing of new complex parts and high-performance components while maximising process efficiency and reducing waste. As mentioned in the sections above, 3D models and raw materials are the only requirements for AM processes. To manufacture a different product, it is only necessary to upload a different CAD file, thus eliminating machine set-up and changeover costs associated with traditional manufacturing. As parts are produced layer-by-layer, neither tools nor moulds are necessary. As a result, there are fewer process and design restrictions, which enables optimised and functionally integrated product designs. Therefore, it is possible to integrate certain functions such as moving parts or cooling systems without requiring additional manufacturing or assembly steps (Weller et al., 2015). The realisation of optimal product designs also allows for the production of lightweight components. In fact, the design flexibility and the use of fewer materials enabled by AM can result in up to 85% weight reduction compared with traditionally manufactured parts. For that reason, AM is being increasingly adopted by the aviation, aerospace and transportation industries, as ‘light-weighting’ brings real and tangible benefits during the use phase by saving fuel (Togwe et al., 2019).

Alternatively, AM can be used in combination with traditional manufacturing processes, instead of producing the end product layer-by-layer. AM processes are employed to produce tools such as moulds/cores that are used for traditional manufacturing processes such as metal casting or composite lay-ups. For example, AM produces sand moulds and cores without the need to produce expensive hard tooling necessary for patterns and core boxes. This enables the fabrication of complex casting and novel design opportunities such as non-uniform parting lines, optimal riser designs and incorporation of undercuts and light-weighting (Lynch et al., 2020).

Due to requiring few inputs (i.e., CAD file and raw materials), as well as not needing machine set-up and changeover, AM also enables product customisation and individualisation without additional costs (Weiler et al., 2015). On one hand, it is possible to create unique digital designs from scratch using CAD tools. Instead of using traditional manual, paper-based sketching, modern technologies, including 3D modelling applications and CAD tools, provide support for design tasks and let the user to build entirely new digital models of objects (Rodriguez-Conde and Campos, 2020). On the other hand, existing digital product models can be modified according to user inputs or requirements to produce a variety of parts without increasing costs. The cost of producing each new part is only the raw materials and energy; tooling and set-up are not needed. The resulting customised products are generated based on the use of different software tools such as configurators and 3D scanners (Holmstrom et al., 2017).

In general, AM overcomes the need for product-specific equipment that typically needs to be amortised over large product volumes. This makes AM suitable for the production of small product volumes or single units. In these cases, the cost of production is significantly reduced and the time-to-market is shortened (Verboeket and Krikke, 2019a).

4.1.3 Opportunities provided by additive manufacturing for Australian agribusinesses

As illustrated in the sections above, additive manufacturing provides new opportunities for where components can be produced and what type of parts can be produced. These capabilities are generally applicable to many contexts and industries. However, in the context of Australian agriculture, additive manufacturing can have strategic impact in addressing industry-specific characteristics. By defining the needs of agribusinesses, it is possible to better understand the potential of additive manufacturing and how it can be used to address real and specific needs. Challenges arise from both external and internal factors interacting with companies. The main categories are:

- **Logistical and infrastructural risks**
  
  Due to the dispersed geography of Australia, infrastructure has a crucial role in the development of agriculture. Australian agriculture is characterised by long supply chains, with the distance between production, processing and markets often exceeding thousands of kilometres (Higgins et al., 2017). In fact, the industry uses 58% of Australian land, or 446 million hectares. Crop and horticulture are generally located in areas fairly close to the coast, while livestock grazing is widespread (Jackson et al., 2020). Therefore, solid infrastructure strengthens the whole supply chain, reduces transport costs and increases access to markets (ACIL Allen Consulting, 2019). This geographical distribution also indicates a preferential location for production suppliers. Additive manufacturing can alleviate this through more distributed production, closer to the point of use.

- **Operational risks**
  
  Operational risks in agricultural operations involve decision-making, as well as equipment and workforce management. Breakdowns in farm equipment represent a significant risk for the continuity of operations (Jaffee et al., 2010). From this perspective, managing reserves of spare parts is considered one of the most important activities to ensure smooth functioning and continuous production (Mirbesvi et al., 2018), and buying these is one of the most expensive aspects of agricultural machinery (Sedokhovod et al., 2020). In addition, due to the locations of agribusinesses, operations can be affected by environmental conditions. For example, in desert-based environments such as non-arable lands destined to livestock, sand, wind, heat and poor transportation can affect operational life and performance of machinery. On the other hand, watercraft-based systems used by fisheries businesses can be affected by water, humidity, salinity and ship motion. Finally, environmental conditions also make storage of supply materials more challenging (Meisel et al., 2016). Additive manufacturing offers options related to spare parts and on-demand production to reduce this risk.

- **Management risks**
  
  A shrinking and ageing workforce has been increasingly affecting Australia’s rural industries over the past two decades. In many cases, older generations of farmers have retired and their children have moved to cities, while in other cases farmers have moved to different industries. This creates pressure to increase productivity through adaptation, such as new technology adoption (Hajkowicz and Eady, 2015).

- **Market-related risks**
  
  Australia has been experiencing increased variability in market demand for food, volatile exchange rates and volatile commodity prices. With the global population expected to grow by 2.3 to 2.4 billion by 2050, and consumption rates predicted to increase due to higher predicted income, demand for food and fibre products is likely to rise. Estimates are that 60-70% more food will be required by 2050 (Hajkowicz and Eady, 2015). In addition, Australian agriculture is an export-oriented industry, and consumer preferences for and expectations of agricultural products are changing as a result of demographic factors and exposure to other cultures (ACIL Allen Consulting, 2019).

- **Weather-related risks and natural disasters**
  
  Changing rainfall and temperature patterns, as well as extreme weather events, are intrinsic risks in the agriculture industry (Jaffee et al., 2010). However, climate change in the coming decade is expected to impact Australian agriculture and food production. As a result, average rainfall patterns are expected to change, more extreme fire weather days are anticipated, and the frequency and severity of tropical cyclones is forecast to change (Hajkowicz and Eady, 2015).

- **Biological and environmental risks**
  
  Drop diseases and contamination, degradation of natural resources and production processes represent common risks in agricultural operations (Jaffee et al., 2010). In addition to those, Australia’s unique ecosystem presents additional risks related to biosecurity. In particular, the increasing number of people arriving via tourism and migration in Australia over the past 50 years comes with an increased risk of exotic disease incursion that could be devastating for agricultural activities. This risk is related to travellers clearing Customs when entering Australia for purposes including tourism, returning home or permanently migrating (Hajkowicz and Eady, 2015). Effective and efficient management of biosecurity surveillance is a priority, and this is handled to very high standards by Commonwealth, state and territory governments (ACIL Allen Consulting, 2019).

- **Policy and institutional risks**
  
  Australian agriculture is heavily export-oriented and therefore highly dependent on international trade. While regulation is fundamental for the integrity of Australian agriculture, it can also be a burden through compliance costs, unnecessary inconsistencies and inflexibility in responding to change (ACIL Allen Consulting, 2019). In some instances, the flexibility of additive manufacturing to change product designs rapidly will be a benefit.
Table 3
Challenges for Australian agribusinesses and additive manufacturing opportunities.

<table>
<thead>
<tr>
<th>Challenge category</th>
<th>Challenge description</th>
<th>Additive manufacturing opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistical and infrastructural</td>
<td>Dispersed geography and long supply chains imply: • High logistical efforts and long transport times. • Limited infrastructure, such as gravel roads, poor electricity networks and lack of high-speed internet in remote locations (Department of Agriculture and Water Resources, 2017). • Need for self-resilience and autonomy, such as the ability to operate, maintain and repair equipment and machineries.</td>
<td>Distributed manufacturing to: • Reduce logistical efforts as production moves to the point of use. • Eliminate the need for solid road infrastructure, as physical transport is needed only for raw materials. • Achieve higher levels of autonomy and resilience, as fewer sources and suppliers are needed.</td>
</tr>
<tr>
<td>Operational</td>
<td>Operating in remote locations and often harsh environments implies: • Limited availability of spare parts and long load times due to long use times of agricultural machines and equipment. • Tough and strenuous use context for equipment and machineries, such as high loads and harsh environmental factors. • Additional efforts in storing and preserving supply materials.</td>
<td>Additive manufacturing to: • Hold a digital inventory for parts and print them on-site whenever they are needed. • Have increased availability for spare parts and tools, as they can be printed on-demand. • Hold physical inventory for raw materials, thus reducing efforts related to storing and preserving goods.</td>
</tr>
<tr>
<td>Management</td>
<td>Shrinking and ageing workforce requires continuous productivity gains.</td>
<td>Reduced fabrication labour for parts, freeing up workers for other tasks. Parts can be customised for ergonomics for each user, potentially lengthening careers with reduced injuries.</td>
</tr>
<tr>
<td>Market-related</td>
<td>Customer health and sustainability awareness – customers are becoming more choosy and want a more diverse range of products and healthier choices, as well as traceability of the origin of ingredients (Hajkowicz and Eady, 2015).</td>
<td>Food printing can address the need for specific and customised amounts of material and nutrition content.</td>
</tr>
<tr>
<td>Weather-related and natural disasters</td>
<td>Climate change is expected to change weather patterns and increase the frequency of severe weather events.</td>
<td>Rapid customisation of components will allow production of new devices and products to adapt.</td>
</tr>
<tr>
<td>Biological and environmental</td>
<td>Unique Australian ecosystem makes agricultural activities particularly exposed to biosecurity risks.</td>
<td>Local production of parts avoids pests hitchhiking from overseas.</td>
</tr>
<tr>
<td>Policy-related and institutional</td>
<td>As Australian agriculture is export-oriented, international agreements, policies and regulations can have a significant impact.</td>
<td>Reduced need for inventory means components are produced only when needed, thereby reducing capital tied up in parts inventory.</td>
</tr>
</tbody>
</table>

4.2 Business models for additive manufacturing

As opposed to traditional manufacturing configurations, AM allows businesses to move production closer to the point of use. Two business models exist – centralised manufacturing and distributed manufacturing – each offering different advantages. In centralised manufacturing scenarios, regional distribution centres become both producers and distributors of parts. Thus, final customers do not own the necessary AM hardware and equipment, but products still need to be delivered to the point of use and shipping times can still have a negative impact. Distributed manufacturing moves the whole production to the point of use, and therefore requires final customers to own all the necessary hardware, but production can be carried out completely on-demand.

These two production configurations unlock new business models and service opportunities. In a centralised manufacturing scenario, on-demand AM service providers offer printing-related services from design through to manufacturing, thus leveraging AM capabilities outside the final customer’s location. These services typically include both a design-related and manufacturing-related component. In general, organisations can choose from three categories of AM services, depending on the extent to which they require support in acquiring the necessary 3D model (Figure 8).

First, businesses need to assess their design capabilities and possible options. Depending on whether 3D designs are readily available or the capability can be built within the organisation, it is possible to choose from the following options (Rogers et al, 2016).

a. Generative services

Generative services transform tangible objects into digital models and then print them. Thus, they include all types of printing-related services required to generate a 3D model and offer the possibility to subsequently print it. These services are suitable for businesses that do not own scanning equipment or the necessary capabilities to build digital models internally. This solution enables high levels of customisation, as well as the opportunity to create a database of 3D models. However, this also raises concerns about security and ownership. • Scanning services employ 3D scanning equipment to acquire the digital copy of an existing object and then use CAD tools to refine it. • Construction services provide a team of designers who produce digital models from scratch based on sketches, photos or other documents.

b. Facilitative services

Facilitative services transform an existing 3D model into an additively manufactured object. They are addressed to customers who already possess a 3D model and wish to print it. Although these providers are focused on manufacturing activities, they can still offer some design-related services prior to manufacturing. In fact, 3D models often need several stages of processing before they can be printed, and these adjustments can be defined by directly contacting the provider or through online tools that dynamically check the model. In either case, parts are manufactured in centralised machine parks, regional distribution centres or by sub-contractors. This allows the provider to maximise machine use while still moving production closer to the point of use.

c. Selective services

Selective services represent a middle road between the two previous categories. They offer a database of existing 3D models that customers can select, customise and print. Some more advanced solutions allow customers to edit digital models on the ‘go’ in online workbenches when placing the order.
In conclusion, the two major options for additive manufacturing uptake are distributed manufacturing or centralised manufacturing, which includes generative, facilitative or selective services.

Distributed manufacturing requires end-use businesses to be responsible for the procurement of raw materials, hardware and design files, but it offers the opportunity to have parts readily available on demand. Centralised manufacturing removes the need for end-use businesses to invest on equipment and designs, but it does not eliminate the need for products to be transported to remote locations – shipping times and costs are reduced to a limited extent. Ultimately, the value of time needs to be evaluated based on business location and specific needs. A moving service provider for high-value activities that may require on-demand parts may offer a middle-ground opportunity in which the service provider transports the fabrication capability closer to activities in high-demand periods. This is particularly relevant during harvesting or planting times when shipping times have a high opportunity cost.
Based on the opportunities presented in the previous section, this chapter provides an overview of selected examples of how additive manufacturing has been successfully adopted by companies in agriculture and across other industries. The section includes agriculture-related examples and examples from industries with similar characteristics where the use case is applicable to the Australian agriculture context.

**5.1 Examples from agricultural industries**

### 5.1.1 Locally manufactured tools for organic farmers

By using low-cost, open-source 3D printers, farmers can produce a variety of objects on site. The presented case demonstrates how it is possible to produce useful objects for organic farming. These are listed in the table below (see Table 5).

The printer used for these applications is the Delta RepRap from the Michigan Tech Open Sustainability Lab, and the choice was based on its low cost (US$450), quality of prints and build volume. Although it can print both in polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) for a range of colours, PLA has been selected as it is a stronger plastic.

All the software required to design and operate the printer is free and open source. Thus, farmers can use OpenSCAD to create designs or customise existing options. The designs have been procured using Appropedia and Yeggi. Appropedia is a collaborative site for solutions in sustainability, appropriate technology and poverty reduction, while Yeggi is one of several 3D model search engines for thousands of designs. Other popular CAD communities are Thingiverse and GrabCAD, while there are many others.

Although many hand tools used in organic farming are too large to be printed using Delta RepRap, they can still be produced as individual components and then assembled. An example of this is the tri-claw apple picker (Figure 9), which is designed to be built on a standard Delta RepRap machine and used on a standard broom handle. However, this specific tool is licensed under the Creative Commons-NonCommercial license (CC-BY-NC), which means that farmers can produce it for their own use but not sell it.

Another example is a customisable shovel handle printed with commercial filament (Figure 10), which has a cost less than one-third less than one-third of one of the commercial plastic D-grip handles.

Other examples include an open-source mobile water quality testing platform (Figure 11), which combines printed parts with off-the-shelf electronics to perform calorimetry for biochemical oxygen demand/chemical oxygen demand, and nephelometry to measure turbidity using ISO method 7027. Simple tool additions such as sausage funnels for meat grinders and corn shellers (Figure 11) are also easier to produce. As maize comes in different sizes, the advantage of printable corn shellers over commercial equivalents is the customisability for the exact location and corn type.

The examples illustrated represent only a small fraction of the number of objects that can be printed, as there are thousands of possible designs freely available, and the number is increasing daily. In addition, all these components present advantages over mass-produced commercial options with regards to customisation of equipment and cost savings. Many polymer filaments can also be generated by recyclebots from either virgin or recycled material. For example, 1 kg of printable HDPE filament can be generated from 20 discarded milk jugs using only US$0.10 worth of electricity (Pearce, 2015).

### Table 5

<table>
<thead>
<tr>
<th>Hand tools</th>
<th>Food processing</th>
<th>Animal management</th>
<th>Water management</th>
<th>Hydroponics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tri-claw apple picker</td>
<td>Water tester</td>
<td>Chicken feed holder</td>
<td>Garden hose splitter</td>
<td>3D Ponics</td>
</tr>
<tr>
<td>Custom shovel handle</td>
<td>Sausage funnels for meat grinders</td>
<td>Ant trap</td>
<td>Gasket</td>
<td>Hydroponic halo ring</td>
</tr>
<tr>
<td>Hand shovel</td>
<td>Cassava press</td>
<td>Field dressing tool</td>
<td>Contoured spigot for 5 gallon bucket</td>
<td>Hydroponic plant pot</td>
</tr>
<tr>
<td>Pulleys</td>
<td>Corn sheller</td>
<td>Gutting tool</td>
<td>Irrigation stake</td>
<td>Peristaltic pump</td>
</tr>
</tbody>
</table>

Figure 9
3D-printed tri-claw apple picker (A); components of the claws (B) (Pearce 2015).

Figure 10
3D-printable shovel handle (Pearce 2015).

Figure 11
Open-source mobile water quality testing platform (top), corn sheller (bottom) (Pearce 2015).
5.1.2 CNH Industrial

CNH Industrial specialises in long-lasting industrial machinery and owns a variety of brands, including vehicle manufacturer Iveco, agricultural machinery manufacturer New Holland and construction equipment manufacturer CASE. In 2019, the company started implementing additive manufacturing to produce components and spare parts in order to provide its customers with rapid availability and support throughout a product's lifecycle. As products can be printed locally and on demand, it is possible to print them within 24 to 36 hours with the optimal amount of resources. The printed part simply requires sanding and painting before being subjected to stringent testing to ensure it meets requirements and specifications.

The first components that the company produced through additive manufacturing included four parts used for buses and agricultural equipment. While these parts were manufactured in plastic, the company is conducting further testing to introduce additive manufacturing for metal parts.

As a result, the company can more quickly supply parts to customers, reduce warehousing costs, and provide assistance for vehicles that are no longer in production (CNH Industrial, 2019b).

5.1.3 Food printing

Food printing provides unique opportunities by combining digital gastronomy and food manufacturing. Food products can be designed and produced to meet specific needs through customising printing materials and nutrition content (Sun et al, 2015). As agriculture faces new trends in customer demand, amid changing tastes, preferences and concerns, food printing allows agribusinesses to create customised food designs and personalised nutrition control. As health is expected to become a prominent driver of food choice (Hajkowicz and Eady, 2015), food printing allows for personalised nutrition, which tailors and fabricates an individual's diet specifically based on their health condition (Sun et al, 2015).

In line with the classification for AM technologies provided by the ASTM F24 Committee on AM (see 3.1.1), food AM technologies can be categorised as shown in Table 6.

<table>
<thead>
<tr>
<th>ASTM classification (AM processes)</th>
<th>Commercial technological solution</th>
<th>Food material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder bed fusion</td>
<td>SLS</td>
<td>Sugar</td>
</tr>
<tr>
<td>Directed energy deposition</td>
<td>N/A for food</td>
<td>N/A for food</td>
</tr>
<tr>
<td>Material jetting</td>
<td>Polyjet</td>
<td>N/A for food</td>
</tr>
<tr>
<td>Binder jetting</td>
<td>3D printing – inkjet printing</td>
<td>Sugar, protein powders</td>
</tr>
<tr>
<td>Material extrusion</td>
<td>FDM</td>
<td>Chocolate, pasta dough</td>
</tr>
<tr>
<td>VAT photopolymerisation</td>
<td>SL</td>
<td>Eggs white, package</td>
</tr>
<tr>
<td>Sheet lamination</td>
<td>LOM</td>
<td>N/A for food</td>
</tr>
</tbody>
</table>

Table 6
ASTM classification for food additive manufacturing (Pinna et al, 2016).

Table 7
Commercial 3D food printing technologies (Sun et al, 2015).

<table>
<thead>
<tr>
<th>Company</th>
<th>Chocedge</th>
<th>Natural Machines</th>
<th>3D Systems</th>
<th>De Grood Innovations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine</td>
<td>ChocCreator</td>
<td>Foodini</td>
<td>ChefJet</td>
<td>FoodJet</td>
</tr>
<tr>
<td>Technologies</td>
<td>Hot-melt extrusion</td>
<td>Room temperature extrusion</td>
<td>Inkjet powder printing</td>
<td>Inkjet printing</td>
</tr>
<tr>
<td>Materials</td>
<td>Food polymer powder such as chocolate</td>
<td>Semi-solid high viscosity material such as dough</td>
<td>Powder such as sugar, starch, corn flour, flavours, and liquid binder</td>
<td>Low-viscosity material such as paste or purée</td>
</tr>
<tr>
<td>Platforms</td>
<td>Motorised stage</td>
<td>Motorised stage</td>
<td>Motorised stage</td>
<td>Motorised stage</td>
</tr>
<tr>
<td></td>
<td>Heating unit</td>
<td>Extrusion device</td>
<td>Inkjet binder printhead</td>
<td>Inkjet printhead</td>
</tr>
<tr>
<td></td>
<td>Extrusion device</td>
<td></td>
<td>Powder bed</td>
<td>Thermal control unit</td>
</tr>
<tr>
<td>Fabricated products</td>
<td>Customised chocolate</td>
<td>Customised pizza and cookies</td>
<td>Sugar cube in full colour</td>
<td>Customised cookies, bench-top food paste shaping</td>
</tr>
</tbody>
</table>
5.2 Examples from other industries

As discussed in section 4.1.1, distributed manufacturing produces parts on demand and in situ. Depending on the level of collaboration between supplier and user, different configurations can be deployed. The following examples present three use cases of distributed manufacturing in which the data file of parts is obtained either using 3D scanners or a pre-loaded part library.

5.2.1 Additive manufacturing for parts printed on-site

The following examples present different frameworks for producing components in situ. The first two case studies are examples of the German Federal Armed Forces and they illustrate a scenario in which the part design is supplied by a R&D unit located away from the site (5.2.1.1) and a scenario in which the component is scanned locally (5.2.1.2). The third case (5.2.1.3) presents a 3D printing maintenance system that produces components in situ and does not require users to have any design experience.

5.2.1.1 Spare parts on demand for the German Federal Armed Forces

Military systems are designed to be long-lasting and failures are sporadic. Therefore, it can be difficult to obtain spare parts when needed, either because they are no longer in production or because of the logistical complexity. AM addresses the sporadic demand for spare parts in remote locations while saving the high costs associated with the inventory.

In this scenario, the 3D designs are developed by highly qualified personnel in R&D facilities operated by the German Federal Armed Forces. The production is performed in situ, for example in an operation area or training mission abroad. Thus, data is acquired in the location where the part is needed, and the use of laser scanners and photographs provide the additional details required. The documents are sent to the R&D centre where the 3D model is refined and tested until the part is verified and proven to be suitable for service. The 3D designs are then sent back to the remote location where the part is needed, along with parameter recommendations.

The parts manufactured locally are generated by models printed by selective laser melting (SLM) and fused deposition modelling (FDM). SLM produces objects from several metallic materials in the form of powder, and for this case the material selected is maraging steel, while the machine is the SLM 280. The material selected for the FDM method is ABS polymer and the machine is the Stratasys Fortus 450mc. The spare part shown in Figure 15 has been produced following the process described above. Although the data acquired locally was of relatively good quality (Figure 15, right), the design division had to re-design 26 features before defining the CAD parametric object (Montero et al, 2019).

Figure 15
Original spare part (left); 3D scanned object (right) (Montero et al, 2019).

Figure 16
Three prototypes of the spare part (Montero et al, 2019).

5.2.1.2 Reverse engineering for spare parts on demand for the German Federal Armed Force

Similar to the case presented above, this scenario presents the production of a spare part on-site through additive manufacturing techniques. However, unlike the previous example, in this case CAD files are created through reverse engineering, that is the process of reconstructing digital models from real physical objects through the use of 3D laser scanning devices. Therefore, design and manufacturing are carried out in the same location.

Typically, there are five steps in the development of a reverse engineered part: scanning, repairing, parametrisation, optimisation and verification. First, the component is scanned, and this results in a file with a point cloud whose quality depends on the scanner in use. As the point cloud gets denser, the file quality improves, and the subsequent steps are better facilitated. This represents the starting point of the digitalisation stages (DS), which aim to create the CAD files and STL files.

Figure 14
Process iterations for spare part printing (Montero et al, 2019).

DS1 has discontinuities and inaccuracies, thus the DS2 point cloud gets repaired by software or smoothing algorithms that reduce the mismatch between the real physical object and the digital model.

DS3 is the most critical part of the digitalisation process, as it requires the developer to identify the important features of the object and define the geometric relations. The features are ranked using a relevance index, which helps to prioritise the geometrical characteristics that characterise the component and the CAD model. For example, in a simple component such as a bolt, the reference geometry is the circle that creates the main cylinder and the zero is located in the centre of the circle. This part of the process is particularly necessary when the analysis comes from a used part, as its use might make the definition of features more difficult.

During DS4, the designer can eliminate the features that do not compromise the functionality of the component, and during DS5, the boundary conditions are verified and the functionality of the component is simulated using relevant software.

Figure 17 summarises the steps of the process presented above.
Examples of successful industry adoption of additive manufacturing

Figure 17
Reverse engineering (Montero et al, 2018).

Figure 18
Evolution of 3D design for a scanned component (Montero et al, 2018).

To show how reverse engineering occurs, a valve cover, which is used in multipurpose diesel electric generators, is outlined as an example. As other similar parts, this type of components breaks very sporadically and therefore it is hard to find available stock in warehouses. The scan of the physical component in DS1 is performed using Hexagon HP-L-20.9 3D Laser Scanner coupled to a metrology arm Romer Absolut. The point cloud obtained is repaired using Innovmetric Polyworks software, which fixes the surfaces that are erroneously scanned and smooths the irregular areas. Using Polyworks Inspector in DS3, it is possible to recognise the main features and extract the dimensions of interest.

For this component, the chosen geometry of reference is a hole that corresponds to a screw used to fix the component with the electrical generator engine block. The recognised features and reference measurements are then used as a basis for the creation of the parameterised model, which is created through the Solidworks software. In order to reduce time and materials, the unnecessary features are eliminated in DS4. These include the tabs used to extract the component when it is cast from the original mould. Finally, in DS5, the design measurements are compared with the ones of the original point cloud obtained in DS1 using the Polyworks software, and maximum deviation of 0.1mm in the relevant areas is allowed.

The evolution of the component through the digitalisation stages is shown in Figure 18.

The equipment used for manufacturing includes a SLM125 Laser Melting machine for the replica in aluminium (AlSi10Mg) and a Stratasys Fortus 450mc fused deposition modelling machine for the replica in polymer (ABS). Figure 19 shows the original component and the re-manufactured one (Montero et al, 2018).

Figure 19
Original component (left); re-manufactured component (right) (Montero et al, 2018).

Figure 20
Digital inventory and on-site printing of spare parts (Kim et al, 2019).
5.2.2 Additive manufacturing for manufacturers

Additive manufacturing is adopted by manufacturers to address the challenges in fulfilling low-volume component fabrication with sporadic demand (Sodhi and Tang, 2017). In particular, production and management of spare parts is considered one of the most promising applications of additive manufacturing in industrial domains. Daimler, Volvo Construction Equipment and Deutsche Bahn are prominent examples, and these are described in the sections below (Heinen and Hoberg, 2019). In addition to these cases, AM can be used to produce specific equipment that can be adapted to different needs. For example, Mineral Technologies has partnered with the University of Technology Sydney to focus on manufacturing precision-engineered mineral separation and mining equipment.

5.2.2.1 Daimler

Since 2016, German automaker Daimler, which owns the Mercedes-Benz brand, has been using AM processes to produce plastic spare parts for Mercedes-Benz trucks and Daimler buses. The components are created by using selective laser sintering (SLS) and include spring caps, cable ducts, clamps, mountings and control elements. Parts are ordered using a special spare part number and they are produced layer-by-layer from powdered polyamide source materials (Daimler, 2020).

In addition to plastic components, Daimler is also working with partners on the application of AM for metal parts using selective laser melting (SLM) and powdered aluminium/silicon, and the first AM aluminium component for trucks is already available as a spare part. Given AM metal parts excel with their high strength and thermal resistance, AM is suitable for low-volume production of thermally and mechanically stressed components. Therefore, the 3D production of metal parts started with rarely ordered aluminium components, which are characterised by almost 100% density and greater purity compared with conventional die-cast aluminium parts. Areas of use include peripheral engine parts, in-engine parts and parts in cooling systems, transmissions or chassis (Daimler, 2017).

As a result, it is possible to guarantee supply of parts with sporadic demand, as well as parts where production is conventionally uneconomical or has ceased. Daimler has found that parts manufacture and delivery is faster, while costs and resources are lower (Daimler, 2020; Taylor and Cremer, 2016).

5.2.2.2 Volvo Construction Equipment (CE)

Volvo CE develops, manufactures and markets equipment for construction and related industries. The company has adopted additive manufacturing for the production of spare parts, as well as the research and development of prototype machinery.

The proprietary archive drawings, 3D models and product information are fed into the printer to produce components. These include parts of a cabin, plastic coverings and sections of air conditioning units.

"Lead-times are significantly reduced with 3D printing and since there are no minimum order quantity requirements, we benefit from quicker delivery of parts, lower inventory levels in our warehouses and an improved ability to balance supply and demand," says Daniel Kalfholm, Project Leader for Aftermarket Purchasing for Volvo CE’s EMEA region (Volvo Construction Equipment, 2018).

Figure 21
Printed thermostat covers (Daimler, 2017).

Figure 22
A 3D printed workshop tool for mounting parts on an axle (Volvo Construction Equipment, 2018).

5.2.1.3 3D printing-based maintenance

A prototype system to support the maintenance of damaged parts using 3D scanners and 3D printers has been developed in order to assist users who have little to no experience in part design. The system aims to support the user by providing the information required for each step and assisting with maintenance tasks such as inspection.

1. Retrieval phase

The point cloud representing the shape of the component is acquired using a 3D scanner. Through similarity-based or keyword-based retrieval methods, it is possible to obtain the part information from a 3D printable part library. The user retrieves the component 3D CAD data along with the necessary information regarding part functions, 3D printing, maintenance and inspection, and CAD data quality.

2. Manufacturing phase

The user enters the CAD data into the printer and refers to the printing-related information to set parameters such as laser power and build.

3. Inspection phase

The printed component is scanned and the acquired point cloud is used to calculate the shape error. Using the CAD data and maintenance information of the part, the user can judge the validity of the replacement.
5.2.2.4 Mineral Technologies (MT) and University of Technology Sydney (UTS)

Mineral Technologies has partnered with UTS to develop AM technology for precision-engineered mineral separation and mining equipment. In particular, gravity concentrators (spirals) (Figure 24) are used by mining companies to separate minerals, and they present several operational challenges. Firstly, they are costly to manufacture and can expose operators to chemicals and other hazards. Additionally, different spiral models are continuously needed in the field, thus operators require numerous customised versions of the same product. Currently, fabrication of the traditionally handcrafted spirals occurs in a single location and the spirals are shipped to mining sites around the world.

A product-specific AM machine has been designed and prototyped to optimise the manufacturing process of gravity concentrators. Products are also equipped with Internet of Things (IoT) sensors that allow them to send feedback about the performance and information regarding the structural characteristics for specific minerals and ore concentrations (IMCRC, 2021). Further, Mineral Technologies can eliminate shipping times by sending a machine to produce spirals to mine sites, rather than the individual spirals – thus employing distributed manufacturing for their custom products.

“Mineral Technologies can eliminate shipping times by sending a machine to produce spirals to mine sites, rather than the individual spirals – thus employing distributed manufacturing for their custom products.”
Australian agribusinesses planning to adopt AM should consider several factors. Consideration of these factors will improve use of the technology and clarify the value proposition of AM. These factors are detailed in this section to provide guidance to industry in this emerging technology, as little institutional knowledge in the agriculture supply chain exists due to very limited adoption to date. Thus, this section aids in reducing the potential obstacles in the uptake of AM by clarifying them.

The degree to which each presented factor will affect a business depends on the characteristics of that business and the environment in which it operates. Similarly, the ease with which these factors are managed may vary depending on the context of each business.

In the context of AM within Australian agriculture, the typical use case is characterised by a company that produces a part or product using AM technology. As such, the environmental conditions in which the business operates will influence the choice of AM technology and the factors that need to be considered. The virtual supply chain provides a slightly different challenge, which varies across different sectors and locations in the supply chain, as it requires some digital infrastructure for digital file handling, manipulation, and potentially new license agreements. Further, the actual production process that brings together the three chains to produce a part is typically less cumbersome than common machining operations used to produce parts and would be straightforward for many.

Figure 25 Model of AM supply chain in agriculture (adapted from Gupta et al, 2020).

6.1 Physical supply chain and printer hardware

A common concern related to the implementation of AM is the cost of hardware. In particular, the cost of printers varies depending on the process type and desired quality. For example, smaller material extrusion printers cost about US$10,000 while the most advanced laser-based machines may cost up to US$500,000. Machine investments should be treated as all equipment investments with the same accounting and business rationale.

Machine features such as weight and size are similarly matched to other production equipment. Heavy machines require additional costs to transport, as they may need to be delivered via truck or helicopter. The user must also ensure they have enough space to fit the machine and other required auxiliary equipment, as well as maintenance access. These considerations are particularly important for users who intend to install machines in transportable containers (e.g. a CONEX container) or small spaces aboard vessels. The size of the build envelope (i.e. the volume in which parts can be produced without need for assembly) can also be a constraint and users need to ensure that the printer meets their intended use (Meisel et al, 2016).

In addition to typical hardware considerations related to cost, size and weight, quality can be another consideration. In particular, most AM processes trade low precision and dimensional accuracy for higher speed and bigger build volumes. Thus, post-processing or awareness of the expected surface roughness of printed parts is key to selection. Using AM may require additional quality control procedures and post-processing activities to achieve a specified surface smoothness or corner sharpness. AM is suitable for the production of low volumes and in most cases does not allow for economies of scale when compared with injection moulding, stamping, or die forming.

Printers also require energy as depreciation is almost always in concert with a heat or energy source. In particular, power requirements may be significant in austere or remote environments. For instance, many AM machines require 230–240VAC three-phase power. Metal AM machines may require 480VAC three-phase power. Some processes also require gas or water supplies for post-processing. For example, metal-based AM processes can require high-purity argon, nitrogen or helium for processing, while Stratasys’ Fused Deposition Modelling and PolyJet requires water (Meisel et al, 2016).

Finally, in the case of agribusiness, the environment in which the machine operates has significant influence on the resulting part quality. Factors like temperature, humidity and dust can affect the part quality. Overall, different environments impose different constraints, and machine manufacturers will specify the preferred operating environments. Set-up and use in new environments will require some tuning to understand how the environment affects performance and the preferred operating parameters. Watercraft-based environments are affected by factors such as water, salinity, noise sensitivity on the ship and rocking of the ship (Meisel et al, 2016), and these may also influence machine performance and part quality. By and large, these environment considerations need to be accounted for when setting up the system and fabrication parameters.

6.2 Physical supply chain and raw materials

Similarly to printer hardware, the cost of raw materials can represent a step in the selection process. Costs vary widely depending on the process to which the material is destined and the form of the raw material (pellet, powder, filament). Polymer materials range US$8–250 per kilogram, while metals range US$78–120 per kilogram and US$340–880 for titanium (Meisel et al, 2016). However, in some cases it is possible to obtain material from recycled objects by using specific machines – recyclers – that produce filament from either virgin or recycled material. For example, a recyclebot can produce PLA filament from virgin PLA pellets (Pearso, 2015).

The availability of printable materials can also present a decision point depending on the intended application. At the moment, there are no commercial printers that process both plastics and metals. In addition, different machines can process specific ranges of materials. For example, while PolyJet and material extrusion processes can process a wide range of polymers, laser sintering can process a much narrower one (Meisel et al, 2016).

Finally, just as environmental conditions affect printer hardware, they also affect raw materials. Often, consumable material such as powder resin or filament needs to be stored in a climate-controlled environment, which in the case of austere or remote locations can require additional planning (Meisel et al, 2016).
6.3 Virtual supply chain and digital files

As digital files are an essential component of AM processes, ensuring access to digital designs may need addressing for specific sectors. Digital designs are protected by intellectual property (IP) rights and for that reason their access must be integrated under contracts between suppliers and developers. A company’s relationship with a supplier changes with its position in the supply chain and it is important to arrange access to digital designs before implementing AM (Boer et al., 2020). Also, the availability of design files depends on the level of digitalisation of the supplier, which may not always have a digital copy of parts.

In some cases, digital designs are not readily available and companies may need to purchase them. In other cases, it is possible to access open-source designs through many 3D model search engines, especially in the case of generic components (see example 5.11).

Although design files are protected by digital use rights, there is still some ambiguity about IP rights, which makes the virtual supply chain vulnerable to IP theft, sabotage, counterfeit production and other threats (Bipeta et al., 2020). The regulation bottleneck also extends to component certification, liability and warranty (Verboeket and Krikke, 2019b). Clear agreements are necessary and these need to specify the conditions for the use of parts and their related warranties in order to ensure continuity of a system (Boer et al., 2020). The issue is not limited to digital files and parts, as new regulations are required for processes to guarantee quality assurance, process certification and process qualification (Verboeket and Krikke, 2019b). While these are emerging concerns, equipment suppliers are moving towards more flexible or aware arrangements that will continue to enable or define the IP and use environment. These difficulties arise from several factors. First, the overall business complexity increases in line with the increased product variety, and AM offers an immediate increase in product variety.

Second, the AM industry is still optimising cost structures (i.e., machine costs, material costs and labour costs), and this generates some uncertainty in cost calculation models (Ballardini et al., 2018; Martinsuo and Luomaranta, 2018). This uncertainty will reduce as markets and sub-markets stabilise. For example, applications further to the right in Figure 4 have less uncertainty and clearer cost models.

Third, the increased collaboration between design, manufacturing and logistics may require more integration between different departments than currently exists within an organisation. Last, implementing AM requires the development of new skills and knowledge at all levels of the organisation, and it may not always be easy to implement the right training programs. This training and skill development is available through universities, a growing number of machine suppliers and online content.

6.4 Business processes

The implementation of AM affects and is affected by other business processes of the organisation. In particular, the attitude towards innovation in an organisation is a key enabling component. The perception of top management regarding relative advantage, compatibility, facilitating conditions and performance expectations is positively associated with the intention to adopt AM (Schneiderjans, 2017).

The lack of established know-how, as well as difficulties in management and implementation, can represent initial barriers for AM adoption (Dettmeier and Hofmann, 2016; Pfahler et al, 2019). These difficulties arise from several factors. First, the overall business complexity increases in line with the increased product variety, and AM offers an immediate increase in product variety. Second, the AM industry is still optimising cost structures (i.e., machine costs, material costs and labour costs), and this generates some uncertainty in cost calculation models (Ballardini et al., 2018; Martinsuo and Luomaranta, 2018). This uncertainty will reduce as markets and sub-markets stabilise. For example, applications further to the right in Figure 4 have less uncertainty and clearer cost models.

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In addition to the management and implementation considerations, the level of collaboration among the company, its customers and its suppliers also affects adoption of AM. For example, including AM in a supply chain may push for a redesign of production networks, where companies could use AM to produce parts using data files provided by their suppliers (Meyer et al., 2020). On the other hand, as AM allows new possibilities for customisation, customers could become more involved in the design phase of products and components. Thus, strong communication and interoperability throughout a supply chain aids in adopting AM.

Finally, the standards and regulations around AM are still evolving. Thus certification of components, processes, and digital formats is in flux or may not be available. This regulatory lag represents an opportunity to help define industry standards, but also a need to remain flexible as guidance or requirements may change over time more quickly than long-established industries.

Table 8 summarises the considerations arising from each component.
Based on the opportunities, barriers and use cases identified in previous chapters, we conducted surveys and interviews to investigate the adoption level of AM in Australian agribusinesses, as well as perceptions and expectations around adoption.

### Empirical findings of additive manufacturing for agribusinesses

#### 7.1 Survey

The survey was intended to get detailed information from a broad range of people across agribusinesses. It was an opportunity to understand the varying needs and knowledge without costly and time-consuming travel to visit each respondent. The initial survey was constructed and distributed in February and went live prior to 4 March 2021. The survey was open for eight weeks prior to the results being summarised in this report.

#### 7.1.1 Survey distribution

Survey distribution occurred through multiple avenues. Notable organisation across agricultural industries were contacted in order to obtain a comprehensive overview of industry needs (Table 9). More than 61 organisations received the survey by way of 77 direct contacts. Recipients received the survey via direct contact from the research team with a request to complete it and distribute it further (distribution channels included industry, government, and locally curated newsletters).

#### 7.1.2 Survey response

Despite the several hundred individuals who received the survey, the response rate was quite low. A low response was attributed to a large number of contemporaneous surveys. The survey was opened 33 times, but the majority did not proceed past the first question of agreeing to participate in the research project. Only four respondents completed the survey in full.

Seven respondents provided information about their demographics. Figure 26 illustrates the main characteristics of this pool of respondents.

#### 7.1.3 Survey results

Given the small response rate, conducting a statistical analysis is not possible nor conclusive. However, useful information about current knowledge, needs and challenges for specific industries was collected.

One respondent from a small organisation (0-4 employees) operating in fisheries provided a series of uses cases applicable to the industry. In particular, the respondent noted that AM can help companies with on-demand production of fish tagging, replacement parts for outboard motors, repairing objects including boat radios and ice boxes, and on-demand production of electronic components embedded in radios, radars and lights for floats. The respondent also pointed out the general risk of corrosiveness and the need for materials that are resistant to salt water.

Another respondent from a large organisation (more than 200 employees) in meat and livestock stated that their organisation is already using small-scale 3D printing for prototyping. The respondent also recognised high potential of AM for prototyping complex parts for automated systems, as well as for the production of mechanical spare parts in remote locations. In addition to these uses, the respondent showed interest in AM for prototyping and producing novel foods.

Some respondents also provided suggestions regarding what elements would assist them in adopting AM. In particular, demonstrations of feasibility and information about the value proposition were listed as helpful factors.
Finally, only two respondents provided their opinion around barriers to adoption. Some of these barriers have been considered as severe by one or both the candidates. These include:

- **Technological barriers**
  - The performance of machines and materials is limited.
  - Machines and materials are too expensive.
  - The organisation lacks CAD skills to create its own parts.

- **Operational barriers**
  - The effort of pre- and post-processing of printed parts is too expensive or requires additional machines.
  - Integrating different departments to adopt additive manufacturing would be a major challenge.

- **Organisational barriers**
  - New skills could be built through specific additive manufacturing training but management is not willing to go ahead.
  - In general, the organisation does not trust new technologies and is not readily willing to adopt them.
  - The organisation focuses on reducing manufacturing costs through economies of scale (large output volumes) and additive manufacturing does not support this.
  - The organisation does not have formal design guidelines to revise parts for additive manufacturing.

- **Supply chain barriers**
  - The industry partners do not have a sufficient level of digitalisation to allow for sharing digital CAD parts.
  - Collaborating with industry partners is a general challenge.
  - The organisation is concerned about the risk of their CAD designs and IP getting stolen or being shared in an uncontrolled manner.

- **The organisation cannot access the standards and certification of processes, materials and components needed for additive manufacturing.

- **The customers are against implementing additive manufacturing.

- **The organisation and its suppliers and customers do not have the infrastructure and systems to share digital CAD files efficiently.

The opportunities and concerns raised in the survey are consistent with broader research into adoption. Many of the concerns can be mitigated with facilitated training and collaboration or through education in successful use cases and scoping of company-specific uses.

### 7.2 Interviews and workshop

As identified in the survey, some organisations find it helpful seeing demonstrations and physical demonstrator parts to understand the variety, feasibility and value proposition of AM. Therefore, in addition to the initial survey, we conducted a targeted workshop at UTS on AM technology and possible uses for agribusinesses. We also conducted in-depth interviews with a subset of industry representatives in order to obtain more information.

### 7.2.1 Interviews

The original project design included an expectation of a sufficient number of respondents in the survey indicating they would like to be contacted for this follow-up interview. We would have then selected respondents from this pool. However, due to the low survey response rate, interviewees have been identified through direct contact and direct referrals separate from the survey.

Two interviews were conducted. Interviewees represented the broadacre (grain and irrigation) and fishing sectors. Interviewees were asked about the prompts and questions as listed in the Appendix, and their general understanding of AM and its use (or potential use).

**Broadacre (grains/irrigation)**

Broadacre producers see themselves as end users and not suppliers of the technology. This position expects others in the industry to adopt and offer fabrication services. The model that seems likely to be successful from the end user perspective is similar to that of an existing parts supplier as a service or facility in a local area or large region that provides the service of additive manufacturing production to end users.

Some concerns included assurance or presentation of the durability of the parts and the desire not to void the warranty on a system when using an aftermarket product. The producer had insufficient experience with the technology but was not hesitant to use it for current needs. AM was likened to other technologies such as drones and robotics in terms of the path to use in the industry.

The range of materials, surface quality and performance of products was not a major concern provided the performance was known at the time of purchase. All presented use cases (see Appendix) were confirmed as relevant for the industry. Adaptation to the new technology by the industry and access to the necessary skills were not significant concerns as the broadacre sector is generally adaptable and already invests in new automation, scanning and drone technology. The trend toward larger corporate farms also indicates ability of the market to adopt technology and adapt with relative ease. Some existing collaboration along the supply chain already includes transferring digital information, but often it does not, which may be a change to manage for AM specifically.

One area where AM offered significant potential value is that of time-critical operations such as harvesting, spraying or planting. Unexpected part failures that occur during these times may cause long overnight commutes to retrieve replacements as fast as possible. As such, the opportunity to have capability on-site or nearby during these critical times to fabricate unexpected or hard-to-source components was very compelling.

It was noted that the ageing workforce could also benefit from mass ergonomic customisation. Mass customisation may also enhance mobility or enable an otherwise disabled workforce to continue and thrive in the industry. Producers were noted as being very price-sensitive, so the major decision factor is expected to be the cost of having the functionality.

The presented business models for centralised and distributed production were confirmed as both being possible and having a role in the industry depending on the parts and need.

**Fishing**

The fishing interviewee works primarily with small fishing entities, which consider themselves quite low-tech. With this in mind, the development, testing and production of customised lures, equipment and traps offered potential value. They believed the exposure to and knowledge of additive manufacturing across the represented segment of the industry was limited.

The product development phase or customised consumer products related to fishing offered the most intriguing use cases. Adoption of AM by individual fishers seemed unlikely given current industry uptake of other technologies and access to relevant software and technical skills. Most challenges to adoption were irrelevant as the use cases were largely not applicable to single or small fishing vessel entities. Semi-distributed manufacturing was of interest to this industry given the potential for vessels to move up and down coasts and the need for parts wherever they may end up. Near-term adoption of AM was considered most likely by fishers wanting fabricated lures with tailored or customised performance, given the substantial cost currently experienced in developing and testing moulded designs. AM can offer rapid iteration without the need for mould development and can test very large numbers of permutations in design. In addition, the potential for customised locking or tamper-resistant equipment to prevent theft from traps was also compelling.
7.2.2 Workshop

In addition to the interviews, the research team hosted a workshop on 23 April 2021 at UTS in the premier additive manufacturing facility ProtoSpace. Nine participants registered. Eight participants attended, representing the red meat, wool and grains industries, livestock technology supply, and investment NSW (part of NSW Treasury). The workshop included an overview and introduction to the breadth, applications, machines and materials available in additive manufacturing, along with an in-depth discussion on the applicability, uses and potential in the represented industries.

According to the participants, a key outcome and take-away from this workshop was a better understanding of AM, and that AM goes far beyond simple desktop 3D printers. The opportunity to manufacture metal parts or multi-material parts combining stiff and flexible materials was seen as both novel and highly relevant for current needs.

Participants identified that additional events like this workshop, presentations at trade shows, and access to the ProtoSpace facility could be very useful for them and their constituents. Participants also mentioned that they had gained a good sense of the main markers that would suggest additive manufacturing provides a significant value proposition, and were forming ideas about where to use it in their respective projects.

Participants noted that potential end users from their industries may be hesitant to adopt AM without a clear value proposition, and were forming ideas about where to use it in their respective projects.

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The discussions and conversations, especially in the second part of the workshop, provided some insights to validate and enhance the survey and interview findings. As some information shared might be business-sensitive, we have abstained from sharing specific details in the following sections.

a. Opportunities and use cases

The participants showed interest in several use cases enabled by AM. In particular, some participants from meat and livestock organisations were interested in using both metal and non-metal AM in order to re-engineer components like spare parts. To reduce the effort required by agribusinesses, the 3D designs of these components could be stored and made available through an online database. Their vision also included decentralised shop units or even mobile units with non-metal printers available across the country to manufacture the components in the near-future, and a similar structure for metal printers in a distant future.

Another participant from the same industry was interested in fast prototyping and producing animal tags. Material-wise, the ability to manufacture multi-material tags with flexible and more rigid parts would allow attachment, with flexibility at the attachment location and rigid materials to protect non-flexible electronic elements. From a research and development (R&D) perspective, local AM machines in Australia would significantly reduce prototyping efforts and accelerate solving this challenge.

In comparison with the usual use of overseas manufacturers, this would reduce prototyping costs by several thousands of dollars, avoid lengthy shipping times, significantly increase the speed of prototyping, and bypass cultural and language barriers and misunderstandings that can affect product quality.

b. Barriers

The barriers mentioned align with those from the survey. These include:

- Digital collaboration. Some participants pointed out the necessity to push ideas and use cases for AM to their suppliers and manufacturers to build synergies within the supply chain. Similarly, in the survey, some respondents recognised collaborating with industry partners would be a potential challenge, as well as the fact that in some cases customers and suppliers do not have the right infrastructure to share, for example, CAD files effectively.

- CAD design skills. In line with those suggestions, another participant noted the need to develop design skills for AM. Often, organisations do not have the necessary design skills to build 3D models of parts. A participant also pointed out a high level of difficulty in finding people with these skills on the market.

- Intellectual property (IP) and certification. With respect to building an envisioned database of 3D designs of agriculture components, unanswered questions remain around IP issues when, for example, commercial spare parts are imitated or redesigned. Another issue is who would be responsible and accountable if a component manufactured based on the provided 3D designs fails. This might require a certification process to ensure safe designs.

- Manufacturing a large number of components. Finally, in the context of animal tracing, a participant highlighted the need for cheap tags produced in high volumes, especially in a scenario where animals are equipped with passive tags. In fact, the volume needed is in the order of millions and the cost needs to be kept at about a few cents per tag, or offer significant value. For this specific application, the performance of AM machines would be limited, and generally AM would not be a convenient option. On the other hand, fast prototyping through AM would offer consistently more benefits in developing a solution.

In general, participants recognised the high potential of AM for production anywhere in Australia, and how it could ultimately enable regional development, along with its ability to create fast and reliable supply chains.
8.1 Considerations and requirements for additive manufacturing deployment

Adoption of additive manufacturing, like other new technology investment, requires consideration of the detailed application and implementation. As the breadth and scale of AM machines and materials is vast, a business and application-specific approach is most suitable, rather than an industry-wide approach. Individual companies can articulate their needs in collaboration with AM experts to identify appropriate options for machines, materials and business models. In addition, the capacity to internalise relevant technical functions or externalise them to other niche suppliers is a key business decision.

Table 10 outlines some of the detailed considerations when selecting a machine, machine and material combination, and can serve as a checklist of decisions that need to be made when considering AM deployment. Working through such a checklist will clarify whether an appropriate process, machine and material combination exists, and whether the company can suitably implement the selection.

8.2 Economics of additive manufacturing

There are several cost models for AM operations. The appropriate model for a given product-machine-material combination will vary. Next, we present an example analysis of the economics and payback volume/price for additively manufactured components to aid in illustrating how to evaluate adoption. This example uses laser sintering, which is a common technology used for the industrial production of plastic parts, and the production costs have been empirically estimated and quantified in Table 11, by Baumers and Holwed. Baumers and Holwed’s experiment aimed to reproduce the costs associated with the AM process of laser sintering, and to empirically support the expected relationship between cost and volume (Baumers and Holwed, 2019).

The article presents two scenarios in which the operator has different levels of expertise. The experienced operator has three years of professional experience compared with the novice operator, who has received only training comprising machine induction, safety briefing, three build demonstrations by an instructor and supervised practice build. In both cases, the operators had to process 14 builds using default parameters.

The build volume is the maximum volume within which parts can be produced, and the degree to which it is used determines how efficiently the set-up costs are spread across parts. In other words, as each build can produce multiple parts at the same time, the operator tries to fit as many parts as possible in one execution to optimise the build space. In this experiment, if the operator commits to the entire capacity available up to the maximum build volume height, they can fit 55 parts.

Table 11 outlines some of the detailed considerations...
Table 11
Example of production costs for laser sintering (Baumers and Holwed, 2019).

<table>
<thead>
<tr>
<th>Cost model element</th>
<th>Data point</th>
<th>Value</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>Labour cost</td>
<td>Full annual labour cost, novice operator</td>
<td>$46,015</td>
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<tr>
<td></td>
<td>Full annual labour cost, expert operator</td>
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<td>/year</td>
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<td></td>
<td>Working days net of holidays</td>
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<td></td>
<td>Total hours worked per year</td>
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<td></td>
<td>Labour cost rate, novice operator</td>
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<td>/h</td>
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<tr>
<td></td>
<td>Labour cost rate, expert operator</td>
<td>$37.61</td>
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<td>Fixed energy consumption per build</td>
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<td>Total machine cost rate</td>
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<td></td>
<td>Total indirect cost rate</td>
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9.1 Summary of findings and insights

This project identified and summarised the opportunities and challenges for adoption of additive manufacturing across several agricultural sectors. The results of a global literature search were combined with direct information gathered from Australian industry representatives. We identified the key value opportunities for additive manufacturing as those where complex geometry, multi-material combinations, high variety of parts, or geospatial constraints draw a premium. The primary hurdles to adoption given the current maturity of additive manufacturing are awareness and adjusting ways of thinking.

To maximise the benefits of additive manufacturing, adjustments are needed in the way people think about how parts and products are produced, and even what is possible. This changed way of thinking takes time and requires exposure at multiple points in the supply chain. To aid this thinking, we collected specific use cases and detailed them in this report.

In addition to the examples found here and the workshop held as part of this project, we recommend additional education and outreach activities be held to socialise the opportunities of this technology. These outreach activities should provide participants with insight into the breadth of options available, consultation time to discuss their individual needs, and guided practice with some facet of the production workflow.

9.2 Limitations of findings

Industry input was limited due to a weak response to invitations. Many other examples of additive manufacturing are available. Those presented were selected from industries with similar features to agriculture, although others may also be applicable in specific contexts.

9.3 Proposed next steps

• Additional education and outreach activities.
• Targeted deployment with training to build confidence.
• Tailored recommendations for specific industries, companies and steps in supply chains.
• Concierge or dedicated support for industry to identify worthwhile adoption strategies.

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9.3 Proposed next steps

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• Targeted deployment with training to build confidence.
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Key survey questions

<table>
<thead>
<tr>
<th>How useful/relevant do you find the use of additive manufacturing in your organisation?</th>
<th>Not relevant</th>
<th>Minor relevant</th>
<th>Somewhat relevant</th>
<th>Very relevant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small-scale 3D printing for prototypes and small objects</td>
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<tr>
<td>Digital inventory</td>
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<tr>
<td>On-demand production</td>
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<tr>
<td>Production in remote locations</td>
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<tr>
<td>Replacement parts</td>
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<tr>
<td>Repairs</td>
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<td></td>
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<tr>
<td>Customisable components</td>
<td></td>
<td></td>
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<tr>
<td>Reverse engineering for old or unsupported equipment</td>
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<tr>
<td>Redesign/optimisation of existing products</td>
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</tbody>
</table>

Key survey questions

<table>
<thead>
<tr>
<th>How likely would this barrier apply to your organisation?</th>
<th>Definitely not an issue</th>
<th>Probably an issue</th>
<th>Definitely an issue</th>
<th>Unclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance of machines and material are too limited for our business</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machines and materials are too expensive</td>
<td></td>
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<tr>
<td>We lack necessary CAD skills to create own parts</td>
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<tr>
<td>Our parts would be too big for an additive manufacturing machine</td>
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<tr>
<td>We believe the technology is not mature enough</td>
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<tr>
<td>The surface quality or precision of printed parts is insufficient</td>
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<tr>
<td>There is a lack of standards and guidelines to support additive manufacturing</td>
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<tr>
<td>We would need new predictive models to predict e.g. material properties, costs, etc.</td>
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</tr>
<tr>
<td>How likely do you think the following barriers apply to your organisation?</td>
<td>How severe is the barrier in respect to your organisation?</td>
<td></td>
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<tr>
<td>---</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Definitely no issue</td>
<td>Probably an issue</td>
<td>Definitely an issue</td>
<td>Unsure</td>
<td>Minor issue</td>
</tr>
<tr>
<td>The benefits of additive manufacturing for my business are unclear.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>It is unclear how to manage intellectual property agreements for our digital CAD parts.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Existing regulations appear too uncertain in terms of e.g. copyright infringements, warranty of self-manufactured spare parts, counterfeit products etc.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The energy consumption is too high and conflicts with our sustainability goals.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Printing materials are difficult and expensive</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How likely do you think the following barriers apply to your organisation?</th>
<th>How severe do you think the following barriers are in respect to your organisation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitely no issue</td>
<td>Probably an issue</td>
</tr>
<tr>
<td>We do not have the necessary IT support for creating CAD parts and printing them.</td>
<td>○</td>
</tr>
<tr>
<td>Digitising our business or gaining access to existing CAD parts is too expensive.</td>
<td>○</td>
</tr>
<tr>
<td>The effort of pre- and post-processing of printed parts is too expensive or requires additional machines.</td>
<td>○</td>
</tr>
<tr>
<td>Business processes will get more complex when additive manufacturing allows for a greater product variety.</td>
<td>○</td>
</tr>
<tr>
<td>Integrating different departments to adopt additive manufacturing would be a major challenge.</td>
<td>○</td>
</tr>
<tr>
<td>Developing new quality control and management measures for additive manufacturing would be a major challenge.</td>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>My organisation does not have the right skill and expertise to adopt additive manufacturing.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>We could build new skills through specific additive manufacturing trainings but the management is not willing to go ahead.</td>
<td>○</td>
</tr>
<tr>
<td>In general, my organisation does not trust new technologies and is not willing to adopt them easily.</td>
<td>○</td>
</tr>
<tr>
<td>My organisation focuses on reducing manufacturing costs through economy of scales (large output volumes) and additive manufacturing does not support this.</td>
<td>○</td>
</tr>
<tr>
<td>My organisation does not have formal design guidelines to review parts for additive manufacturing.</td>
<td>○</td>
</tr>
</tbody>
</table>

<table>
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<th>How likely do you think the following barriers apply to your organisation?</th>
<th>How severe do you think the following barriers are in respect to your organisation?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitely no issue</td>
<td>Probably an issue</td>
</tr>
<tr>
<td>Our industry partners do not have a sufficient level of digitalisation to allow for sharing digital CAD parts.</td>
<td>○</td>
</tr>
<tr>
<td>Collaboration with industry partners is a general challenge.</td>
<td>○</td>
</tr>
<tr>
<td>We are concerned about the risk of our CAD designs and IP getting stolen or shared in an uncontrolled manner.</td>
<td>○</td>
</tr>
<tr>
<td>Difficulties in handling sensitive materials like IP prevents my organisation from implementing additive manufacturing.</td>
<td>○</td>
</tr>
<tr>
<td>My organisation cannot access the standards and certification of processes, materials and components needed for additive manufacturing.</td>
<td>○</td>
</tr>
<tr>
<td>Our suppliers are against implementing additive manufacturing.</td>
<td>○</td>
</tr>
<tr>
<td>Our customers are against implementing additive manufacturing.</td>
<td>○</td>
</tr>
<tr>
<td>We and our suppliers and customers do not have the infrastructure and systems to share digital CAD files efficiently.</td>
<td>○</td>
</tr>
</tbody>
</table>

https://www.researchgate.net/publication/272349519_Rapid_Agricultural_Supply_Chain_Risk_Assessment_A_Conceptual_Framework


References


