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Transport Replacement and Sustainability aspects associated with Additive manufacturing

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Sustainability aspects associated with Additive manufacturing

Introduction and abstract

Additive manufacturing has a range of characteristics that suggest enhancements to sustainability should be possible. The nature of the process influences not only how products can be made, but also how they can be delivered. Logistics and the global supply chain are central aspects to manufacturing, and considerable attention is being paid to making the supply chain more sustainable. This often makes sound economic sense without any consideration of the environmental benefits, as this usually delivers energy reductions and reduced reworking or redelivery.

Additive manufacturing has also secured increasing attention from a sustainability standpoint, but this has in the main focussed on the embodied energy of the products created, and the various aspects of the production processes used. Not all Additive manufacturing processes are parsimonious in their use of power.

CAD/Cam design has long permitted global design collaborations, independent of the locations of the collaborators, with manufacturing located in the most advantageous location. The expansion of the whole design, production and delivery process afforded by 3D printers requires the growth in (Southworth and Wigan, 2008) global logistics to be included in a broader perspective.

One that has to date had very limited attention in the literature is the integration of the final retail sales aspects with the distributed manufacturing processes that 3D printers now permit.

Only a few market segments are yet affected, but it is reasonable to expect that as 3D printers expand in capacity, and the diversity of materials and levels of precision possible using them expand, that more and more market segments will require such a broader view.

The growth in global logistics has become critical to the now-readily changed choice manufacturing locations and to the integration of product and partially manufactured product flows, to warehousing, and to final retail distribution (for those products sold via retail).

Biological printing will not be addressed in this paper.

The characteristics of Logistics

Logistics includes storage, shipping and aspects of manufacture. It is data intensive and global, and has become an integral part of global product creation, production and delivery. The most visible impacts of these changes are seen in transport, especially by road, where freight movements have been growing rapidly. A further doubling of freight flows by 2030 is widely expected in UK, Australia and North America.

Only fairly recently has the even more rapid growth of small trucks and delivery vehicles been noticed: these are growing at an even higher rate, but are often not easily distinguished from private vehicles (Browne et al., 2002). The steady growth in the level and extent of urban congestion means that reductions in the flows of such small vehicle will have disproportionately beneficial effects on the transport network functioning as congestion levels rise.

The development of Additive Manufacturing (AM) techniques now permit an increasing number of products to be manufactured at global locations – but the focus on component manufacturing in such advanced Additive manufacturing sectors as aircraft engines means that the assembly still takes place in a specific location, and global logistics movement and storage and synchronisation requirements continue to apply. Manufacturing a jet engine turbine blade in Australia – however economically - still requires the blade to travel to an assembly location the other side of the world.

The logistics function is increasingly carried out by specialists with a global reach, and who have their own incentives to enhance the sustainability of their function. This within- 'industry' activity focuses on minimising the costs of movement, storage and energy usage between each customer collection or delivery point.

Different sectors are addressing supply chain issues at different rates: packaged finished consumer goods have become extremely effective, but the customer-facing retail industry that they serve have not progressed nearly as far (kpmg.uk, 2011) . Issues such as reduced packaging can be as important as transport movement reductions.

Adding endpoint product creation to AM and Supply Chains

Kpmg noted that has a potential impact on retail supply chains, but did not consider that the expansion of the context to encompass manufacturing in the home or at the business wanting the final product takes the supply chain considerably further. It is then necessary to examine what the impacts are likely to be if manufacturing becomes distributed in this sense, and what the implications are for the various parties in the overall supply and production and final delivery chain.

This is not surprising, as this is an example of yet another industry feeling the early impacts of disintermediation. Retail trade has increasingly had to focus on improving its multidomestic advantages of proximity to the customer, to ward off competition from direct purchases from overseas. Currently this competition is largely between retailers over seas and retailers locally, but the shift to manufacturer direct to customer is already apparent in a number of ways.

As information rich information exchanges expand through more rapid and more comprehensive communications, so too do the opportunities for disintermediation of enhanced customisation and direct production to consumer requirements.

This trend, of mass customisation, has been growing in many areas but is most apparent in car manufacturing where a whole range of cars, every one different from every other one, can now be see on single production lines all across the world.

The global linkage of supply chains is now such that the vulnerabilities to disturbance are substantial. As presented to the World Economic Forum:

> *'Volatility is the new normal in supply chain and logistics. We need to be more dynamic, more savvy and more informed than ever before to optimize and mitigate risk.''*

This aspect of supply chains will accelerate and increase the value of disintermediation of production and creation locations wherever possible: this is a role for AM, certainly for end products that can be created by AM at the destination point, but also for intermediate products as the value of reliability rises steadily in supplier and shipper evaluations of supply chain evaluations (Fuller et al., 2003).

Not surprisingly, as an industry beginning to see disintermediation starting to threaten part of their core function, the logistics industry sees itself as the natural provider for 3D printing, in view of their 'last mile' specialisation, and therefore see it as the role of the logistics industry to create local and regional 3D printing facilities integrated with their 'last mile expertise' (DHL, 2010). This strategy has already been picked up by UPS (UPS, 2013) in the USA using Stratasys uPrint SE Plus printers for public use at their facilities.

On the other hand, the retail trade itself has already moved to make home oriented 3D printers available in mass consumer market chains such as Staples office equipment in the USA (Staples Office Equipment, 2013) and Maplin high street electronic stores in the UK (Bell, 2013). These developments will accelerate disintermediation not only of the logistics industry but also the retail trade itself, albeit not the stores selling electronic equipment, with new services already emerging such as the 3D scanning and printing services at ASDA stores in the UK (ASDA UK, 2013). This new service orientation, by ASDA and UPS, exemplify product growth that requires no logistics services at all beyond the generic working feedstocks.

The rate of development of the industry supplying 3D printers (additive manufacturing devices) has 'hit an inflexion point' (Basiliere et al., 2013), and is predicted to double every year for the next few years with a concomitant precipitous drop in the cost and increase in the capabilities. Clearly the logistics and supply chain processes both by logistics operators and by retailers will be equally challenged by household purchases of 3D printers: albeit initially only those capable of making what is already a rapidly increasing number of smaller items.

Market segmentation for sustainability and environmental impacts

The sustainability and environmental aspects of growing use of AM (3D Printing) will affect different market segments at different rates. Major categories can usefully be grouped as follows for this purpose:

- Local (e.g. household focused)
- Regionally (e.g. relocalised manufacture/warehouses: services at ASDA etc)
- Globally (e.g. supply chain restructuring)
- Out of this world (ISS, AMAZE, lunar construction)

In each case developments are either under way, in operation, or at an early stage in implementation.

A useful phrase when considering the sustainability and environmental aspects is 'zero length supply chains', complemented by 'reduced waste'. Both have quite different types of contributions to make.

Another segmentation is in terms of the industries involved, with examples:

- Individuals (product replacement)
- Special interest groups (vintage car enthusiasts)
- Retail (mass customisation and services)
- Manufacturing itself (economic small runs, every one potentially different, at no incremental cost: hearing aids, spectacles, orthotics, footware, customised medical metal surgical and other devices and biological items)

A further segmentation is in terms of manufacturing technologies themselves:

- Factories of the Future (productivity, standardisation, quality, precision)
- New materials (lunar regolith, titanium and other mixed feedstocks)

These are the areas where state and national combined or sponsored research efforts are being applied. Several examples will be discussed here. In each case success will expand the footprint of additive manufacturing, and bring with it changes in logistics requirements and utilisation, and a wider range of products and processes.

Sustainability in these strategic efforts is more on waste reduction and energy utilisation in production, better precision and standardisation in improving these aspects as well as expanding the technical capacities. Such strategic initiatives are essential for AM to reach its full potential, but the explosive rates of expansion of the 'do it yourself' and small manufacturing-targeted products mean that for some time these will be the most salient.

Quantitative aspects

Environmental sustainability aspects must be matched to financial ones for a solid foundation. Ironically, although AM has been in use at a low level for over thirty years, it is the home that is the first to reach wide scale fiscal sustainability.

A recent combination of a RepRap (home-scale 3D printers that can print most if not all of its own components) taken to a second generation, plus a systematic assessment of breakable small household items led to a very high rate of return over a short period.

> "*What they found was a stark contrast between buying complete goods and making them at home: It would cost a consumer from $312 to $1944 to purchase the 20 items online compared to $18 to print them over the course of a weekend*" and *"the unavoidable conclusion from this study is that the RepRap is an economically attractive investment for the average U.S. household already"* (Wittbrodt et al., 2013).

It is therefore unsurprising that mass retailers are already selling 3D printers of this general entry level capability, and offering services to help to build the already-booming market for them off what is, for them, a low base..

Current entry level 3D printers almost all use plastic feedstocks of various kinds. The environmental impact of these plastics needs to be considered. Metal printers have quite different characteristics and will be considered separately, as part of the distributed limited-run manufacturing segment.

At the **micro** scale, 3D printing using plastics can show lifecycle energy costs reductions of 42-74% (Krieger and Pearce, 2013).

At the **macro** scale, logistics (transport administration warehousing in the main) represents 6-10% of the GDP of western nations. So even tiny fractional gains can be large in absolute terms (Rantasila and Ojala, 2012), so any savings from distributed manufacturing will bear directly on these broader logistics and supply chain costs as stockholding, movement, transport and handling costs can be at ,east to some extent be avoided. For countries like Australia, with a diminishing bulk manufacturing base, a huge land area, and a small (20m population) markets, these costs can be far from trivial within the country let alone when global supply chains are currently used.

The supply chain for manufacturing in Australia (to continue to use this developed country example) is complicated by the small market for manufactured goods. Global economies of scale are not available within this huge continent, and manufacturing is therefore moving steadily offshore. Additive Manufacturing (here mostly that requiring metal components) can change the economics substantially. RMIT Advanced Manufacturing Centre has found that runs of 100-1500, suitable for Australia, are economic using metal 3D printing as the fabrication technology. This makes bringing manufacturing back home (for suitable products) already a reality, with the vastly shrunken supply chain outside the continent obviated, even within the country distributed low run production via AM has much to offer in reduced logistics and transport.

One of the areas frequently missed is the effect of AM on stockholding for obsolete and discontinued goods. Stockholding and work in progress gains are well covered in many forums as they are common to all locations, but regulations requiring up to 10 years of stockholding of goods no longer made available for sale is part of the Australian legal framework. If regulations were to be changed to permit this requirement to be met simply by holding Additive manufacturing data files and suitable compatible equipment, then this area of storage and stockholding space and costs can also be reduced to a very low level.

As metal AM is best suited to advanced technology items, the short sales life and rapid change builds up significant storage and stock holding costs. As the usage may be very low, adds waste and production cost overheads and all the energy and environmental costs would then not need to be incurred, this is another area of sustainability benefit.

This strategy would also extend the availability of AM manufactured spare parts etc for a period far longer than the current 10 years, with no further costs. This consumer benefit is not simply theoretical. Veteran car enthusiasts are already customers for 3D scanning and AM production.

There are excellent tools for assessing the full lifecycle environmental and physical energy and Co2 costs of logistics alternatives (enlighten). However these inevitably omit the search, travel and other costs attributable to the end customer when retail is involved (Benatmane, 2010). A key feature emergent in the use of enlighten's package is the identification of waste reduction as a key approach when addressing lifecycle Co2 and energy accounts.

How long will we have to wait?

Most industry views are that mass AM and 3D printing "*will take another 10-15 years to make major inroads*".

This neglects the pressures of consumer demand on retail trade. There are several trends that are likely to shorten this horizon, certainly for many types of goods.

One factor is the growth of home 3D printing, where the capacity to replace broken small plastic parts (often a source of substantial profit for the retail trade) will add impetus to the provision of better and more economic servicing of spare parts at the retail point. UPS illustrates where actions are already being taken to respond to this anticipated pressure. 3D scanning offers a further pressure point, and a retail opportunity already being grasped.

In many ways 3D printing is closely analogous to the introduction of laser printers and microcomputers in the early 1980s. The printing industry response was similar, yet even at the early stages laser printing was economic at a household and small business level, and the costs and rates of change in 3D printing developments are far more rapid.

At the industrial level, GE considers that 30% of its manufactures will use AM to some extent 'by 2020'.

Some industries are more likely to feel the first effects more quickly than others. The sustainability benefits will necessarily depend on the characteristics of each industry. Sissons et al (Sissons and Thompson, 2012) assessed in 2010 which industry sectors would take up AM. Already changes have occurred. It is clear that furniture, rubber and plastic products, art works, toys, footware, fashion clothing and vanity goods are all picking up quickly. The sustainability benefits will vary widely: art works very little, apart from less waste., and the benefits are likely to be perceived mostly in terms of better tailoring to specific customer needs (and shapes) than the sustainability and transport gains that come with them.

The key area that combines consumer demand, retail industry and manufacture is mass customisation. This will affect consumer demand substantially over time, as the expectation of complete tailoring of a product becomes embedded consumers minds. Previously the economics of mass production has brought locational concentration of manufacture, global supply chains to support these locations, and global logistics to deliver them in a multi stage retail commercial chain of importers, wholesalers and retailers via shippers and 3 and 4 PLs information driven systems.

The vulnerability of retail sales business models to disintermediation of some of these levels by internet purchasing has become a matter of great concern –and growing financial impact - to retail commerce. Am/3D Printing will bring manufacturers into this growing web of disintermediation as mass customisation, which might have been thought to be a great marketing benefit to retail trade, will inevitably move closer to direct consumer to manufacturer links.

This disintermediation will accelerate as information rich designs proliferate, and the demand for mass customised and individualised products grows. The lead times will pressure existing retail trade structures, where fashion goods have long been treated as perishables and created rapid response supply chian services to respond to this. Some retailers have responded by having very short production runs and rapidly changing lines (Zara is typical). These may be the first able to move to complete individualised customisation as a survival strategy.

It is not entirely evident, but a large amount of waste n the retail supply and outlet chain is due to products that cannot be sold, and must be disposed of. This is an area of waste minimisation that the combination of AM enabled mass customisation and individualised product production will address. A fresh area of sustainability from the stock control and ordering component of the overall supply chain. This type of wastage can be very high.

Another area of sustainability significance is the production of specific metals for 3D printing. Titanium is a key metal, and the Australian CSIRO (CSIRO Future Manufacturing Flagship, 2014) has developed a means of creating 3D printer feed powders from Australian titanium ore. Previously it was mined in Australia, shipped (neccesarily) very long distances overseas as only processing for Titanium Oxide TiO was processed in Australia). The Titanium metal was then shipped back for use in Australia. The production of titanium is extremely expensive in energy, and any waste is therefore equally expensive. The sustainability contribution of this end of the overall product chain is rarely even considered in analyses of manufacturing sustainability, but in the case of metal AM it is a crucial omission when such long supply chains with multiple handling are otherwise involved.

A further trend that will offer synergies to these disintermediation processes (with the overall sustainability gains secured thereby) is the trend to embed RFID (Radio Frequency Identification) devices in an ever widening range of items. These allow identification of every item, tracking of its location, and in the case of goods that require maintenance, can be set up to talk to the internet and place orders for replacement with the manufacturer before an impending failure occurs.

RFID as a supply chain element is very well established. It is the next increment of information and communication that will change the ground rules; the so called "Internet of Things", where items all have internet enabled identification and response capacities.

These two examples have been given to show how the rapid rise in information intensity will cause the capacities of AM/3d printing to grow and expand a great deal faster than would otherwise be expected.

Intellectual Property regime barriers to AM/3D printing

Currently intellectual property regimes do not greatly constrain home not for profit use of 3d scanning/printing (Bradshaw et al., 2010). There is little doubt that rear guard action by industry will arise very quickly, but if modelled on the behaviour of the entertainment industry is very likely to be rejected by the community and will force the creation of new business models. This has been recognised in the legal domain, with a recent paper explicitly asserting that:

> *"rather than focusing on stringent IP laws, the future in dealing with emerging technologies which challenges IP laws lie in adopting new business models in adapting to technologies such as 3D printing." (Mendis, 2013)*

One of the direct response strategies already created by what is widely regarded by communities as IP over-reach (see the strong responses in Europe to the leaked TPP copyright chapter as a directly applicable example) are the Open Source, Kickstarter and Creative Commons movements. The RepRap projects are entirely Open Source, and are helping to frame the consumer expectations and culture accordingly. Wittbrodt et al took care to include all the additional (RepRap2) components in their paper on the economics of household ownership of current 3D printers.

A recent major review of the UK IP regime found that

> *"The copyright regime cannot be considered fit for the digital age when millions of citizens are in daily breach of copyright, simply for shifting a piece of music or video from one device to another. People are confused about what is allowed and what is not, with the risk that the law falls into disrepute. The changes recommended ... will help change this" (Hargreaves, 2011)*

The UK has already moved to implement many of the Hargreaves recommendations, and there have been rapid actions on this front since the Hargreaves report. The pressure to adjust IP polices to meet the impact and realise the benefits of AM and 3D printing are summarised as follows:

> *"3D printing is poised to be one of the most disruptive technologies of recent decades, and its transition to a mass market must be carefully and proactively considered by businesses and government alike" (Sissons and Thompson, 2012)*.

The speed of takeup of just the 3D printing community (as distinct from can readily be gauged from the annual surveys of the P2P Foundation Open source oriented site (Moilanen, 2013)

Zero Length Supply Chain applications and their benefits

The environmental impacts of rocket launches are substantial, as are the costs of lifting mass into low earth orbit. The estimates of SpaceX for their commercial rockets is around $3000 USD/Kg – a vast improvement on the now retired US space shuttle program at up to ten times this. However the zero supply chain effect of even a limited 3D printer in low earth orbit is already economic – and one has been space certified and will be launched too the ISS during 2014. Similar arguments (if less extreme in costs and environmental impacts) apply to remote locations such as Antarctic research stations – and warships.

Space applications have been a target of really large scale efforts in the European Union since 2004, as part of a series of Factories of the Future initiatives by the European Commission, addressing such key issues as standardisation as well as direct work on printing habitats, and developing metal capable 3D printers with the objective of space deployment. Lunar deployments – where even SpaceX estimate $15000 USD/Kg – are actively being pursued as the zero length supply chain potential offered by AM methods and equipment can bring the fiscal costs of all kinds (let alone the huge emissions savings from fewer rocket launches) into medium term scope. Space is often dismissed as an area of importance, but the sheer scale of space enterprise is ever expanding and has long become part of the global communications (and thus supply chain support as well).

The economic and environmental costs of building and transporting a habitat to the moon are huge. However a lunar regolith proxy has already been used to create a multi-ton habitat structure using 3D printing in Europe as part of this overall program. The project group concerned (AMAZE) has wider goals, as well as space applications.

AMAZE (AMAZE, 2012)(Additive Manufacturing Aiming Towards Zero Waste and Efficient Production of High-Tech Metal Products) began in January 2013, and the ESA (European Space Agency) is committed to complex printed parts made of metal that can withstand temperatures up to 3500C° – fit for space and the most demanding Earth applications, often impossible to make any other way, complementing the 3D printing of lunar habitats for the South Pole of the Moon already discussed. Factory sites are now being set up in France, Germany, Italy, Norway and the UK to develop a full industrial supply chain with production, metrology, Quality Assurance etc, and a substantive aim is to deliver the first 3D metal printer for the ISS.

The first basic 3D printer for the ISS has already passed microgravity testing (Made In Space, 2013), and AMAZE and the related projects will deliver the next major step. At the same time the aim is to reduce waste to less than 5%, and speed up build rates by a factor of ten.

So what next for AM and sustainability?

From the areas discussed the drivers for sustainability gains are tied to the following trends, which we have argued we can expect:

- Lower costs, wider access and easier use of simple 3D printing in the home and at retail service points

- Home production and personal sustainability gains very soon – some even now – as travel, search and other costs of minor part replacement are reduced

- Demand and delivery of more mass customisation before seeing transformed supply chains and business models

- Massive logistics sustainability gains in Space in the medium term

- Demands for lower cost and easier access to spare parts for obsolete consumer items

- New enterprises exploiting the sharply lowered entry and resource cost barriers to specialist manufacturing

- Reduced Ore-Product supply chains for metals such as titanium

- New IP lock downs limiting access and innovation in the AM area could derail much of the potential now emerging.

Examining supply chains from ore to final product in the hands of the eventual purchaser, plus the end of life accounting for product disposal, puts many applications of 3D printing/Additive manufacturing is a favourable light. Clearly not all types of product or market is well matched to these fresh capacities, but the sustainability aspects are important.

The lowering of the barriers to entry of advanced complex manufactured items has already been lowered, simultaneously with a huge advance in literally home production, and in mass customisation in economic small production runs. Substantive contributions to sustainability are already evident, with many more to come..

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