Manufacturing 2075

Manufacturing on the Moon

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Contents

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Manufacturing 2075 - Overview

By Professor Raj Roy, Director of Manufacturing, Cranfield University

What will manufacturing look like in the year 2075 and how can we prepare for this?

It is about building on our country's heritage in science and technology, building on our entrepreneurial and adventurous nature to understand and address the needs of the next century. At Cranfield University we are fortunate to have a group of people – and this is about people – who think long-term.

Three years ago we chose "Manufacturing on the Moon" as the subject for our National Apprenticeship Competition as a starting point to focus the attention of the upcoming generation on future challenges. As a nation it is important we raise the ambition of our workforce to be skilled and able to meet the demands the next century may bring.

At Manufacturing 2075 we began to look at what these future needs and technologies might be. Our speakers included materials scientists working with process specialists, machine builders, and digital technologists, all working together to influence the future.

Building for the future is about management practices as well as technology. This is where Cranfield can make a difference. We work in both technology and management, and make

technology that works at an industrial scale to serve people and meet their needs. During our event we looked at these challenges with a horizon of 50, 60, even 100 years from now.

The conference was structured on keynote talks followed by group work. We invited students from local schools to hear how they thought their lives would change in the next 60 years and for them to challenge us over our ideas.

One hundred years ago, we did not have many things: we did not have, for example, any space activity. Now we do. And the next 100 years will see an even faster pace of change.

Four main things will impact manufacturing over the next 50 and 100 years.

The first is people and how our lifestyle is going to change. This will have a profound impact on what products we need and how we use them.

Our life expectancy and our population size will extend. We will have to feed nine billion people: that's the first massive job.

The second is personalisation. Everybody wants customised personalised devices. In the Cranfield manufacturing community we talk about genetically customising food for individuals. Think about optimising food for the military. But we may not have even a human military force: it could be all robots by 2075. We see our democratic system is leaning more to nationalism – where will that end in 50 years' time?

The next trend or force is the global environment and energy. Climate change is going to drive what materials we can use today. There are soil fertility issues. We will see a significant shift in energy supply, using solar technology in some countries and other countries will have a surfeit supply of electricity beyond their needs.

A more local manufacturing push is going to come, using intelligent materials. There will be big materials development in the future is to drive things like sustainable materials with a low energy footprint. Fusion technology for energy is going to come in the next 60 years.

Finally, about technology, especially autonomous technology. Driverless cars, human-less machines, computers are going to have more decision-making ability than humans. If we get this right then computers and humans will work together to deliver services in the future. That singularity is going to shift manufacturing the most.

I hope you enjoy this report -- and I look forward to seeing you at Manufacturing 2075 in December 2017.

A full transcript of all the speeches can be found at **www.manufacturing-2075.org/**

"It is really important as a nation that we raise the ambition of our workforce and our citizens for future challenges."

Professor Rajkumar Roy
Director of Manufacturing at Cranfield University

Future Materials

The Future of Bulk Metallic Glasses

Prof Inoue is a material scientist, member of Japan Academy and global expert on bulk metallic glasses and advanced non-equilibrium materials. His presentation showed that new advanced materials, with very broad applications, are making a step-change in what can be manufactured more competitively.

> "Effective manufacturing technniques can control new industries, even though some novel materials with functional properties are now under license by certain institutions."
>
> **Professor Akihisa Inoue**
> Director of the International Institute for Green Materials
> Josai University Japan

Professor Inoue gave an overview of glass and its properties. It is a common material It is a common material with many types, including polymorphous, metallic and conventional silica glass. It can have a rapid or slow calling rate, and accelerating the cooling produces amorphous structures. There are non-ferrous alloy systems and ferrous alloy systems, providing versatility.

Bulk metallic glasses (BMG) were defined as alloys with critical cooling rates low enough to allow formation of amorphous structures in thick layers of over one millimetre. They have a glass-like structure, but unlike common glasses, which are typically electrical insulators, amorphous metals have good electrical conductivity. These are important materials for industry: BMGs have been commercialised for use in aerospace structures, sports equipment, medical devices, and as cases for electronic equipment.

Bulk metallic glasses began in the 1960s with the first synthesis of Au-Si amorphous alloy by Professor Pol Duwez. The first commercialisation of Fe-SI-B alloys came 24-years later. In the 1990s, researchers successfully synthesized BMG with copper mould casting. By 2014 BMGs has gained significant influence, their commercial value rose above $10bn. Looking to 2075, Professor Inoue said, no-one knows what new materials and properties we will be able to achieve, but BMGs will become more widespread.

Professor Inoue believes we are now involved in the fourth materials revolution. The first was steel, in the middle of the nineteenth century. In the 1940s the second revolution, plastic, occurred, which brought about huge changes. Around 1990 saw the introduction of liquid metals. The foundation of bulk metallic glasses was in the 1990s.

Applications

Popular applications of BMG include smart phone electronics, SIM card trays, knives, components for drones, batteries and Tesla motors. A typical unit price for BMG is $10-15 and the market valuation of BMGs is rising. "It's important to mix these manufacturing synergies and physical properties to achieve the best materials," Inoue said. There are important lessons from the industrialisation process of BMGs for manufacturing in 2075. "Effective manufacturing techniques can control new industries, even

though some novel materials with functional properties are now under license by certain institutions."

Several slides showed BMG's physical properties, including some of the challenges they present. Their nano-scale properties, and controlling the spacing between atomic structures, mean BMGs are good for **reading and writing data**, they make good recording media.

There are many applications in electronics and micro-machines. For advanced gear motors, BMGs can achieve very fine motor geometries. Inoue showed BMG used in the smallest geared motor with a diameter of 1.5mm. BMGs are being tested in advanced medical equipment, for micro industries and micro-factories. Also for metallic glass diaphragms for pressure sensors, fan motors in computers and AC/DC transformers.

Liquid-alloy BMGs create less heat than the normal metal one.

Alloy sheets for RFID chips, computer processors, mobile and smartphones.BMGs make highly efficient power conversion inductors. In the form of a metallic glass coating BMGs have extremely high temperature resistance and permeability. This makes them good for dentistry and medical applications, and it can create unique compounds.

Metallic liquid engineering

BMG liquid engineering can help create fine shapes and complicated 3D geometries that are hard to fabricate using other methods like casting and machining. Due to their strength, amorphous structure, and liquid metallic properties, BMGs are environmentally friendly compared with normal alloys.

The Moon Village

“ The Moon is a good place to do life science experiments in a lab, and learn how we can adapt to life in another, more hostile place.”

Dr. Bernard H. Foing
Executive director, International Lunar Exploration Working Group (ILWEG) European Space Agency ESTEC,
The Netherlands

Dr Foing is the chief scientist at the European Space Agency’s European Space Research and Technology Centre.

He presented colonising the Moon and manufacturing in space.

The **European Space Agency’s** vision is to build a moon base, where humans and robots coexist, to “live off the land” by making food here, manufacture and build another economy on this eight continent. To build an Earth-Moon economy that will go beyond merely a lunar base.

There are four main drivers behind this:

- Scientific research – proving the technology
- A growing Earth population
- Mining and manufacture. To see if Moon habitation could be self-sufficient
- Tourism: “In 30-years there will be opportunities to have a real *honey*Moon”

Why ?

The International Lunar Exploration Working Group is developing a moon landing programme and is talking about creating a Moon Village by 2035.

Professor Johan Wörner, director-general of ESA, is a keen supporter of the moon village idea and promoted it in an ESA press conference on 1 March 2016 that was widely reported.

Criteria

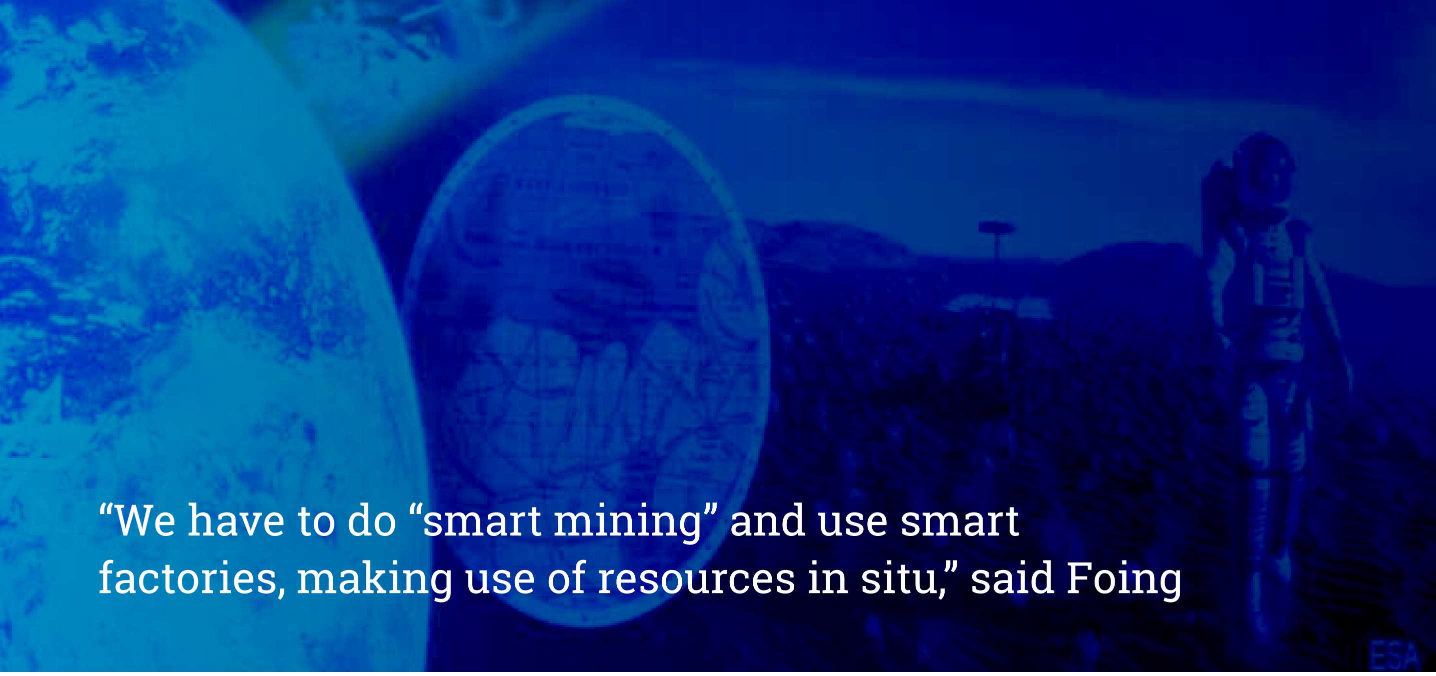
The Moon Village has a lot of promise in terms of exploration, human & robotic trialling, international partnerships, science on the Moon, soil analysis, and understanding planetary processes.

In terms of science and technology, Foing said “We can place telescopes that can see the ‘dark edge’ of the universe, viewed through all wavelengths, x-rays, gamma rays,

“The Moon is a good place to do life science experiments in a lab, and learn how we can adapt to life in another, more hostile place.

”However, the development of technology is needed to sustain life in an artificial environment. Some of the assets used on Earth can be built in space.

“We speak of an industrial revolution in space, where real manufacturing is possible.” “Space can generate fascination, inspiration, motivation. The Rosetta Mission proved this – it landed on a comet times three times and measured compounds



that were around in the original solar system.”

Additional factors identified by Foing were the Moon project needs to be a good use of taxpayers’ moneyInternational collaboration would be essential.

It would be a bridge between countries and could potentially smooth tension between Russia and the US. There is a need for more open architecture, for engineers to share and contribute data.

China is not part of the ISS, European laws prevent this. The Moon project proposes that architecture is more open for the next generation, and involves China.

The International Space Station (ISS)

In December 2016, ESA and NASA approved the extension of the ISS on the European side, to 2024. There are now more opportunities to use the ISS as the next step to explore space, including the Moon project. The International Space Station will not last forever though and the Moon Village could be the next step.

Transportation and resources

You need 50x less energy to leave the Moon than to launch from Earth. It would cost less to produce water on the Moon than to send it from the Earth. Water could be extracted on planet and then used in lunar food development.

The moon is a destination for mining and exploiting raw minerals. Minerals found on the moon include metal oxides with quantities of aluminium, calcium, titanium, iron and magnesium. While it is not economically viable to export such materials to Earth, they could be extracted and used to make products for lunar use. “We have to do “smart mining” and use smart factories, making use of resources in situ,” said Foing.

“MANUFACTURING ON THE MOON’

Every year Cranfield University runs a competition “MANUFACTURING ON THE MOON’, for teams of engineers and young people to design and produce a business plan for a lunar manufacturing base. For more information visit:
www.national-apprenticeship-competition.org.uk

Manufacturing and Industrial Evolution – the future

"What if manufacturing didn't employ anybody?"

Professor Steve Evans, Institute for Manufacturing, University of Cambridge

Key themes

- "What if manufacturing didn't employ anybody?"
- Convergence of politics, society, technology and manufacturing = interdependence
- The foraging factory
- Last mile logistics

Professor Evans has a lead expert role in producing the Government Science Office's Foresight Report into the Future of Manufacturing in 2013, a global study.

The single fact that knocked me out the most was that by 2011 in UK manufacturing there was more than a 1:1 ratio of managers to operators. The first trend is that future growth in manufacturing will be jobless. Manufacturing plays at the intersection between politics, and economics and technology. "Political rhetoric says that manufacturing needs to grow, in part because it provides a public good of employment. But what if manufacturing didn't employ anybody?

China has embarked on the largest programme of installing robots in history. This job displacement will be a political problem for the Chinese government to solve.

Donald Trump made a key policy of this, the loss of jobs from the US to China. There is an argument that free trade allows that. Containerisation made this happen. "You can't move a job from the US to China if it is physically too expensive to move stuff. Mix containers with free trade and you get a very powerful force." With so much to say about the forces shaping future manufacturing, Evans' main points for Manufacturing 2075 are summarised as follows:

Material science and biology

- We will be using new materials we don't know about yet.
- There will be greater use of biology than mechanics in manufacturing; growing cellular structures rather than subtracting material. "We will grow our own furniture."
- Professor Evans prediction: Over 50% by weight of what we see coming from factories in 2075 will come from a biological origin.

Metrics

- We must move from GDP as a measure of manufacturing contribution to the economy to discuss manufacturing in terms of **value.**

Difficulty of accessing raw materials

- In the future the supply of certain minerals may be seriously disrupted. The growing political reason to resist imports and develop national resilience.
- Customers will become more sensitive to the provenance of the goods, to deselect buying them from areas of dispute and conflict.
- Countries will become less happy about sharing materials.

Tax bad things only

- Change the tax system to tax people on consumption, carbon and destruction rather than on knowledge accumulation.

The "foraging factory" as a future model

- A factory must get its raw materials within a 40-mile radius. By 2025 everything will be sensor-connected so people will know where things are sourced.
- Better communication between farmers and makers; the time of harvest, what raw material will be available when and its proximity.

> "We will get much better at extracting value from raw materials because more value will become available."

> "Climate change is not our biggest problem, and that really scares me – soil fertility is our biggest problem"
>
> **Steve Evans**
> Institute for Manufacturing,
> University of Cambridge

We will understand value much better

- Not just the beer but the bottle and the process of glassmaking. No sending expensive glass coatings in products as a bi-product for road-fill.
- We will get smarter at retaining value.

Scale of manufacturing will change

- New steel plants will be smaller than the ones in the 1970s.
- We will be making more things locally but using global knowledge

Soil fertility

- The average fertility around the world now is 30-years. "Climate change is not our biggest problem, and that really scares me – soil fertility is our biggest problem."

Last mile logistics is free - so making things locally becomes affordable.

Conclusions

1. Factories in 2075 will deliver 4x value not 4x GDP
2. A three-day working week because work is good but we will have more technology.
3. We will use half the material to create 4x more value because we will keep the value in the loop for longer.

Case study: Buzzbike

What's the most valuable thing about a bike? Transportation? It could be advertising.

Leave your bike outside your desirable residence, promise to park somewhere public and the most valuable part of the bike is the advertising space on the bike.

If you have the right, valuable address, you get the bike for free. We must think of the total value in manufacturing: it is much more than the utility of the product.


We will live
in cities dotted
with mega-

Global manufacturing: The next 100-years

Peter Marsh, Author and manufacturing expert

Peter Marsh identified three big changes which will shape manufacturing:

1. The merger of biology and electronics.
2. Customisation: a greater connection between people wanting something and then having it made.
3. An increasingly interconnected world will be glued together in an even more intense way by a global series of networks of people and ideas

Background

When comparing axe-heads of one million years ago with the iPhone of today and then technologies in 100 years' time, Marsh said the big differentiator is the increase in the amount of information added to materials to make the product. The knowledge of how to make an axe-head only needs one person. No single person in the world could ever make an iPhone.

In 100 years' time we will have amalgams of electronics and biological materials, he predicted. The information that comes out of that is even richer, will require more complicated manufacturing pathways and need more collaboration.

Population

Both 200 years ago and today, China was the biggest manufacturing country in the world, mainly because it has the biggest population. The global population in 100 years' time will be about 11 billion people. The population in Africa will be about four billion, a similar proportion to that of China in the global population today. China's population is likely to go down.

Marsh said Africa could become the world's biggest manufacturing power. In less than 100years it will have big brands – there are already shoe manufacturers using the "Made in Africa" brand.

" About seven billion sorts of things get made every year, and I wouldn't be surprised if that number was multiplied at least by five in several years' time, but using even fewer people than now."

Peter Marsh
Author and manufacturing expert

The drivers of manufacturing have not changed much, people still require the same sorts of things that they needed 100 years ago to satisfy their needs and meet their goals.

The big forces driving manufacturing today can be reduced to the 'three Cs': connectivity, creativity, and customisation. More products are being made to order and it is all being brought together by digital technology.

Biology and electronics:
Biological computers are being developed. The brain has 86 billion neurons or nerve cells, in the future you will be able to get human-style processing added to computer functions.

Biotransistors: A US company is making pills with built-in sensors. When they are digested in the gut the sensors will provide information to doctors and computer centres about how that person's body is reacting with the pharmaceutical, helping the process of therapy.

The merger of robotics and biology: Touch Bionics, a US company, is making replacement hands for people, and other companies makes robots for helping people in the home, such as Honda's Asimo robot.

Solid Biosciences in Ireland is using synthetic biology to make a pharmaceutical reagent that is needed to test every pharmaceutical in the world. The current treatment takes the reagent from the blood of horseshoe crabs, this reduces the crabs' life expectancy. Solid Biosciences has found a synthetic way of making this. More synthetic biology will be developed over 100- years.

In South Africa **AgriProtein** operates huge fly farms occupying vast buildings. The fly larvae create a rich protein-based material which goes into products such as animal feed. The factory is operated by an army of robots. More novel food growth businesses will develop.

There will be an explosion in **sensor technology** and more **drones** will be used for surveillance. There will be more sensors and robotic devices merging robotics with biology such as with bionic hands that measure temperature and pressure.

More products will be made **on demand** using 3D printing, and in new ways such as rearranging atoms. Marsh said "If we take all the things with atoms in them the number of things you can produce from that combination is 10 to the power of 70, which indicates what you could do, if it were possible to arrange those atoms."

We will be able to 3D print biological materials in the lab, another example of where biology and electronics will come together. This industry will be linked by a huge network of people collaborating.

Mini-fusion reactors
One independent inventor is working on new small fusion machines that will run at 100 million °C, the temperature of the Sun. He plans to have these reactors ready for 2050, because "the world can't wait until 2100 when big industrial reactors will come into operation".

Future Manufacturing Research

Katie Daniel, Theme Lead, Manufacturing the Future Engineering & Physical Sciences Research Council

The Engineering & Physical Sciences Research Council (EPSRC)'s vision is for the UK to be the best place in the world to research, discover and innovate in the fields of engineering and physical sciences.

"We invest in long-term, basic and applied research in engineering and physical sciences. EPSRC is committed to excellence – and impact" Daniel explained.

"We are committed to supporting talented scientists, engineers and postgraduate research students. Through research, they discover new knowledge, explore new ways of thinking, and drive innovation that has value to society and the economy."

Research and discover

EPSRC's investments are focused on the future – we don't know where the next disruptive technologies will come from. We support a broad range of research activity and seek to identify those areas that could have major impact at an early stage.

One example of these emerging technologies is the area of quantum technologies. In 2013 the government committed £270 million to set up the National Quantum Technologies Programme. Quantum Technologies are those that promise future changes in the technological capabilities of several key areas, including secure communications, metrology, sensor technologies, simulation and computation. Today research in quantum technologies comprises approx. £190 million (or 4% of total) EPSRC funding, which is significantly higher than before the programme commenced.

Research and innovate

As part of our *Manufacturing the Future* theme, EPSRC supports an extremely broad portfolio of manufacturing research with a strong focus on research that leads to applications being developed by companies.

Our flagship investments are our eight Future Manufacturing Research Hubs and four Centres for Innovative Manufacturing (CIMs). Looking to the future, these investments have been selected to reflect the most valuable and important areas of manufacturing to society and business. The Hubs and CIMs will have a broad impact; from improving the materials used in land and air vehicles, to personalising healthcare and revolutionising the electronics industry.

EPSRC's visions for the future of manufacturing

Through discussions with the research and business communities, EPSRC has identified four visions for the future of manufacturing research. These are the areas we encourage our researchers to focus on today, in order to have impact in 10, 20 or even 50 years.

- 21st century products – what are the products that we can't imagine today? Will they involve new materials, control matter in different ways or use of biological processes?
- Digital manufacturing – how can we incorporate digital technologies into design, manufacturing and services? How can we enable intelligent factories?
- Sustainable industries – how can we ensure that new high tech manufacturing processes are sustainable? How can we meet the needs of the present, without compromising the ability of future generations to meet their own needs?
- New industrial systems – how can we ensure that new manufacturing systems will be local, anchored in the UK and create value for the British economy?

These visions must be supported by research that backs new, emerging technologies and big ideas. All of this forms part of EPSRC's twin goals; to research and discover – and to research and innovate.

Summary – Manufacturing research for the future

- EPSRC's two goals are to 'research and discover' and 'research and innovate'.
- We don't know where the innovations of the future will come from, so EPSRC supports a broad portfolio of fundament and applied research.
- We look to identify those technologies with the most potential at an early stage and seek to advance research in these areas.
- Within manufacturing our future visions are:
  - 21st century products
  - Digital manufacturing
  - Sustainable industries
  - New industrial systems

The Future of Manufacturing Technologies

Dr Phill Cartwright, Chief Technology Officer, High Value Manufacturing Catapult

Dr Phill Cartwright, then CTO of the HVM Catapult, summarised some the main technologies that will transform manufacturing in the coming year, where the seven HVM Catapult centres are playing a role to connect companies to mid-TRL (Technology Readiness Level) research.

The fourth industrial revolution moves from a period of computer-controlled and assisted industry to 'cyber physical systems' where products and machines talk to each other to improve productivity and increase customisation.

Autonomous devices in factories and business chains will affect this change, including sensors built into products that interact with material conveyors in smart factories, autonomous, self-navigating trucks for material delivery and drones to make product deliveries between suppliers and customers.

The use of robots in advanced manufacturing will increase. This is evident in several HVM Catapult centres, such as the Advanced Manufacturing Research Centre with Boeing (AMRC) where robots are used to help BAE Systems create an automated counter-sinking cell to enable robots to accurately machine holes in composite aircraft components.

Engineering design and simulation will increasingly be completed both in 3D CAD and using virtual reality (VR) technology, to visualise assemblies in a VR setting before manufacture. VR will also be used in factory design and configuration. Siemens in Congleton has already followed this route after trialling a VR CAVE suite at the Manufacturing Technology Centre (MTC).

Machines in smart factories will use wifi and sensors to detect and transmit data about their product flow and efficiency to sister machines. This will optimise asset usage and reveal spare capacity and bottlenecks

"The Catapult is a collaborative organisation and its goal is to engage with many companies and academics to bring new ideas into viable industry solutions as often as possible"

Dr Phill Cartwright
Chief Technology Officer, High Value Manufacturing Catapult

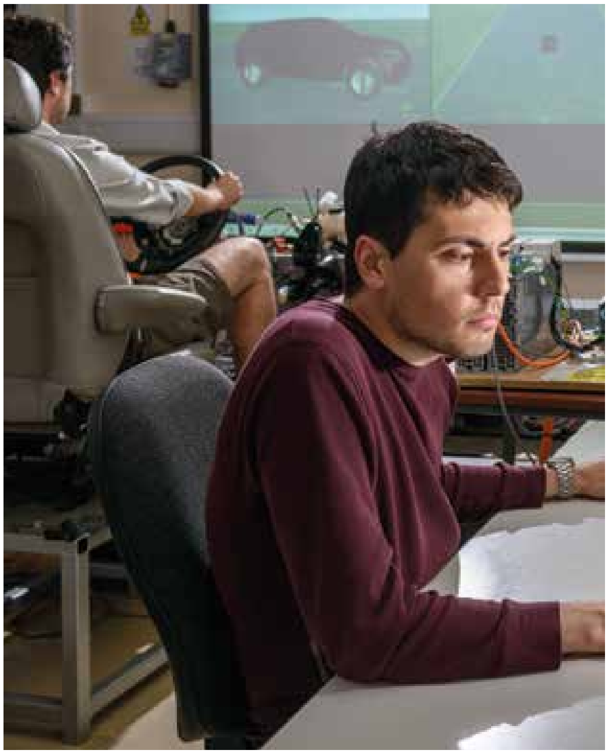
in busy factories. Cartwright mentioned the Catapult's newest building, the Factory2050 in Rotherham, as a fully equipped test bed for these wireless, “4IR” (4th industrial revolution) technologies.

Additive manufacturing (AM) will be a core future technology. Already used for a variety of engineered components, the tolerances and material range will increase so more ‘critical’ rather than cosmetic components can be made with AM processes.

Construction company Skanska, which in December joined the MTC, is an early adopter of AM in the building sector, developing a 6-axis 3D concrete printing process. Building engineer Laing O'Rourke is also using modular manufacturing techniques to construct buildings off-site in “kit form”, to be assembled on-site, making some types of new build quicker and less expensive.

Demonstrated at the Factory2050 expo and conference in September 2016, more OHMD (Optical Head Mounted Displays) will be used in both product design research and product experience scenarios to test how users and customers respond to an engineered product.

Cartwright said that more pay per use rather than ownership models will prevail in the future and manufacturers have to adopt this into their business plans. We see this with aerospace engines, train operating contracts and mobile phones already but it will expand into areas such as all transportation, where shared car ownership will grow. Cars of the future will be smart, with hundreds more sensors, electronics and software on board to detect the driver's environment, driving patterns and efficient fuel consumption.



There are big opportunities in smart car technology for UK companies, he said. This will accelerate the adoption of autonomous cars which will become increasingly prevalent as pilot studies increase and more driverless car safety data is gathered.

Industrial sustainability is a big theme of the future and the HVM Catapult's work encourages companies to design for life and reuse materials wherever possible. Business as usual models of use and dispose cannot be sustainable, Cartwright suggested. The Catapult is a collaborative organisation and its goal is to engage with many companies and academics to bring new ideas into viable industry solutions as often as possible.

Cartwright's last slide showed a robot viewed through a smart tablet, signifying how more manufacturing operations will be monitored and controlled by apps installed on tablet and smart phones in the future.

"The team discussed potential international conflict, which countries claim “ownership” of the Moon, and which are entitled to profit from it?."

M2075 Workshop Outputs

The aim of the workshops was to identify and discuss future challenges associated with each subject area, capturing any emerging themes and ideas that could be explored now, through research and innovation, to help to address these challenges.

The focus of each workshop represents a potentially significant research concept for manufacturing by 2075. Each concept was identified by the Cranfield Manufacturing 2075 Community through an internal think tank event.

Manufacturing on the Moon

This workshop identified initial challenges to the opportunity and challenges that manufacturing on the moon presents.
These were;

- The drivers for manufacturing on the moon
- The manufacturing scenarios
- The research challenges
- The practical constraints
- The resources needed

Severe environmental pressures (on Earth) may require toxic or polluting processes are carried out ‘off world’.

Humans may need to exploit resources such as new, precious materials and the mining and harvesting on the Moon of nuclear fusion materials for clean energy.

The requirement for human space exploration could mean that the Moon serves as a springboard to Mars and deep space missions. Weaker gravitational forces will make spacecraft more fuel-efficient when launched from the Moon.

Scenarios in which manufacturing on the Moon could be an advantage were discussed. The Moon offers the opportunity for:

- mining and fabrication of new materials
- developing new markets for ‘moon products’, to export to Earth
- enhanced solar energy harvesting
- space and moon junk reuse and recycling
- human habitation, requiring unique infrastructure development, and
- growing food for the inhabitants of the Moon and the Earth, and
- supporting a space tourism industry

Research challenges

The research challenges are many. In health, radiation effects in space can damage human health but there may be ways in which the radiation can be harnessed for specific illnesses. Health degradation is observed with longer-term space living, particularly bone structure and eyesight. There may be psychological and emotional impacts on humans residing in space long term, due to the lack of contact with family, nature, culture and comfort. Finally, what are the health implications if humans were born on the moon and in space? It may be that more capable and autonomous robots will be a viable alternative to human deployment.

There are challenges with infrastructure, transport, food and water resources. New research will be needed in infrastructure degradation and repair, and organic and self-healing processes for space and moon structures, to negate the need for human intervention in maintenance.

With transportation, bigger, more efficient vehicle design will be needed as current spacecraft are too small to travel back and forth to a moon settlement, with the high volumes of fuel required. Harvesting, collecting, transporting and control of solar or nuclear energy for export to Earth will require new research solutions, as will the development of levitation systems as an efficient transportation method for lunar displacement.

Constraints

A primary constraint is the physical conditions; lack of a protective and breathable atmosphere, meteorite protection and exposure to cosmic rays and radiation.

Also, the long-term effects of living in a reduced gravitational field are unknown. The harshness of the moon environment, with a lack of food and water, will heavily affect our ability to utilise the moon. Another constraint is the challenge surrounding geo-politics, legislation and culture – for example "who owns the Moon and the right to exploit its resources?" will require clarification. Moreover, the Moon has religious and spiritual significance for many; would manufacturing here be a conflict with these?

People prepared to train for and work here was discussed. Non-traditional, interdisciplinary education will be needed, (e.g. architecture and physics, engineering and biology), so as to generate a suitable skills base and ambition to colonise the Moon.

Another constraint is the challenge surrounding geo-politics, legislation and culture – for example "who owns the Moon and the right to exploit its resources?" will require clarification.

Developing Evolvable Products for Adaptation

The workshop asked "what if, in the future, products could evolve to repair themselves, and adapt both to the needs of the environment and to the user?'

Self-healing materials already exist, as do thermal and photoresponsive shape memory materials, and there are numerous biological examples that demonstrate some of the underpinning elements required such as regeneration, self-cleaning surfaces and adhesive proteins. However, new research will be needed to combine all of these functions into products that align to user requirements in a more dynamic, responsive way.

Initial challenges identified were;

- What are the enablers for evolvable products?
- How will business models need to change?
- What applications are suitable for evolvable products?
- What constraints need to be considered?

The workshop discussed the relationship between customisation and evolvability and the varying demands placed on each.

Some enablers which support the development of evolvable products are:

- software applications - supporting the diagnosis of problems in consumer products
- self- healing and smart materials (i.e. the product identifies a problem and auto-corrects it)
- shape changing and shape memory materials
- the development of new nanomaterials that can sense damage
- sensors that support communication between products and machine processes, allowing failures to be predicted and updates for maintenance requirements to be updated automatically.

Industries using evolvable products will likely use different business models. A circular economy ethos will be suitable for such products. Once functionality has been exhausted, the products are then recovered and the materials reused and repurposed for new products once again. "Whole life product services" as well as new industries focused on preventative maintenance and evolvable design will be required.

Evolvable products are more important to some sectors, such as aerospace, where failures in turbine blades or surface fatigue could be mitigated by self-healing materials or shape memory materials. Self-healing materials can be applied in transport, such as railway and road maintenance, and also civil structures.

Constraints

A primary constraint to the development of evolvable products is the requirement for new materials capable of self-diagnosis and sensing, self-healing, morphing into different shapes, and re-purposed functionality. This may require aspects of artificial intelligence to be built in and a greater level of understanding of relevant biological examples to support the application of appropriate knowledge. But caution should be taken not to over-engineer products but to develop products that are fit for task. A second constraint may be the establishment of suitable value systems that support the notion of evolvable products – will society move away from consumerism and status associated with material goods to become more accepting of reuse and recycling concepts?

The Future for Customisable Manufacturing

Customisable manufacturing infers the re-establishment of cottage industries engaged in production for the local community, reduced volume output and increased flexibility in comparison to the tightly controlled mass production of similar or replicate items. Industry 4.0 – digitalised manufacturing, aka “4IR” – centres on how increased connectedness (e.g. via the internet of things), flexibility, adaptability and resilience will lead to an increase in unique, individualised items produced on-demand and with a high degree of customisation available.

This will require the true customisation of production, products, services and the supply chain through extremely high agility levels in reconfiguration and autonomous adaptation. Such customisation will need to be able to consider an individual’s requirements (preferences, wants, needs, desires) and those dictated by society through culture, trend patterns and status.

Challenges

The challenges to customisable manufacturing include:

- the ability to clearly define ‘customisation’ (does it include remanufacturing or where standard parts are combined to produce a ‘customised’ item?)
- understand what products need customising and how
- what is the balance between customising a brand versus a product, and the impact that the different needs of individuals can have on customisation (e.g. age, geographical location).
- It will be more expensive and complicated but will still be required to deliver in a timely and responsive manner.

Traditionally, customisation has been applied to consumer industries and products, but could this expand to include for example building designs, construction and architecture? Rather than making more things customisable, will customisation actually be needed? With a move to a different cultural value system and the importance of resource and sustainability issues as well as changing lifestyles, ownership and consumerism may not be prevalent in the future.

Considerations

The first focuses on the role of local production; could this incorporate repurposing production centres to support a circular economy model? Clusters of centres could become information and knowledge and information foci and not be restricted to a manufacturing remit. The drive for customisation to move from ‘want’ to ‘need’ due to constraints such as money, security, oil etc. further highlight the potential significance of local production and for the need for digital customisation of factories as control of the supply chain becomes simpler and more efficient.

A second consideration is the importance of being able to produce items at the molecular level up, enabling the introduction of multi-state and multi-phase materials. Last minute customisation and the true personalisation of items, such as bio-engineered clothes and drugs matching an individual’s requirements, will be made possible.

Finally, it was agreed that customisation will rely on automated technologies based on collated data but will this prevent people thinking and creating for ourselves?

What Could Life Look Like in 2075?

16-18 year old age group from Bedford School and Kimberley STEM College near Bedford

Key ideas that will shape the future:

- Changing politics, the democritisation of society and ownership
- Climate and society changes; bigger, greener cities
- Lifestyle and leisure time
- New inventions; autonomous vehicles and instant language translation

This workshop, with students from Bedford School and Kimberley College, discussed the history of the four industrial revolutions, from the introduction of mechanical production to the emerging exploitation of "cyber-physical systems" to support evermore complex industrial systems. A change in communication methods has led to the globalisation of networks as well as the move towards instant, real-time engagements.

Climate and societal changes – higher mean temperatures, ageing population, lower fertility rates – will affect employment opportunities and rates while greater automation could lead to 'technological unemployment'. There is a universal sustainable agenda in place, as approved by the United National General Assembly, in the form of 17 Sustainable Development Goals, including the reduction of poverty and sustainable agriculture. Having a 'vision of the world' in 2075 will help us understand the drivers, priorities and values of society, and therefore the demands of future manufacturing.

The students considered the impact of these factors as well as what future factors may become significant on our lifestyle, healthcare, the environment, education and new opportunities that may become available.

Lifestyle changes could involve working less due to reduced job availability perhaps leading to socialism, or alternatively, until death due to poor pay and reduced benefits. Transport will change to more automated and on-demand services as well as the introduction of hover or flying vehicles. In terms of leisure, genetically engineered and robotic pets could be common as well as the use of virtual reality holidays. Government of countries could change with a rise in part-time politicians as more members of the public get involved in government representation.

In healthcare, new technologies could allow the printing of human body parts, vessels and limbs, and medical products supporting whole body scanning to diagnose and treat health conditions. This scanning ability could enable treating medical conditions before birth.

Species extinction could lead to the establishment of Noah's Arks, possibly in space, since the Earth may no longer support the health and propagation of life. With a growing population, the availability of green spaces may fall as cities expand, leading to climbing carbon dioxide levels and other greenhouse gases. The move from fossil fuels towards clean energy could lead to a greater

focus on solar energy, aligned to further space exploration.

Technology could also support the real-time translation of languages and specialised communications (e.g. highly academic) into verbal input suitable for lay individuals.

Opportunities from these changes include a changing job market with lower employment but growth in spin-out companies and innovation as people have more time. Currency could become obsolete and so a system of time bartering may become a more useful form of exchange.

Professor Rajkumar Roy summarised the workshops:

"Within two hours, we have come up with some new directions and new areas of research. Some of this has already happened in Europe, at the European Space Agency. Now it is our role is to get really engaged, develop these ideas and seek funding from people like the EPSRC and Innovate UK so we can invest in developing some of these ideas."

Cranfield University

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Manufacturing in the future will be impacted by organic and disruptive technologies and systems, new materials, changing lifestyles, values and political and social developments.

We need to start imagining the future now to ensure we can answer the challenges thrown up by the future manufacturing landscape. Research, education and skills development will play key roles in meeting these changes.

Manufacturing 2075 is a new, globally-focused forum to discuss very long-term manufacturing challenges and to start thinking now about how we might address and influence them.

Our collective views can shape the direction of research, ensure tailored, timely practical solutions and support innovation in education models.

Manufacturing 2075 – 6 December 2017
www.manufacturing-2075.org

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