

connected
everything.

DIGITAL WORLD 2050





In memory of Nigel Rix, a valued member and mentor of the Connected Everything Network.

FOREWORD

Manufacturing in 2050 will look profoundly different to today. The products and services we consume, how they get made, delivered and reused across all sectors will need to be delivered by a production system or value chain that delivers at net zero or better.

Digital technology and its successful development and implementation will help enable that and also allow us to reimagine the future of work within engineering and manufacturing. This reimagined value chain has to function effectively in disrupted times offering resilience in product delivery and to the local economies, engaging local communities and inspiring the next generation to innovate further.

Over the past six years, the Connected Everything Network has engaged with many different experts from a range of backgrounds. These experts have brought different academic, technical and industrial perspectives to some of the challenges that we face as we aim to increase the extent to which we embed digital technologies in the manufacturing life cycle, and the impact of those technologies on efficiency and productivity.

The 2050 report has brought together these views and framed them across a series of themes which take a holistic approach. One of the original goals of the Connected Everything approach was to bring new voices and insights into the debates and challenges facing the development and implementation of digital manufacturing technologies; this report presents the outputs of discussions between those new voices and perspectives and those with extended valuable experience in the reality of implementing digital manufacturing technologies in a range of sectors and settings.

This report compellingly outlines the challenges, the UK strengths and the opportunities for the UK in leading during this transformation and how we can bring together the manufacturing, academic and technology strengths to deliver UK prosperity that has a global impact. The coming together of many across those areas to feed into this reports and the alignment of ideas is the template for how we can accelerate towards that net zero manufacturing future.



Sarah Sharples, Chief Scientific Adviser for the Department for Transport and Professor of Human Factors in the Faculty of Engineering at the University of Nottingham



Chris Courtney, CEO of the National Manufacturing Institute Scotland and UK Research and Innovation (UKRI) Challenge Director for Made Smarter Innovation

EXECUTIVE SUMMARY

Digital technology is becoming embedded throughout manufacturing and society, so it has a critical and growing part to play in addressing manufacturing challenges and delivering a sustainable and resilient future. Maximising digital technology's contribution will depend on the decisions we make today, and the actions of governments, industry and funders.

Connected Everything is an Engineering and Physical Science Research Council (EPSRC) funded Network Plus that aims to accelerate multi-disciplinary collaboration, foster new collaborations between industry and academia and tackle emerging challenges which will underpin the UK academic community's research in support of digital manufacturing. Connected Everything has embarked on horizon scanning activities, undertaken in collaboration with industrial partners and policy makers, to generate new knowledge on the challenges and opportunities for Digital Manufacturing practice and policy in 10, 20 and 30 years' time.

The horizon scanning activity has been focused on four cross-cutting themes that emerged from consolidation with the digital manufacturing community, via surveys and workshops and guidance provided by the Connected Everything Executive group.

Throughout 2021 and early 2022, Connected Everything hosted roundtable discussions on each theme to share perspectives and research for understanding the future of digital manufacturing. Participants were also encouraged to recommend literature and case studies, which have been analysed to support the conclusions drawn from this report. The roundtable topics were:

1. Industrial Digital Technologies in 2050: Industrial digital technologies (e.g. robotics, machine learning, virtual reality) underpin and enable digital manufacturing. Emerging industrial digital technologies are having far-reaching implications for how we produce things, exchange information and interact across supply chains and with customers. This theme identified both future uses of industrial digital technologies (e.g. large-scale system modelling, sensors to measure key variables and reprogrammable production lines) and emerging technologies (e.g. nano embedded

sensors, edge Artificial Intelligence (AI) and continuous machine learning) that offer exciting opportunities for manufacturers to meet today's and tomorrow's challenges.

- 2. Digitisation and The Manufacturing Workforce of the Future:** As the adoption of digitisation accelerates, the impact on the manufacturing workforce is currently uncertain. This theme aims to understand the way that this will change the fundamental nature of work, and the way that we, therefore, design the technology and systems which will enable the future workplace is key to the delivery of future safe, effective and productive workplaces. New opportunities for the manufacturing workforce emerged, including improving manufacturing transparency, aiding decision making, reducing knowledge barriers and formation of new manufacturing roles.
- 3. Digital Support for Achieving Net Zero Manufacturing by 2050:** The manufacturing and construction sector is the third largest sector in terms of carbon emissions. While there are many routes to net zero, digital technologies are becoming central to all modern economies and understanding how they can help manufacturers achieve net zero by 2050 is crucial. Five clear methods by which digital manufacturing can support the journey towards net zero manufacturing were proposed, which included the digital-enabled circular economy, design of the next generation of sustainable products, data-driven sustainable decision making, real-time data of supply chain emissions and enabling new clean energy sources.
- 4. Digitally Enabled Manufacturing Resilience:** Over the past two years, manufacturers have faced unprecedented disruption with the combination of the UK leaving the European Union, the global pandemic and the humanitarian disaster in Ukraine, combined with soaring transport, energy and raw material costs. This theme explored both how digitisation can play a key role in making manufacturing systems more resilient (e.g. enable agile manufacturing, enable collaborative resilience and enable new resource streams) and also identified what risks and challenges digitisation poses to resilience (e.g. understanding process manufacturing vs discrete manufacturing resilience requirements, lack of trust in digital manufacturing, compliance with regulation, incorrect application of digital solutions).

A particular aim of the roundtables was to identify recommendations to improve policy evidence gathering, policy analysis and policy-making to support addressing the challenges from each theme. A total of 27 recommendations emerged from the Connected Everything roundtable discussions which included: encouraging researchers to quantify

digital solution impact; supporting the design of sustainable products; providing financial incentives for manufacturers to decarbonise; and removing legislation preventing waste from being used as a viable alternative resource. Across the four themes, five recommendations emerged strongly and consistently and are illustrated in **Figure 1**.



Connect digital technology developers to manufacturers

Greater support is needed to connect manufacturing businesses with the UK innovation community, creating opportunities, increasing productivity and solving industry challenges. This will ensure future digital manufacturing research will develop solutions that fit manufacturing priorities.



Reduce digital manufacturing knowledge barriers

Digital manufacturing solutions need to become as simple and intuitive to use as installing a new mobile phone app or using a self service checkout. An example of this is the no-code revolution that allows anyone to create software through more intuitive visual interfaces. This helps put the power to design flexible, scalable, customisable applications in the hands of manufacturing experts.



Consolidate digital manufacturing guidance

Manufacturers seeking digital manufacturing guidance are exposed to many sources of, sometimes conflicting, advice about where to start. More signposting to initiatives like Made Smarter and Knowledge Transfer Network is needed to help manufacturers access the expertise required to implement digital manufacturing solutions.



Support employee wellbeing during transition

Digitisation may lead to employee anxiety from the uncertainty of future job security and demand for reskilling. Communicating clearly and consistently with employees about how the opportunities digitisation offers them can help people engage with the digital transformation and not be left behind.



Transparency of value chain data

To enable many digital manufacturing solutions will require transparency of supply chain data (e.g. emissions). Support to improve data sharing and transparency is needed to understand the environmental and social impact of manufacturing decisions, to drive more sustainable choices.

Figure 1
Cross-cutting recommendations to improve the use of digital manufacturing to meet the challenges leading up to 2050

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1. INTRODUCTION

The manufacturing sector is the economic engine of the UK, and its source of innovation, wealth and prosperity.

Manufacturing directly accounts 9% of the country's gross domestic product, however, this rises to 15% and 23% when considering the indirect (e.g. supply chains) and induced (e.g. spending by manufacturing employees) respective impacts [1]. Manufacturing is no longer just about production, it is a much wider set of activities that create value for the UK and benefits for wider society.

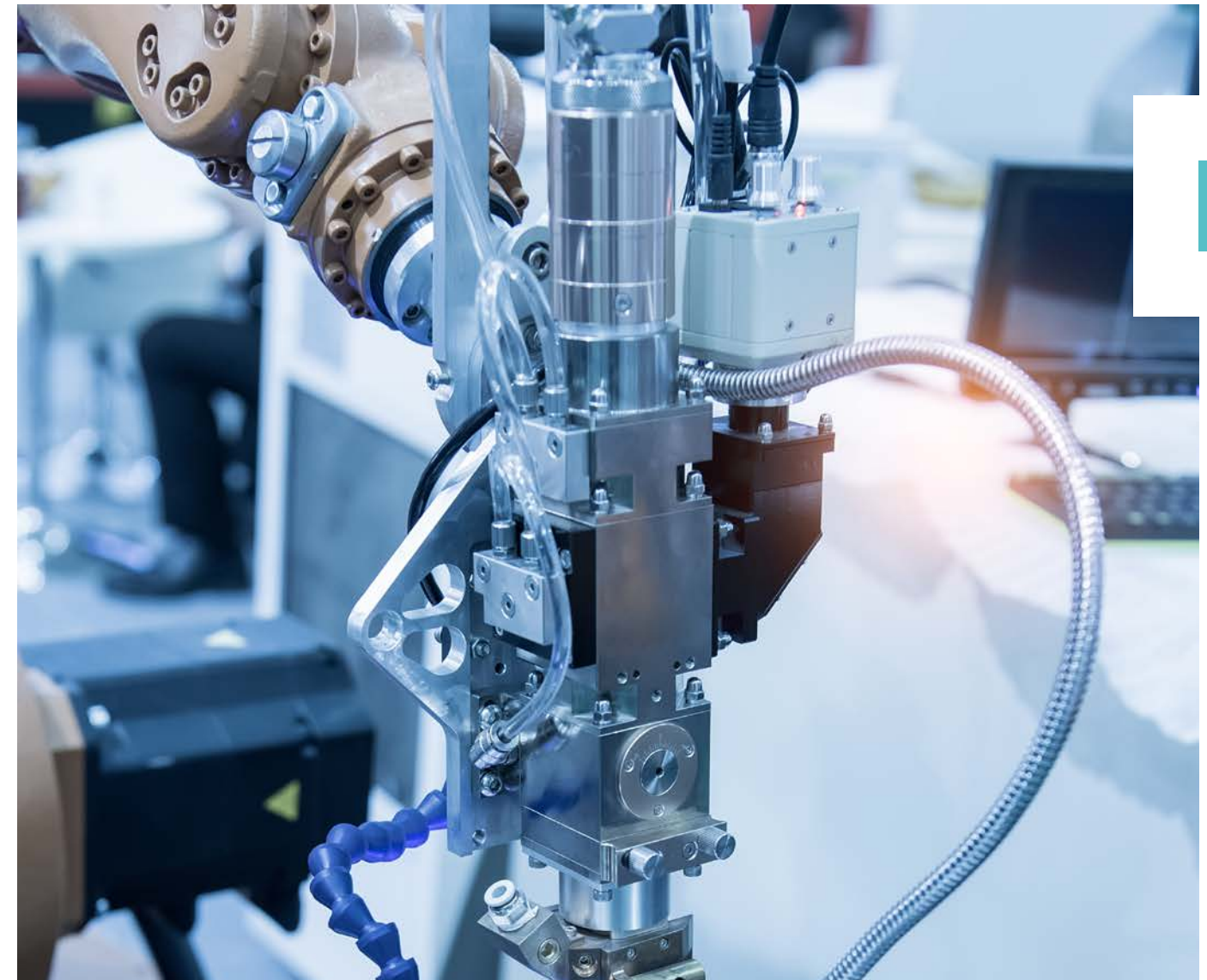
Innovation is a key driver of economic growth and improvements to living standards, through the development of new ideas, products and processes and their adoption and diffusion across the economy. In the last few years, the economic environment in which manufacturers are now operating in has dramatically changed. With seismic changes in the UK economy's situation following the UK's exit from the European Union (EU), global pandemic and war in Ukraine. This poses risks to innovation by shifting resources towards protecting against the uncertainty

of the immediate future rather than taking on risks that may better society and the UK's growth. The manufacturing sector must be forward thinking, bold, and innovative if the UK is to remain one of the world's leading manufacturing nations.

The digitisation of manufacturing heralds a revolution that has undeniable implications for the manufacturing sector and wider society. The 'digitisation of manufacturing' is also commonly termed the 'fourth industrial revolution'. It refers to the use of digital technologies, data and applications to deliver advancements in manufacturing-related operations (including the broader value chain of manufacturing activities), to enhance the performance of manufactured products (and related services) in both established and emerging sectors. These digital technologies each bring significant new capabilities, but their real potential lies in their convergence and connectivity, with innovative firms identifying new business models and new ways to disrupt established ways of working. Such extensive and potential disruption requires industry and governments to plan and prepare for radical change.



Figure 1.1
Connected Everything's
Thematic Areas



As digital technology advances, the manufacturing sector must adapt and respond to a great number of drivers and barriers. Connected Everything is an Engineering and Physical Science Research Council (EPSRC) funded Network Plus that aims to accelerate digitisation of the UK's manufacturing sector. This network supports multi-disciplinary collaboration, foster new collaborations between industry and academia and tackle emerging challenges which will underpin the UK academic community's research in support of people, technologies, products and systems for digital manufacturing. Connected Everything focuses our research through multidisciplinary thematic areas (Figure 1.1) that which bring together different disciplines to develop collaborative working practices and encourage discussion and information sharing resulting in improved insight into the challenges associated with industrial systems in a digital age.

Connected Everything activities aim to have specific influence on policy and society more generally through understanding the specific opportunities for UK industry and academia within a rapidly changing international landscape. For example, Connected Everything played a leading role in informing the research challenges incorporated into the 'Made Smarter' Wave 3 bid to the Industrial Strategy Challenge Fund. Manufacturing in 2050 will look very different from today, and will be virtually unrecognisable from that of 30 years ago. Connected Everything has embarked on horizon scanning activities, undertaken in collaboration with industrial partners and policy makers, to generate new knowledge on the challenges and opportunities for Digital Manufacturing practice and policy in 10, 20 and 30 years' time. This report presents the outputs from this horizon scanning study, which will help industry identify suitable collaboration partners for future research, and determine opportunities for investment in new technologies.

2. METHODOLOGY

This study follows the UK government foresight methodology that takes big, cross-cutting themes, summarises the evidence, and explores future possibilities.

Cross-cutting themes are additional areas that intersect with the main project (i.e. what will manufacturing look like in 2050?) and can be easily integrated into the project without losing focus of the main goal. Responses from a survey sent to Connected Everything's 500+ members were used to identify a shortlist of cross-cutting themes that will remain of critical importance to manufacturers over the next 30 years. The Connected Everything Executive Group then reviewed and oversaw the formulation of the final cross cutting themes for investigation. The Connected Everything Executive Group membership is drawn from a wide range of institutions and disciplines and includes representatives from UKRI, Catapults, other invested initiatives (e.g. ISCF Made Smarter Challenge, Brunel Challenge). Four cross-cutting themes were identified to explore within this study:

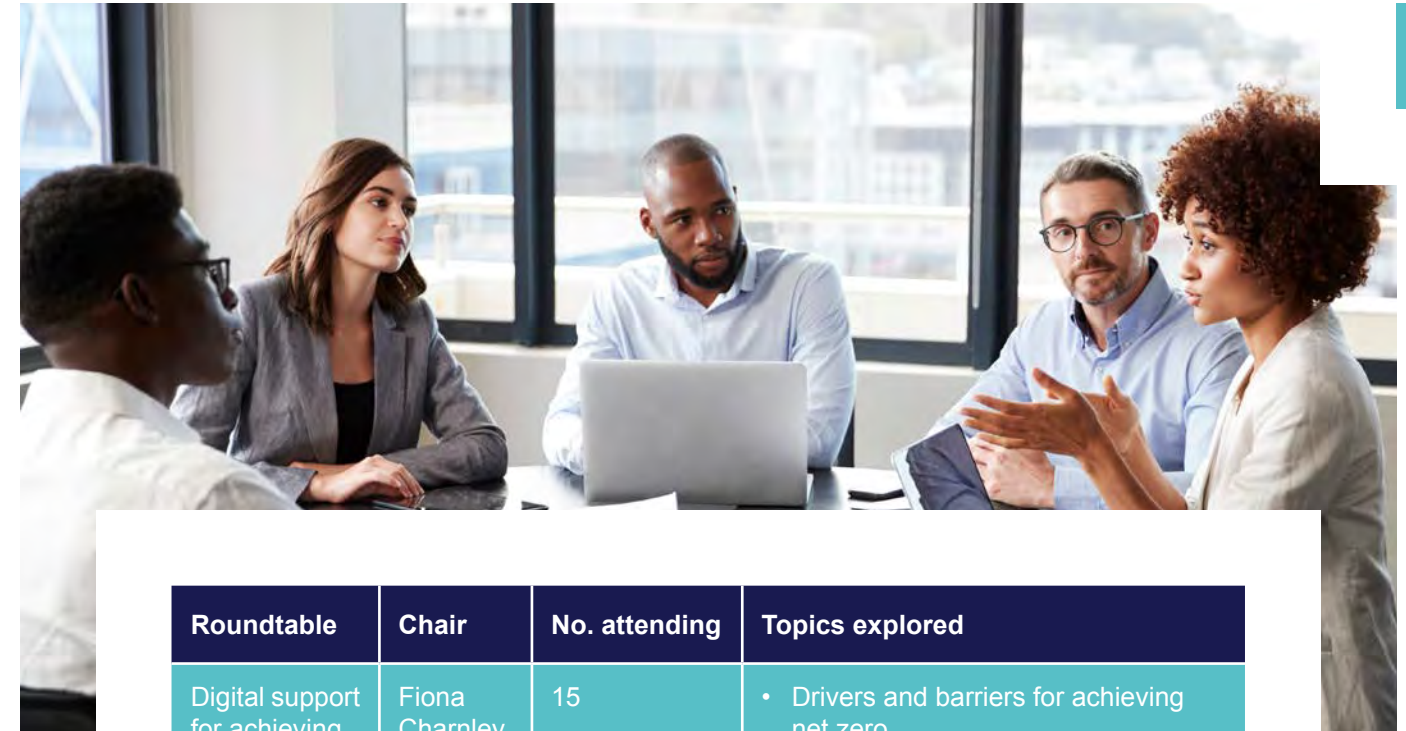
- 1. Industrial Digital Technologies in 2050:** Industrial digital technologies (e.g. robotics, machine learning, virtual reality) underpin and enable digital manufacturing. Emerging industrial digital technologies are having far-reaching implications for how we produce things, exchange information and interact across supply chains and with customers.
- 2. Digitisation and The Manufacturing Workforce of the Future:** As the adoption of digitisation accelerates, the impact on the manufacturing workforce is currently uncertain. This theme aims to understand the way that this will change the fundamental nature of work, and the way that we, therefore, design the technology and systems which will enable the future workplace is key to the delivery of future safe, effective and productive workplaces.
- 3. Digital Support for Achieving Net Zero Manufacturing by 2050:** The manufacturing and construction sector is the third largest sector in terms of carbon emissions. While there are many routes to net zero, digital technologies are becoming central to all modern economies and understanding how they can help manufacturers achieve net zero by 2050 is crucial.

- 4. Digitally Enabled Manufacturing Resilience:** Over the past two years, manufacturers have faced unprecedented disruption with the combination of the UK leaving the European Union, the global pandemic and the humanitarian disaster in Ukraine, combined with soaring transport, energy and raw material costs. This theme explored both how digitisation can play a key role in making manufacturing systems more resilient.

The study utilised three key methods as part of a framework for evidence gathering and analysis. Firstly a review of grey literature (e.g. reports, policy literature, working papers, newsletters, government documents, white papers) to understand digital manufacturing research emerging outside of traditional publishing channels. Secondly, an engaged scholarship approach to obtain the advice and perspectives of key stakeholders (in this case leaders from academia, industry and policy) to understand and solve a real-world problem. Lastly, case studies to understand current and future applications of digital manufacturing within the context of the four cross-cutting themes.

The advice and perspectives from stakeholders were acquired through several methods including: workshops at manufacturing conferences (e.g. Digital Manufacturing Week 2020, UK), survey, consolidation with Connected Everything Executive Group and a series of roundtables. The roundtables were chaired by Connected Everything investigators and invited leaders from academia, industry and policy to share their thoughts and experiences relevant to the purpose of this study. Four roundtables took place between May 2021 and January 2022. Each roundtable table address one of the cross cutting themes and conversations were focused around a set of predefined topic points, agreed by the roundtable chair, and shared with the attendees in advance of the roundtable. The roundtables are summarised in **Table 2.1**.

A mural board for each topic area was created and used to collect data from the discussion. Connected Everything team members also recorded minutes of the discussion. Qualitative analysis of the data was then performed to draw out common themes within comments made by the roundtable participants. The findings were then shared with roundtable attendees and Connected Everything Executive Group who reviewed and validated the conclusions drawn. In addition, the results were presented and feedback provided during a workshop at the Connected Everything Annual Conference 2022, Liverpool, UK.



Roundtable	Chair	No. attending	Topics explored
Digital support for achieving net zero manufacturing by 2050	Fiona Charnley,	15	<ul style="list-style-type: none"> • Drivers and barriers for achieving net zero • Digital support for achieving net zero • Recommendations for policy, initiatives and support to achieve net zero • Vision for 2050 net zero manufacturing
Future workforce	Sarah Sharples	13	<ul style="list-style-type: none"> • Workforce challenges • Digitally related workforce challenges • Digital solutions
Industrial digital technologies	Nik Watson	10	<ul style="list-style-type: none"> • Current and future manufacturing challenges • Current and future uses of IDTs • Emerging IDTs • Recommendations for policy, initiatives and support to increase use of IDTs
Digitally enabled manufacturing resilience	Fiona Charnley	15	<ul style="list-style-type: none"> • Drivers and barriers for achieving resilience • Digital support for resilience • Recommendations for policy, initiatives and support to achieve net zero • Risks to resilience from digital

Table 2.1
Overview of roundtables
topic explored