Sustainable distributed recycling via additive manufacturing (SDRAM): from a technical to systemic challenge

Workshop: Responsible Design for AM

Fabio A. CRUZ SANCHEZ

| Nancy 06 September, 2022

UNIVERSITÉ DE LORRAINE

ERPI Equipe de Recherche sur les Processus Innovatifs Université de Lorraine

LORRAINE INP Ensgsi NANCY

Outline

1. Who I am?
2. Societal challengues for sustainable manufacturing
3. Approach of Distributed Recycling via Additive Manufacturing (DRAM)
4. Put in reality
5. Some Future considerations

Who am I?

Fabio A. Cruz Sanchez
fabbiocrux

🇨🇴🇫🇷 Research associate at Université de Lorraine in distributed recycling for additive manufacturing

ERPI Laboratory
Nancy, France
https://fabbiocrux.com/
@fabbiocrux

ERPI
Equipe de Recherche sur les Processus Innovatifs
Université de Lorraine

Research

The Research team on innovation process

A research team on Industrial Engineering specialized on the research of innovation processes management. Its activities concerns the methods, tools and knowledges allowing to optimise innovation projects management.

LORRAINE FAB LIVING LAB®

Demonstrator

The platform for the prospective evaluation of the uses and acceptability of innovation

The LF2L supports the creation and use of "demonstrators" of new products, processes, services, organizations mobilizing companies, territories and academics for creative and sustainable territories.

ensgsi
Ecole Nationale Supérieure en Génie des Systèmes et de l'Innovation

Training

The 1st French Graduate School specialized in Innovation!

A French National Engineering School aiming to train engineers with expertise in leading complex industrial projects and implementing innovation processes in organisations.

Innovation:

- As a product.
- As a process.
- As a complex system.
- As territorial asset.

How I started in the 3D Printing world.?

ensgsi
Ecole Nationale Supérieure en Génie des Systèmes et de l'Innovation

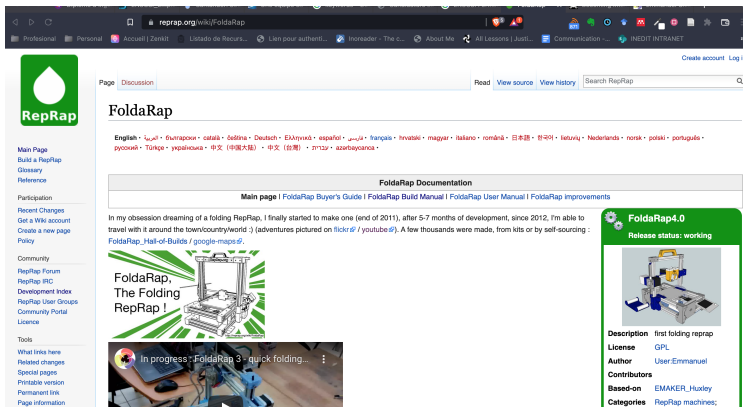
Cré@ction 2005

GSILab

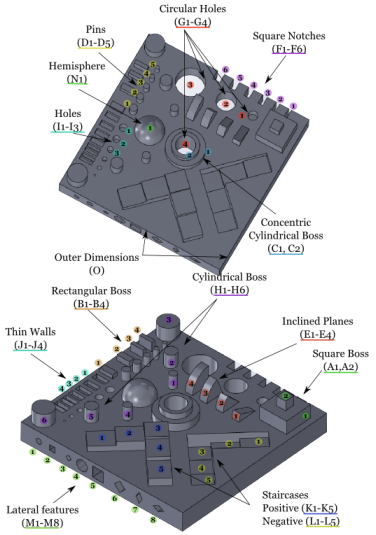
2011 FABLAE

ENSGSI
INNOVARE HUMANUM EST

GSI LAB



1. Geometric Benchmarking Model



2. Design of Experiments

Control Factors

Paramètres de contrôle	Simbole	Value			
		1	2	3	Unités
L'épaisseur de couche	F1	0.127	0.178	0.254	mm
Largeur de route	F2	0.54	0.62	0.71	mm
Vitesse de mouvement de la tête	F3	25	50	75	mm/s

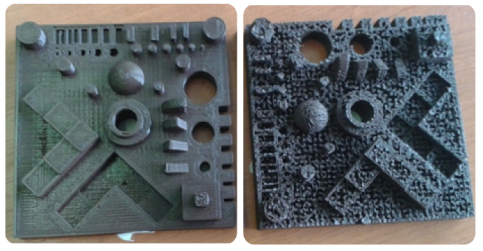
Experiments

# Essai	Facteurs		
	L'épaisseur de couche [mm]	Largeur de route [mm]	Vitesse de mouvement de la Tête [mm/s]
1	0.127	0.54	25
2	0.127	0.62	50
3	0.127	0.71	75
4	0.178	0.54	75
5	0.178	0.62	25
6	0.178	0.71	50
7	0.254	0.54	50
8	0.254	0.62	75
9	0.254	0.71	25

Taguchi method

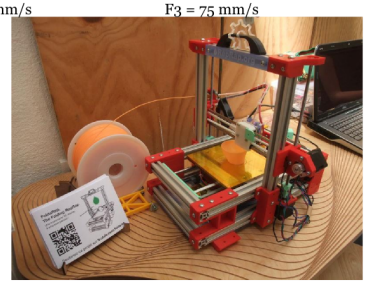
3. Fabrication

Sample 1 **Sample 8**



F1= 0.13mm
F2 = 0.54 mm
F3 = 25 mm/s

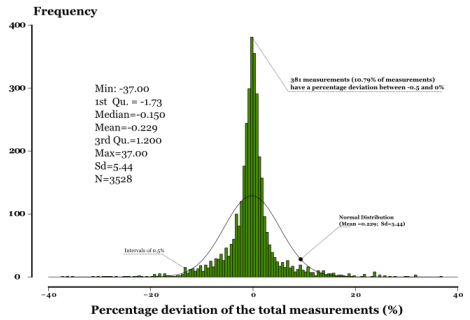
F1 = 0.25mm
F2 = 0.62 mm
F3 = 75 mm/s

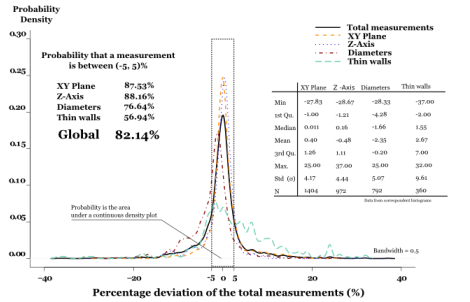


Open Source 3D printer
-FoldaRap-

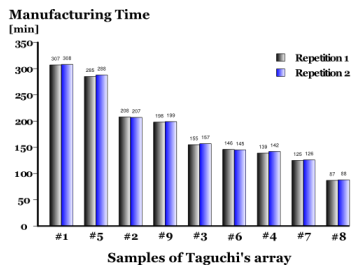
4. Results

Geometrical precision





Manufacturing time

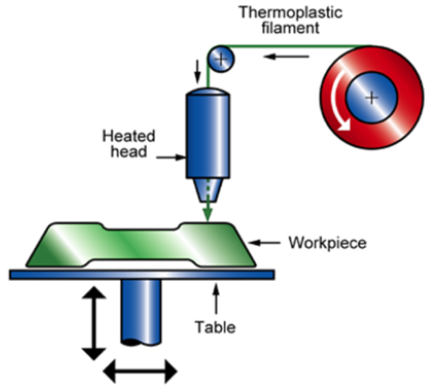


Experimental protocol of geometrical performance evaluation in order to characterise OS 3D printers based on Design of Experiments (DoE), integrating different families of geometrical objects and ANSI-ISO's International Tolerance (IT) Grades

Cruz Sanchez, F. A., Boudaoud, H., Muller, L. & Camargo, M. Towards a standard experimental protocol for open source additive manufacturing. Virtual and Physical Prototyping 9, 151–167 (2014).

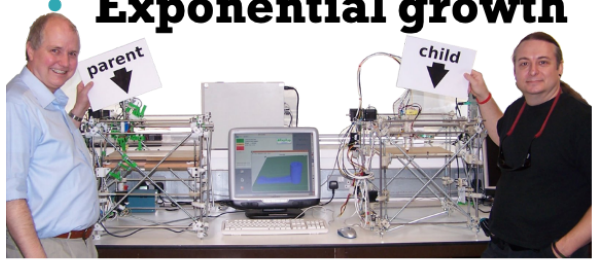
Fused Deposition Modeling (FDM)

Deposits a thread of molten material usually from a plastic filament, onto a substrate with the use of a movable head.

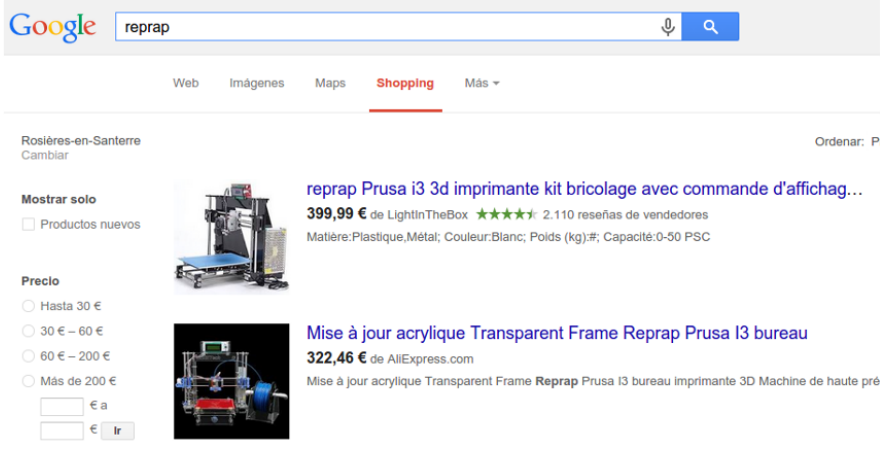


RepRap Project

- *FDM patent expired in 2005*
- **Rep**licating **Rap**id-prototyper freely *Available for the benefit of everyone*
- Open source approach . (available Information)
- Global community / Global knowledge, local needs.
- Low cost (<$5000)
- Quality? **Standardization?** Repeatability? … (High enough)
- **Exponential growth**



Materials: ABS / PLA



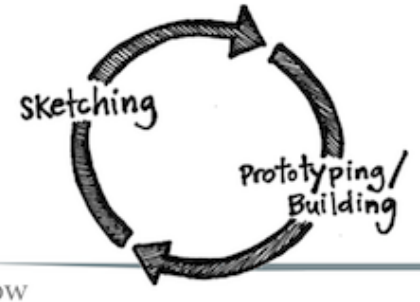
Self-replicating manufacturing machine --> Paradox of Jevons?

Future of Additive Manufacturing

Degree of Corporate

Worldwide

Only prototyping



- Low engagement because the reliability and intuitiveness of the technology

Desktop factories at home

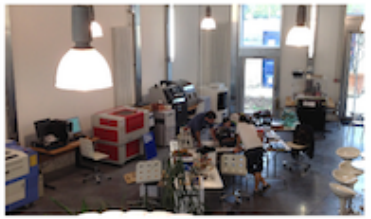
- High appropriation
- 3DP impact in Education / Childhood
- Circular economy

People's Engagement

Low

High

Community Crafts



- Co-production and collaboration
- 3DP in non-/without profit community
- Hobbyists and enthusiasts for technology

Localized Manufacturing

- 3D printing retail and service bureau
- Mass customization

Local

(Birtchnell and Urry 2013)

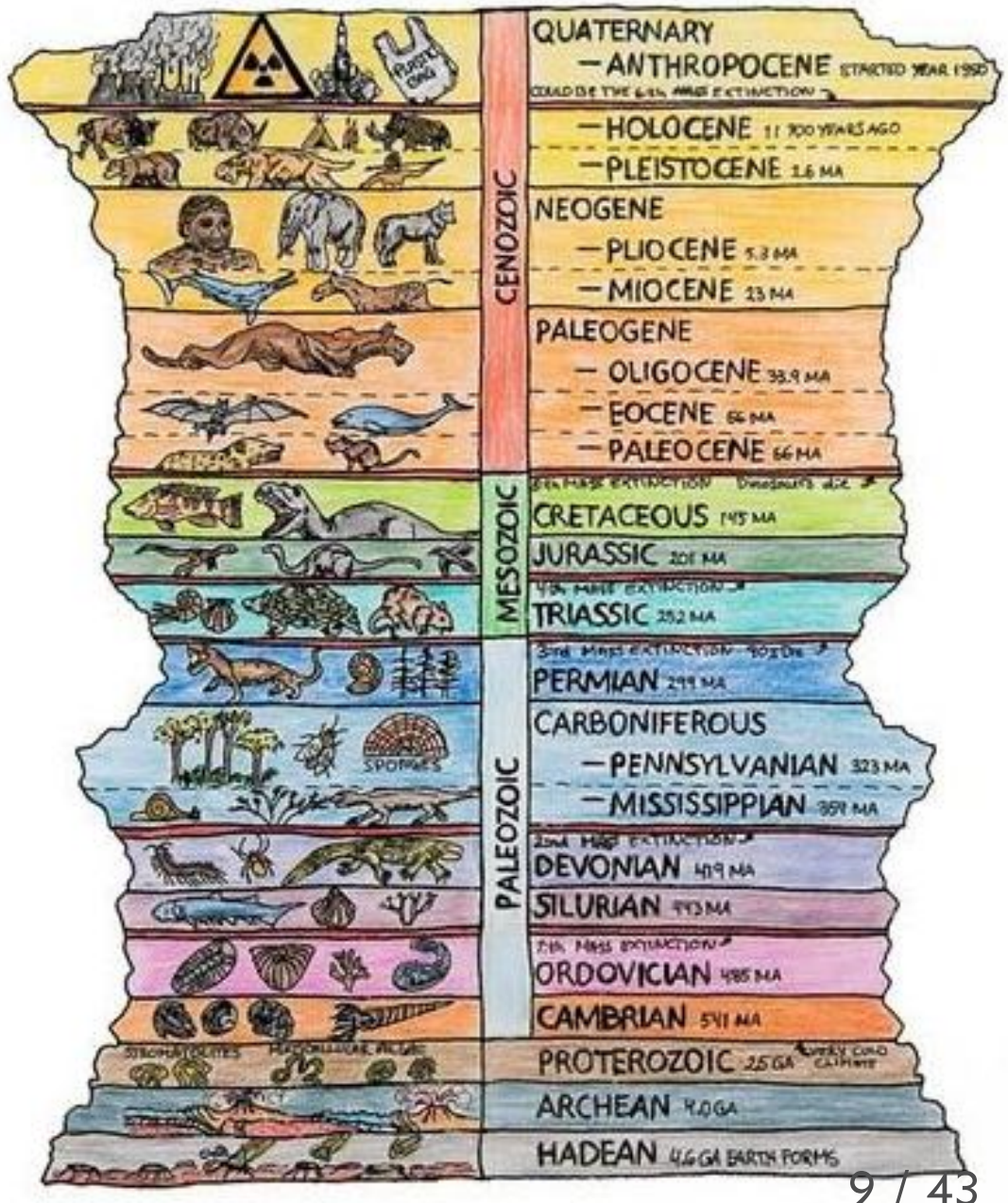
Outline

1. Who I am?
2. Societal challengues for sustainable manufacturing
3. Approach of Distributed Recycling via Additive Manufacturing (DRAM)
4. Put in reality
5. Some Future considerations

Anthropocène: Humans as a geological force …

Steffen, et al. The Anthropocene: conceptual and historical perspectives. Phil. Trans. R. Soc. A. 369, 842–867 (2011).

- Earth is now moving out of its current geological epoch (Holocene)
- human activity is largely responsible for this exit



Anthropocène:
Humans as a geological force …

Steffen, et al. The Anthropocene: conceptual and historical perspectives. Phil. Trans. R. Soc. A. 369, 842–867 (2011).

- The Great Acceleration since 1950
- CO2: 311ppm (1950) --> 369 (2000)
- Capitalocene rather than Antropocene.

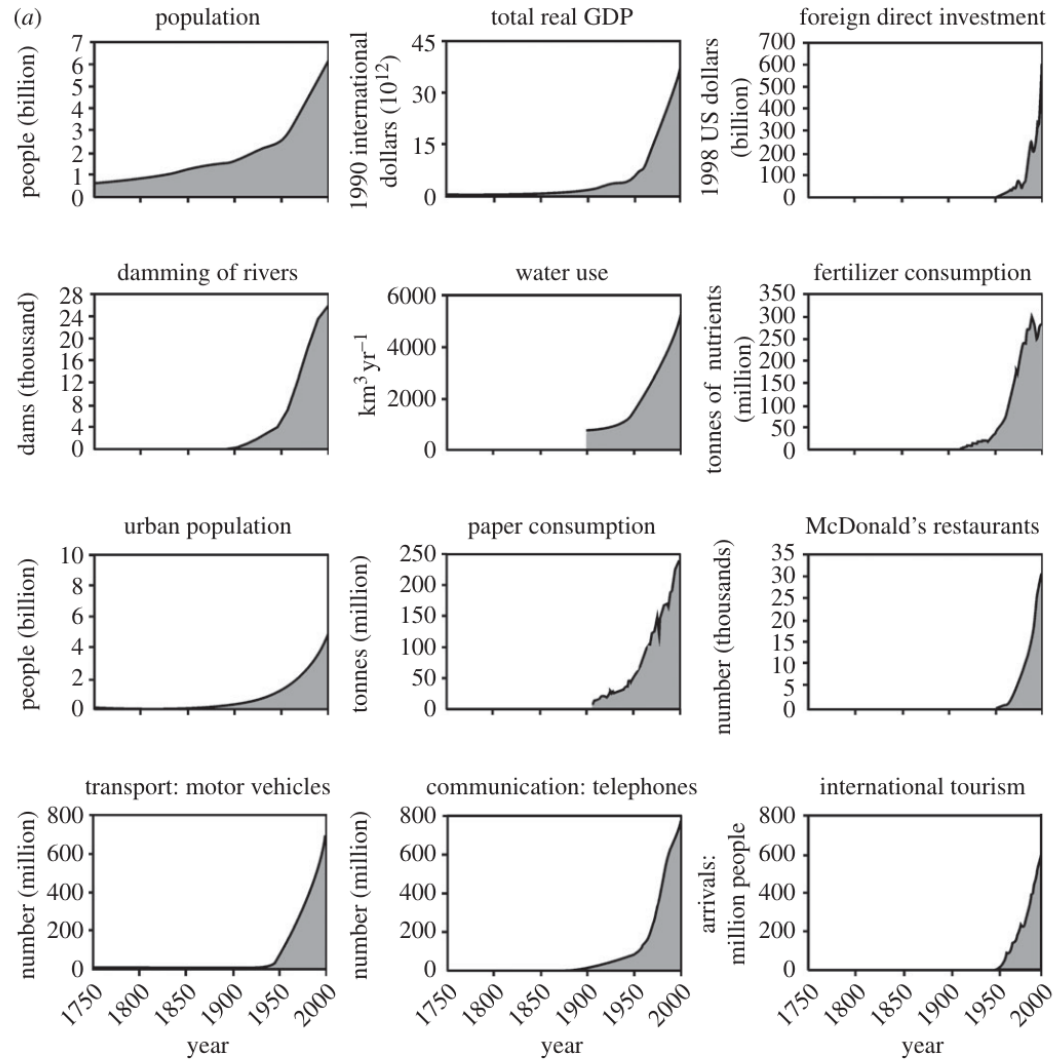
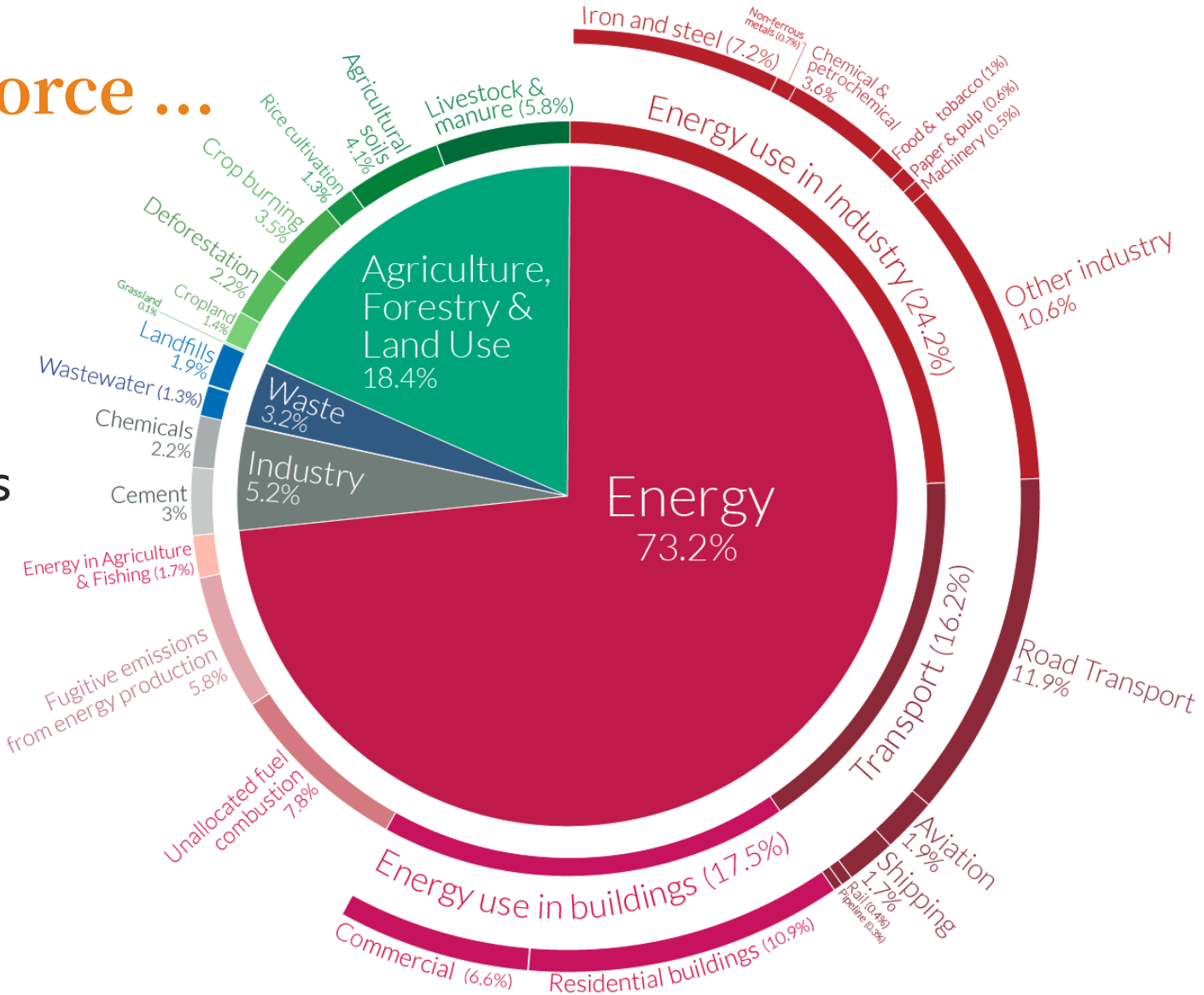


Figure 1. (*a*) The increasing rates of change in human activity since the beginning of the Industrial Revolution. Significant increases in rates of change occur around the1950s in each case and illustrate how the past 50 years have been a period of dramatic and unprecedented change in human history.

Anthropocène:
Humans as a geological force …

- [in CO2] .

- Climate neautrality & decarbonization
- Improvements in sector counts



Anthropocène:
Humans as a geological force …

- [in CO2]
- [in Plastic pollution].

De-la-Torre, G. E., Dioses-Salinas, D. C., Pizarro-Ortega, C. I. & Santillán, L. New plastic formations in the Anthropocene. Science of The Total Environment 754, 142216 (2021).

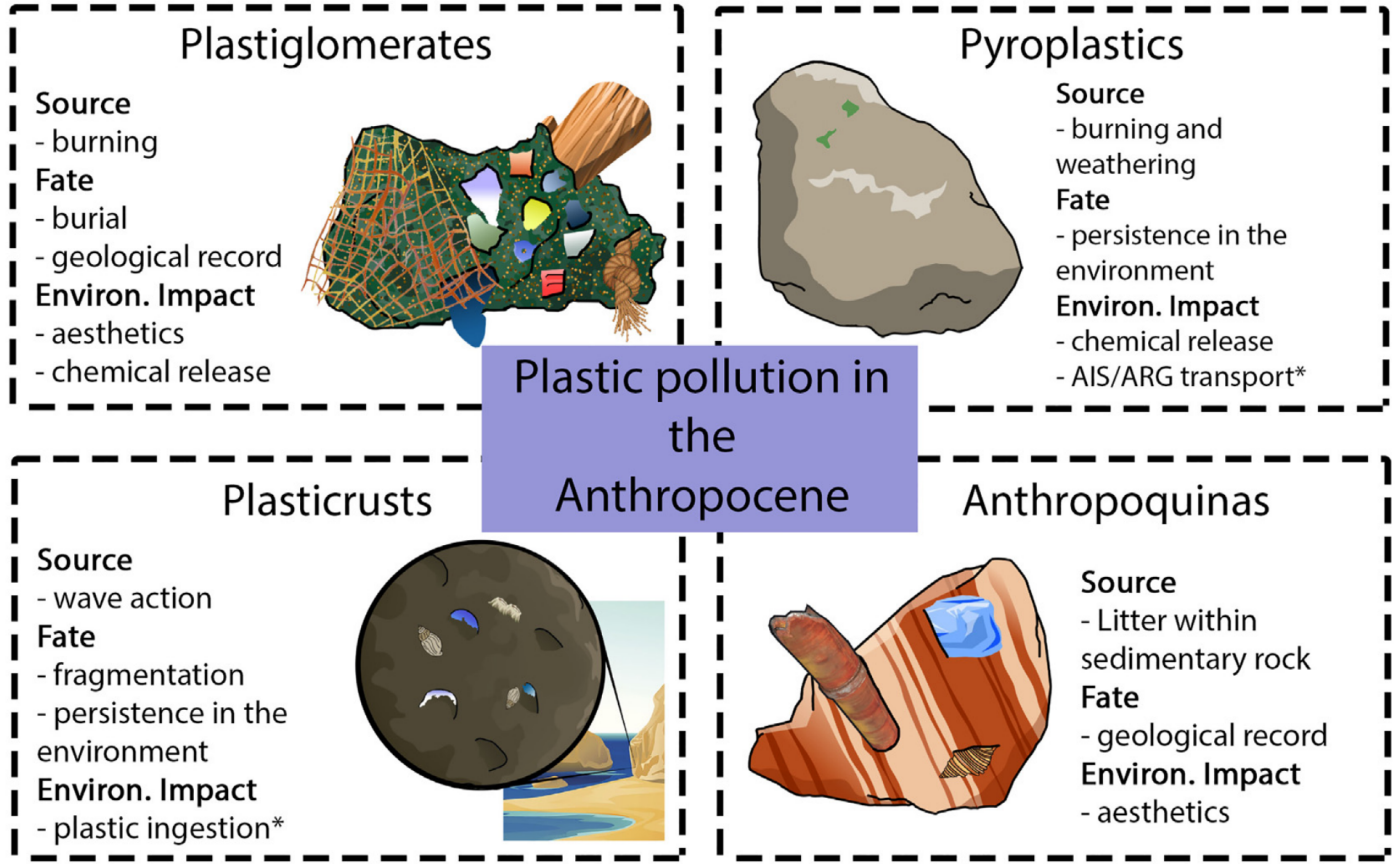


Fig. 3. Visual representation and main characteristics of the new plastic formations described in the literature. *: Suspected environmental impact.

Today, we need to include circularity in a micro/meso/macro level !!

Towards Circularity

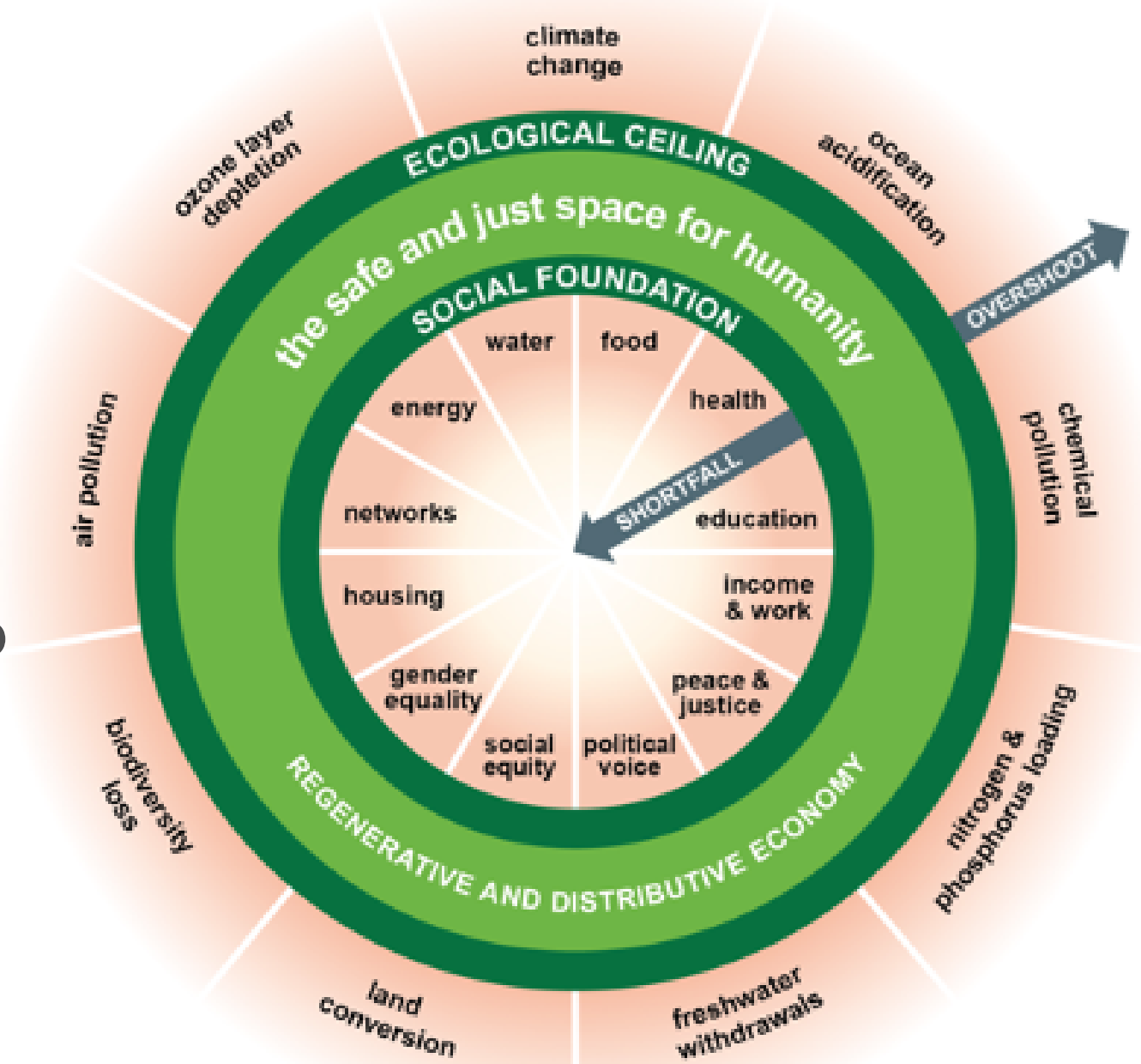
Calisto Friant, M., Vermeulen, W.J.V., Salomone, R., 2020. A typology of circular economy discourses:
Navigating the diverse visions of a contested paradigm.
Resour. Conserv. Recycl. 161, 104917.
https://doi.org/10.1016/j.resconrec.2020.104917

Table 2
Concepts within each circularity discourse type.

Discourse	Concepts from the Timeline	
Reformist Circular Society (20 concepts)	**N. 20 Circularity 3.1 concepts:** 1. Rio Declaration on Environment and Development (UN, 1992) 2. Regenerative design (Lyle, 1994) 3. Natural Capitalism (Hawken et al., 1999) 4. Sound Material-Cycle Society (Government of Japan, 2000) 5. Cyclical Economy (Young et al., 2001) 6. Materials Matter (Geiser, 2001) 7. Cradle to Cradle (McDonough and Braungart, 2002) 8. The Natural Step (Robèrt, 2002) 9. Performance Economy (Stahel, 2010)	10. Blue economy (Pauli, 2010) 11. Material Efficiency (Allwood et al., 2011) 12. Third industrial revolution (Rifkin, 2013) 13. Eco-system economy (Scharmer and Kaufer, 2013) 14. Regenerative capitalism (Fullerton, 2015) 15. Sharing Economy (Frenken, 2017) 16. Doughnut Economics (Raworth, 2017) 17. Symbiotic Economy (Delannoy, 2017) 18. Social Circular Economy (Social Circular Economy, 2017) 19. Spiral Economy (Ashby et al., 2019) 20. Coviability (Barrière et al., 2019)
Transformational Circular Society (30 concepts)	**N. 13 precursor concepts:** 1. Gandhian economics (Kumarappa, 1945) 2. The Economics of the Coming Spaceship Earth (Boulding, 1966) 3. The entropy law and the economic process (Georgescu-Roegen, 1971) 4. The Closing Circle (Commoner, 1971) 5. Social Ecology (Bookchin, 1971) 6. Ecological Design (Papanek, 1972) 7. Limits to Growth (Meadows et al., 1972) 8. Small is Beautiful (Schumacher, 1973) 9. Conviviality (Illich, 1973) 10. Steady-state economics (Daly, 1977) 11. Permaculture (Mollison and Holmgren, 1978) 12. Décroissance (Gorz, 1980) 13. Deep Ecology (Næss and Rothernberg 1989) **N. 17 Circularity 3.2 concepts:** 1. Transition Movement (Hopkins, 2008)	2. Degrowth (Latouche, 2009) 3. Eco-socialism (Löwy, 2011) 4. Laudato Si' (Pope Francis, 2015) 5. Transition design (Irwin, 2015) 6. Economy for the Common Good (Felber, 2015) 7. Post-growth (Jackson, 2016) 8. Permacircular Economy (Bourg, 2018), 9. Voluntary Simplicity (Trainer and Alexander, 2019) 10. Convivalism (Caillé, 2019) 11. Buen Vivir/ Sumark Kawsay (Government of Ecuador, 2008) 12. Ubuntu (Shumba, 2011) 13. Ecological Civilization (Zhang et al., 2011) 14. Ecological Swaraj (Kothari et al., 2014) 15. Suma Qamaña / Vivir Bien (Artaraz and Calestani, 2015) 16. Buddhist, Confucian and Taoist ecology (Arler, 2018) 17. Radical Pluralism/ Pluriverse (Kothari et al., 2019)
Technocentric Circular Economy (19 concepts)	**N. 15 concepts from Circularity 2.0:** 1. Industrial Ecology (Frosch and Gallopoulos, 1989) 2. Circular Economy (Pearce and Turner, 1989) 3. Eco-design /Design for environment (Ryan et al., 1992) 4. Cyclic Economy (Tibbs, 1993) 5. Industrial Metabolism (Ayres and Simonis, 1994) 6. Cleaner Production (Baas, 1995) 7. Reverse Logistics (Rogers and Tibben-Lembke, 1998) 8. Eco-industrial parks and networks (Côté and Cohen-Rosenthal, 1998)	9. Biomimicry (Benyus, 1998) 10. Product Service System (Goedkoop et al., 1999) 11. Extended Producer Responsibility (Lindhqvist, 2000) 12. Industrial Symbiosis (Chertow, 2000) 13. Closed-loop Supply Chain (Guide et al., 2003) 14. Biobased Economy / Bioeconomy (OECD, 2004) 15. The Biosphere Rules Unruh, 2008 **N. 4 Circularity 1.0 concepts:** 1. Waste-Water Treatment (Holcomb, 1970) 2. Integrated Solid Waste Management and Recycling (Levick and Davies, 1975) 3. Bio-Digestion (Hughes, 1975) 4. Energy Recovery (Boyle, 1977)
Fortress Circular Economy (3 concepts)	**N. 3 precursor concepts:** 1. The tragedy of the Commons (Hardin, 1968) 2. The Population Bomb (Ehrlich, 1968) 3. Overshoot (Catton, 1980)	

Doughnut Economics

- Beyond GDP growth
- 'Sweet spot'
  minimal social requirements **AND**
  Planetary earth's boundaries.

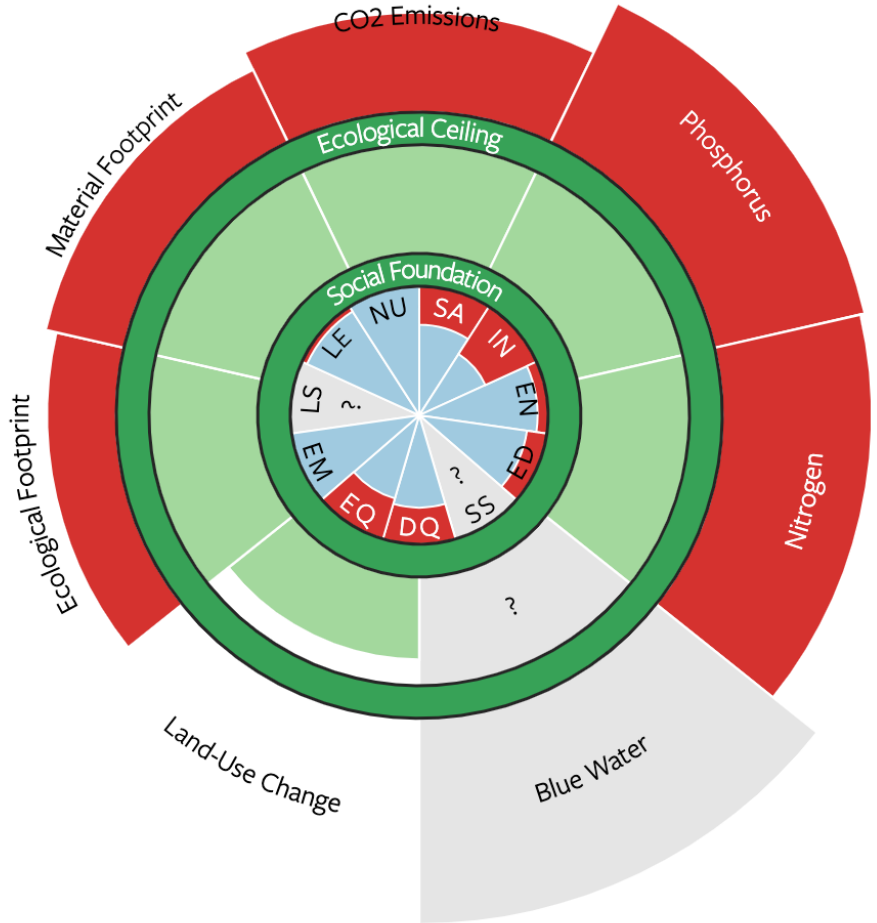


Raworth, K. A Safe and Just Space for Humanity: Can We Live within the Doughnut? Oxfam: Oxford, UK, 2012.

Doughnut Economics

World at 2015

- Beyond GDP growth
- 'Sweet spot'
  minimal social requirements **AND**
  Planetary earth's boundaries.

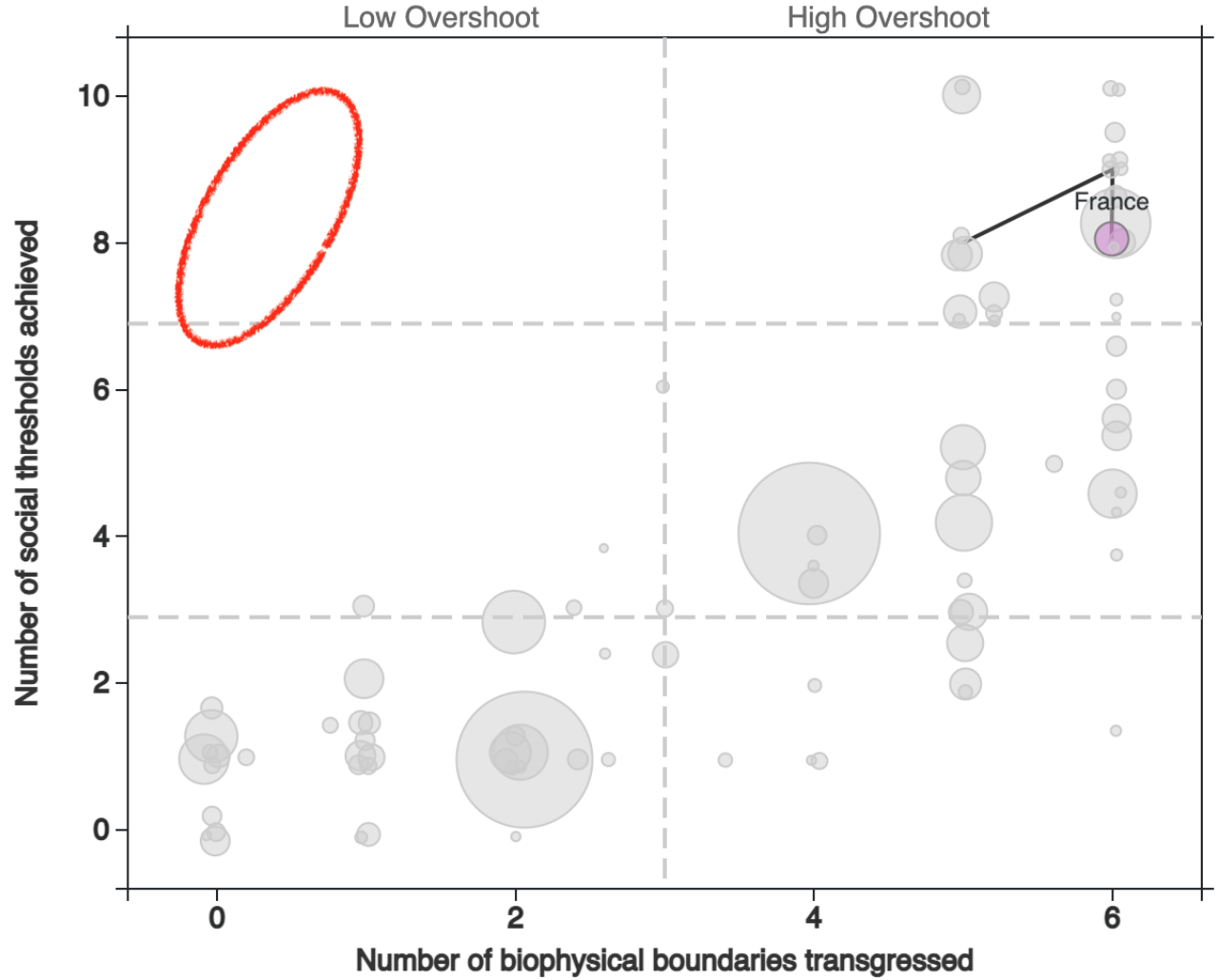


LS - Life Satisfaction	LE - Life Expectancy	NU - Nutrition	SA - Sanitation
IN - Income Poverty	EN - Access to Energy	ED - Education	SS - Social Support
DQ - Democratic Quality	EQ - Equality	EM - Employment	

O'Neill, D. W., Fanning, A. L., Lamb, W. F., & Steinberger, J. K. (2018). A good life for all within planetary boundaries. Nature sustainability, 1(2), 88-95. More details: https://goodlife.leeds.ac.uk .

Doughnut Economics: World at 2015

- No country satisfy the basic needs without transgression



O'Neill, D. W., Fanning, A. L., Lamb, W. F., & Steinberger, J. K. (2018).
A good life for all within planetary boundaries. Nature sustainability, 1(2), 88-95.
https://goodlife.leeds.ac.uk

Outline

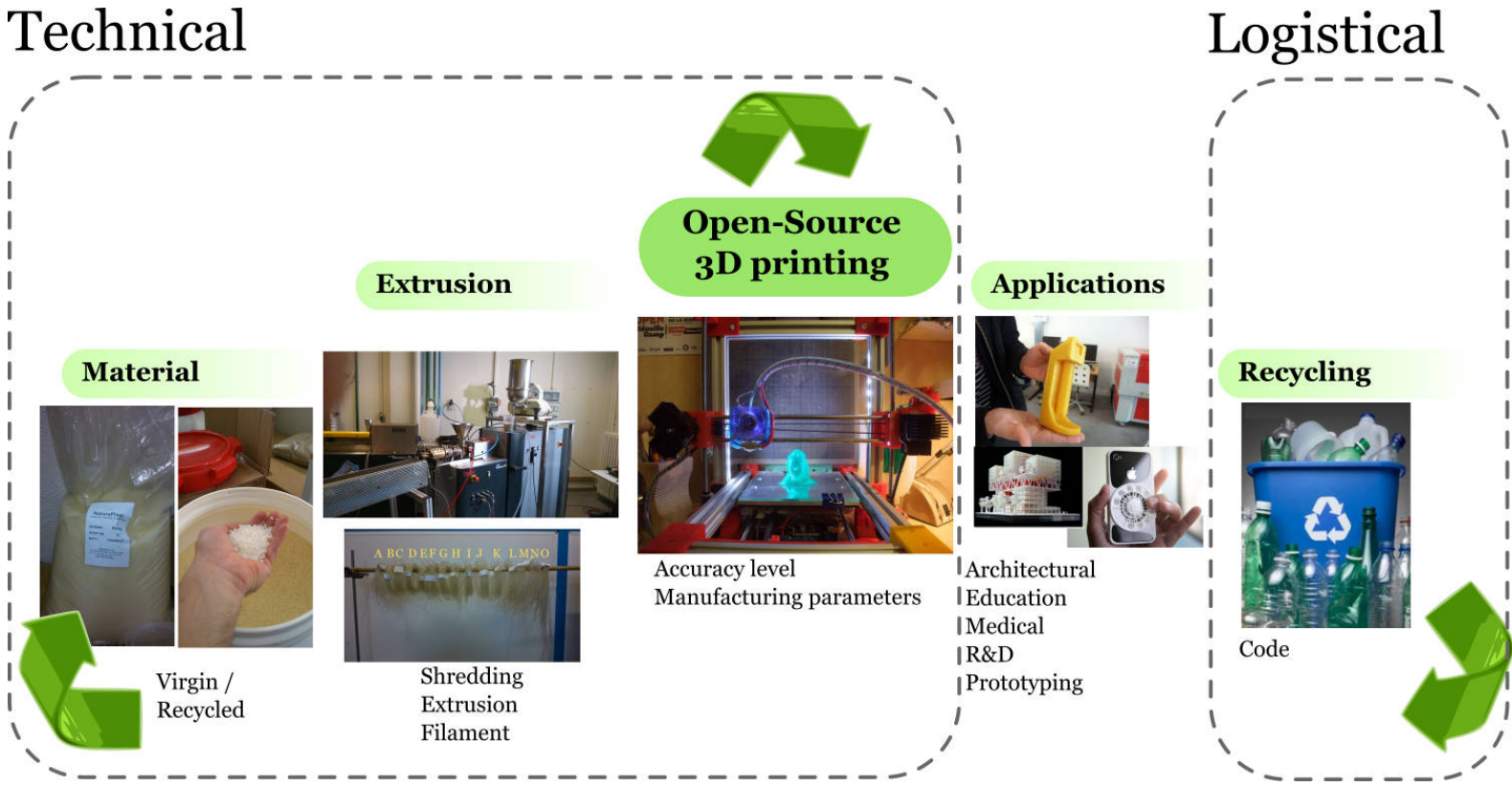
1. Who I am?
2. Societal challengues for sustainable manufacturing
3. Approach of Sustainable Distributed Recycling via Additive Manufacturing (SDRAM)
4. Put in reality
5. Some Future considerations

Distributed recycling via additive manufacturing

- Local closed-loop ➡️ Virgin / recycled ➡️ FFF / FGF

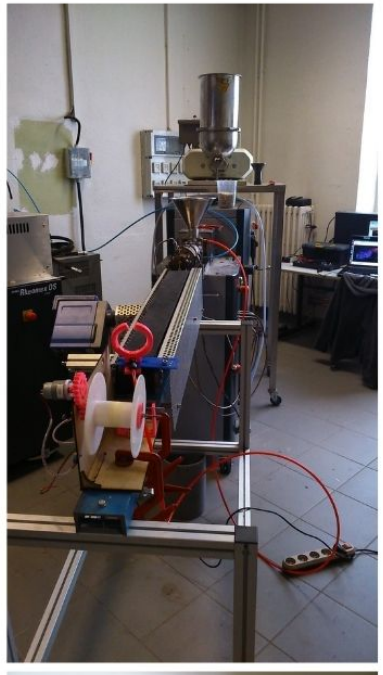
Green FAB LAB

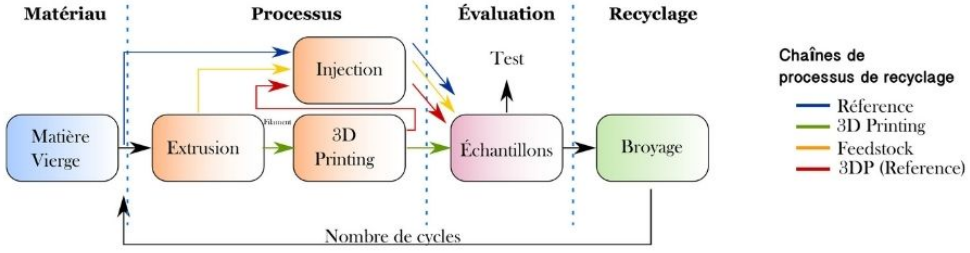
https://lf2l.fr/projects/green-fablab/



Technical validation of DRAM

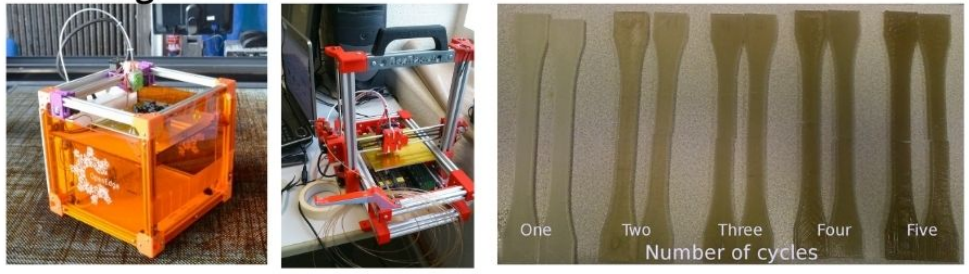
2013 - 2016

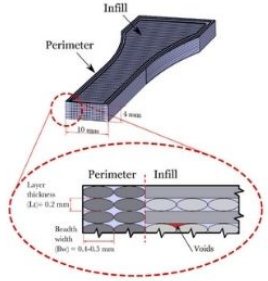




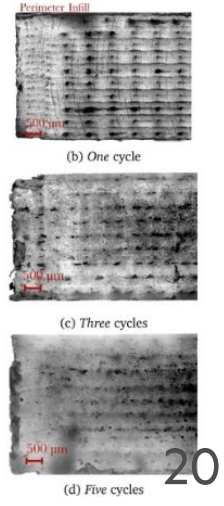
Injection

3D Printing





(a) Schematic morphology of printed samples with *one* cycle.



(b) *One* cycle

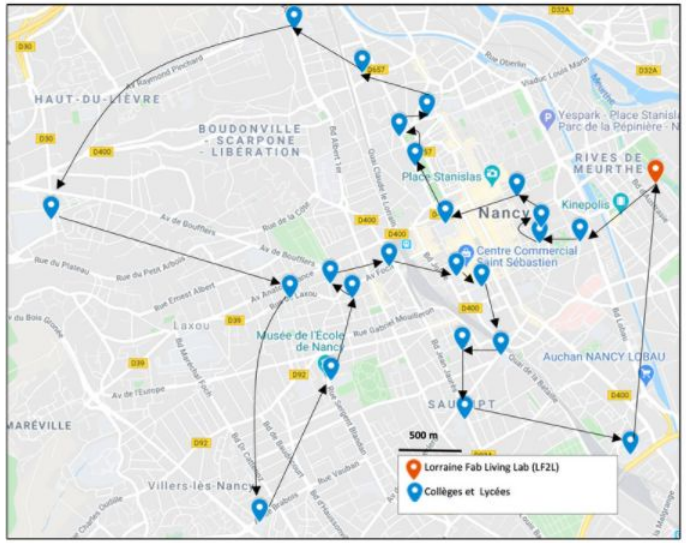
(c) *Three* cycles

(d) *Five* cycles

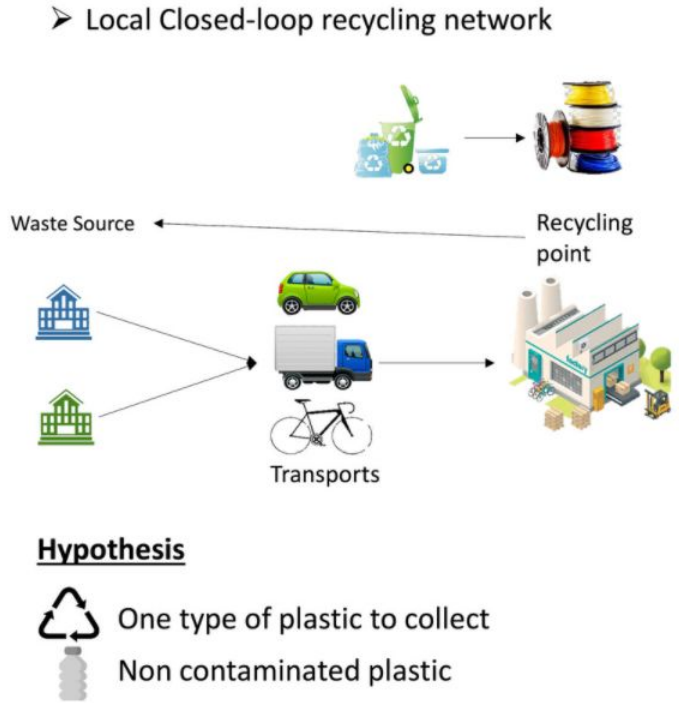
LABORATOIRE RÉACTIONS ET GÉNIE DES PROCÉDÉS

Logistical validation of DRAM

Pavlo Santander

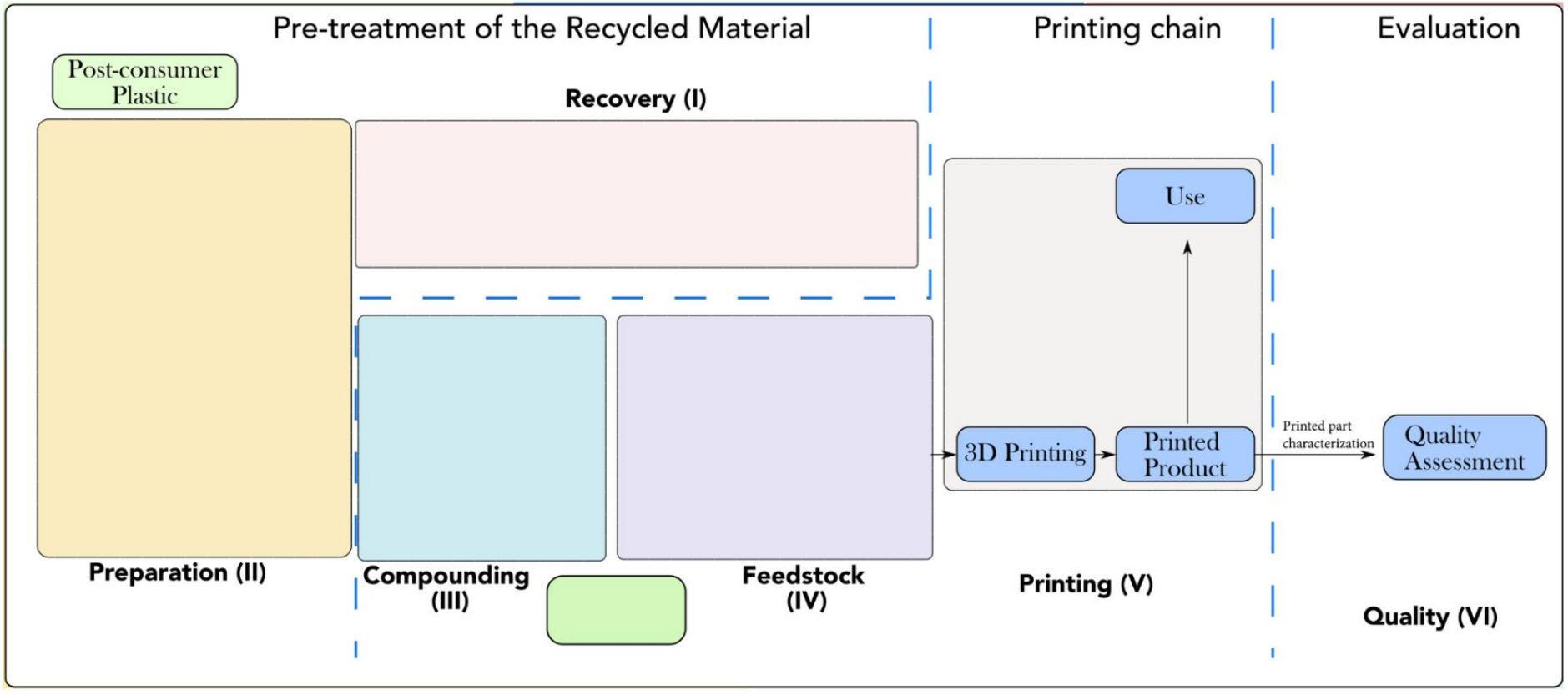


(Santander et al ., 2020)

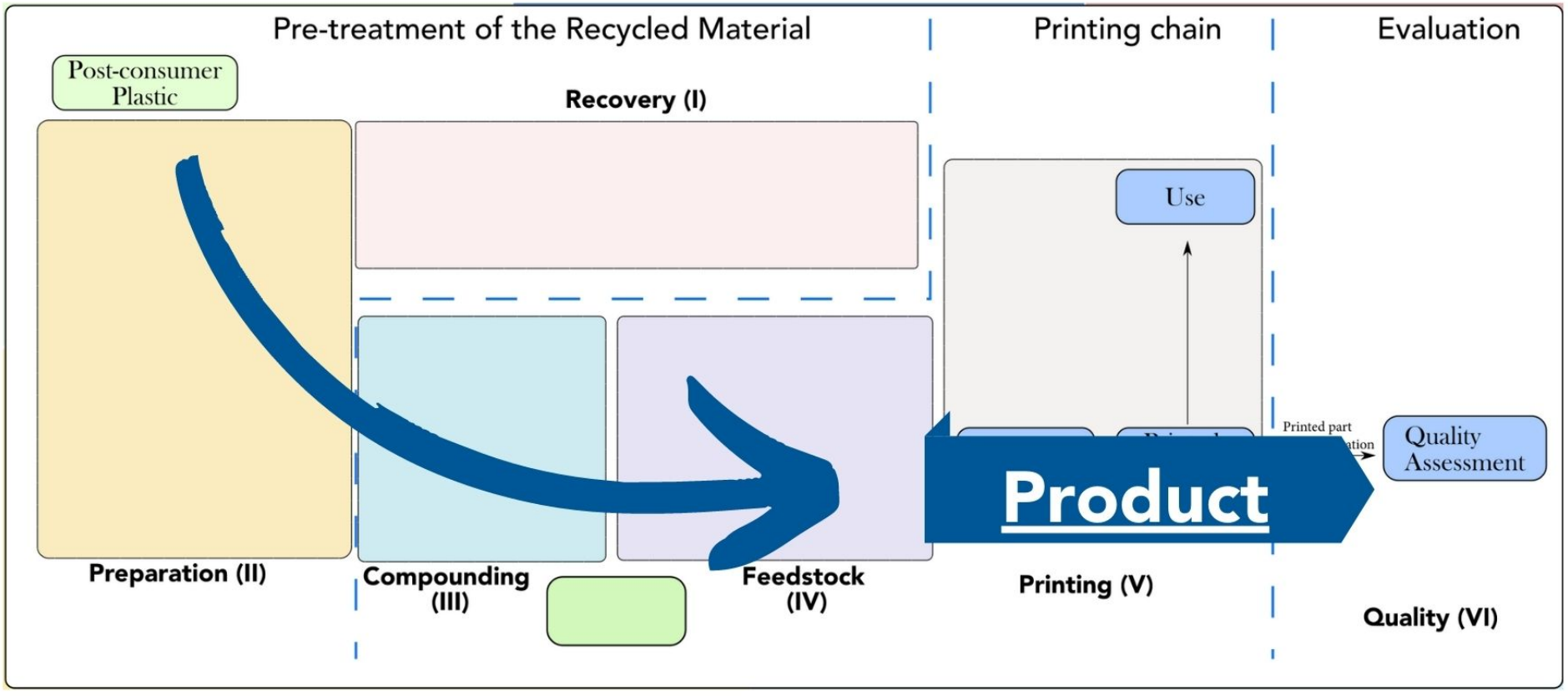


[Conf]: IEEE / ICE - 2020

[ACL]: Resources, Conservation and Recycling - 2020
[Conf]: IEEE / ICE - 2018



Cruz Sanchez, et al. Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy. Journal of Cleaner Production (2020).



Cruz Sanchez, et al. Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy. Journal of Cleaner Production (2020).

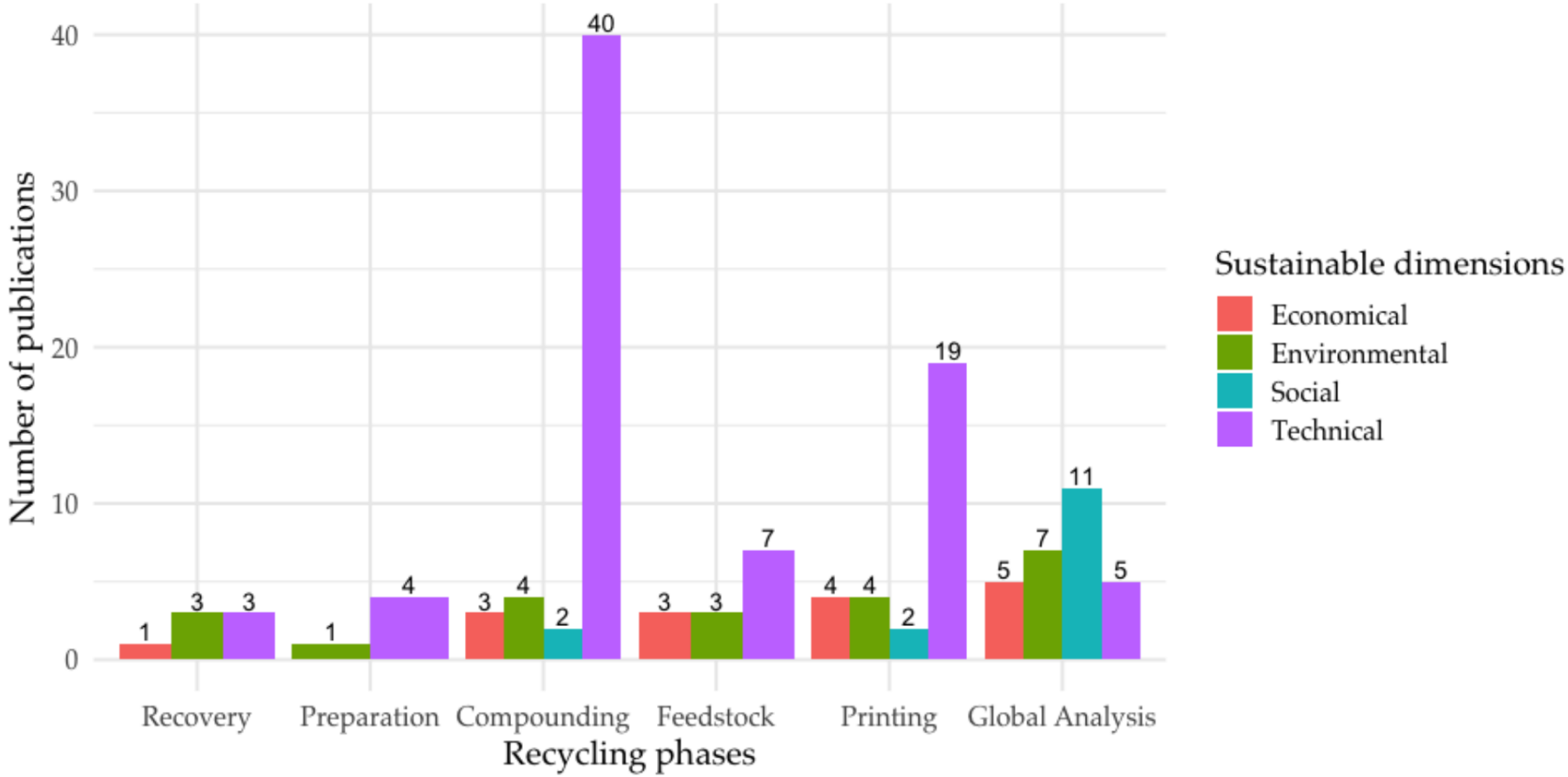
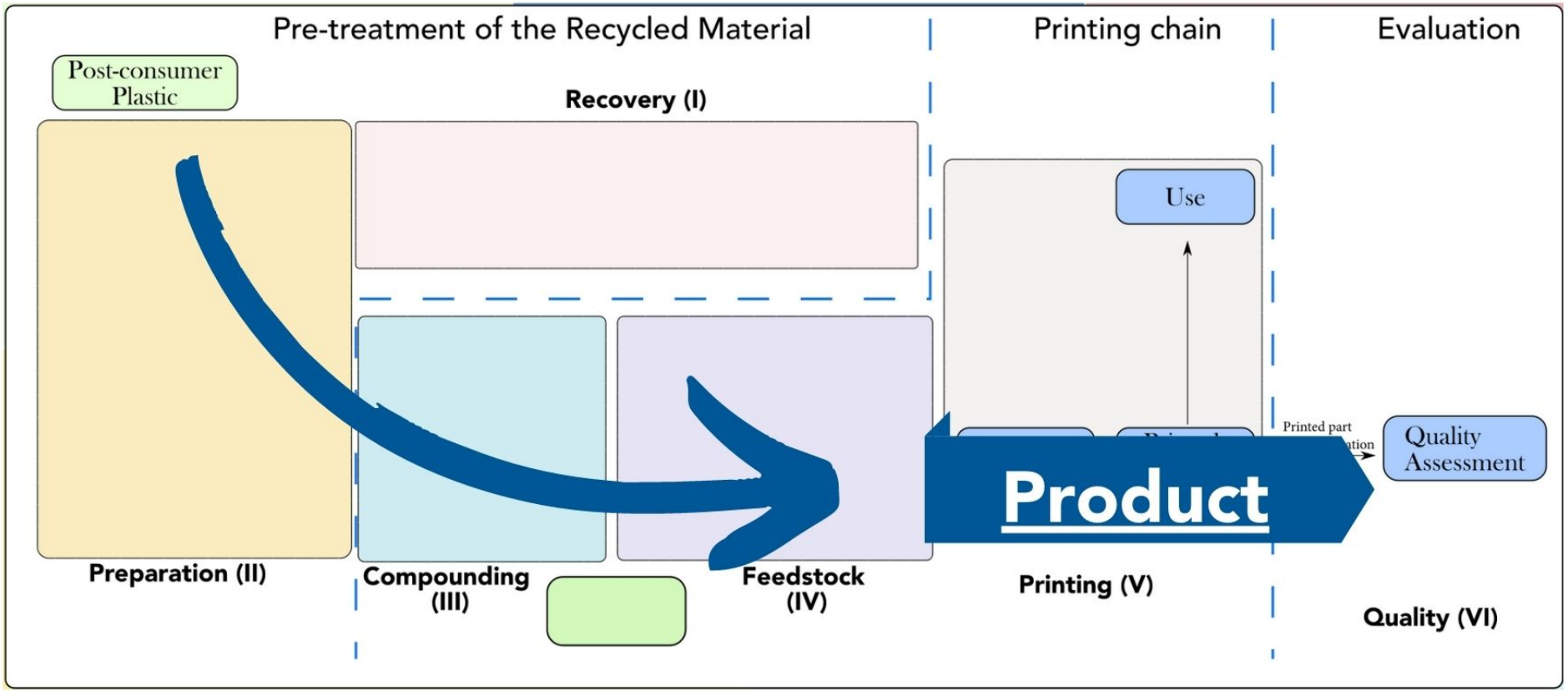
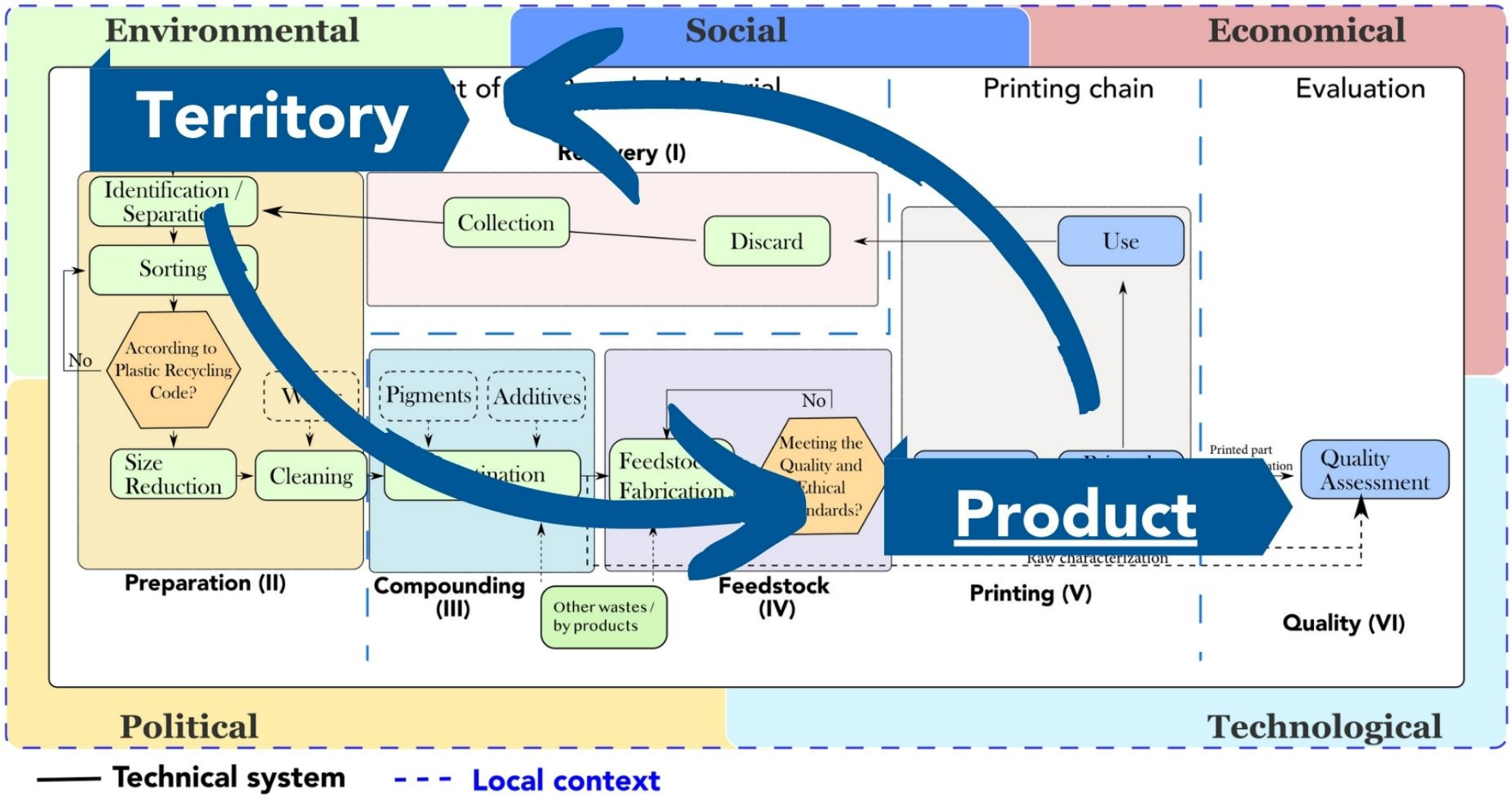


Figure 7: Global results of the literature review.

Cruz Sanchez, et al. Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy. Journal of Cleaner Production (2020).

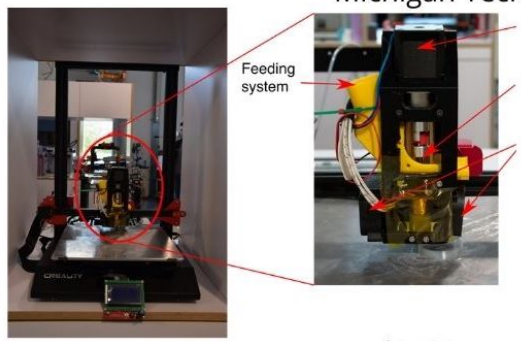


Cruz Sanchez, et al. Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy. Journal of Cleaner Production (2020).

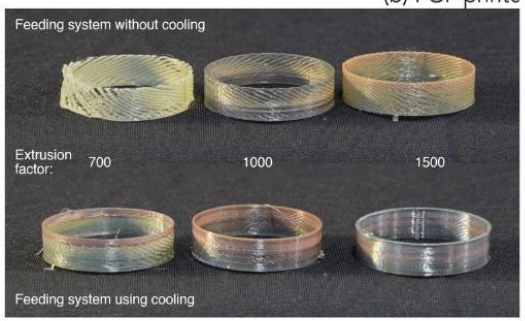

Environmental
Social
Economical
Territory
Printing chain
Evaluation
Identification / Separati
Sorting
According to Plastic Recycling Code?
No
Size Reduction
Cleaning
Collection
Discard
Use
Pigments
Additives
No
Meeting the Quality and Ethical ndards?
Feedstoc Fabrication
Printed part
Quality Assessment
Product
Raw characterization
Preparation (II)
Compounding (III)
Other wastes / by products
Feedstock (IV)
Printing (V)
Quality (VI)
Political
Technological
Technical system
Local context

2020

Michigan Tech

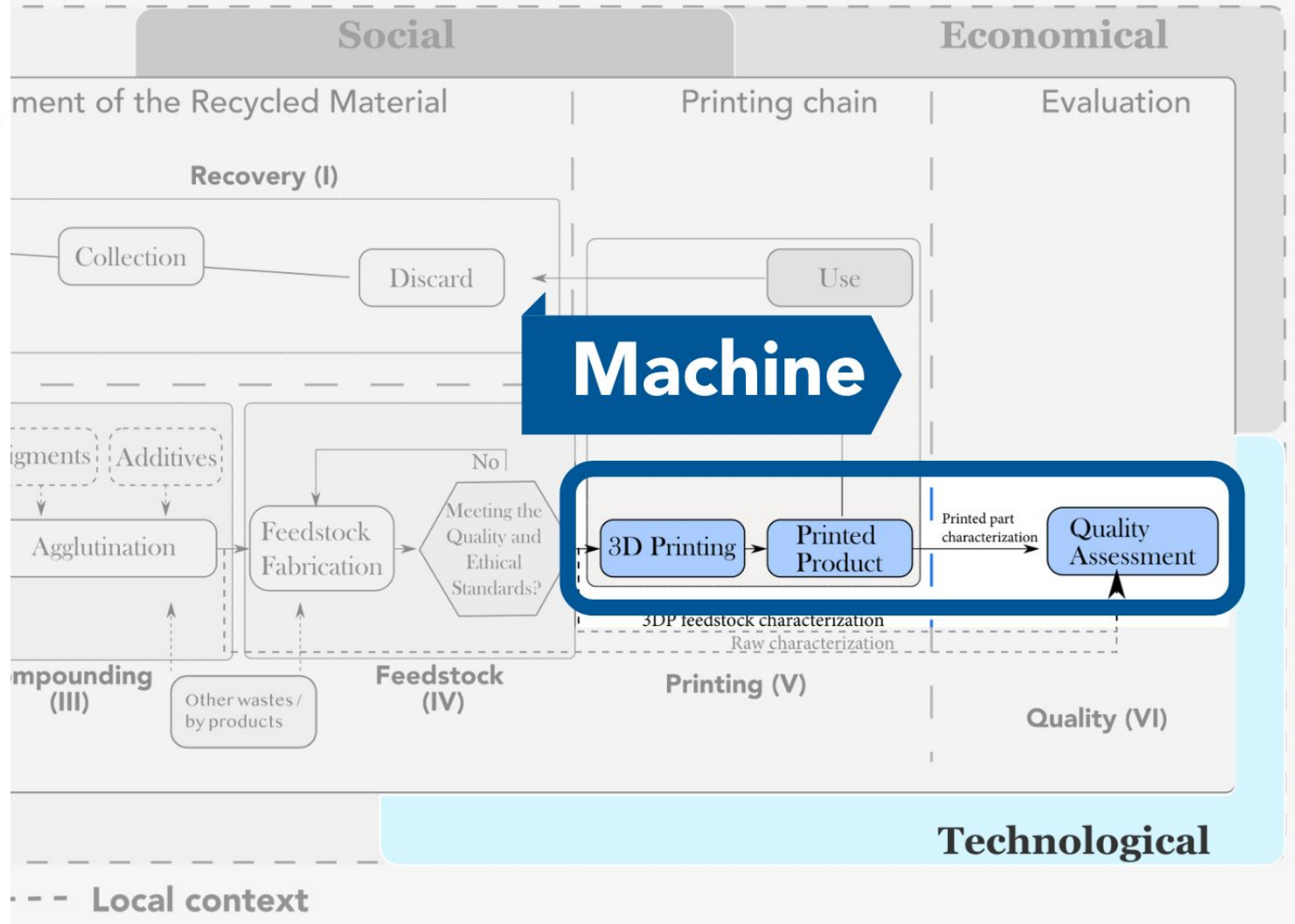


(b) FGF printe

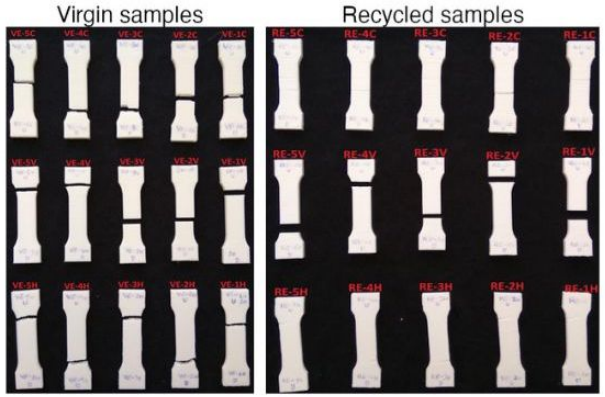


Fused Granular Fabrication

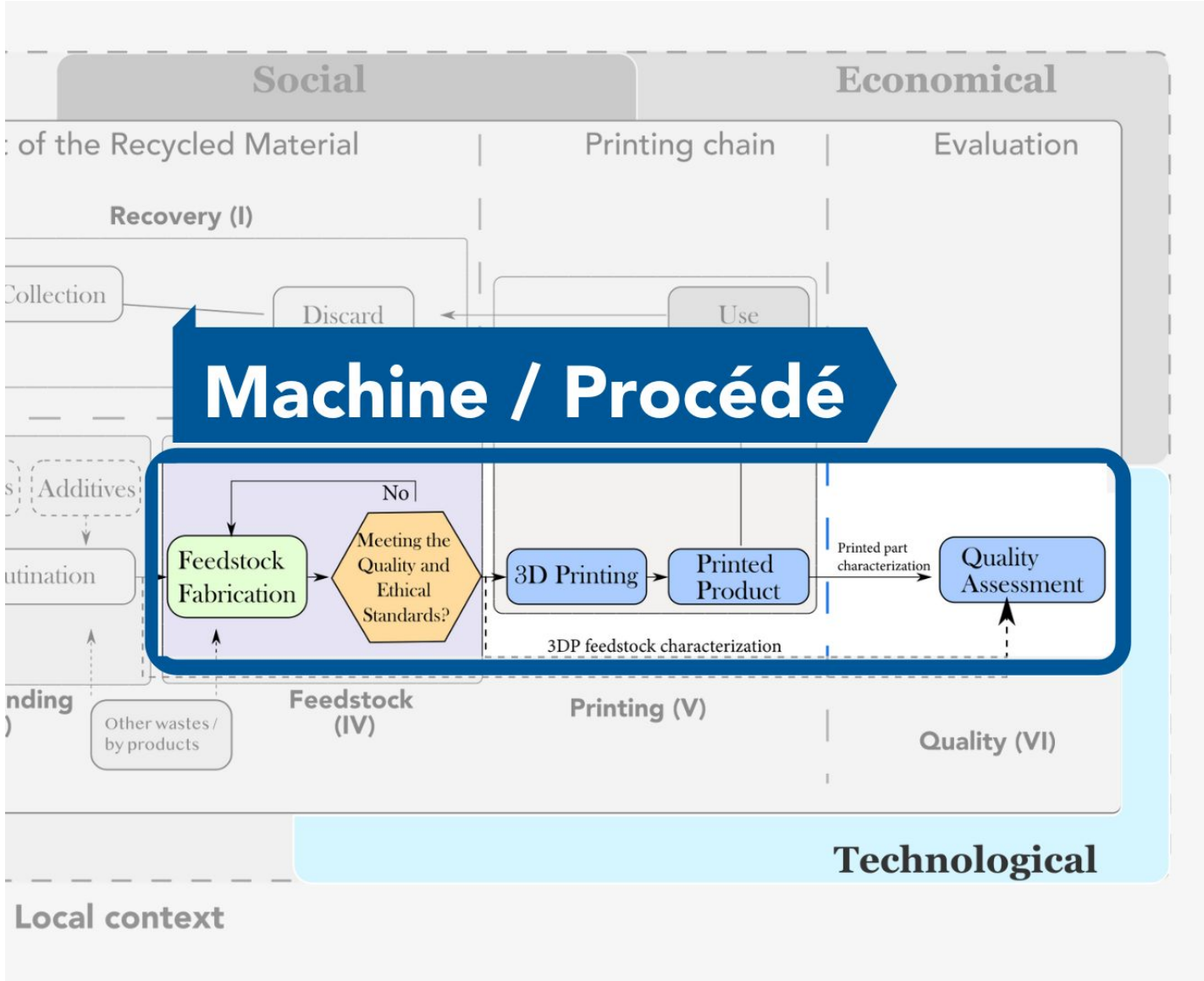
Alexandre, et al. *Mechanical Properties of Direct Waste Printing of Polylactic Acid with Universal Pellets Extruder: Comparison to FFF on OS 3D Printers*. 3D Printing and Additive Manufacturing



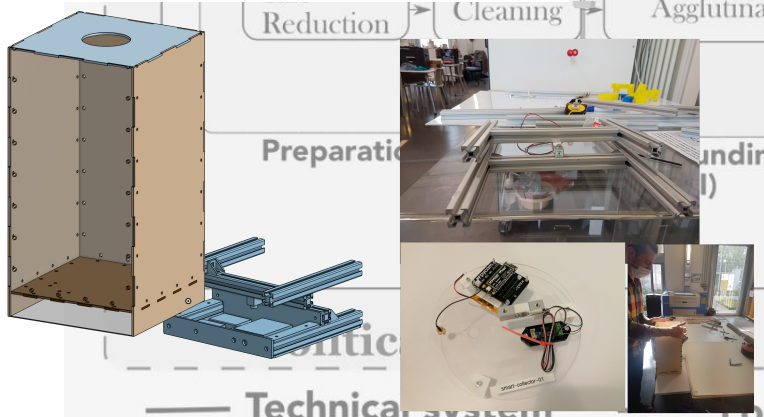
Universidade Vigo



López, V. M., Carou, D. & Cruz S, F. A. **Feasibility study on the use of recycled materials for prototyping purposes: A comparative study based on the tensile strength.** Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture doi: 10.1177/09544054221113378.



Open Source IoT-based Collection Bin Applied to Local Plastic Recycling. HardwareX. *In review.*



Santander, P., Cruz Sanchez, F. A., Boudaoud, H. & Camargo, M. **Social, political, and technological dimensions of the sustainability evaluation of a recycling network. A literature review.** Cleaner Engineering and Technology 6, 100397 (2022).

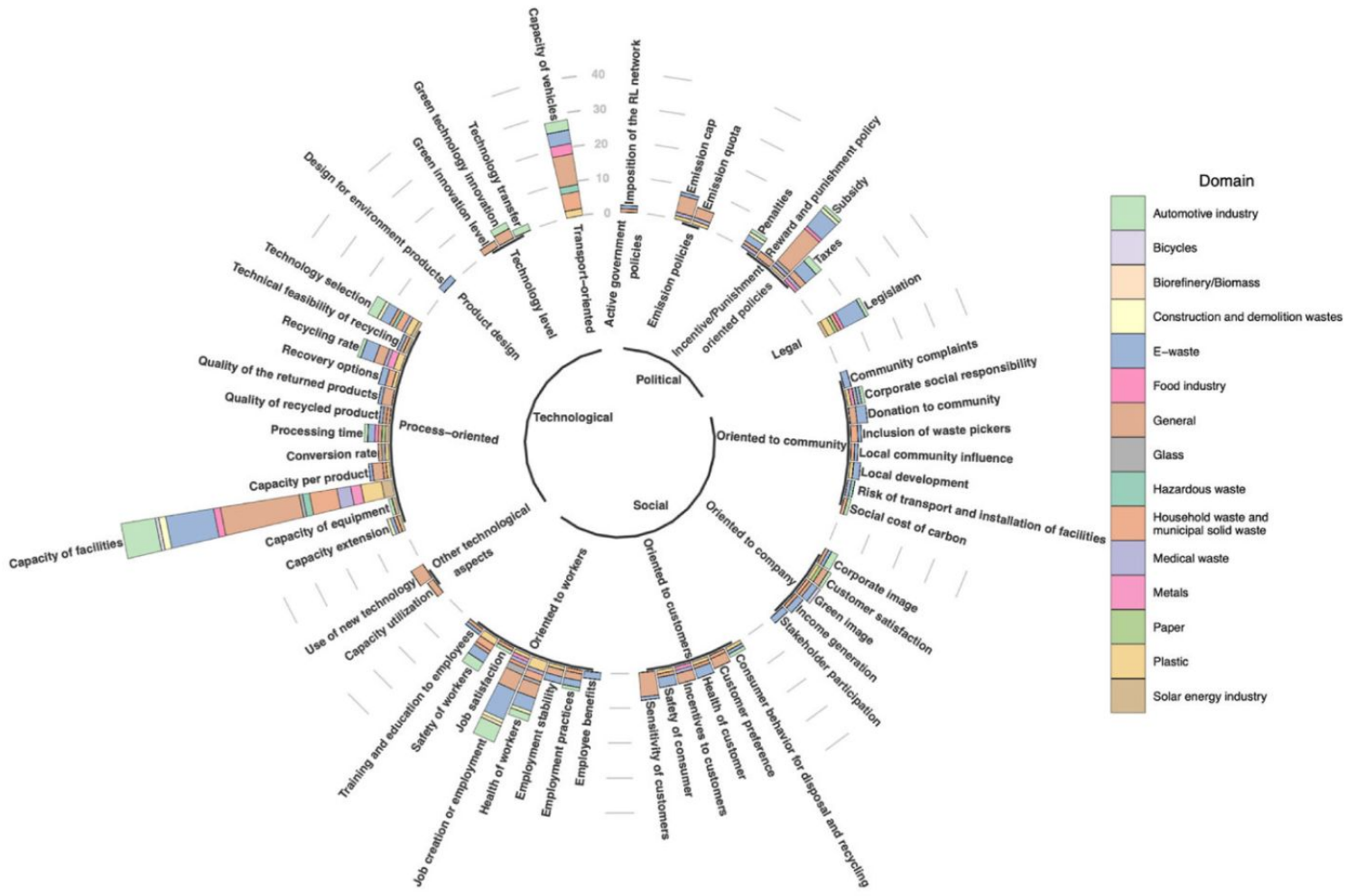
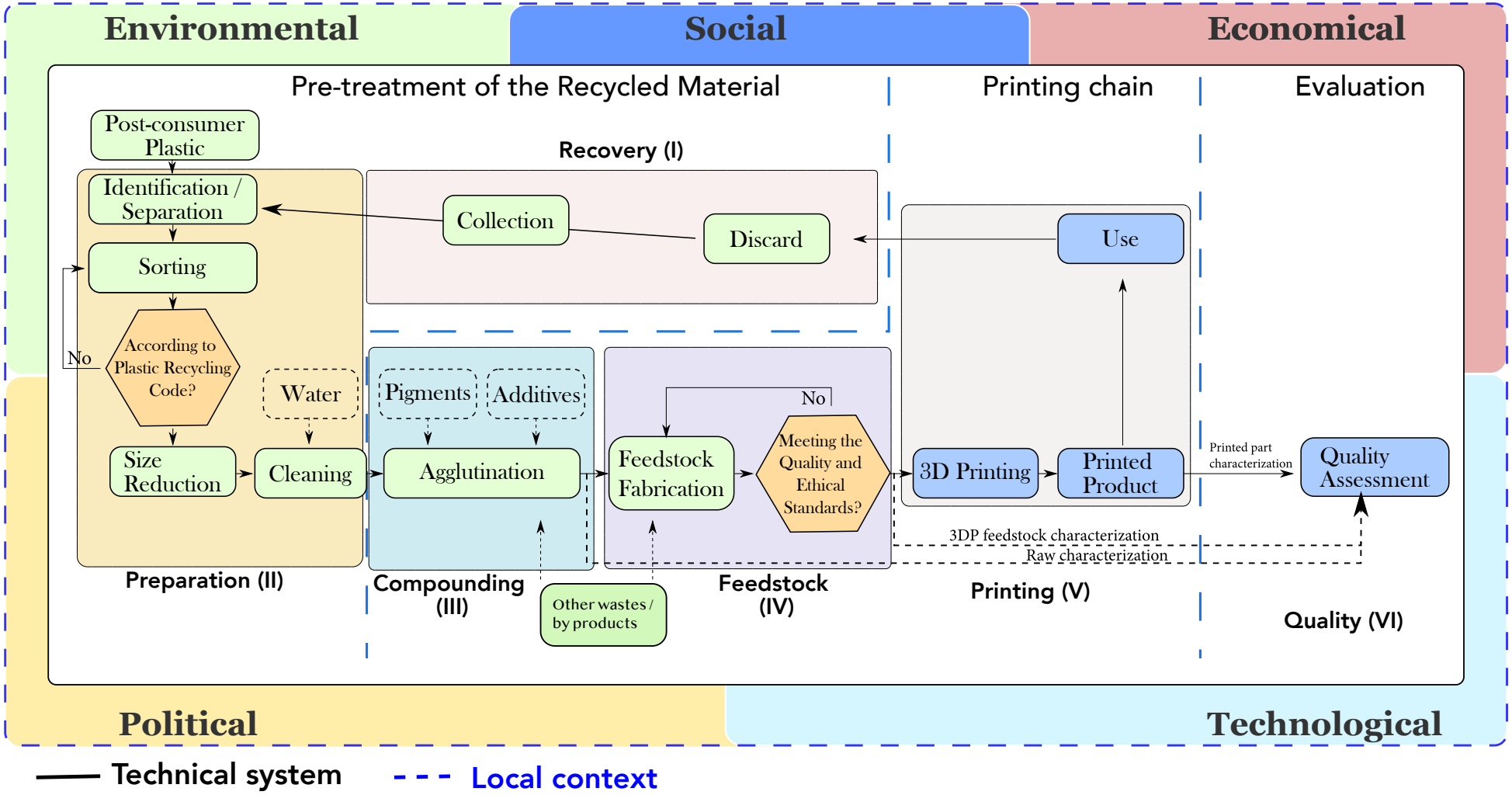


Fig. 12. Global analysis of main criteria and application domains per dimension-orientation.

SDRAM: .... Work in progress ...



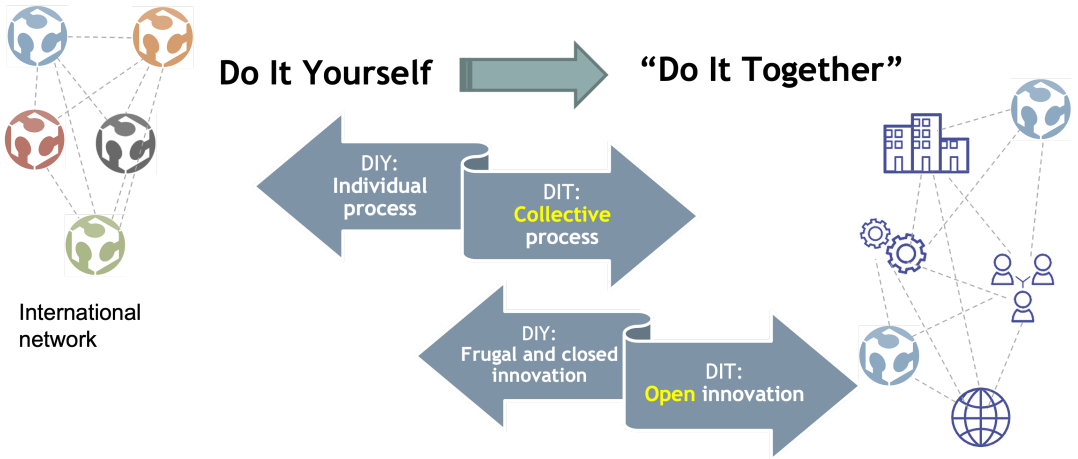
Outline

1. Who I am?
2. Societal challengues for sustainable manufacturing
3. Approach of Sustainable Distributed Recycling via Additive Manufacturing (SDRAM)
4. Put in reality
5. Some Future considerations

Mode Do-It-Together

Projet EU H2020 INEDIT

Open INnovation Ecosystem for Do-It-Together process



- From DYI to the definition DIT ✓
- Formalisation DIT ✓
- Open Manufacturing Demostrator (OMDF)
- Demostrator (UL)

Green FAB LAB

Green FAB LAB

Open and creative ecosystem supported by

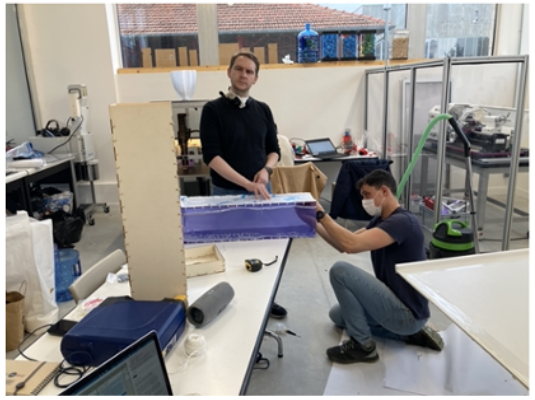
INEDIT

GA 869952

UNIVERSITÉ DE LORRAINE

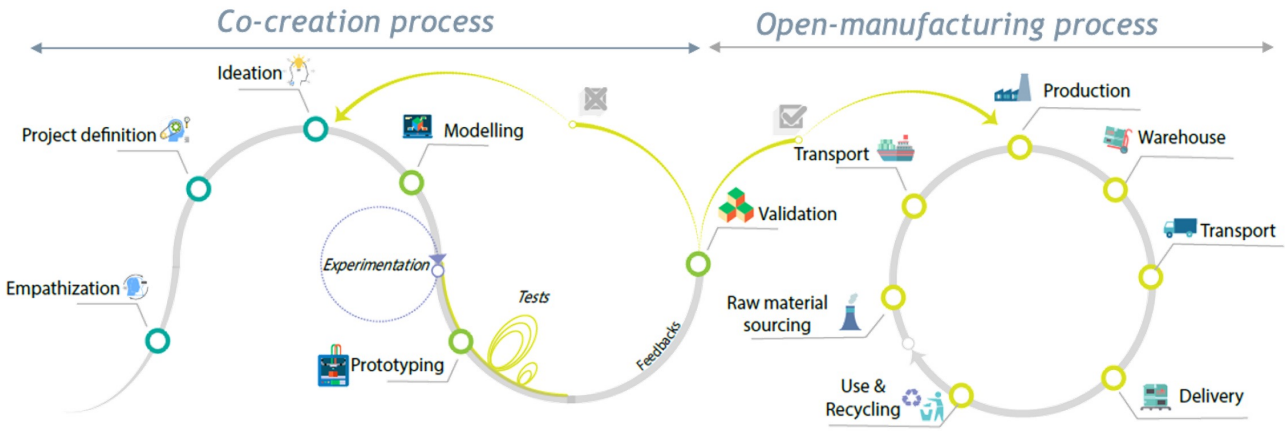
ERPI
Equipe de Recherche sur les Processus Innovatifs
Université de Lorraine

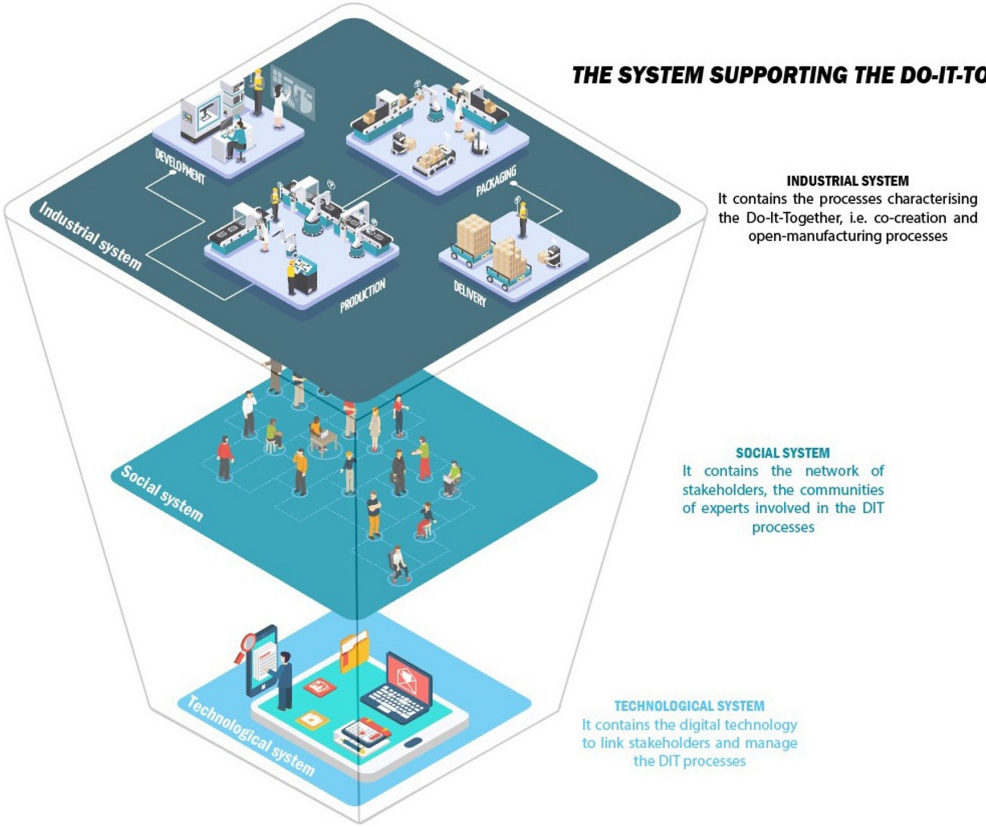
LORRAINE FAB LIVING LAB®



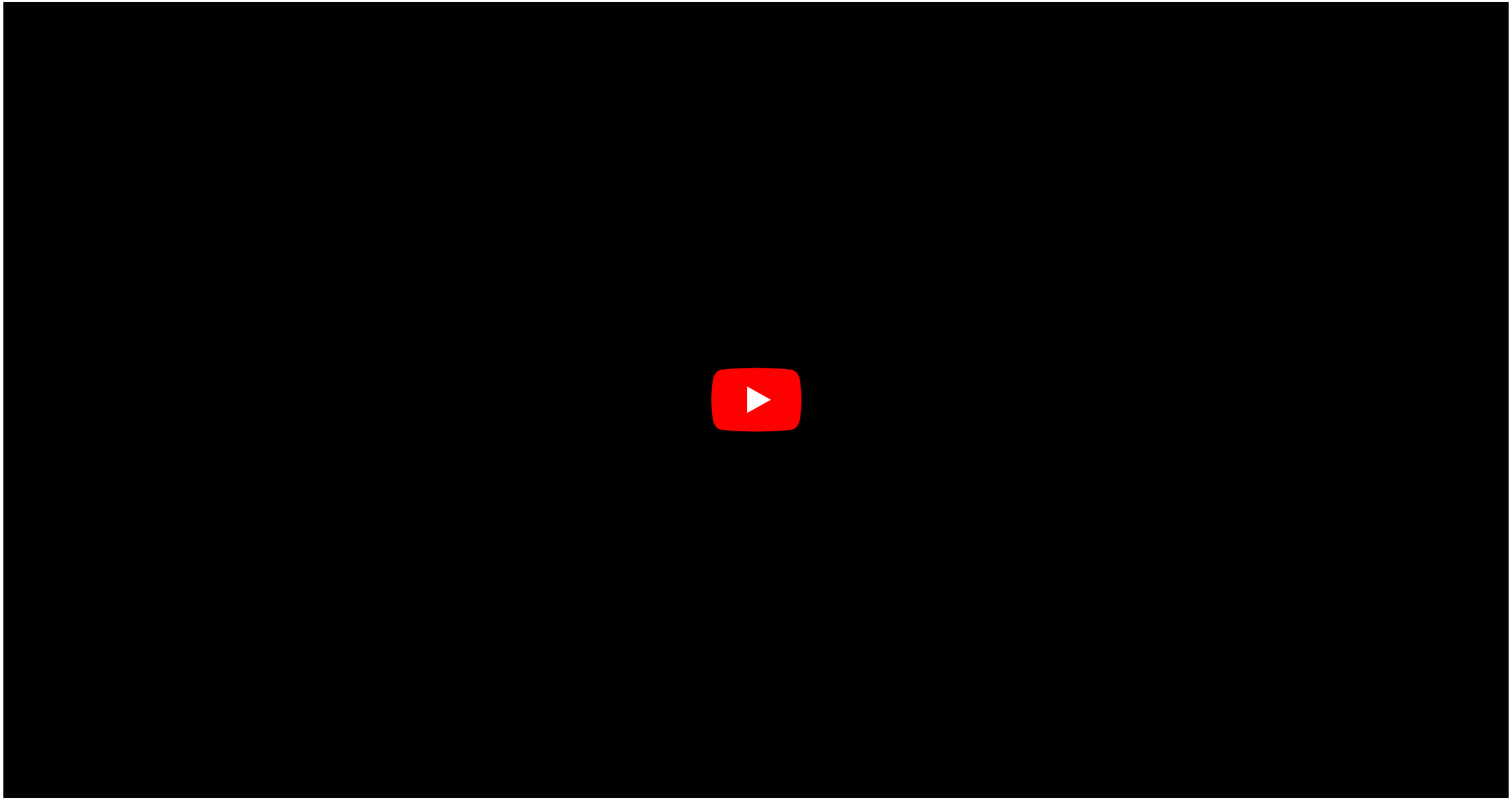
L'OCTROI Nancy
Association OK3

Projet EU H2020 INEDIT



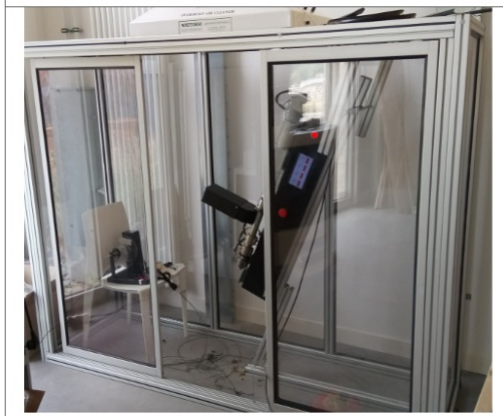


MARCHE Brunelle, KASMI Fedoua, MAYER Frédérique *et al.*, « Implementing Do-It-Together: The Cross-fertilization of Do-It-Yourself and Open Manufacturing », *Journal of Innovation Economics & Management*, 2022/0 (Prepublication), DOI : 10.3917/jie.pr1.0122. URL : https://www.cairn.info/revue-journal-of-innovation-economics-2022-0-page-I.htm

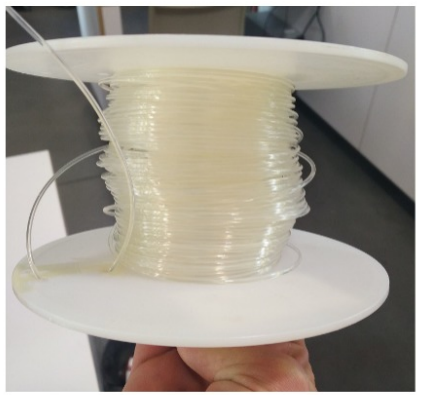


2016 2018 2019 2020

Extrusion of recycled polymer

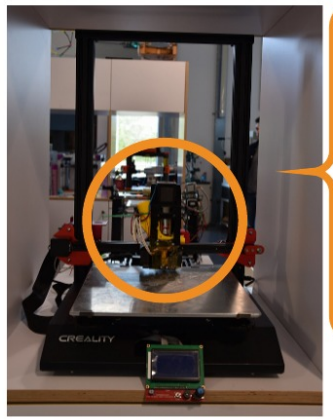


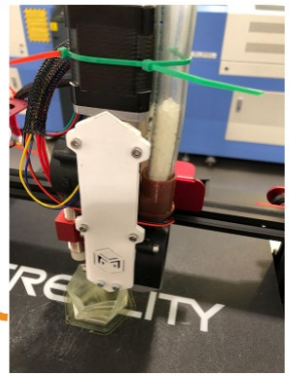
Virgin Recycled



Mobile extrusion for local recycling

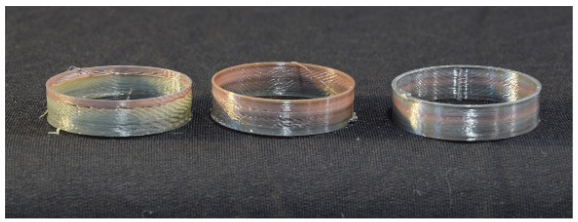
Fused particle fabrication





Virgin

Recycled



Filament assets

Printed objets assets

Outline

1. Who I am?
2. Societal challengues for sustainable manufacturing
3. Approach of Sustainable Distributed Recycling via Additive Manufacturing (SDRAM)
4. Put in reality
5. Some Future considerations

Future

Micro-industrial urban factories in the Antropocene:

- Only **tech-economic criteria** not enough for informed decision making.
- Need to assess value chains to include **all impacts on ecosystems**
- Bottom-up integration of **territorial and industrial systems** at levels:
  - Material
  - Process
  - Systems
  - Planetary

Source: PBL, WUR, CICES 2014

Future

Micro-industrial urban factories in the Antropocene:

- Only tech-economic criteria not enough for informed decision making.
- Need to assess value chains to include all impacts on ecosystems
- Bottom-up integration of territorial and industrial systems at levels:
  - Material 💡
  - Process 💡
  - Systems
  - Planetary

View PDF

Trends in Biotechnology

Available online 1 September 2022

In Press, Corrected Proof

Review

Killing two birds with one stone: chemical and biological upcycling of polyethylene terephthalate plastics into food

Laura G. Schaerer [1], Ruochen Wu [2], Lindsay I. Putman [1], Joshua M. Pearce [3, 5, @], Ting Lu [4], David R. Shonnard [2], Rebecca G. Ong [2, 6, @], Stephen M. Techtmann [1, @]

Future

Micro-industrial urban factories in the Antropocene:

- Only tech-economic criteria not enough for informed decision making.
- Need to assess value chains to include all impacts on ecosystems
- Bottom-up integration of territorial and industrial systems at levels:
  - Material 💡
  - Process 💡
  - Systems
  - Planetary

View PDF

Trends in Biotechnology

Available online 1 September 2022

In Press, Corrected Proof

Review

Killing two birds with one stone: chemical and biological upcycling of polyethylene terephthalate plastics into food

Laura G. Schaerer [1], Ruochen Wu [2], Lindsay I. Putman [1], Joshua M. Pearce [3, 5, @], Ting Lu [4], David R. Shonnard [2], Rebecca G. Ong [2, 6, @], Stephen M. Techtmann [1, @]

Sustainable distributed recycling via additive manufacturing (SDRAM): from a technical to systemic challenge

Workshop: Responsible Design for AM

Fabio A. CRUZ SANCHEZ

| Nancy 06 September, 2022

cruzsanc1@univ-lorraine.fr

UNIVERSITÉ DE LORRAINE
ERPI Equipe de Recherche sur les Processus Innovatifs Université de Lorraine
LORRAINE INP Ensgsi NANCY