Constructing a Sustainable Industry 4.0: Foresight as Enabler of Circular Additive Manufacturing Business Models

Mikkel Stein Knudsen, Jari Kaivo-oja & Theresa Lauraéus
Finland Futures Research Centre, Turku School of Economics, University of Turku
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Manufacturing 4.0 – strategies for technological, economic education, and social policy adoption

Funded by The Strategic Research Council of the Academy of Finland for the call of Adaptation and Resilience for Sustainable Growth for the period of 2018-2020.

The consortium includes seven research groups, five work packages and four universities.

WP1: Future Research (FFRC, UTU)
WP2: Automation and Distributed Manufacturing
WP3: Decision-making, potential, and business models
WP4: Education
WP5: Reshaping Social policies

Website: [http://mfg40.fi/](http://mfg40.fi/)
The manufacturing sector in Finland has already lost 100,000 jobs since 2007.

Source: Statistics Finland
Digitalisation: Data and AI increasingly represents added value, integrates to all sectors of the economy.
The Fourth Industrial Revolution

Industry 1.0:
The age of steam and new mechanized manufacturing
End of 18th century

Industry 2.0:
The age of electricity and new mass manufacturing
Start of 19th century

Industry 3.0:
The age of information and new automated manufacturing
Start of 1970s

Industry 4.0:
The age of cyber-physical systems and new intelligent and distributed manufacturing
Today

End of 18th century Start of 19th century Start of 1970s Today
Components of Industry 4.0
(adapted from Jabbour et al., 2018a)
There is a enormous need for solutions that bridge technological futures with sustainable futures.

According to Tseng et al. (2018) Scopus returns 4060 hits on "Industry 4.0" and 2452 hits on "Circular Economy". For the combination of "Industry 4.0" and "Circular Economy", the result is a mere 3 articles.
They say it’s happening, but …

… ”There are rarely any sustainability assessments for Industry 4.0 available” (Stock et. al., 2018)
“Each small moment of convenience [with Alexa] – be it answering a question, turning on a light or playing a song - requires a vast planetary network, fueled by the extraction of non-renewable materials, labour and data”

Crawford & Joler (2018)
## Common carbon footprint benchmarks

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>CO₂ Equivalent (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundtrip flight b/w NY and SF (1 passenger)</td>
<td>1,984</td>
</tr>
<tr>
<td>Human life (avg. 1 year)</td>
<td>11,023</td>
</tr>
<tr>
<td>American life (avg. 1 year)</td>
<td>36,156</td>
</tr>
<tr>
<td>US car including fuel (avg. 1 lifetime)</td>
<td>126,000</td>
</tr>
</tbody>
</table>
| Transformer (213M parameters) w/ neural architecture search | 626,155

Sources:
- Hao (2019), Training a single AI model can emit as much carbon as five cars in their lifetimes, MIT Technology Review, June 6 2019
Additive manufacturing: 8 manufacturing scenarios based on customization, volume and complexity

3D Printing Disrupts Manufacturing
How Economies of One Create New Rules of Competition

3D printing may represent a disruption to the manufacturing industry as profound as the Industrial Revolution.

Irene J. Patrick and Timothy W. Simpson
Eight manufacturing scenarios and environmental benefits and concerns

Source: Kohtala (2015), Making Sustainability: How Fab Labs Address Environmental Issues
Factories of the future

... surely they are sustainable?

Sources: EFFRA, VTT
Circular economy

• "In a Circular Economy, companies concentrate on rethinking products and services from the bottom up to "future proof" their operations and prepare for the inevitable resource constraints – all the way through to the customer value proposition" (Pagoropoulos et al., 2017)
# A call to arms: Needs for a new research agenda

<table>
<thead>
<tr>
<th>New business logics</th>
<th>Mass customization</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Co-creation and platforms</td>
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<tr>
<td></td>
<td>Decentralisation and prosumer-thinking</td>
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<tr>
<td>Industry 4.0</td>
<td>Digitalisation</td>
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<td>Automation and robotics</td>
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<td>Additive manufacturing and 3D-printing</td>
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<td>Machine learning and AI</td>
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<tr>
<td>Planetary boundaries</td>
<td>Circular economy</td>
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<td>Security of supply of minerals</td>
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</table>
A scramble for the minerals used in renewable energy is under way

Security of supply and scarcity of raw materials

Figure 12.2 Criticality assessment for EU path to the decarbonisation of the energy sector

<table>
<thead>
<tr>
<th>Element</th>
<th>Rating</th>
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</thead>
<tbody>
<tr>
<td>Rare Earths: Dy, Eu, Tb, Y</td>
<td>High</td>
</tr>
<tr>
<td>Rare Earths: Pr, Nd</td>
<td>High</td>
</tr>
<tr>
<td>Gallium</td>
<td>High</td>
</tr>
<tr>
<td>Tellurium</td>
<td>High</td>
</tr>
<tr>
<td>Graphite</td>
<td>High-Medium</td>
</tr>
<tr>
<td>Rhenium</td>
<td>High-Medium</td>
</tr>
<tr>
<td>Indium</td>
<td>High-Medium</td>
</tr>
<tr>
<td>Platinum</td>
<td>High-Medium</td>
</tr>
<tr>
<td>Rare Earths: La, Ce, Sm, Gd</td>
<td>Medium</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Medium</td>
</tr>
<tr>
<td>Tantalum</td>
<td>Medium</td>
</tr>
<tr>
<td>Niobium</td>
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</tr>
<tr>
<td>Vanadium</td>
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</tr>
<tr>
<td>Tin</td>
<td>Medium</td>
</tr>
<tr>
<td>Chromium</td>
<td>Medium</td>
</tr>
<tr>
<td>Selenium</td>
<td>Medium-Low</td>
</tr>
<tr>
<td>Lithium</td>
<td>Medium-Low</td>
</tr>
<tr>
<td>Hafnium</td>
<td>Medium-Low</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Medium-Low</td>
</tr>
<tr>
<td>Silver</td>
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</tr>
<tr>
<td>Nickel</td>
<td>Low</td>
</tr>
<tr>
<td>Gold</td>
<td>Low</td>
</tr>
<tr>
<td>Copper</td>
<td>Low</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Low</td>
</tr>
</tbody>
</table>
A call for arms: Needs for a new research agenda

- Applying CE-principles for Industry 4.0-enabling technologies
  - Example: Despeisse et al., 2017
- Applying Industry 4.0 to enable Industrial symbiosis
  - Example: Tseng et al., 2018
- Applying Industry 4.0 to empower Circular Economy implementation
  - Example: Lin, 2018
- Integration of 4.0 and CE with Lean Manufacturing
  - Example: Sanders et al., 2016
- Business model innovation and new 14.0/CE business models
  - Example: Antikainen et al., 2018
- 14.0/CE implications for management and organization
  - Example: Laboure et al., 2018
- Combining Circular Economy with the value-drivers of Industry 4.0
  - Example: Blunck & Werthmann, 2017

Source: Knudsen & Kaivo-oja (2018), Bridging Industry 4.0 and Circular Economy: A New Research Agenda for Finland?
A call for arms: Foresight as enabler

We need:
• Long-termism
• Futures consciousness
• Interdisciplinarity and engagement of multiple stakeholders
• Technical research
• Academic and vocational training

=> Integrating customer concerns, manufacturing needs, and environmental issues
Set-up of a project?

Product and/or process renewal

1st step: Identifying relevant products and/or products lines suitable for examination and an innovation project.

2nd step: Sketching out what this could look like.

3rd step: Identifying and organizing relevant partners for achieving the project.

Derived supply-side sustainability challenges

1st step: Scoping sustainability challenges derived from chosen focus of WP1.

Demand-side sustainability challenges

1st step: Identifying the relevant customers for the given products.

2nd step: Literature scan, horizon scanning in order to scope a foresight study aimed at the future operating environment of the customers, with a focus on sustainability challenges.

3rd step: Identifying and organizing relevant partners, planning the work.

Co-innovation project application

Photos: Pixabay
Can we measure circular economy?

Source: Moraga et al. (2018)
What’s next?

Challenges to adoption of Industry 4.0 technologies

Select an approach to ReSOLVE

Identify suitable Industry 4.0 technologies

Adapt SOM decisions

Develop cooperation in supply chain

Create performance indicators and small and achievable targets

Industry 4.0

Sustainable Operations Management

CE

Source: Jabbour et al. (2018b)
Some key references

- Pagoropoulos et al. (2017), The emergent role of digital technologies in the Circular Economy: A review. *Procedia CIRP.*
- Jabbour et al. (2018), Industry 4.0 and the circular economy: A proposed research agenda and original roadmap for sustainable operations. *Annals of operation research.*
Thank you for the attention

Mikkel Stein Knudsen, Jari Kaivo-oja, Theresa Lauraéus