Rapid Technology Assessment: 4D Printing

4D printing uses 3D printing techniques with "smart" materials to create structures that can dynamically reshape themselves in response to external stimuli such as heat, water, light and sound. The technology is less mature than 3D printing but offers a range of potential benefits with applications in different sectors from infrastructure to textiles.

Introduction

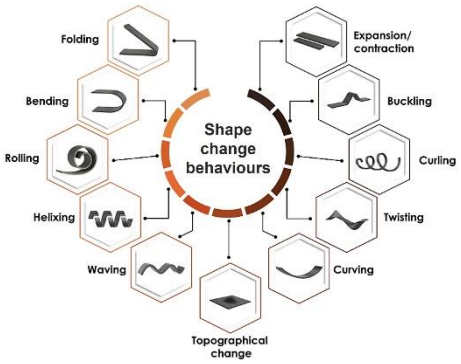
- The process of 4D printing is essentially the same as 3D printing, where a structure is built layer by layer. However, 4D printing uses unique, programmable "smart" materials and novel designs to allow the finished product to respond to stimuli in a predictable way. This adds the 4th dimension – time.
- 4D printed materials could be developed to **self-assemble, self-repair, adapt to their environment, or transform in response to specific triggers.** The combination of different "smart" materials (e.g., shape-memory alloys which can be deformed and then return to their original shape when heated) that respond to one or more stimuli allows complex structures and behaviours.
- **4D printing has wide-ranging potential uses** across sectors such as defence, medicine, electronics, infrastructure, aerospace, manufacturing, energy, and textiles. **However, the technology is at an early stage and is not ready for widespread commercialization.**

UK Position

- The UK has an active academic research sector for 4D printing, behind Singapore, the USA, and China. From 2014 to 2021 the UK ranked 6th for patent filing when adjusting for GDP with annual growth rates on average lower than comparator nations.

Recent Developments

- **Commercialisation of 4D printing is most advanced in healthcare,** where 4D printed products could form advanced drug delivery systems that target particular tissues or organs, be used in tissue and organ regeneration, and provide novel materials for rehabilitation or musculoskeletal support tools.
- Prototypes are in development for a range of applications:
  - **Energy –** Solar panels that follow the sun.
  - **Aerospace –** Responsive carbon fibre engine inlets to regulate airflow, reducing the need for mechanical systems, and wing components that change shape in response to different aerodynamic requirements.
  - **Infrastructure –** Intelligent underground pipes that can expand, contract, and self-repair cracks.
  - **Textiles –** Clothing that changes colour or becomes more breathable.
- **4D printing is an early stage technology** with patent applications at around 1% of those for 3D printing. It is still the preserve of academia with a focus on material and prototype development and nascent industry demand.



Shape changes in 4D printing.
(Adapted from Azhar & Pei, 2021)

Opportunities

- **Economic potential.** 4D printing has potential applications across a range of high value industries important to society. The rapid growth in research output and patent applications globally suggests strong potential for commercialisation, particularly in healthcare.
- **Sustainable development.** As a developing technology at a low TRL, there is an opportunity to encourage research and industry development towards sustainable practices, e.g. reusing materials, recyclable components, and encouraging use of sustainable and ethical supply chains.
- **Longevity & resilience.** Self-repair capabilities could increase the longevity of 4D printed items, reducing wastage and pollution. Self-repairing infrastructure (e.g. cracking pipes) could reduce maintenance costs.

Challenges & Risks

- **Multidisciplinary research.** 4D printing technologies span a range of disciplines including engineering, chemistry, biology, design, and material sciences. Coordinated cross-discipline research is likely required to develop 4D printing.
- **Low industry confidence.** The scale of potential demand for 4D printed products is unclear, but experts noted industry interest could be low considering the slow adoption of 3D printing. However, significant scale up of 4D printing capabilities such as self-repair could be disruptive.
- **Domestic capability.** The UK has a limited domestic supply chain. However, the future strategic importance of domestic capability in 4D printing is unclear.
- **Regulations & standards** do not currently exist for animate materials and could support commercialisation and sustainable development.

This is a summary of a report completed in March 2021. There may have been developments and additional data since then that are not captured in this summary. Patent data was provided by the IPO. Search terms available on request. We would like to thank the following for their contribution and expert review: BEIS, DSTL, IPO, UKRI, Dr Eujin Pei, Dr Veronika Kapsali, and Dr Jin Sun.