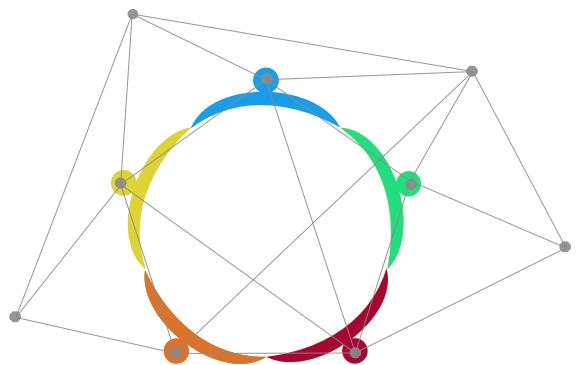


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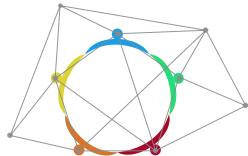


INEDIT
open INnovation Ecosystems
for Do It Together process

D6.4 3D Printing of recycled plastic demonstrator

WP6 T6.5

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Title: Report on the 3D printing of Recycled Plastic Demonstrator

Description: Description of the conceptual framework of distributed recycling via additive manufacturing (DRAM) and its concrete implementation in a DIT approach. The technologies, materials and methods are reported. Several illustrative case studies are presented

Version: Version 2

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1 Introduction

2 This deliverable deals with the description and implementation of the 3D printing of recycled
3 plastic demonstrator. This corresponds to the task 6.4 according to the descriptive of actions.
4 The main goal of this task is to validate the logistical and technical feasibility of recycled assets
5 to be used in the DIT approach.. These technical and logistical elements were implemented in
6 relevant environment in order to prove the integration of a distributed and local plastic recycling
7 chain around Open Manufacturing Demonstration Facilities (OMDF). The ambition of this use case
8 is to test the feasibility of the distributed recycling via additive manufacturing (DRAM) ([Cruz](#)
9 [Sanchez et al., 2020](#)) concept with the purpose to integrate in the Do-It-Together approach.
10 Thanks to the INEDIT projet, a pilot plateform calle the ‘Green Fablab’ was developed based
11 on open design approach in order to be replicable to other countries.

12 The outputs of this use case aims to illustrate how the 3D printing of recycling recycled plastic
13 demonstrator give a concrete results on the the high-level objectives that the INEDIT project
14 aims to achieve:

- 15 • To unleash the creativity of consumers and designers towards co-creation of new pieces
16 of furniture addressing the needs of the single user in an industrial context.
- 17 • To democratise the access to production resources in the furniture sector.
- 18 • To support SME operating in the furniture sector in finding new business opportunities.
- 19 • To create a framework of solutions for creation, engineering and distributed production
20 of customer driven pieces of furniture.
- 21 • To define, design and manufacturing strategies focusing on lowering ecological impact and
22 addressing societal challenges.
- 23 • To create an ecosystem of all stakeholders within Europe.

24 1.1 Outline

25 The report is structured into three main parts The section [Section 2](#) provides a baseline intro-
26 duction regarding the plastic recycling issues in European Union The section [Section 3](#) gives
27 an overview of the context that the 3D printing Recycled demonstrator have in order to give
28 the main technical and methodlogical features. The section [Section 5](#) presents in detaill the
29 operationalization of the demonstrator in the DIT approach. This is illustrated the step-by-step
30 technical elements to consider and the illustrateive experimentation made. The rapport finish
31 with a conclusion section.

2 Plastic Issues for the European Union

33 Since 1950', our society have gained enormous advantages in terms of quality of life thanks to
34 the technical development of the development of plastic and polymer materials. Plastic is a
35 material that is widely used in our daily lives and plays a fundamental role in industry and eco-
36 nomic development. The plastic material are found in almost all our products: food packaging,
37 cars, technological tools, clothing, among others. The main reason is that plastic materials
38 offer a variety of chemical and mechanical properties to be useful for a wide array of applica-
39 tions. Plastics are extremely useful, but their mismanagement has affected the environment
40 and our health. The over-consumption and especially bad practices (single use, difficulty of
41 reuse, etc.), make plastics one of the major societal challenges of an ecological transition that
42 has become imperative. The main problem is the end-of-life treatment which traditionally uses
43 a centralized system where plastic waste often has to travel thousands of kilometers... to be in-
44 cinerated or landfilled. In addition to the energy and environmental impact of their production,
45 there is also the impact of the end of life.

46 Unfortunately, the plastic waste pollution poses a major threat because of the issue of non-
47 degradability affecting the ecological environments ([Hopewell et al., 2009](#); [Ryberg et al., 2019](#);
48 [Thompson et al., 2009](#)). Indeed, recycling rates remain small (approx. 14%) in the plastic
49 packaging field on a global scale ([Hahladakis and Iacovidou, 2018](#)). Even in Europe, which
50 tends to lead on environmental stewardship, the recycling rate is about 32.5 wt% ([Plastics,](#)
51 [2019](#)). However, these values consider the amount of plastic waste collected, rather than the
52 total amount in circulation ([Kranzinger et al., 2018](#)). Rethinking the development and use of
53 plastics is central to the circular economy paradigm, to provide less harmful options for the
54 environment. Thus, more types of plastic packaging are available, but each reflects diverse
55 circular economy strategies

56 To tackle this accumulation waste problem, the European strategy for plastics in the circular
57 economy (CE) is gaining attention in the policy and business debate surrounding sustainable de-
58 velopment of industrial production ([European Commission, 2018](#); [Geissdoerfer et al., 2017](#)). CE
59 tackles a central societal issue concerning the current principle "take, make, dispose" (linear
60 economy) and its negative effects caused by the depletion of natural resources, waste gener-
61 ation, biodiversity loss, pollution (water, air, soil) and non-sustainable economics ([van Buren](#)
62 [et al., 2016](#)). The validation (technical, economic, legislative) of waste plastic as a secondary
63 raw material in industrial processes is considered now a core target to integrate CE into the
64 plastic value chain ([Simon, 2019](#)). Strategies of open and closed-loop recycling as well as upcy-
65 cling and downcycling functionality approaches can offer paths to validate the secondary raw
66 materials ([Zhuo and Levendis, 2014](#)). The promotion of cross-sectorial valorization of plastic
67 wastes through Industrial symbiosis approaches seems to be a relevant strategy for the circular
68 economy strategies of the EU ([Karayilan et al., 2021](#))

69 Based on this context, it is presented the demostration of the INEDIT project called '3D Printing
70 of Recycling Plastic' that was developed and implemented. In the

3 Context of the 3D Printing of Recycled Plastic Demonstrator

72 3.1 Presentation of the scale of the demonstrator: Rives de Meurthe district 73 (Nancy, France)

74 The demonstrator is placed at the City of Nancy - France, in the region of Lorraine at the
75 northeastern. Nancy is the capital of the Meurthe-et-Moselle department and has a population
76 of approximately 105,000 inhabitants. More precisely, our interest is the *Rives de Meurthe*
77 district as presented by the Figure 1. This district extends between the city center and the
78 Meurthe River for about 7 km from north to south (extending into the municipalities of Jarville-
79 la-Malgrange upstream and Maxéville downstream) and is between 250 and 1,000 m wide.

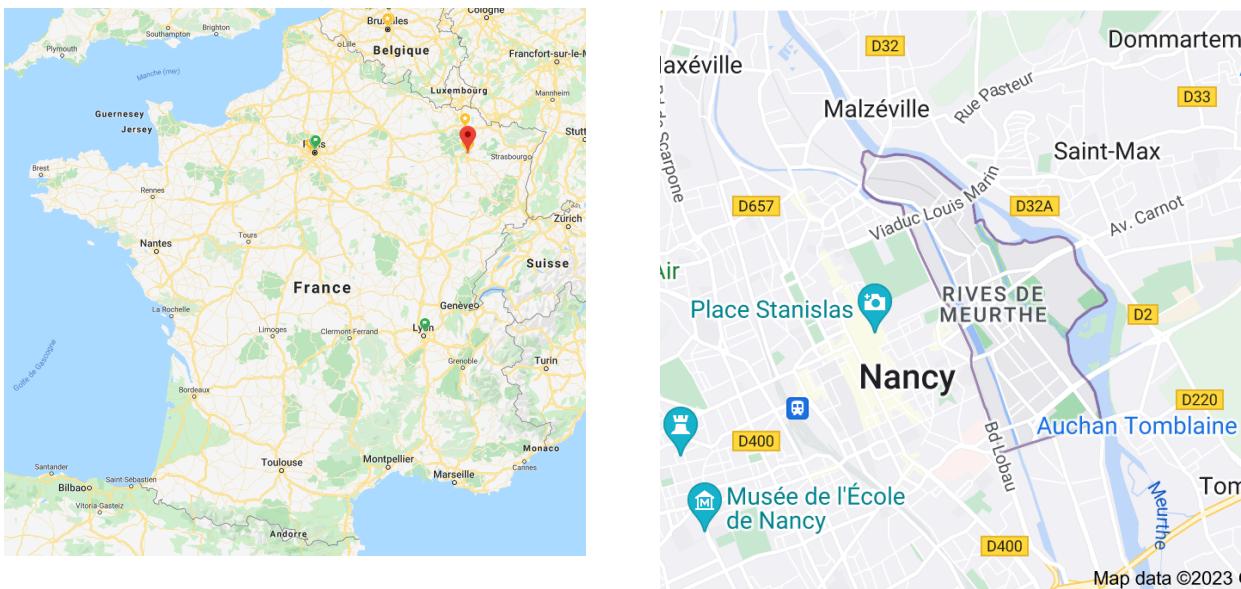


Figure 1: Localization of the Rives de Meurthe district at Nancy, France.

80 Nancy was not born around a waterway and its commercial potential. Its port and river side has
81 long been rather reduced, contrary to the great majority of cities. However, the main interest
82 of the Rives de Meurthe district concerns that it has been a case study in the light of urban
83 regeneration due to flood risk presented in this area (Chiffre et al., 2014; Edelblutte, 2006).
84 Therefore, since end of 1980's, there have been a series of renewal policies of the district with
85 the purpose of going beyond a simple reconversion by broadly rethinking the role of the central
86 and pericentral space of the city.

87 Among the multiples choices, one of the strategic actions taken by the government have been
88 the transformation of the old site of the slaughterhouses in the heart of the Rives de Meurthe
89 district. In 1996, the slaughterhouse activity was transferred to the Épinal-Mirecourt ZAC,
90 marking the end of the site's industrial life. As soon as the activities ceased, a rehabilitation
91 process began in parallel with the development project of the district. The vast 6-hectare site
92 was first carefully demolished to bring back the main buildings constructed at the beginning of
93 the 20th century.

94 In 2017, the city administration took the decision by a public concertation to create exemplary
95 actions in terms of ecological transition at the city level ([Ville de Nancy, 2018](#)). Thus, the
96 creation on the site of the former slaughterhouses was taken. This gives birth in 2019 to the
97 creation of the OK3 association to develop and animate the cultural project of *L'Octroi Nancy*
98 towards the creation of a Cultural and Creative Incubator.¹

99 Given the pandemic situation at the beginning on 2020, the end of works was only finished in
100 2021.

101 3.2 Third place Octroi Nancy

102 The third place Octroi Nancy is a urban project that transforms the former slaughterhouses of
103 the city of Nancy into “cultural, creative and citizen” third place with 4600 m² of renovated
104 buildings ([Pallot et al., 2021](#)).

105 Four large buildings (Figure 2) were refurbished to provide a convivial and multidisciplinary
106 meeting place between culture and innovation; open to experimentation and intended to operate
107 as a creative laboratory for the city. The first building (1) are called the ‘La Petite Halle’
108 (*The Small Hall*) which is an space of 900 m². The purpose is to develop a creative laboratory
109 from which projects of all artistic and creative disciplines may emerge. The second building (2)
110 is the ‘L’Octroi Sud’ (*South Octroi*) where it is intended the professionalization for the actors
111 of the territory, through the installation of resource organizations. The third building (3) is the
112 ‘La Grande Halle’ (*The big Hall*). It is a hangar building of 2,200 m² space for the organization
113 of events, exhibitions and demonstration of artistic and cultural projects. Finally, the fourth
114 bilding (4) is the ‘La Halle ouverte’ (*the Open Hall*) which is an open space of 700 m² to host
115 in particular a weekly organic market and several intermitent cultural activities mostly in the
116 summer holidays.

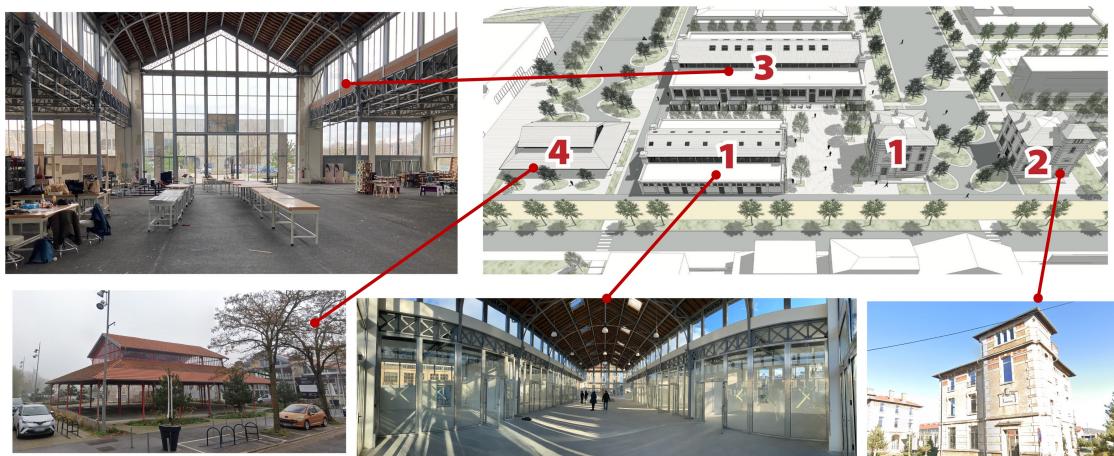


Figure 2: Overview of the Octroi facilities at the Rives de Maeurthe district

117 In summary, these type of third places are open ecosystems that will bring together artists,

¹See more details in <https://www.octroi-nancy.fr/>

118 researchers and creative people with the public, the city's inhabitants and businesses. This
119 initiatives cab be enframed as a socio-technical imaginary projects with new goals and desirable
120 urban transitions in Europe ([Fratini et al., 2019](#)). Starting from existing facilities, this type of
121 urban initiatives can give an opportunity for socially inclusive and environmentally responsible
122 new roles of the local actors regarding the city development.

123 3.3 Lorraine Fab Living Lab®

124 Connected to the Octroi ecosystem, the **Lorraine Smart Cities Living Lab (LSCLL)** is a trans-
125 disciplinary resource center of the Université de Lorraine. It aims to support and link the
126 different societal challenges of the Lorraine territory with the local resources. It enables the
127 integration of different users, implementing collaborative and agile approaches in the service
128 of *Research, Development of Innovations, Training and a Citizen Culture*. Since 2010, this
129 initiative is member of the European Network of Living Labs (ENoLL)², seeking to develop public-
130 private-population partnerships (PPPPs) to disseminate innovation and related practices.

131 Since 2014, the LSCLL formalizes its strategic intention with the the Lorraine Fab Living
132 Lab®(LF2L®) research platform for prospective assessment of innovative usages ([Dupont et al.,
133 2016](#)).

134 The LF2L physical environment is constituted by a collaborative and a fablab space. The collab-
135 orative space allows users to foster co-operation in engineering design with different stakeholders
136 in order to new create concepts/designs. On the other hand, the fablab space allows users
137 to materialize the concepts/designs in an easy and quick way in order to have an prospective
138 evaluation ([Boujut and Blanco, 2003](#); [Dupont et al., 2015, 2014](#)). The synergy of these two
139 spaces enables the project development in a living lab approach taking into account the user
140 centered design principles. The conceptual framework is composed of three main elements as
141 illustrated in Figure 3:

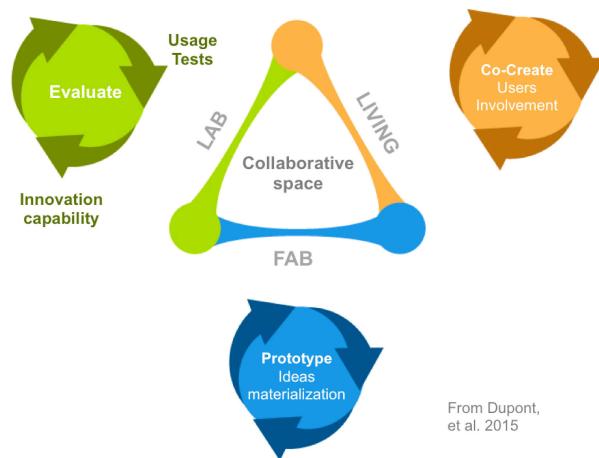


Figure 3: The Lorraine Fab Living Lab methodology.

²4th wave of labelisation)

- 142 1. *Co-creation*: Creative process to find alternative resolution concepts to a problem-topic
143 given integrating the key stakeholders in the process.
- 144 2. *Prototyping*: Materialization (virtual/real) of the concept in order to have a first and quick
145 in-sight.
- 146 3. *Evaluation*: Establishment of the pertinence of the concepts in order to create a feed-
147 back/improvement process.

148 The conceptual innovation framework of LF2L takes into consideration the 2D (concept), 3D
149 (object), 4D (over time) approaches involving different type of stakeholders (e.g. researches,
150 companies, networks,) in order to have a foresight usage evaluation of a new concept, tech-
151 nology or project. The stages and 2D/3D/4D resources allowing prospective assessment of
152 innovative usages in order to support this conceptual framework inside this “innovation space”
153 as indicated in figure 2.3 ([Dupont et al., 2016, 2015](#)). This approach is useful to accelerate the
154 deployment of industrial and/or urban demonstrators.

4 3D Printing of recycled plastic demonstrator: the “Green FabLab”

156 4.1 Rationale for the technological system of the 3D printing recycling demonstra- 157 tor

158 The main goal of the 3D Printing of Recycled Plastic Demonstrator, also known locally as the
159 ‘*Green Fablab*’ as illustrated in the Figure 4, is to validate the logistical and technical feasibility
160 of recycled assets to be used in the DIT approach. The logistical and technical aspects were
161 implemented in a relevant environment in order to prove the integration of a distributed and
162 local plastic recycling chain around Open Manufacturing Demostration Facilitites (OMDF). The
163 *Green Fablab* is the recycling pilot platform based on open design approach with the purpose to
164 be replicable to other countries. The results of this experimentation can be a baseline for many
165 archetypes of open communities such as fablabs, hackerspaces or even industrial prototyping
166 zones. This socio-technical demonstrator combines the hardware development of distributed
167 recycling with a living lab approach that a citizen third place ecosystem can foster.
168 The different key performance indicators were established and validated.



Figure 4: Initial overview of the Green Fablab at November 2021

169 Initially, the initial technical equipment of the Green fablab was first incubated at the the
170 facilities of the LF2L building. This was part of a consolidation of previous research works
171 ([Sanchez, 2016](#)). After the Covid Pandemic situation and the refurbishing that were made at
172 the Octroi ecosystem, the Green Fablab was installed only since November 2021.

173 One of the main ambitions of this demonstrator in the INEDIT project is to prove that plastic
174 waste material can have several uses, and therefore several values, during its life cycle. The
175 same material could be recycled and transformed into new raw material for different products.
176 It is in this spirit that many associations, SMEs, local authorities and individuals are developing
177 new local recycling practices that could allow us to aim for an economy that is more respectful
178 of the environment, fairer for society and more engaging for local politicians.

179 Therefore, it was imperative to understand the key conditions under which to deploy a notion

180 of circular economy with plastic waste to possible establish a secondary raw material market.
181 Likewise, it was required the study of technical parameters for the technological diversity to
182 possible use the waste material including the open source 3D printers and manual desktop injec-
183 tion. The outputs are, not only by minimizing use of the environment as a sink for residuals but -
184 perhaps more importantly - by minimizing the use of virgin materials. Hence, the environmental
185 impact of this technology is significantly reduced.

186 4.2 Distributed recycling via Additive Manufacturing DRAM

187 The technical development of Green Fablab demonstrator is based on the **distributed recycling**
188 **via additive manufacturing (DRAM) approach** ([Cruz Sanchez et al., 2020](#)). This conceptual
189 framework is a major scientific output from the INEDIT project as a proposition of the future
190 industrial landscape.

191 The Additive manufacturing (AM) technology -also known as 3D printing- which is an important
192 industrial vector given its direct (and distributed) manufacturing capabilities. This set of tech-
193 nologies are becoming a key industrial process that could play a relevant role in the transition
194 from a linear to circular economy ([Despeisse et al., 2017](#)). AM technologies is expected to trans-
195 form the production process ([Chen et al., 2017; Jiang et al., 2017; Rahman et al., 2018](#)) thanks
196 to its ability to transform a numerical model into a deposition of material (points, lines or areas)
197 to create a 3D part ([Bourell et al., 2017](#)). The expiration of the first patents has contributed
198 to an increased interest, creating consumer value and potential for disruption ([Beltagui et al.,](#)
199 [2021; West and Kuk, 2016](#)). In economic terms, the global additive manufacturing market is
200 expected to reach USD 23.33 billion by 2026 ([Data, 2019](#)). However, determining when and
201 how to take advantage of the benefits is a challenge for traditional means of production. From
202 a societal viewpoint, Jiang et al. ([2017](#)) reported that the product development could change
203 from traditional stage-gate models to iterative, agile processes changing the scenario by 2030.

204 DRAM is defined as the use of recycled materials by means of mechanical recycling process in
205 the 3D printing process chain. In the literature, DRAM approach emphasizes the technical steps
206 required to reuse plastic waste through the recycling chains for material-extrusion-based 3D
207 printing ([Cruz Sanchez et al., 2020; Little et al., 2020](#)). The use of recycled material, either
208 in the form of raw material or blended with virgin material, is a method of special interest to
209 contribute to sustainable manufacturing ([Zhao et al., 2018](#)).

210 Figure 5 illustrates the conceptual model of DRAM.

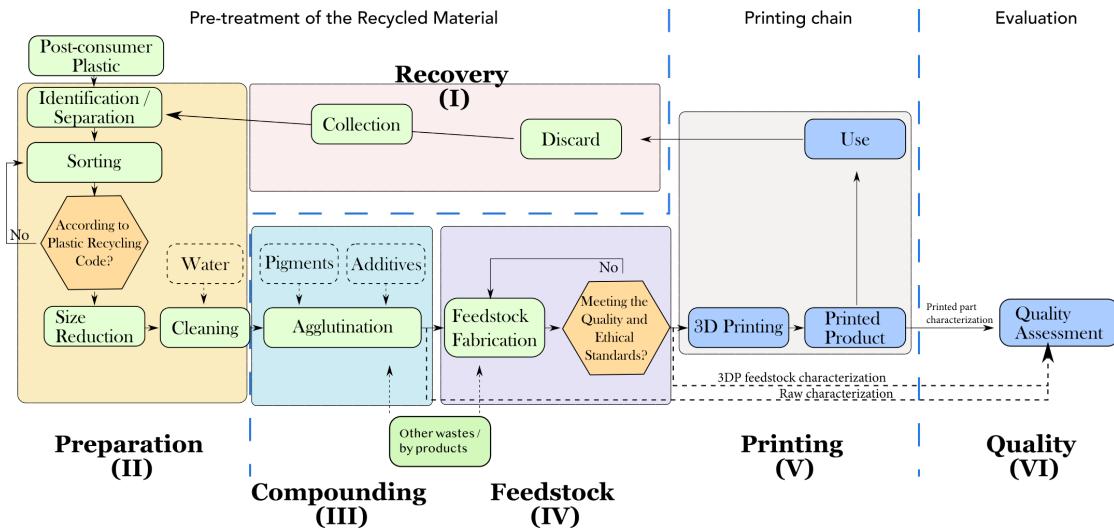


Figure 5: Distributed recycling via additive manufacturing (DRAM) approach (Cruz Sanchez et al., 2020)

In a general overview, the **Recovery (I)** phase concerns the logistic operations to consider to collect the plastic wastes to be reused in DRAM. The **Preparation (II)** phase corresponds to the actions and strategies to identify, separate, sort, size reduce and clean waste plastic to guarantee adequate quality for DRAM. The **Compounding (III)** phase refers to the development of mono- and composite-materials. The **Feedstock (IV)** phase identifies the actions to fabricate the material usable for the printing process, either filament for Fused Filament Fabrication (FFF) or the particle size for Fused Granular Fabrication (FGF). The **Printing (V)** stage identifies applications and process improvements for the recycled printed part. The **Quality (VI)** phase identifies the multi-level technical characterization performed to the recycled material.

A large number of products can already be manufactured with AM, which affects the geographical spread and density of global value chains (Laplume et al., 2016). It is expected that the reach of AM printable products will be much greater in the future, as the production of multi-material and built-in functionalities (e.g. electronics) will be possible to a large extent. In addition, the production of spare parts can be carried out on-site, modifying the role of suppliers in the production lines (Zanoni et al., 2019). Matt et al. (2015) explored the stages of distributed model factories and decentralized production types ranging from distributed capabilities to cloud production. Thus, the need of transport will be much more carefully because the fact that AM will enable decentralization of production to localities near customers or in the most extreme distributed scenario at the customer's premises (Bonnin Roca et al., 2019; Petersen and Pearce, 2017; Wittbrodt et al., 2013). Moreover, AM technology makes it possible to reduce market entry barriers, reduce capital requirements and achieve an efficient minimum scale of production to promote distributed, flexible forms of production (Despeisse et al., 2017).

The distributed manufacturing/recycling approach enables an alternative option from an economy-of-scale to an economy-of-scope, where the products are highly personalized sat-

236 isfying niche communities or even individuals (Hieneth et al., 2014; Petrick2014?). For
 237 these reasons, the AM technology could be a driver for a shift in manufacturing from globally
 238 distributed production to local facilities. Significant efforts are being made by industry and
 239 the scientific community to move AM techniques from rapid prototyping and tooling stages
 240 towards direct digital manufacturing (DDM) (Gibson et al., 2010; Holmström et al., 2016),
 241 with the concomitant environmental and social benefits. Nevertheless, Niaki et al. (2019)
 242 demonstrated that environmental and social benefits are not the key preferential factors in the
 243 adoption of AM technologies in different industrial sectors. Only the economic factor remains
 244 relevant in the AM implementation, considering time- and cost-saving as the most important
 245 reasons.

246 4.3 Positionnement of Use case for OMDF Functions

247 Regarding the structuration of the INEDIT project³, the 3D printing of recycled plastic demon-
 248 strator is positioned in certain stages of the INEDIT approach as presented in the figure Figure 6.

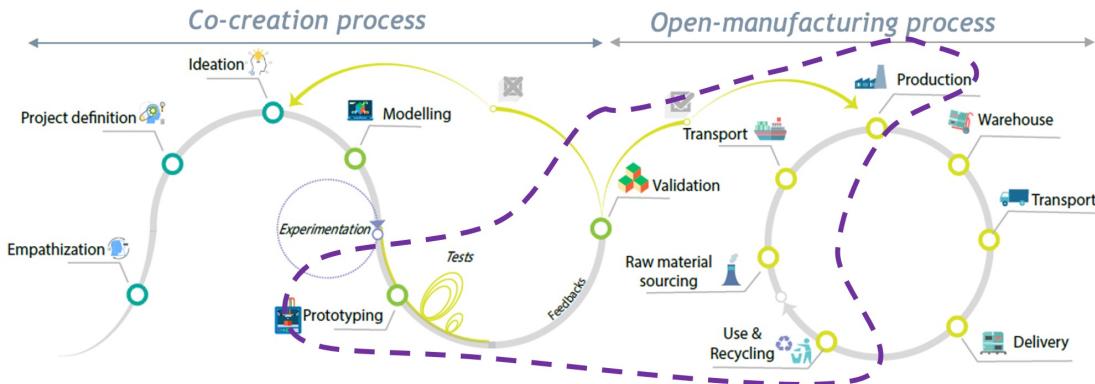


Figure 6: Conception of the DIT with the INEDIT approach

249 On the co-creation phase, the use case deals with the prototyping aspect of the possible fur-
 250 niture. On the other hand, in the open-manufacturing process, our use case deals mainly with
 251 the raw material sourcing, production and recycling aspect. These outputs are linked with a
 252 validation stage.

253 Additionally, in the light of the specification of the open manufacturing demonstration facilities
 254 (OMDF) framework⁴ in which defines the role and functions that the demonstrator need to
 255 assure at an industrial scale. Figure 7 illustrated the connection of the primary, secondary and
 256 constraint functions of the OMDF with the 3D printing of recycled plastic demonstrator entails.

³Deliverable 2.2 DIT DESIGN OF THE DIT APPROACH AND XD FRAMEWORK

⁴Deliverable 4.2 SPECIFICATION OF EACH PHYSICAL DEMONSTRATOR (OPEN MANUFACTURING)

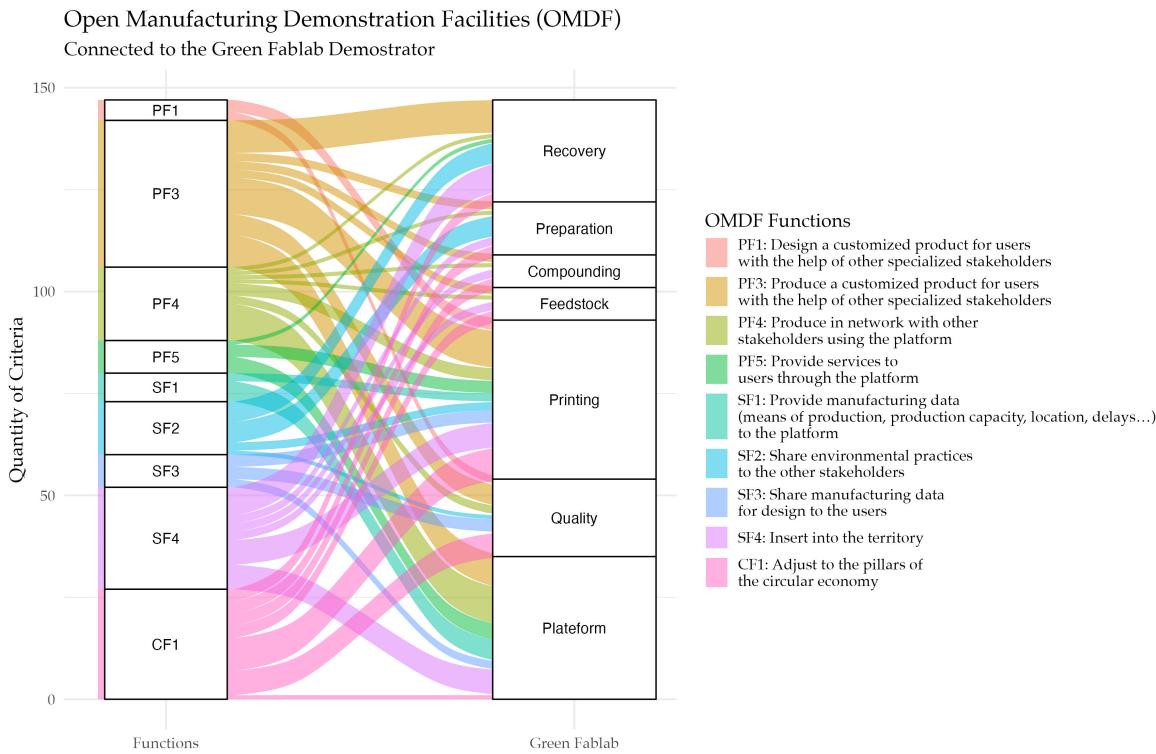


Figure 7: Connection of the 'Green Fablab Use case with the Open Manufacturing Demonstration Facilities (OMDF) functions

257 As presented in the figure, several OMDF functions are treated in the this demonstrator with
 258 each stage of the distributed recycling approach. A more detail analysis is made in the de-
 259 liverable WP4 to explain the detailed success and missing criteria from the user case in the
 260 deployment phase.

261 In the following lines, we explain the assumptions made in the deployment of the demonstrator
 262 and the technical characterization of each phase. The technical characterization entails the
 263 technologies mobilized.

264 **4.3.1 Hypothesis of UL case for deployment in reality**

265 The implementation of the Green Fablab needs to be done considering certain assumptions and
 266 simplifications to reduce the complexity of this socio-technical system. The following assump-
 267 tions were assumed in terms of geographical scale, material recollection and manufacturing
 268 aspects:

- 269 • From a material perspective, only certain types of plastic wastes are considered. Specifi-
 270 cally, Polyethylene terephthalate (PET), High density Polyethylene (HDPE), Polypropylene
 271 (PP) and Polylactic Acid (PLA). The major reason is from the technical perspective relies
 272 on the availability of these materials at the local area around the physical demonstrator.

273 - PLA is one of the most used plastics in 3D printing. Thus, as plastic waste source,
274 PLA waste can be found from printed prototypes or 3D printed parts discarded.

275
276 - HDPE is a thermoplastic widely used in the packaging.

277
278 - PET is the main material of water bottles in the market.

- 279
- 280 • The sorting, separation and cleaning process of plastics wastes are critical processes of
281 the recycling. Therefore, to possible make technical experimentation, the source waste
282 niches needs to be with a non/low contaminaed level. For example, discarded 3D print-
283 ing parts used for prototyping. They are usually mono-material and with a low level of
imurities in the polymeric matrix.
 - 284 • From a geographical point of view, only plastic waste collected from the smart collectors
285 was considered. This is a as minimal viable option to possible control the input of material
286 on the Green fablab facilities.

287 Based on these assumptions, we present the technical characterization of the Green Fablab

288 4.4 Technical characterization of the 3D printing of recycled demonstrator

289 4.4.1 Recovery I

290 The first step in the implementation of the Green Fablab OMDF is the activity of *Recovery I*.
291 This phase aims to establish a minimal baseline logistic operations to consider to collect the
292 plastic wastes to be recycled in the process. In the scientific literature, the reverse logistic and
293 closed loop supply chains have been extensively studied in the scientific literature. For instance,
294 Santander et al. (2022) evaluated the benefits of a near loop and closed loop recycling network
295 focused on additive manufacturing, mainly producing recycled filament. The main results show
296 an economic and environmental benefit of sourcing filament from recycled plastic rather than
297 purchasing exported virgin filament.

298 This process is the first step to create a closed-loop supply network approach for the distributed
299 manufacturing.

300 The collection tasks consists of collecting plastic waste at different established points, which
301 are then transported to a treatment center where it is recycled. The collection and recycling
302 process aims to generate a recycling micro-network at the local level (neighborhood scale),
303 which allows the recovery and revaluation of plastic waste through 3D printing. This allows to
304 save impacts related to the traditional treatment of plastic waste, as well as to increase the
305 recycling capacity in the city, giving more independence over the recycling process.

306 The main difficult relies in the pertinent identification and the quality state of the plastic
307 waste. Therefore, in the framework of the INEDIT project, the UL case demonstrator devel-
308 oped a “smart collector prototype” as illustrated in the Figure 8. The complete documentation
309 of the technical device can be found in the following open access reference (Gabriel and Cruz,
310 2023). Given the possible implementation in other contexts, the source files are shared in
311 open-source repository with the purpose that open communities to take advantage the experi-
312 ences developed at the Université de Lorraine. Eventually, the open communities can propose

313 improvements and better versions.

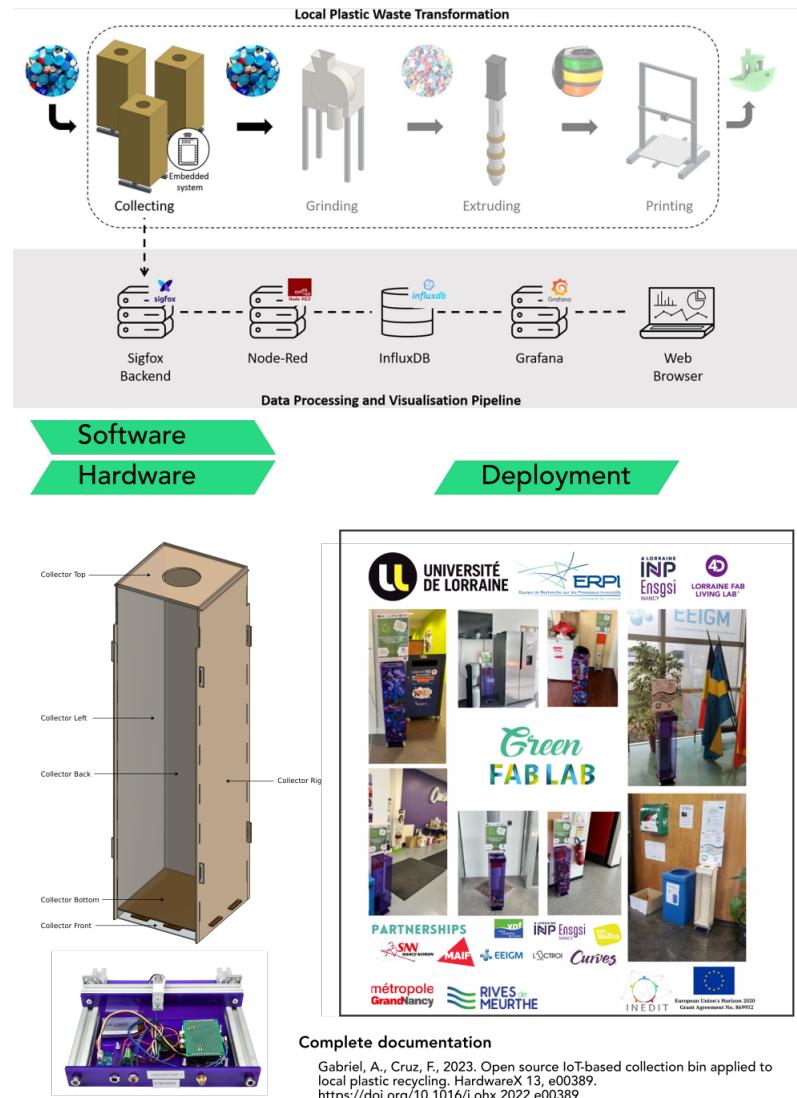


Figure 8: Description of the developed Smart collector

314 This is a relevant strategy given the cross-line of Industry 4.0 and circular economy, which is
315 opening up fields such as smart waste management systems options to improve the effectiveness
316 of different materials, including plastic waste (Ranjbari et al., 2021) using information
317 technology tools with the advent of the Internet of Things (IoT) (Fatimah et al., 2020; Rejeb et
318 al., 2022). Smart waste management system (SWMS) consists of public garbage collectors with
319 embedded technology that is used to monitor real-time level of garbage bins in public places
320 (Bano et al., 2020). The interest of this system is to optimize the path for the garbage collecting van that eventually reduces fuel cost. However, this work is mainly based on simulation.
321 Therefore, there is an avenue to simplify experimentation in this domain using common open-

323 source technology (hardware and software) ([Pearce and Mushtaq, 2009](#)) to implement projects
324 that require heavy infrastructure such as routers and a gateway to deploy in the territory.

325 The main functional requirement of the smart collector is to collect and provide data about
326 plastic waste production in order to design a local and distributed recycling chain of value.
327 However, the smart collector may be used in various use cases such as:

- 328 • Monitoring the quantity of any other product that is collected over a large area.
- 329
- 330 • Generating data about behavior to more precisely dimensions public infrastructure.
- 331
- 332 • Monitoring the transformation and recycling process inside the transformation unit to
333 follow the state and quantity of raw material and final product.
- 334
- 335 • Initiating a digitization process in the waste management process as the information sys-
336 tem element present here is flexible and commonly used in various types of projects.

337 The device uses a controller compatible with batteries and use WAN technology to avoid the
338 deployment of routers for data acquisition. Although using various types of sensors allows us to
339 achieve better results ([Catania and Ventura, 2014](#)) by crossing data, the main indicator remains
340 the weight.

341 The process illustrated by the Figure 8 can be described in the as follows:

- 342 1. **Smart Collector installation:** The first step is to identify the main actors in the neigh-
343 borhood through meetings, visits and interviews in order to propose integration into the
344 recycling network by installing a smart collector on their premises.
- 345 2. **Supervision:** The monitoring is done through a dashboard that provides direct informa-
346 tion sent by the smart collector. This allows to know the weight of each installed smart
347 collector, allowing to have an approximation of its degree of occupancy.
- 348 3. **Receiving and storing plastic waste:** The storage area must be organized and functional
349 with respect to the needs of the demonstrator.
- 350 4. **Plan and execute the collection:** This step aims to establish the collection routine.

351 The main result is to guarantee a constant supply chain of raw material that can be used inside
352 the recycling facilities

353 4.4.2 Preparation II

354 The second phase corresponds to the actions and processes to identify, separate, sort,
355 size reduce and clean waste plastic to guarantee with the purpose to obtain feedstock material
356 that is adequate for the distributed recycling process. Figure 9 displays an overview of the space
357 and the machines used presented in the Green Fablab facilities to treat the plastic waste.

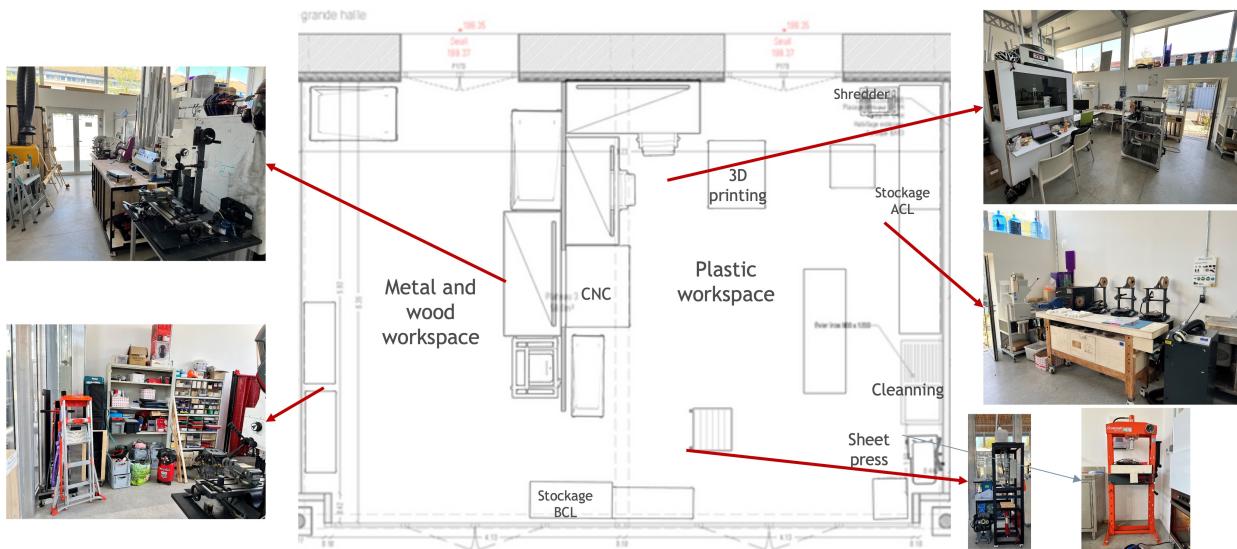


Figure 9: Adequation spaces for the preparation of the waste material

358 The plastic waste preparation process aims to conditioned the collected plastic to the requirements
359 of 3D printing. Four main sub-processes are considered:

- 360 • **Identification and Sorting:** These two processes aim to identify the type of plastic given
361 the regular standard for the polymer industry. The process of identification and separation
362 of plastics is done manually and allows to separate the plastics that can be used as raw
363 material for further production processes.
- 364 • **Cleaning:** This process is aims to remove the traces of any other substance that may be
365 present in the plastic waste. In this way the processing machines will not be exposed to
366 possible anomalies linked to material impurities.
- 367 • **Size reduction:** The size reduction process is carried out to possible obtain an adequate
368 granulometry. This process allows to adapt the plastic waste for the direct injection
369 process and/or the extrusion process.
- 370 • **Drying phase:** This step prevents the formation of bubbles in the recycled material when
371 it is melted during the following extrusion step. Moreover, complete elimination of water
372 prevent hydrolytic decomposition of the molecular chains during the melting or plasticiza-
373 tion, so that the treated material has to be as dry as possible.

374 **4.4.3 Compounding III**

375 The **Compounding** phase is related to the operation, strategies in the development of composite
376 materials using recycled feedstock intended to be use in a printing process. There have been
377 several literature reviews about the technical aspect of composite materials in the additive
378 manufacturing context ([Brenken et al., 2018](#); [Hofstätter et al., 2017](#); [Mohan et al., 2017](#); [Singh
379 et al., 2017](#)).

380 In the context of the Green Fablab demonstrator of INEDIT project, the focus is to study the 1) mono-recycled material and 2) the virgin-recycled blend material. The development of recycling niches of mono-material where the additive manufacturing can be implemented is key to
381
382 study.

384 The interest is to take into account the inner variability that could be in the recovery process,
385 concerning the type of material given the fact, while there are seven types of recycling symbols
386 for each type of polymer, one major constraint in the current systems is that each manufacturing
387 company have a patented use of the additive in the polymer matrix, in order to fulfill its initial
388 function of the product.

389 4.4.4 Feedstock IV

390 The Feedstock III phase refers to the processes in order to transform the plastic waste into
391 usable material material for the fabrication stage. Two outputs are seen in this etape: 1) the
392 filament feedstock and 2) the pellet feedstock. The use of filament or pellet material are in
393 coherence with the machine process used in the fabrication.

394 The filament and pellet production process makes it possible to produce the necessary raw
395 material from plastic waste. The production of these intermediate products allows the use of
396 different technologies related. Before using these products (filaments and pellets) it is neces-
397 sary to carry out evaluation tests to assess the geometrical characteristics that are necessary
398 in the printing process.

399 Figure 10 present the technical characteristics of the material equipment:



Type of techno: 3DEVO's extrusion machine transforms plastic pellets (new or recycled) into a quality filament for 3D printing.	Parameters - type of material: Within the Green Fab-Lab, for the realization of the filament two types of plastics are used for the moment. PLA and HDPE with a filament diameter of 1.75 mm. Here is the parameters used: <table border="1"><thead><tr><th>Plastic</th><th>°C 1</th><th>°C 2</th><th>°C 3</th><th>°C 4</th><th>Extruder speed</th><th>Fan speed</th></tr></thead><tbody><tr><td>PLA</td><td>170</td><td>185</td><td>190</td><td>170</td><td>3,5 rpm</td><td>40%</td></tr><tr><td>HDPE</td><td>200</td><td>215</td><td>230</td><td>240</td><td>3,5 rpm</td><td>40%</td></tr></tbody></table>	Plastic	°C 1	°C 2	°C 3	°C 4	Extruder speed	Fan speed	PLA	170	185	190	170	3,5 rpm	40%	HDPE	200	215	230	240	3,5 rpm	40%
Plastic	°C 1	°C 2	°C 3	°C 4	Extruder speed	Fan speed																
PLA	170	185	190	170	3,5 rpm	40%																
HDPE	200	215	230	240	3,5 rpm	40%																
Operating mode : <ol style="list-style-type: none">1. Turn on the machine2. Download the 3DEVO software3. Connect the connector of the machine to the computer4. Set up the extrusion according to the type of material5. Empty the material6. Place the new material Extruder et unpack the filament	Safety Rules: Wear gloves when emptying and winding the filament.																					
Production capacity: Practical information: <ul style="list-style-type: none">• PLA 1 hour of extrusion = 340 g• HDPE 2 hours of extrusion = 200 g																						
Advantages : <ul style="list-style-type: none">• Easy to use• Allows us to recycle our own waste• Continuous checking of the filament diameter, thanks to the sensors integrated on the machine.• Use of recycled plastic caps• Saves on the purchase of a spool	Constraints : <ul style="list-style-type: none">• Heating time• Time to adjust the filament diameter• Placement of the filament on the spool• Complete emptying of the extruder when changing material or color.• Difficulty to put the spool holding nut on the rod																					

Figure 10: Extrusion machine to fabricate recycled filament feedstock

400 Filament is produced at 0.4 kg/h using 0.24 kWh/kg with a diameter $\pm 4.6\%$.

401 4.4.5 Manufacturing process - Technological mix to valorize the recycled material

402 In this step, the major output is the valorisation of the plastic waste material using different
403 two alternative paths: 1) desktop injection molding process (small and medium sizes), and 2),
404 3D printing process (fused filament fabrication -FFF- and fused granular fabrication -FGF-).

405 As matter of the validation of the demonstrator at TRL 6 level, the ambition of the demonstrator
406 in the INEDIT project is to experiment and prove a technological ecosystem mix that seeks to
407 valorise in a distributed approach different plastics for different purposes and stakeholders.
408 Therefore, the initial choice is these two paths to create objects injected and 3D printed parts
409 that are useful to the local ecosystem of the demonstrator. The technologies are presented in
410 the following paragraphs.

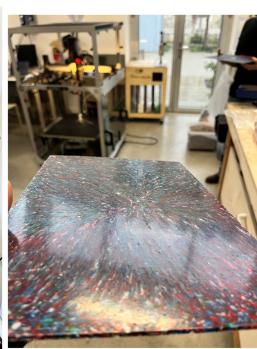
411 4.4.5.1 Desktop injection moulding Injection moulding is one of the most used technique 412 to form plastic materials.

413 Figure 11 present the major technologies in the ‘Green Fablab’ case to propose a manual recy-
414 cled aspect to possible reuse the plastic waste into small and medium plastics sheets.

Small pieces



Medium size sheets



Plastic injection parts can be very useful to make small ornaments or to generate visual information. (HDPE, PP)

Figure 11: Manual injection in small and medium sizes

415 4.4.5.2 3D printing process: Fused Filament & Granular Fabrication (FFF & FGF) In the
416 era of the additive manufacturing technology, without a doubt, the material extrusion-based
417 systems such as the fused filament fabrication (FFF) has been one of the prominent processes.
418 In fact, the technological development of open-source 3D printers is creating more affordable
419 Additive Manufacturing (AM) machines for society in different applications. It provides the
420 possibility of mass diffusion of this technology, and consequently, AM is being recognised as a
421 disruptive that could up-end the last two centuries of approaches to design and manufacturing
422 (Birtchnell and Urry, 2013; Pearce2014d?).

423 In the Green Fablab demonstrator, we have two types of material-based systems: 1) Fused
 424 filament fabrication (FFF) and 2) Fused Granular Fabrication (FGF):

425 The principle of the filament fabrication was developed and patented in 1989 by Scott Crump as
 426 *Fused Deposition Modelling*, and since 2009, the technology became open source ([Crump1992?](#)),
 427 known as Fused Filament Fabrication, to establish the difference between the registered mark.
 428 A schematic representation of this technology is presented in Figure 12. This process usually
 429 uses thermoplastic polymer filaments that are heated until a temperature slightly higher than
 430 the melting temperature at the nozzle of the machine, reaching a semi-liquid state. At this
 431 point, the polymer is extruded on the platform to create the first layer of the object and after
 432 that, the polymer continues to be printed on top of the previous layer, so that, filament fuses
 433 with the previous layer and then is solidified at room temperature after printing ([Cruz Sanchez et al., 2017; Ngo et al., 2018](#)).



Principle

Type of technic:	Parameters - type of material:		
3D printing in Fused Filament Fabrication (FFF). Additive manufacturing (3D printing) is defined as a process of joining materials to manufacture objects from 3D models, where the manufacturing process is made layer by layer.			
Production capacity:	Type of material	rHDPE	vPLA
Product of	T1	240	190
•Width: 200 mm	Bed T°	60	200
•High: 250 mm	Speed printing mm/s	60	50
•Length: 200 mm			
Operating mode :	Safety Rules:		
1. Machine cleaning (bed and nozzle)	•Don't handling while the machine printing		
2. Turn on	•Be careful with heating and electronic elements.		
3. Home the machine			
4. Check the level of the nozzles in relation to the bed.	Constraints :		
5. Pre-heat the machine	• The print size is relatively small		
6. Put the filament			
7. Upload the G-code file in the machine.	Advantages :		
8. Pre-feeding test	•Very easy to use		
9. Start the printing.	• Quality impression		
10. Waiting the printing process	•Easy to move and adaptable to different environments		
11. Remove the object from the bed	•Recyclability (feed recycled filament plastic)		
12. Turn off the machine			

Figure 12: Fused filament fabrication -FFF- principle

435 On the other hand, the Fused Granular Fabrication is a direct extrusion systems of pellets is a key
 436 technical advancement to facilitate the use of recycled material in the printing process. ?@fig-
 437 **gigabot** present the Gigabot X XL machine used in the experimentation. This machine has a long
 438 barrel with 3 heating elements or zone which helps in the melting of the thermoplastic. There
 439 are three main temperatures T1 being the heating block near the nozzle while T2 being in the
 440 middle of T1 and T3. Gigabot X XL is equipped with nozzle of 1.75mm diameter that influences
 441 the deposition rate. As 3D printing smaller cross-section is very hard without a cooling system
 442 near the nozzle therefore a cooling system was designed, 3D printed using ABS material and
 443 installed onto the system



Principle

<p>Type of techno: 3D printing in Fused Granular Fabrication (FGF). Additive manufacturing (3D printing) is defined as a process of joining materials to manufacture objects from 3D models, where the manufacturing process is made layer by layer.</p>	<p>Parameters - type of material:</p> <table border="1"> <thead> <tr> <th>Type of material</th><th>rPet-rHDPE</th><th>vPLA</th><th>vPET</th></tr> </thead> <tbody> <tr> <td>T1</td><td>264</td><td>190</td><td>240</td></tr> <tr> <td>T2</td><td>230</td><td>185</td><td>200</td></tr> <tr> <td>T3</td><td>220</td><td>170</td><td>185</td></tr> <tr> <td>Bed T°</td><td>85</td><td>60</td><td>80</td></tr> <tr> <td>Speed printing mm/s</td><td>20</td><td>60</td><td>50</td></tr> </tbody> </table>	Type of material	rPet-rHDPE	vPLA	vPET	T1	264	190	240	T2	230	185	200	T3	220	170	185	Bed T°	85	60	80	Speed printing mm/s	20	60	50
Type of material	rPet-rHDPE	vPLA	vPET																						
T1	264	190	240																						
T2	230	185	200																						
T3	220	170	185																						
Bed T°	85	60	80																						
Speed printing mm/s	20	60	50																						
<p>Production capacity: Product of •Width: 500 mm •High: 450 mm •Length: 650 mm</p>	<p>Safety Rules: •Don't handling while the machine printing •Be careful with heating and electronic elements.</p>																								
<p>Operating mode : 1.Machine cleaning (bed and nozzle) 2.Turn on 3.Intranet connexion 4.Home the machine 5.Check the level of the nozzles in relation to the bed. 6.Set up the machine parameters in the intranet 7.Pre-heat the machine 8.Charge of the material 9.Upload the G-code file in the intranet. 10.Before extrusion check the temperatures indications 11.Pre-feeding test 12.Start the printing. 13.Waiting the printing process 14.Remove the object from the bed 15.Turn off the machine</p>	<p>Constraints : • Feeding issues for high size pellets • High skills required for its upgrading</p>																								
	<p>Advantages : •Large dimension a printing • Reduction in printing time •Open source machine •Capacity of complex objects manufacturing •Don't filament required •Recyclability (feed recycled plastic)</p>																								

Figure 13: Fused granular fabrication -FGF- principle

444 In the following section, we present how was the operationalization of the DIT for the 3D printing
445 of recycled Plastic demonstrator.

5 Operationalization of DIT process for the Use Case

5.1 Integration of the 3D Printing Recycled Plastic

⁴⁴⁷ Explanation of the INEDIT project but focusing on the Open Manufacturing Demonstration Facilities process

Steps ID	Steps Description	Corresponding ID_DIT process
STEP 1 - RECEIVE DESIGN AND SPECIFICATION	Information about materials, finish, colour, texture, etc. from the INEDIT platform are sent to the manufacturing centre chosen by the ERP module and the Sustainability Driven Orchestrator (SDO). The expected files to be imported are: CAD file of the object, colour and texture, technical requirements identified in the design phase.	7_1
STEP 2 - VALIDATION OF THE TECHNICAL SPECIFICATIONS OF MODEL TO FABRICATE	Furniture producers or FabLab with the support of 3D printing technical experts evaluate the printability (if the part can be printed with the available technology) as well as validate the design.	7_2
STEP 3 - IDENTIFY LOCAL SOURCES OF PLASTIC WASTE	This step starts identifying local sources of plastic waste at least 2 km far from the production site. Designers and technicians will evaluate the quantity and quality of possible plastic wastes that could be used as secondary raw material.	9_2
STEP 4 - PUT IN PLACE SMART COLLECTOR	By using the Smart Collector developed by UL in the local areas (< 2 km) it is enabled to collect plastic waste from the sources identified before.	9_6
STEP 5 - TRANSPORT WASTE MATERIAL TO THE RECYCLING FACILITIES	All the recycled plastic waste is collected and transported to the recycling facilities	9_9
STEP 6 - ADEQUATION AND PREPARATION OF THE MATERIAL, MATERIAL PRINTABILITY VERIFICATION	The collected material has to be adequate in order to be utilised as recycled feedstock (sorting of usable material, cleaning, etc). The treated material needs to be tested and validated (evaluation on usage and printability).	10_4
STEP 7 - PATH PLANNING-3D PRINTING	Path planning software generates the best printing strategy to reduce the material used and time. The high-tech solution developed by UL manufactures using at least 30% of recycled plastic the product in the previously chosen manufacturing centre.	5_1_2
STEP 8 - POST PROCESSING	If needed, a post-processing phase refines the product in terms of aesthetic quality in order to meet customer requirements. Some parts need to be assembled in the manufacturing site before shipping to the customer.	5_1_2
STEP 9 - TEST BY USE	The DIT innovation space enables the designer to test the just realized prototype, to ensure proper functioning in real conditions.	6_1_1
STEP 10 - RE-DESIGN AND AFFINATION OF FABRICATION	If the test by use of the prototype fails, the failure is improved and corrected, repeating the process (re-involving the necessary stakeholders and the technologies used).	5_2_2
STEP 11 - VALIDATION	The use case ends validating the product printed, first by the manufacturer and the designer, second by a responsible entity for verification of design feasibility that provides safety and environmental certification and lastly by the customer use (feedback).	6_1_2

450 5.2 Step 1 - Receive Design and Specification

451 The first step in the reception of the design models and specifications from the INEDIT platform.
452 The starting point of this activity is the downloading the respective documents that contains
453 the 3D model to be manufactured by the use case as presented in the Figure 14.

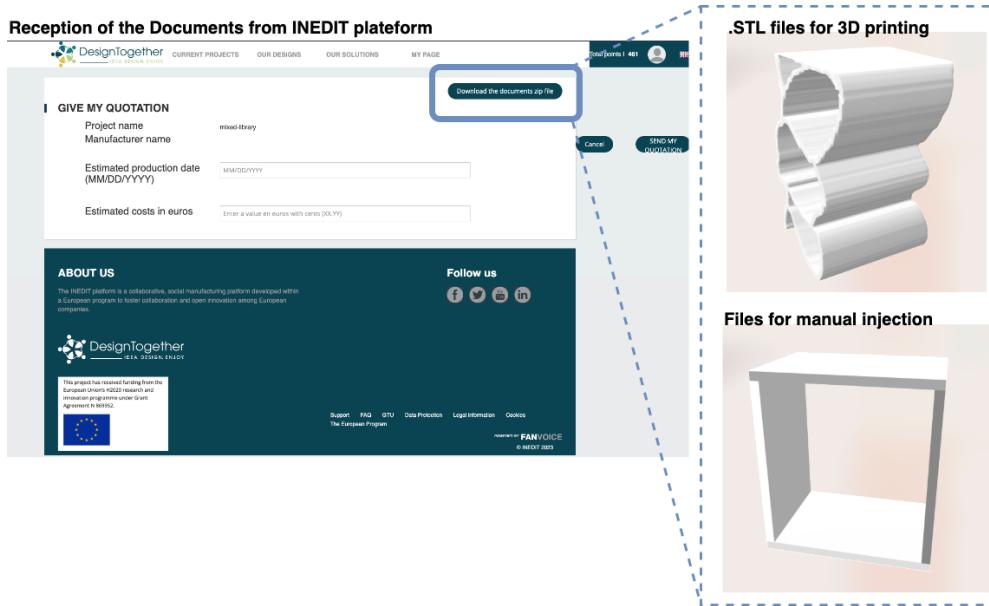


Figure 14: Reception of the exploitable documents for the fabrication process

454 One of the outputs of the co-creation phase of INEDIT plateform is the creation of a first initial
455 model that can be exploitable in the open manufacturing process. In that way, the model is
456 received taking into account the specific requirements of the customer, and the required inputs
457 to determine if the technologies available in the demonstrated have the capacity to produce the
458 product. In the case that it cannot be produced, it is necessary to notify immediately together
459 with the arguments why it cannot be produced and offer ways of improvement.

460 5.3 Step 2 - Validation of the technical specifications of model to fabricate

461 The main purpose of the second step is to establish the criteria for the validation specifications
462 of the model to fabricate. In the case of the Green FabLab, three main criteria were established
463 concerning:

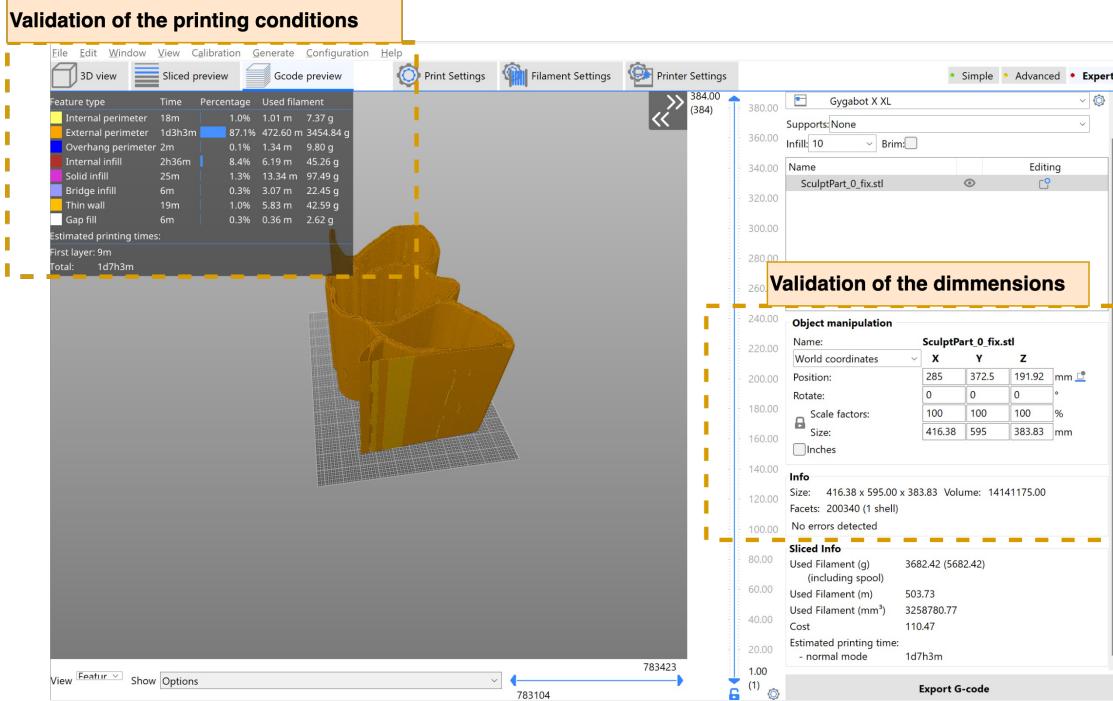


Figure 15: Validation of the printing conditions

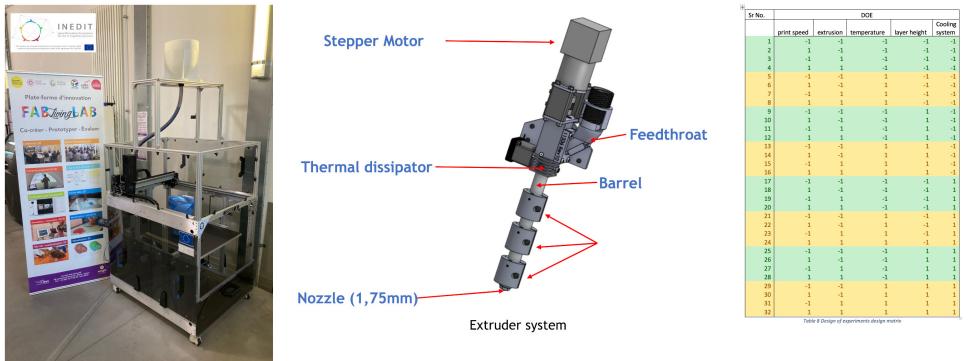
- 464 1. the dimensions of the part
 465 2. the orientation and quality of the STL
 466 3. the printability of the material

467 Using the software SuperSlicer and the machine-specific configuration (e.g. for FGF or FFF
 468 printer), it is validated that the global dimensions of the proposed part are coherent. This
 469 needs to be in the range of the maximal working dimensions of the 3D printers.

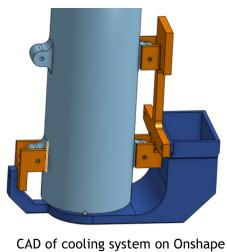
470 Lastly, the printability test are based on the characteristics of the material and the variables
 471 of the machine (namely, the temperatures of the barrel, the rotation of the stepper motors
 472 and the diameter of the nozzle). Different tests of printability were made in order to have a
 473 baseline of usable printed part as illustrated in the Figure 16.

474 The test of printability consist in the selection the technical parameters of the machine
 475 (e.g. print speed, extrusion factor, temperature, layer heighth) using a Design of Experiments
 476 (DoE) approach. Then, with a basic benchmarking model (e.g. lines, cubes, pyramids
 477 in Figure 16b), it is possible to identify the errors in the printing process using statistical
 478 approaoches as ANOVA and measures of standard error.

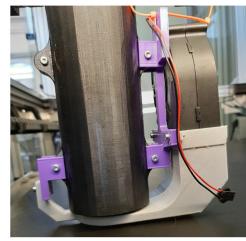
479 A technical paper to describe in more detail the results of this printability approach is being
 480 prepared at the time of writing this final rapport.



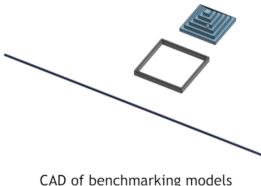
Improvements



CAD of cooling system on Onshape



3D printed Cooling system by FDM using DfAM principles



CAD of benchmarking models

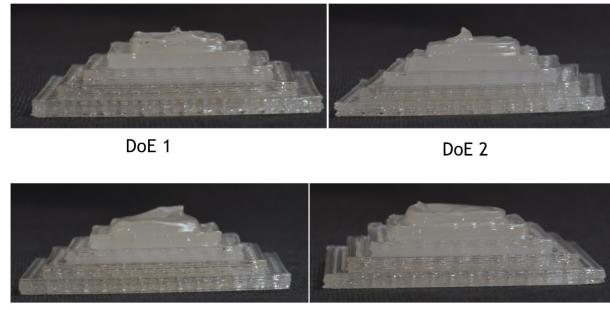
(a) Test of printability

Visual Inspection

Print quality - colour unevenness.

Process parameter affecting it - print speed and T1 heating block temperature

T1 heating block temperature and print speed at higher limit results in early colour unevenness.



Sr No.	DOE				
	print speed	extrusion	temperature	layer height	Cooling system
1	-1	-1	-1	-1	-1
2	1	-1	-1	-1	-1
5	-1	-1	1	-1	-1
6	1	-1	1	-1	-1

(b) Validation of the printability

Figure 16: Experimental protocol to validate the printability tests.

481 5.4 Step 3 - Identify local source of plastic waste

482 This step seeks to establish a first network of plastic wastes source from the local ecosystem.
 483 The task of the identification of local source of plastic is fundamental as the first stage in the
 484 recovery process. An exchange with key actors in territorial development was necessary in
 485 order to achieve this task.

486 The first step was to identify relevant stakeholders in the local ecosystems to inquire on the
 487 issue of plastic wastes source. First, they needed to belong into a geographical range perimeter
 488 (less than 2km around the facilities) following the observations of ([Cruz Sanchez et al., 2020](#);
 489 [Santander et al., 2020](#)). Limiting the geographical perimeter of collection helps in the
 490 reduction of environmental impact because of the reduction of transport impact. Second, the
 491 diversification of the actor profile that can be sensibilized to the participation of the collection
 492 (general public, employees, students) and/or stakeholder's status (Public, Private, Associative)
 493 where the smart collector can be deployed. These two elements were essential to consider
 494 because the experimentation seeks to establish a baseline of the recovery process given the
 495 uncertainties of participation of the local context and the sensitization to the management of
 496 the plastic by the general public.

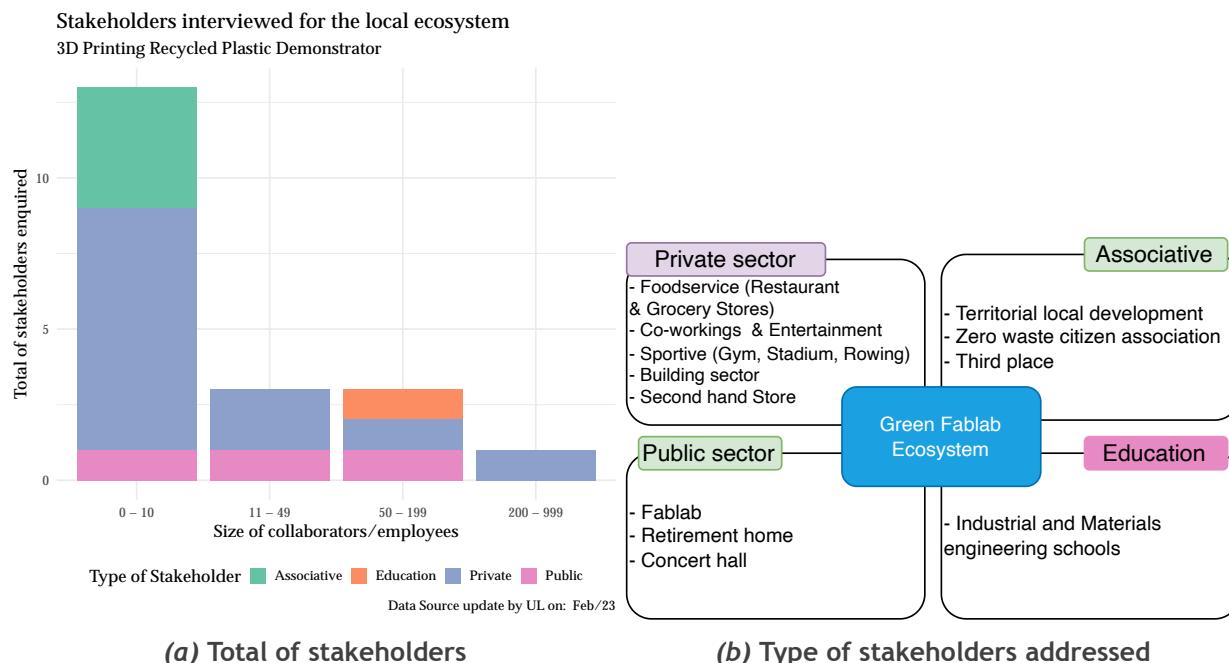
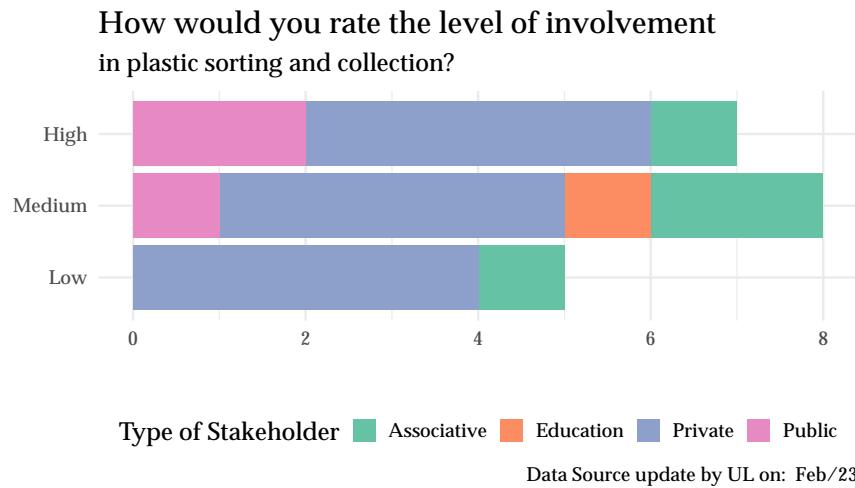


Figure 17: Local ecosystem interviewed about the implementation of 3D printing recycled demonstrator

497 A total of 23 actors were interviewed, of which 21 by physical or telephone interview and
 498 2 by electronic questionnaire. They were mainly companies (X% small and Y% medium size),
 499 associative entities, academic sector. The diversity of the public was an interesting criterion
 500 for the study. Participants in the economic, cultural and social dynamics of the district through
 501 their membership in the local association of economic actors of the territory.

502 The scope of activity of most of the respondents is local (at the level of the neighborhood or
 503 city) which may reflect a strong territorial anchoring and a commitment to local concerns and
 504 issues (waste management, social welfare, local job creation...). The majority of their business
 505 decisions are made locally, which reduces the risk of depending on the interests of entities
 506 outside the territory.



(a) Local ecosystem interviewed about the implementation of a 3D printing recycled demonstrator



(b) Acceptability of the possible use of ‘smart collector’ for the

Figure 18: Answers of the local ecosystem enquired about the implementation of a through the smart collector prototype

507 First, an inventory of their plastic waste practices was carried out.
 508 The majority of the establishments surveyed generate plastic waste which is mainly food waste
 509 (bottles and packaging). However, they do not all have a specific system for the management
 510 of this waste, but above all they sort glass and cardboard/paper. This can be explained by a
 511 lack of internal resources, such as the absence of suitable materials for sorting plastic, or the

512 lack of dedicated skills (only 5 establishments have staff in charge of waste management). In
513 some cases, the sorting process is not complete, as the sorted waste is mixed with other types
514 of waste at the time of collection due to a lack of awareness. Other establishments depend
515 on the system of public or private collection companies, which limits their involvement in the
516 management of this plastic, and sometimes leads to a lack of information on what happens to
517 this waste after collection. The majority of respondents confirm that they were favorable to
518 participate in civic initiatives, to commit to environmental protection and to participate in the
519 dissemination of these good practices to their local ecosystem.

520 When mentioning a smart collector to the interviewees, this means for them a collector “*that*
521 *does the sorting by itself*” or a technology that allows to “*count plastic waste on a territory*
522 *scale*”. These terms reflect a need for such equipment to help these facilities manage their
523 waste more easily, especially when most of them do not have plastic-specific sorting equipment.
524 Most of the interviewees were motivated to receive one or more smart collectors: “*a large*
525 *quantity of plastic caps and bottles are available at our place*”, “*very good, we'll go for it!*”,
526 “*why not all that goes in the direction of the improvement of the daily life...*”. However,
527 these comments are accompanied by some fears such as the difficulty in managing the external
528 public to respect the material, that other waste is mixed with plastic, or the need to take
529 the time to explain the approach to the internal and external people of the institutions. The
530 minority refusing to receive a smart collector or to participate in the experimentation. The
531 stated reasons and constraints such as the low frequentation of the building, the lack of time
532 to manage such an approach, the need to have a consensus at the level of all the occupants
533 decision-makers of the building, lack of visibility on the technique, or by personal conviction
534 (e.g. “*I am not too electronic and assisted, I like it when people manage by themselves*”).

535 Based on these insights, we could made a mapping of the role of each actor that could have in
536 the recovery process. Secondly, we identified the sources of plastic waste collection, and then
537 identify the sources of 3D printing and potential synergies with the Green Fablab.

538 5.5 Step 4: Put in place smart collectors

539 Thanks to the step 3, we have identified the collection sites at the local territory for the de-
540 ployment of the smart collector. In this step the main purpose was the deployment of a set
541 of *smart collectors* around the neighborhood. Figure 19 presents the selected points around
542 the Green FabLab for the installation of the prototype. The smart collector is produced and
543 mounted manually at Green FabLab facilities. The specific details and step-by-step assemble
544 process can be found in the technical paper ([Gabriel and Cruz, 2023](#)).

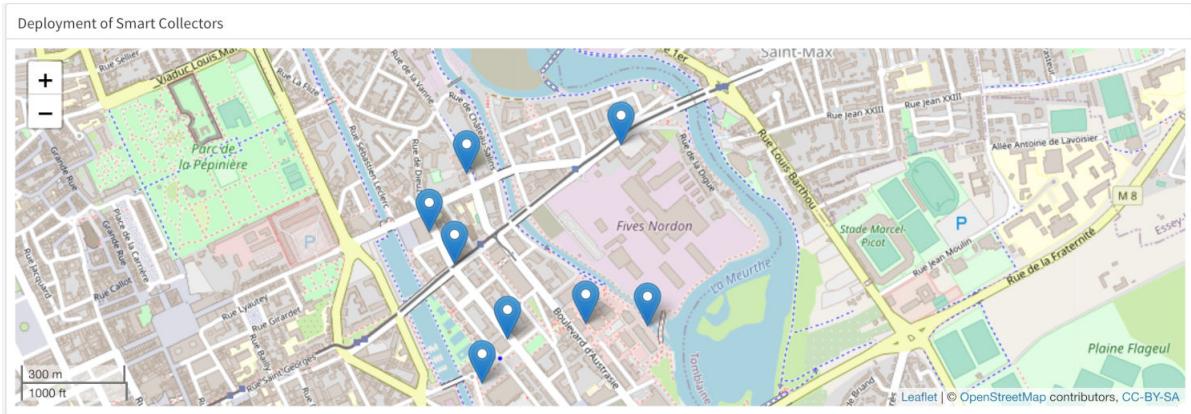


Figure 19: Deployment of the Smart Collectors.

545 The selection of the places were based on the steps 3. For the experimentation, eight sites
 546 were selected for the deployment as listed in the Table 1.

Table 1: Selected points of deployment of the smart collector in the neighbourhood of Rives de Meurthe, Nancy - France.

ID	Type	Potential public	Main activity
1	Association	+300	Cultural/leisure activities
2	Association	+1000	Third place, Co-working space
3	Private Enterprise	+100	Sport Gym
4	University	300	Engineering school
5	Private Enterprise	50	Mutual Insurance
6	University	500	Engineering school
7	Public Enterprise	50	Management of waterways network
8	Association	+100	Sports club (Rowing)

547 First, face-to-face meetings with the local actors were made to obtain the agreement for the
 548 installation of the prototype. As a relevant criteria, the installation needed to be in a location
 549 where the visitors/employees/customers of the selected point are able to see the device. We
 550 designed an appropriate communication that enables to explain the purpose of the device and
 551 connect to the information of INEDIT projet (see Figure 20)

552 Then, a system activation is putted in place to begin the collection gate. Once the smart
 553 collector is online, it is necessary to survey the online dashboard to control the waste plastic
 554 quantity. In the moment that the dashboard present a weight more than 3 kg, we mapped
 555 the collection point in the stage of ‘to collect’ and we plan the recovery. The distance of the
 556 collection place is less than 2 km so is carried out by bicycle or on foot to avoid the possible
 557 impact produced for a combustion or electric vehicle. Once the recovery process is made, at
 558 the Green Fablab When the waste plastic is collected, it is stored at the facilities of the Green



(a) Smart collector at the collection point



(b) Communication strategy of the device

Figure 20: Deployment example of the smart collector at the collection point

559 FabaLab before posterior treatment and adequation.

560 we have build a central collector where the material is stored before it is treated.

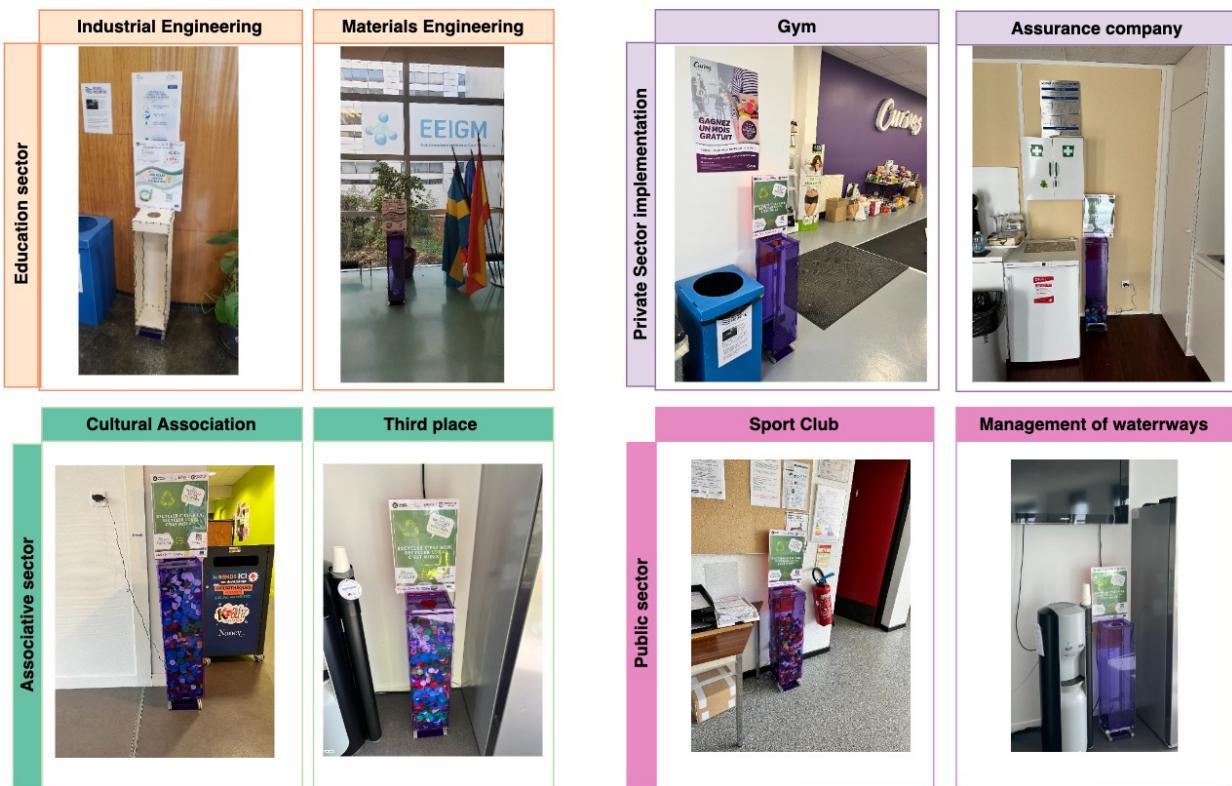


Figure 21: Smart collectors deployed in the territory

561 5.6 Step 5: Transport waste material to the recycling facilities

562 The recovery process took place once a week on average. The plastic waste is collected and
 563 transported to facilities, and then it is stored in a central collector as illustrated by the figure
 564 Figure 23.

565 Throughout the experimentation of the deployment, we have mapped the quantity of collected
 566 material. Figure 23 corresponds to the profile of quantity collection per month. In average, we
 567 have collected 3kg per week.



(a) Central storage of plastic waste



(b) Communication flyer for the smart collector

Figure 22: Smart collector

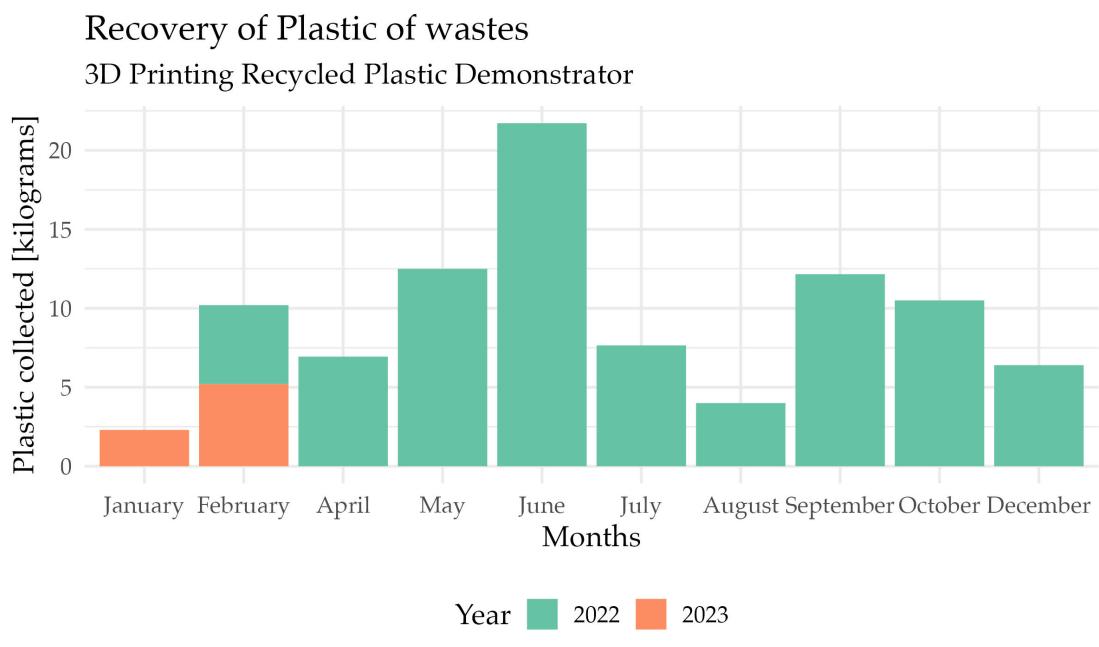


Figure 23: Recovery profile of plastic

process is much more controlled. The process is carried out in a small ultrasonic cleaning machine, to ensure that impurities are removed. The cleaner ultrasonic machine wash 200gr of plastic en 1 L of water. This process takes 20 mins with a consuption of 2kWh.



Type of technuo:
the pulsation of the simultaneously generated micro-currents ensures the continuous removal of impurities from the surface of the parts to be cleaned.

Production capacity:
3L container

- Operating mode :**
1. Set up the cleaner on a flat, stable surface.
 2. Add the cleaning solution of your choice to the water in the tank, making sure that the tank does not overflow when the part to be cleaned is immersed in it. Add the object to be cleaned.
 3. Connect the cleaner to the mains and turn the switch on.
 4. Set the temperature and duration of the cleaning cycle.
 5. Turn on the power.
 6. To stop the cleaning or heating process, press the corresponding buttons again

Advantages :

- Deep cleaning
- Easy to use
- fast cleaning cycles, between 15 to 20 minutes

Parameters - type of material:

Type of material	rPet-rHDPE	vPLA	vPET
T1	264	190	240
	230	185	200
	220	170	185
Bed T°	85	60	80

Safety Rules:

- Do not move the tank when it is full.
- In case of water leakage, turn off the power at the circuit breaker.
- Do not touch the power cable with wet hands
- Never leave the appliance running without supervision.
- Never connect the appliance without water in the tank

Constraints :

- small size for cleaning of large quantities

Figure 26: Technical characterization of the ultrasonic cleaning

The second step in the preparation of the waste material is the size reduction process. In this step, the washed and sorted plastic is sent through shredding machine where it is grounded into smaller pieces of plastic. A critical parameters in the control of the granulometry. The purpose of the size reduction is to obtain plastic waste where the granulometry correspond to the extrusion / printing. The plastic waste need to be in reduced from a range of between 25-50 mm to 3-5mm approximately after grinding. A cutting mill machine SM 300 Retsch® with a selectable speed range from 700 to 3,000 rpm was used. The selected speed was 1500 rpm. Normally we use a rotational speed of 1500 which produces an energy consumption of 0.7 kWh. The process takes 15 minutes per kilogram of material with a loss of approximately 10%. Therefore, after shredding it is necessary to sieve to possible identify the optimum size.



Type of technuo:
Small injected products: To melt plastics (virgin and recycled), then to inject them into molds by manual force.

Production capacity:
depends on the size of the part, the volume of the container is 3 L

- Operating mode :**
1. Make sure it is clean
 2. Turn on
 3. Set the speed
 4. Puts the desired material inside
 5. Once the material has been crushed, turn it off.
 6. Disassemble the container and collects the material
 7. Cleaning

Advantages :

- Easy and quick to use
- Possibility to adjust the speed (700rpm to 3000rpm)

Parameters - type of material:

Type of material	rHD PE	rPP	PLA
RPM	1500	1500	1500

Safety Rules:

- Use of gloves and protective glasses.
- Sound-isolating headphones

Constraints :

- Cleaning must be carried out carefully
- Noisy during operation
- Small feeding container

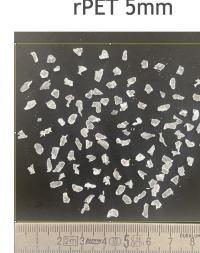
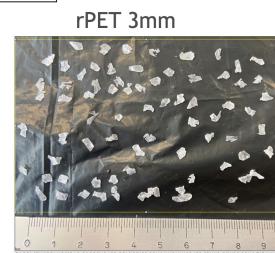


Figure 27: Photo of the Shredding process

629 printability tests, the initial model was developed using the CAD software Onshape to validate
630 the technical printability of PLA virgin assets. Using the case of a personalization of a commer-
631 cial furniture-arranging tool as displayed in Figure 30, several printed parts were manufactured
632 to evaluate the technical pertinence of the results as part of a existing furniture.



From 3D model to personalize existing furniture

Figure 30: Personalizing a existing furniture

633 In this case, only 3D printer Gigabot was used to validate the robustness and the quality of the
634 printed part.

635 5.10.2 Refurbishing of the an old furniture

636 In this case, the experimentation was a step further. The main idea was to refurbishing of the
637 an old wood workbench, connecting the tools of INEDIT. Therefore, the idea was to use the
638 scanner and the sketch features of the DesignTogether tool developed by the colleges of ENSAM
639 / TTPS. Based on that inputs, the manufacturing tools at the Green fablab including the 3D
640 printing were mobilized.



Figure 31: Refurbishing an old wood workbench using the INEDIT technologies

641 Figure 31 presents the processes entailed in the experimentation. First, once the workbench
 642 was dismantled, it was scanned using the an Ipad Pro considering the technical characteristics
 643 needed for the application. Then, the model was upload in the DesignTogether application in or-
 644 der to make a brainstorming ideas of features that are required to consider for the refurbishing.
 645 This was in input in the co-creation aspect of the process.

646 Afterwards, the model enables a first materialization of the of the proposition that could be
 647 made. So, the different manual task started in function



(a) Initial recovered workbench



(b) Refurbished workbench

Figure 32: Experimentation on refurbishing an wood workbench model

648 5.10.3 Connecting the Recycling part and the Smartification

649 In this experimentation, the idea was to connect the smartification process developed by the
 650 Uninova partners with the capabilities of our use case manufacturing. The purpose was to built
 651 a piece of furniture to test the integration of the plastic and smartification technologies. In
 652 this case, Figure 33 illustrates the manufacturing of a recycled plastic bar specifically made to
 653 be part of the entire furniture.



Figure 33: Fabrication of a prototype kitchen at the ICE-IAMOT Conference at Nancy June 2022

654 Therefore, as a part of the ICE-IAMOT conference demonstrator that took place on June 2022
655 at Nancy, we have built the complete wood structure of a kitchen furniture as presented in the
656 Figure 34. The colleges of Uninova installed the electrical components in order to adjust the
657 kitchen to the smart options. Here, the recycled plastic bar was used as sensor protection and
658 masking of the sensor needed in the electrical mounting. Moreover, the value of the recycled
659 material added a personalisation finishing of the final prototype.



Figure 34: Smartification of a kitchen

660 **5.10.4 Collaborative Desk building**

661 At the INEDIT consortium, it was decided to build a collaborative desk. The challenge in this
662 experimentation was to connect all the different competences that are present in the different
663 use cases. Regarding our use case, we supported the creation of the prototype of this desk
664 in a reduced scale using recycled filament. Additionally, it was also the opportunity to make
665 recycled production from printing and injection processes for the customization pieces.

666 Firstly, Figure 35 illustrates several attempts made using the DesignTogether tool for ideas of
667 personalization of the furniture. A workshop with 20 students of the National National School
668 in Industrial Systems Engineering (ENSGSI) was organized to create several ideas on the same
669 object.

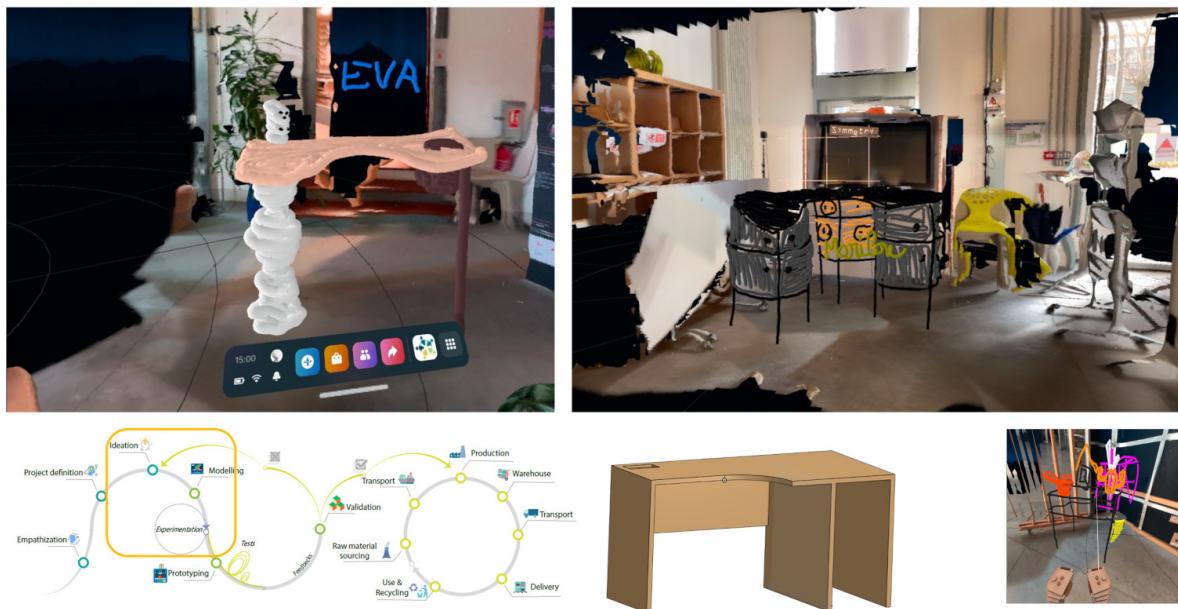


Figure 35: Co-creation stage on the personalization for the

670 Once the ideation phase was made, a second step was focused on the manufacturing of a small
671 prototype of the desk using plastic assets as presented in figure Figure 37. This made possible
672 to define the components that were manufacturing at real scale.

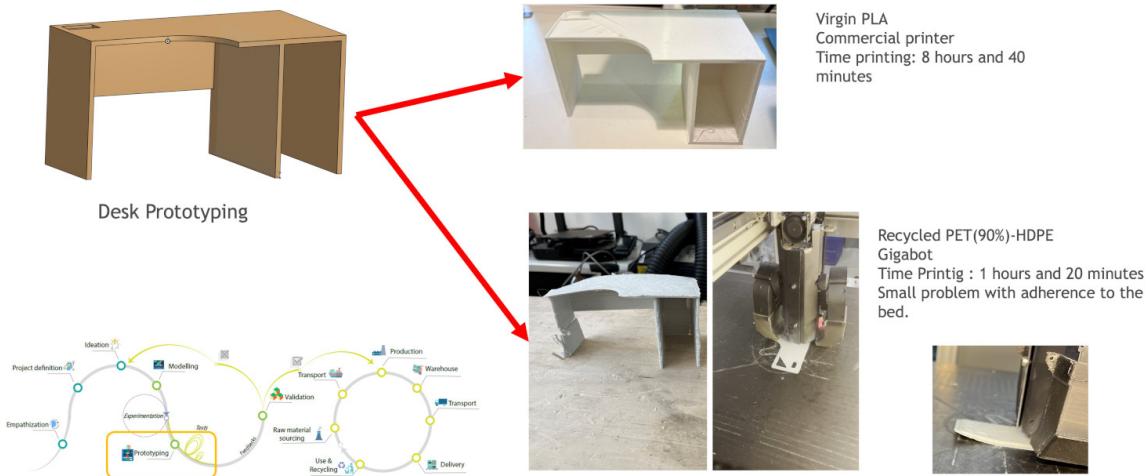


Figure 36: Prototype of the desk

673 The prototype enabled to identify three main customization object, namely 1) PC monitor sup-
 674 port, 2) an ajustable folder separation and 3) the drawer handler. as displayed in the Figure 37.
 675 The PC monitor support was built entirely using the manual injection molding. The drawer han-
 676 dler was completely 3D printed. On finnaly, the ajustable folder was a combination of injection
 677 and 3D printed processes

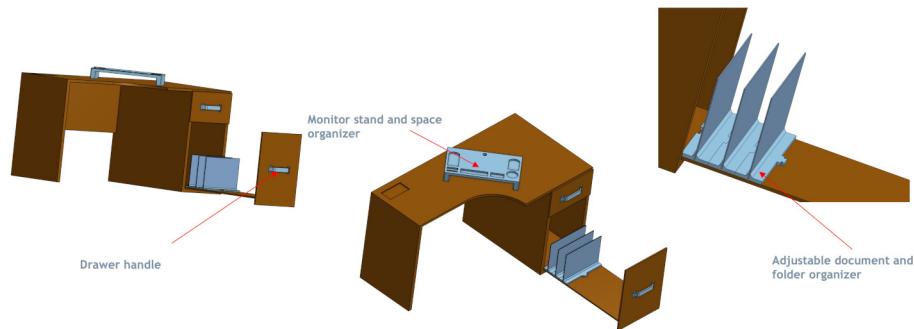


Figure 37: 3D model of the recycled pieces to be made

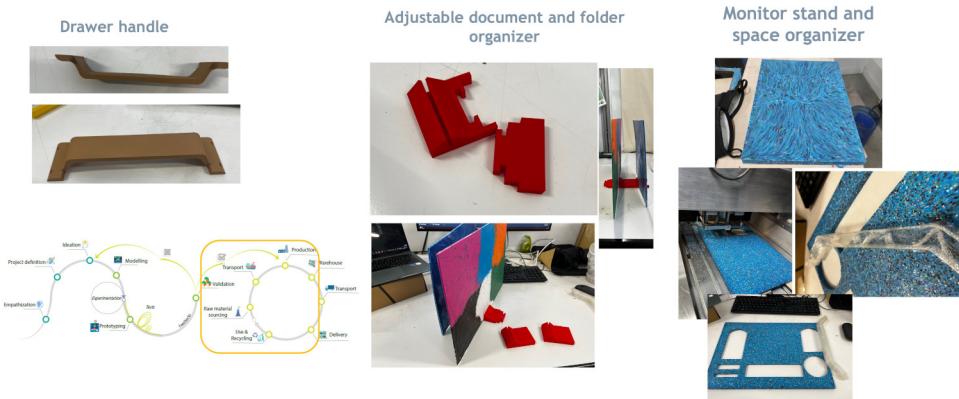
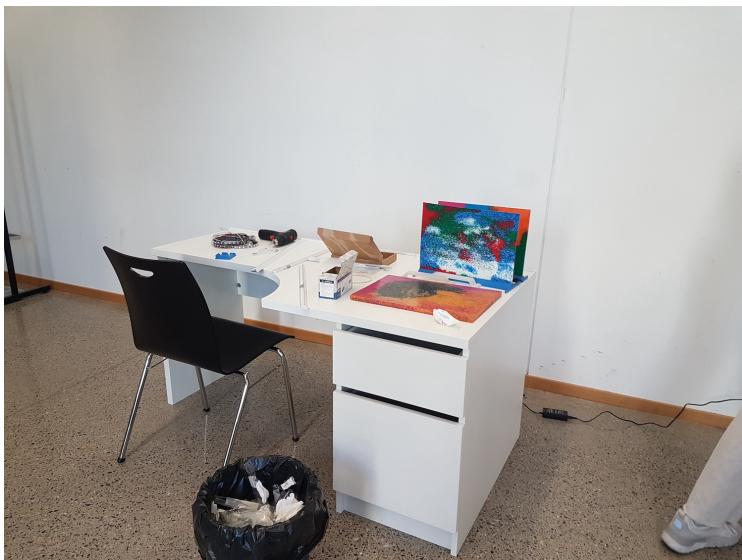


Figure 38: Manufacturing of the recycled parts (PC support, adjustable folder separation and drawer handler)

678 This experimentation was then confronted with the consortium to obtain a feedback about the
 679 possible improvements in the technical level. But more importantly, to identify the possible
 680 continuum and interaction between the different technologies and models. Figure



(a) Final assembling of the desk



(b) Exchange and discussion on the interaction and possible improvements

Figure 39: Feedbacks on the improvement of the recycled printed and injected parts

681 **5.10.5 Bookshelf**

682 Working on....

683 **5.10.6 Local collaboration with the Green fablab: the case of the ‘L’appaillet’ &**

684 One important element of INEDIT project is the interaction with external designers and local
685 ecosystem. The implementation of the Green Fablab inside the Octroi ecosystem make this
686 interaction valuable and fruitful to better align the expectations of designers and architects
687 with the possible maturity that the different technologies can have inside the INEDIT project.

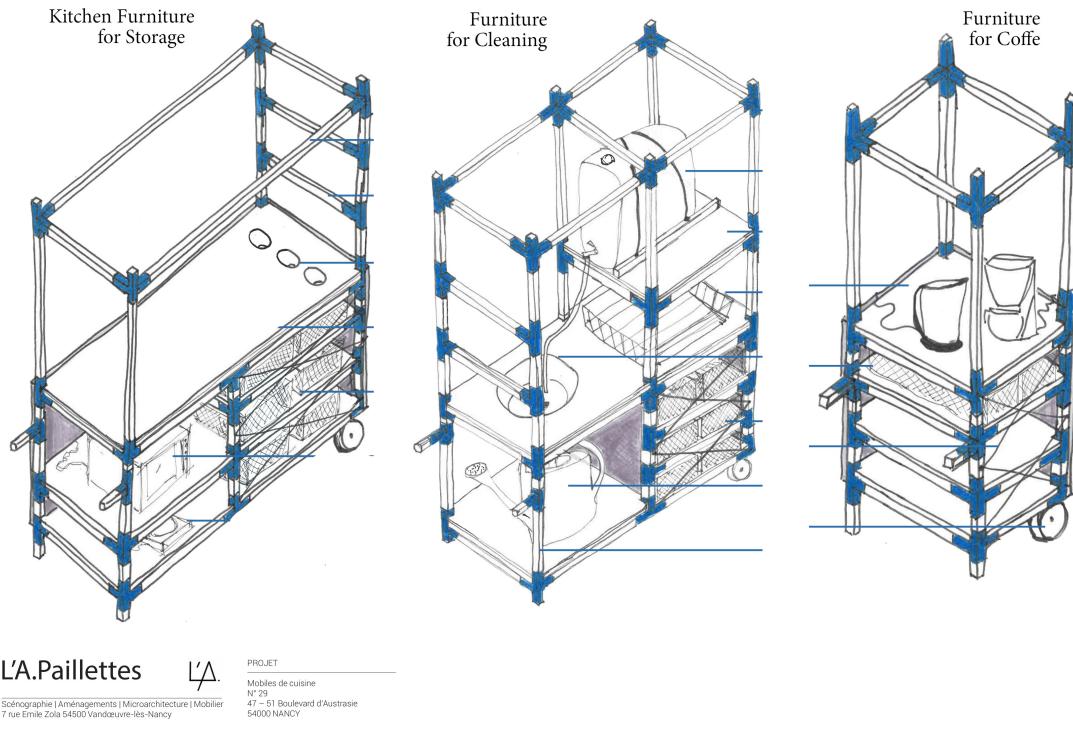


Figure 40: Sketch models designed by the local actor L'A.Paillette

688 For instance, we made an experimentation project with the local association of designers called
689 **L'A.Paillette**⁵. The project was to design and build 3 mobile modules and movable for a kitchen
690 for the Octroi community. These modules will allow heating equipment, preparation equipment
691 and cleaning equipment to be placed and moved. The first proposition of the models are pre-
692 sented in the Figure 42b.

⁵See the communication page at <https://www.facebook.com/L.A.Paillettes/>

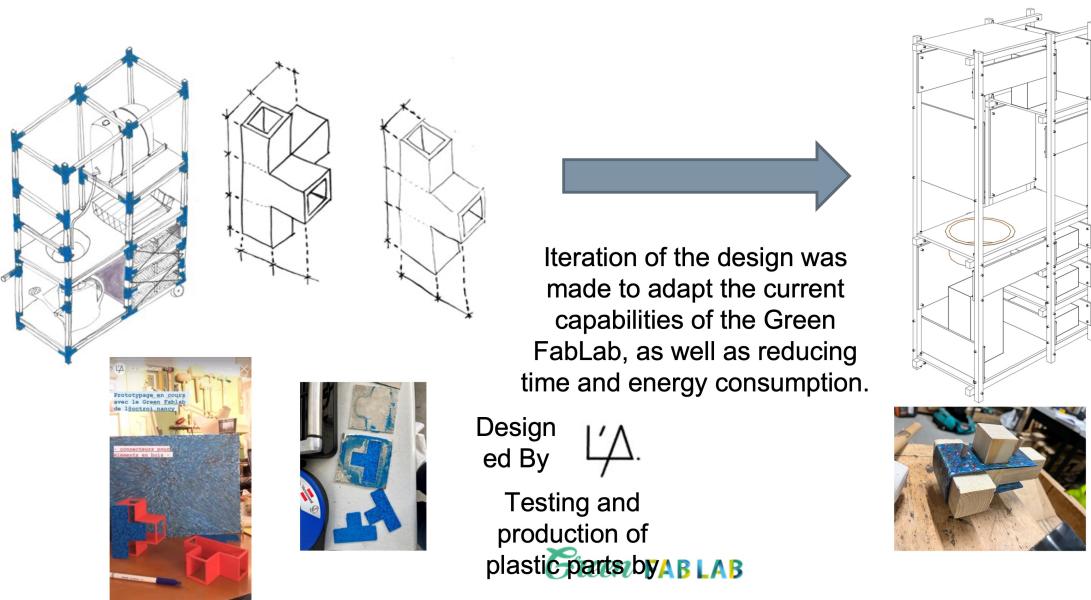


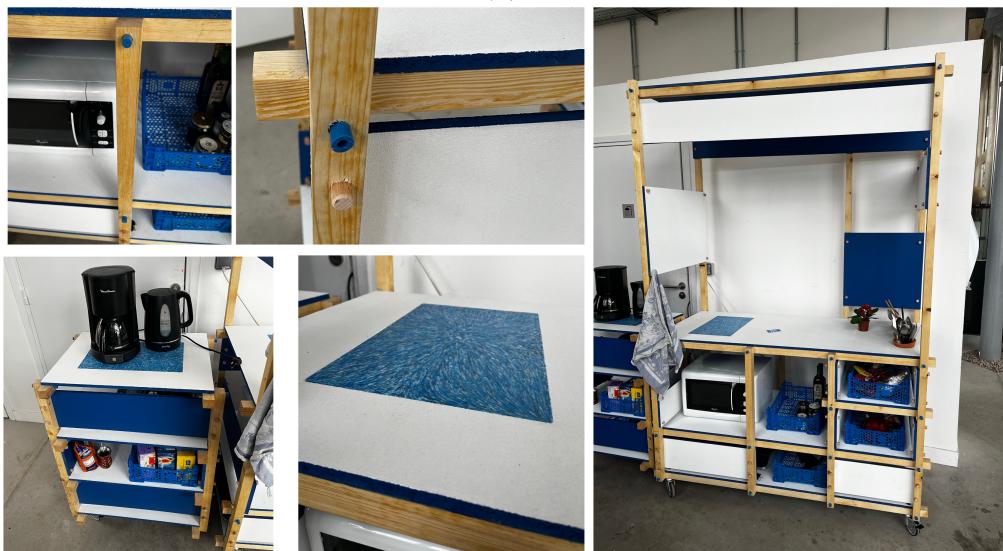
Figure 41: Iteration and re-design of the proposed recycled parts

693 Several iterations were need in order to transform the initial requirement into possible manu-
 694 factured pieces given the possibilities of the technology presented of our use case as displayed
 695 in Figure 41. Based on a prototype and a test by use, we could identified certain failures in the
 696 proposed part. Therefore, the failure was improved and corrected involving the designers of
 697 the l'A.Paillette.

698 Finally, the production consisted on 3 sheet in rAfter several attemps, a version of recycled
 699 wheets, pins were decided to fabricate. This final model was fabricated using 400g per sheet,
 700 96 plastic pin joints (20g per pin), having a total recycled plastic used about 3,1 kg aprox.
 701 (around 800 bottle taps). The final furniture made is presented iin the Figure 42.



(a)



(b)

Figure 42: Final furniture made in collaboration with the local designers at Octroi.

6 Conclusions

703 More examples neeed it in the recycling for education purposes

Bibliography

- 705 Bano, A., Ud Din, I., Al-Huqail, A.A., 2020. AloT-Based Smart Bin for Real-Time Monitoring and
706 Management of Solid Waste. *Scientific Programming* 2020. <https://doi.org/10.1155/2020/6613263>
- 708 Beltagui, A., Sesis, A., Stylos, N., 2021. A bricolage perspective on democratising innovation:
709 The case of 3D printing in makerspaces. *Technological Forecasting and Social Change* 163,
710 120453. <https://doi.org/10.1016/j.techfore.2020.120453>
- 711 Birtchnell, T., Urry, J., 2013. Fabricating Futures and the Movement of Objects. *Mobilities* 8,
712 388-405. <https://doi.org/10.1080/17450101.2012.745697>
- 713 Bonnín Roca, J., Vaishnav, P., Laureijs, R.E., Mendonça, J., Fuchs, E.R.H., 2019. Technology cost
714 drivers for a potential transition to decentralized manufacturing. *Additive Manufacturing* 28,
715 136-151. <https://doi.org/10.1016/j.addma.2019.04.010>
- 716 Boujut, J.-F., Blanco, E., 2003. Intermediary Objects as a mean to foster Co-operation. *Engineering Design Computer Supported Cooperative Work* 205-219.
- 718 Bourell, D., Kruth, J.P., Leu, M., Levy, G., Rosen, D., Beese, A.M., Clare, A., 2017. Materials
719 for additive manufacturing. *CIRP Annals* 66, 659-681. <https://doi.org/10.1016/j.cirp.2017.05.009>
- 721 Brenken, B., Barocio, E., Favaloro, A., Kunc, V., Pipes, R.B., 2018. Fused filament fabrication
722 of fiber-reinforced polymers: A review. *Additive Manufacturing* 21, 1-16. <https://doi.org/10.1016/j.addma.2018.01.002>
- 724 Catania, V., Ventura, D., 2014. An approach for monitoring and smart planning of urban solid
725 waste management using smart-M3 platform, in: Conference of Open Innovation Association,
726 FRUCT. IEEE Computer Society, pp. 24-31. <https://doi.org/10.1109/FRUCT.2014.6872422>
- 727 Chen, L., He, Y., Yang, Y., Niu, S., Ren, H., 2017. The research status and development trend
728 of additive manufacturing technology. *The International Journal of Advanced Manufacturing
729 Technology* 89, 3651-3660. <https://doi.org/10.1007/s00170-016-9335-4>
- 730 Chiffre, E., Mathis, D., Mathis, A., 2014. Les inondations à Nancy - Anciennes et nouvelles
731 problématiques. Développement durable et territoires. Économie, géographie, politique,
732 droit, sociologie.
- 733 Cruz Sanchez, F.A., Boudaoud, H., Camargo, M., Pearce, J.M., 2020. Plastic recycling in additive
734 manufacturing: A systematic literature review and opportunities for the circular economy.
735 *Journal of Cleaner Production* 264, 121602. <https://doi.org/10.1016/j.jclepro.2020.121602>
- 736 Cruz Sanchez, F.A., Boudaoud, H., Hoppe, S., Camargo, M., 2017. Polymer recycling in an
737 open-source additive manufacturing context: Mechanical issues. *Additive Manufacturing* 17,
738 87-105. <https://doi.org/10.1016/j.addma.2017.05.013>
- 739 Data, R.A., 2019. ReportsAndData2019. Additive Manufacturing Market To Reach USD 23.33
740 Billion By 2026.
- 741 Despesse, M., Baumers, M., Brown, P., Charnley, F., Ford, S.J., Garmulewicz, A., Knowles, S.,
742 Minshall, T.H.W., Mortara, L., Reed-Tsochas, F.P., Rowley, J., 2017. Unlocking value for a
743 circular economy through 3D printing: A research agenda. *Technological Forecasting and
744 Social Change* 115, 75-84. <https://doi.org/10.1016/j.techfore.2016.09.021>
- 745 Dupont, L., Morel, L., Hubert, J., Guidat, C., 2014. Study case: Living Lab Mode for urban
746 project design: Emergence of an ad hoc methodology through collaborative innovation, in:
747 2014 International Conference on Engineering, Technology and Innovation (ICE). IEEE, Berg-

- amo, pp. 1-9. <https://doi.org/10.1109/ICE.2014.6871550>
- Dupont, L., Morel, L., Lhoste, P., 2015. L'innovation Médiation scientifique, territorialité et développement local. Actes des Journées Hubert Curien, session Médiation Scientifique, territorialité et développement local, Colloque Science & You 2-8.
- Dupont, L., Pallot, M., Morel, L., Pallot, M., 2016. Exploring the Appropriateness of Different Immersive Environments in the Context of an Innovation Process for Smart Cities. 22nd ICE/IEEE International Technology Management Conference, 13-15.
- Edelblutte, S., 2006. Renouvellement urbain et quartiers industriels anciens : l'exemple du quartier Rives de Meurthe/Meurthe-Canal dans l'agglomération de Nancy. Revue Géographique de l'Est 46.
- European Commission, 2018. A european strategy for plastics in a circular economy, COM (2018). European Commission, Brussels. <https://doi.org/10.1021/acs.est.7b02368>
- Fatimah, Y.A., Govindan, K., Murniningsih, R., Setiawan, A., 2020. Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia. Journal of Cleaner Production 269, 122263. <https://doi.org/10.1016/j.jclepro.2020.122263>
- Fratini, C.F., Georg, S., Jørgensen, M.S., 2019. Exploring circular economy imaginaries in European cities: A research agenda for the governance of urban sustainability transitions. Journal of Cleaner Production 228, 974-989. <https://doi.org/10.1016/j.jclepro.2019.04.193>
- Gabriel, A., Cruz, F., 2023. Open source IoT-based collection bin applied to local plastic recycling. HardwareX 13, e00389. <https://doi.org/10.1016/j.ohx.2022.e00389>
- Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy - A new sustainability paradigm? Journal of Cleaner Production 143, 757-768. <https://doi.org/10.1016/j.jclepro.2016.12.048>
- Gibson, I., Rosen, D.W., Stucker, B., 2010. Additive Manufacturing Technologies, Assembly Automation. Springer US, Boston, MA. <https://doi.org/10.1007/978-1-4419-1120-9>
- Hahladakis, J.N., Iacovidou, E., 2018. Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity? Science of The Total Environment 630, 1394-1400. <https://doi.org/10.1016/j.scitotenv.2018.02.330>
- Hienerth, C., von Hippel, E., Berg Jensen, M., 2014. User community vs. Producer innovation development efficiency: A first empirical study. Research Policy 43, 190-201. <https://doi.org/10.1016/j.respol.2013.07.010>
- Hofstätter, T., Pedersen, D.B., Tosello, G., Hansen, H.N., 2017. State-of-the-art of fiber-reinforced polymers in additive manufacturing technologies. Journal of Reinforced Plastics and Composites 36, 1061-1073. <https://doi.org/10.1177/0731684417695648>
- Holmström, J., Holweg, M., Khajavi, S.H., Partanen, J., 2016. The direct digital manufacturing (r)evolution: Definition of a research agenda. Operations Management Research 9, 1-10. <https://doi.org/10.1007/s12063-016-0106-z>
- Hopewell, J., Dvorak, R., Kosior, E., 2009. Plastics recycling: Challenges and opportunities. Philosophical Transactions of the Royal Society B: Biological Sciences 364, 2115-2126. <https://doi.org/10.1098/rstb.2008.0311>
- Jiang, R., Kleer, R., Piller, F.T., 2017. Predicting the future of additive manufacturing: A Delphi study on economic and societal implications of 3D printing for 2030. Technological Forecasting and Social Change 117, 84-97. <https://doi.org/10.1016/j.techfore.2017.01.006>
- Karayılan, S., Yılmaz, Ö., Uysal, Ç., Naneci, S., 2021. Prospective evaluation of circular

- 793 economy practices within plastic packaging value chain through optimization of life cycle impacts and circularity. Resources, Conservation and Recycling 173, 105691. <https://doi.org/10.1016/j.resconrec.2021.105691>
- 794 Kranzinger, L., Pomberger, R., Schwabl, D., Flachberger, H., Bauer, M., Lehner, M., Hofer, W.,
795 2018. Output-oriented analysis of the wet mechanical processing of polyolefin-rich waste
796 for feedstock recycling. Waste Management & Research 36, 445-453. <https://doi.org/10.1177/0734242X18764294>
- 797 Laplume, A.O., Petersen, B., Pearce, J.M., 2016. Global value chains from a 3D printing per-
798 spective. Journal of International Business Studies 47, 595-609. <https://doi.org/10.1057/jibs.2015.47>
- 799 Little, H.A., Tanikella, N.G., J. Reich, M., Fiedler, M.J., Snabes, S.L., Pearce, J.M., 2020. To-
800 wards Distributed Recycling with Additive Manufacturing of PET Flake Feedstocks. Materials
801 13, 4273. <https://doi.org/10.3390/ma13194273>
- 802 Matt, D.T., Rauch, E., Dallasega, P., 2015. Trends towards Distributed Manufacturing Systems
803 and Modern Forms for their Design. Procedia CIRP 33, 185-190. <https://doi.org/10.1016/j.procir.2015.06.034>
- 804 Mohan, N., Senthil, P., Vinodh, S., Jayanth, N., 2017. A review on composite materials and
805 process parameters optimisation for the fused deposition modelling process. Virtual and
806 Physical Prototyping 12, 47-59. <https://doi.org/10.1080/17452759.2016.1274490>
- 807 Ngo, T.D., Kashani, A., Imbalzano, G., Nguyen, K.T.Q., Hui, D., 2018. Additive manufacturing
808 (3D printing): A review of materials, methods, applications and challenges. Composites Part
809 B: Engineering 143, 172-196. <https://doi.org/10.1016/j.compositesb.2018.02.012>
- 810 Niaki, M.K., Torabi, S.A., Nonino, F., 2019. Why manufacturers adopt additive manufacturing
811 technologies: The role of sustainability. Journal of Cleaner Production 222, 381-392. <https://doi.org/10.1016/j.jclepro.2019.03.019>
- 812 Pallot, M., Dupont, L., Fleury, S., Araque-Tellez, G., Richir, S., 2021. Investigating the Impact
813 of Visual Representations during Ideation: Towards Immersive eXperience Design, in: 2021
814 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC). IEEE,
815 p. 1. <https://doi.org/10.1109/ICE/ITMC52061.2021.9570244>
- 816 Pearce, J.M., Mushtaq, U., 2009. Overcoming technical constraints for obtaining sustainable
817 development with open source appropriate technology. TIC-STH'09: 2009 IEEE Toronto In-
818 ternational Conference - Science and Technology for Humanity 814-820. <https://doi.org/10.1109/TIC-STH.2009.5444388>
- 819 Petersen, E., Pearce, J., 2017. Emergence of Home Manufacturing in the Developed World:
820 Return on Investment for Open-Source 3-D Printers. Technologies 5, 7. <https://doi.org/10.3390/technologies5010007>
- 821 Plastics, E., 2019. Plastics - the Facts 2019.
- 822 Rahman, Z., Barakh Ali, S.F., Ozkan, T., Charoo, N.A., Reddy, I.K., Khan, M.A., 2018. Additive
823 Manufacturing with 3D Printing: Progress from Bench to Bedside. The AAPS Journal 20, 101.
824 <https://doi.org/10.1208/s12248-018-0225-6>
- 825 Ranjbari, M., Saidani, M., Esfandabadi, Z.S., Peng, W., Lam, S.S., Aghbashlo, M., Quatraro,
826 F., Tabatabaei, M., Shams Esfandabadi, Z., Peng, W., Lam, S.S., Aghbashlo, M., Quatraro,
827 F., Tabatabaei, M., 2021. Two decades of research on waste management in the circular
828 economy: Insights from bibliometric, text mining, and content analyses. Journal of Cleaner
829 Production 314, 128009. <https://doi.org/10.1016/j.jclepro.2021.128009>

- 838 Rejeb, A., Suhaiza, Z., Rejeb, K., Seuring, S., Treiblmaier, H., 2022. The Internet of Things
839 and the circular economy: A systematic literature review and research agenda. Journal of
840 Cleaner Production 350, 131439. <https://doi.org/10.1016/J.JCLEPRO.2022.131439>
- 841 Ryberg, M.W., Hauschild, M.Z., Wang, F., Averous-Monnery, S., Laurent, A., 2019. Global envi-
842 ronmental losses of plastics across their value chains. Resources, Conservation and Recycling
843 151, 104459. <https://doi.org/10.1016/j.resconrec.2019.104459>
- 844 Sanchez, F.A.C., 2016. Methodological proposition to evaluate polymer recycling in open-source
845 additive manufacturing contexts (PhD thesis). Université de Lorraine.
- 846 Santander, P., Cruz Sanchez, F.A., Boudaoud, H., Camargo, M., 2022. Social, political, and
847 technological dimensions of the sustainability evaluation of a recycling network. A liter-
848 ature review. Cleaner Engineering and Technology 6, 100397. <https://doi.org/10.1016/j.clet.2022.100397>
- 849 Santander, P., Cruz Sanchez, F.A., Boudaoud, H., Camargo, M., 2020. Closed loop supply chain
850 network for local and distributed plastic recycling for 3D printing: A MILP-based optimization
851 approach. Resources, Conservation and Recycling 154, 104531. <https://doi.org/10.1016/j.resconrec.2019.104531>
- 852 Simon, B., 2019. What are the most significant aspects of supporting the circular economy in
853 the plastic industry? Resources, Conservation and Recycling 141, 299-300. <https://doi.org/10.1016/j.resconrec.2018.10.044>
- 854 Singh, S., Ramakrishna, S., Singh, R., 2017. Material issues in additive manufacturing: A review.
855 Journal of Manufacturing Processes 25, 185-200. <https://doi.org/10.1016/j.jmapro.2016.11.006>
- 856 Thompson, R.C., Moore, C.J., vom Saal, F.S., Swan, S.H., 2009. Plastics, the environment and
857 human health: Current consensus and future trends. Philosophical Transactions of the Royal
858 Society B: Biological Sciences 364, 2153-2166. <https://doi.org/10.1098/rstb.2009.0053>
- 859 van Buren, N., Demmers, M., van der Heijden, R., Witlox, F., 2016. Towards a Circular Economy:
860 The Role of Dutch Logistics Industries and Governments. Sustainability 8, 647. <https://doi.org/10.3390/su8070647>
- 861 Ville de Nancy, 2018. NANCY 2030 CAP SUR LA VILLE ÉCOLOGIQUE. calameo.com.
- 862 West, J., Kuk, G., 2016. The complementarity of openness: How MakerBot leveraged Thingi-
863 verse in 3D printing 102, 169-181. <https://doi.org/10.1016/j.techfore.2015.07.025>
- 864 Wittbrodt, B.T., Glover, A.G., Laureto, J., Anzalone, G.C., Oppliger, D., Irwin, J.L., Pearce,
865 J.M., 2013. Life-cycle economic analysis of distributed manufacturing with open-source 3-D
866 printers. Mechatronics 23, 713-726. <https://doi.org/10.1016/j.mechatronics.2013.06.002>
- 867 Zanoni, S., Ashourpour, M., Bacchetti, A., Zanardini, M., Perona, M., 2019. Supply chain
868 implications of additive manufacturing: A holistic synopsis through a collection of case
869 studies. The International Journal of Advanced Manufacturing Technology 102, 3325-3340.
870 <https://doi.org/10.1007/s00170-019-03430-w>
- 871 Zhao, P., Rao, C., Gu, F., Sharmin, N., Fu, J., 2018. Close-looped recycling of polylactic acid
872 used in 3D printing: An experimental investigation and life cycle assessment. Journal of
873 Cleaner Production 197, 1046-1055. <https://doi.org/10.1016/j.jclepro.2018.06.275>
- 874 Zhuo, C., Levendis, Y.A., 2014. Upcycling waste plastics into carbon nanomaterials: A review.
875 Journal of Applied Polymer Science 131, n/a-n/a. <https://doi.org/10.1002/app.39931>