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D6.4 3D Printing of recycled plastic demonstrator

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

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

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

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

1.1 Outline

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

2 Plastic Issues for the European Union

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

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

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

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

3 Context of the 3D Printing of Recycled Plastic Demostrator

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

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

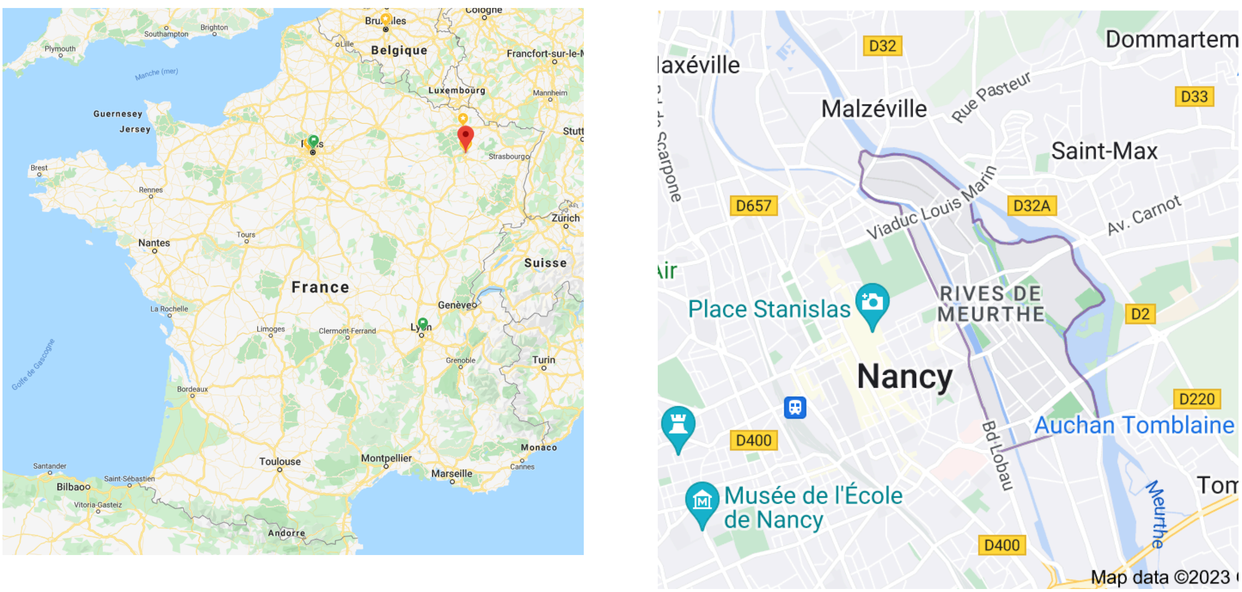


Figure 1: **Localization of the Rives the Meurthe district at Nancy, France.**

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

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

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

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

3.2 Third place Octroi Nancy

The third place Octroi Nancy is a urban project that transforms the former slaughterhouses of the city of Nancy into *"cultural, creative and citizen"* third place with 4600 m^2 of renovated buildings (Pallot et al., 2021).

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

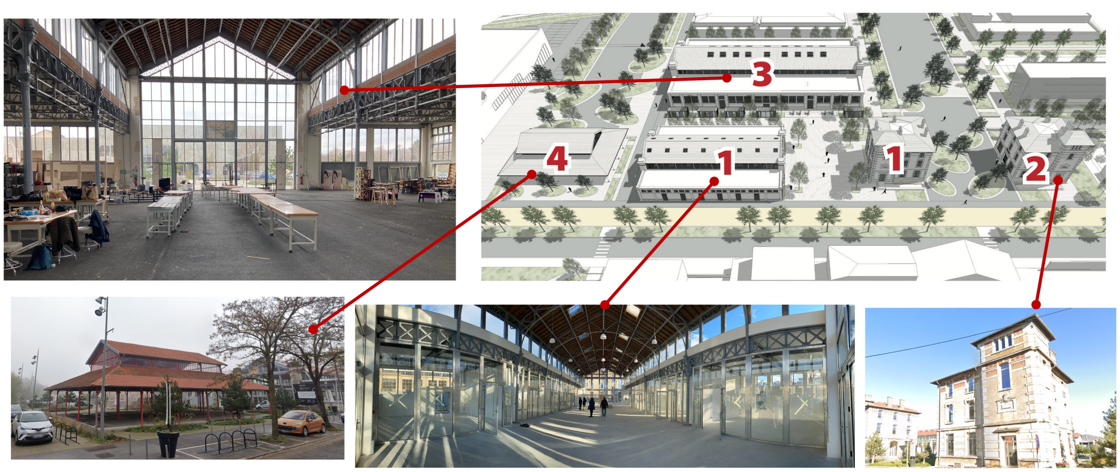


Figure 2: **Overview of the Octroi facilities at the Rives of Maeurthe district**

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

[1] See more details in https://www.octroi-nancy.fr/

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

3.3 Lorraine Fab Living Lab®

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

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

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

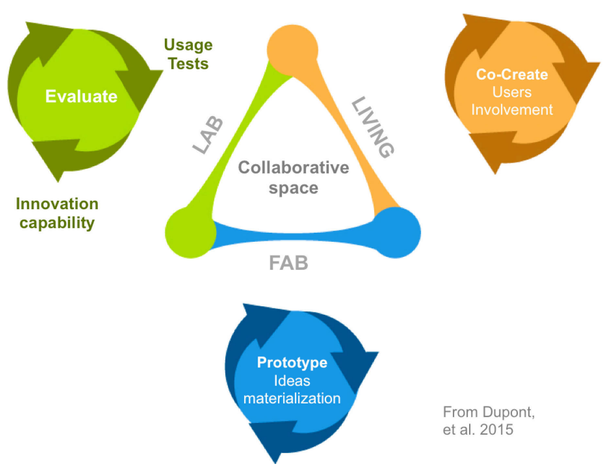


Figure 3: **The Lorraine Fab Living Lab methodlogy.**

[2] 4^{th} wave of labelisation)

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

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

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

4.1 Rationale for the technological system of the 3D printing recycling demonstrator

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

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

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

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

Therefore, it was imperative to understand the key conditions under which to deploy a notion of circular economy with plastic waste to possible establish a secondary raw material market. Likewise, it was required the study of technical parameters for the technological diversity to possible use the waste material including the open source 3D printers and manual desktop injection. The outputs are, not only by minimizing use of the environment as a sink for residuals but – perhaps more importantly – by minimizing the use of virgin materials. Hence, the environmental impact of this technology is significantly reduced.

4.2 Distributed recycling via Additive Manufacturing DRAM

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

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

DRAM is defined as the use of recycled materials by means of mechanical recycling process in the 3D printing process chain. In the literature, DRAM approach emphasizes the technical steps required to reuse plastic waste through the recycling chains for material-extrusion-based 3D printing (Cruz Sanchez et al., 2020; Little et al., 2020). The use of recycled material, either in the form of raw material or blended with virgin material, is a method of special interest to contribute to sustainable manufacturing (Zhao et al., 2018).
Figure 5 illustrates the conceptual model of DRAM.

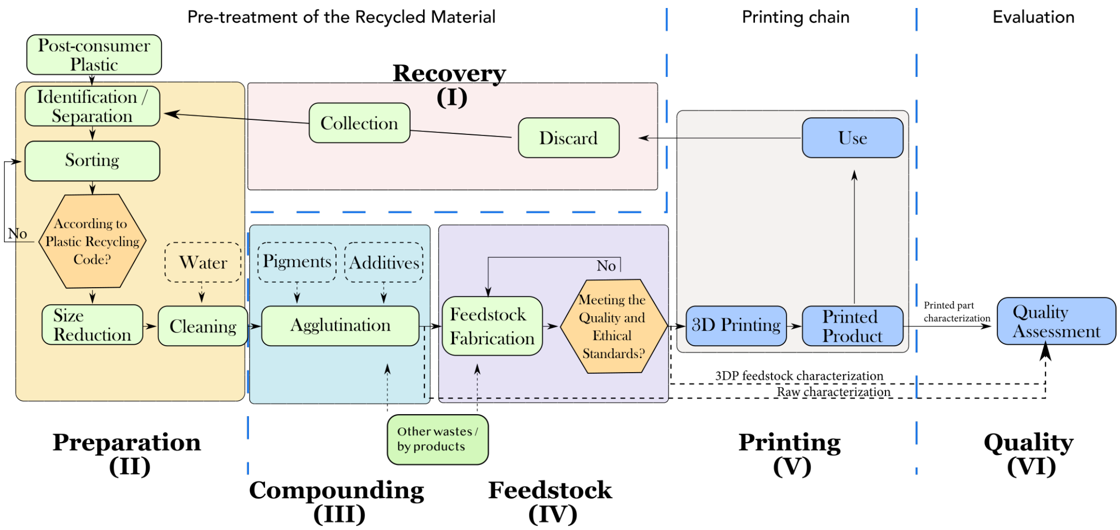


Figure 5: **Distributed recycling via additive manufacturing (DRAM) approach (Cruz Sanchez et al., 2020)**

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

4.3 Positionnement of Use case for OMDF Functions

Regarding the structuration of the INEDIT project[3], the 3D printing of recycled plastic demonstrator is positioned in certain stages of the INEDIT approach as presented in the figure Figure 6.

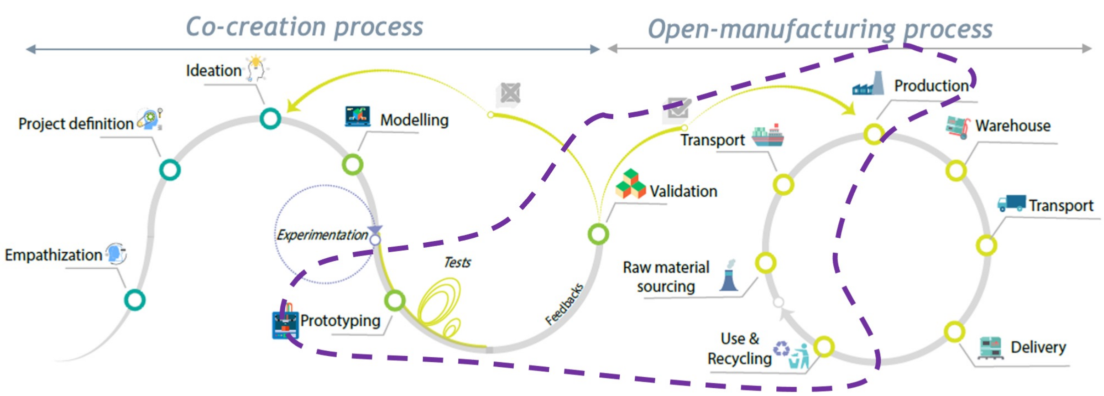


Figure 6: **Conection of the DIT with the INEDIT approach**

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

Additionally, in the light of the specification of the open manufacturing demonstration facilities (OMDF) framework[4] in which defines the role and functions that the demonstrator need to assure at an industrial scale. Figure 7 illustrated the connection of the primary, secondary and constraint functions of the OMDF with the 3D printing of recycled plastic demonstrator entails.

[3]Delivrable 2.2 DIT DESIGN OF THE DIT APPROACH AND XD FRAMEWORK

[4]Delivrable 4.2 SPECIFICATION OF EACH PHYSICAL DEMONSTRATOR (OPEN MANUFACTURING)

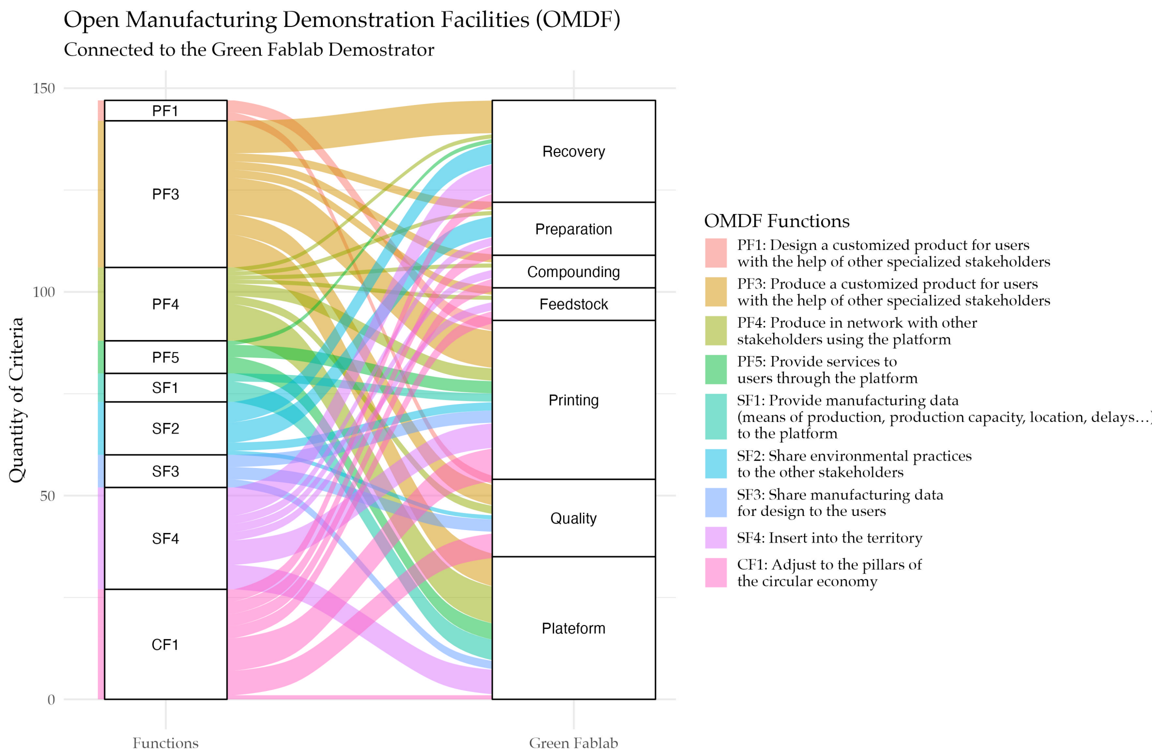


Figure 7: **Connection of the 'Green Fablab Use case with the Open Manufacturing Demonstration Facilities (OMDF) functions**

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

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

4.3.1 Hypothesis of UL case for deployment in reality

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

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

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

- HDPE is a thermoplastic widely used in the packaging.

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

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

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

4.4 Technical characterization of the 3D printing of recycled demonstrator

4.4.1 Recovery I

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

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

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

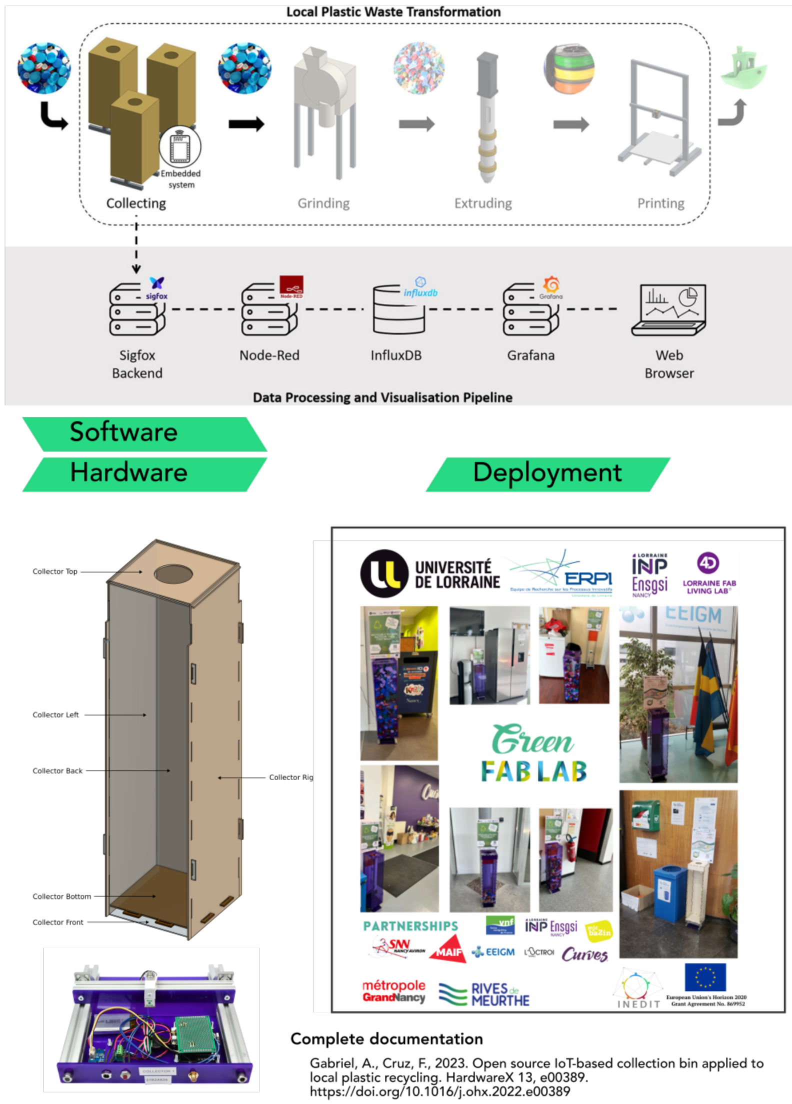


Figure 8: **Description of the developed Smart collector**

This is a relevant strategy given the cross-line of Industry 4.0 and circular economy, which is opening up fields such as smart waste management systems options to improve the effectiveness of different materials, including plastic waste (Ranjbari et al., 2021) using information technology tools with the advent of the Internet of Things (IoT) (Fatimah et al., 2020; Rejeb et al., 2022). Smart waste management system (SWMS) consists of public garbage collectors with embedded technology that is used to monitor real-time level of garbage bins in public places (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. Therefore, there is an avenue to simplify experimentation in this domain using common open-source technology (hardware and software) (Pearce and Mushtaq, 2009) to implement projects that require heavy infrastructure such as routers and a gateway to deploy in the territory.

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

- Monitoring the quantity of any other product that is collected over a large area.

- Generating data about behavior to more precisely dimensions public infrastructure.

- Monitoring the transformation and recycling process inside the transformation unit to follow the state and quantity of raw material and final product.

- Initiating a digitization process in the waste management process as the information system element present here is flexible and commonly used in various types of projects.

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

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

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

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

4.4.2 Preparation II

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

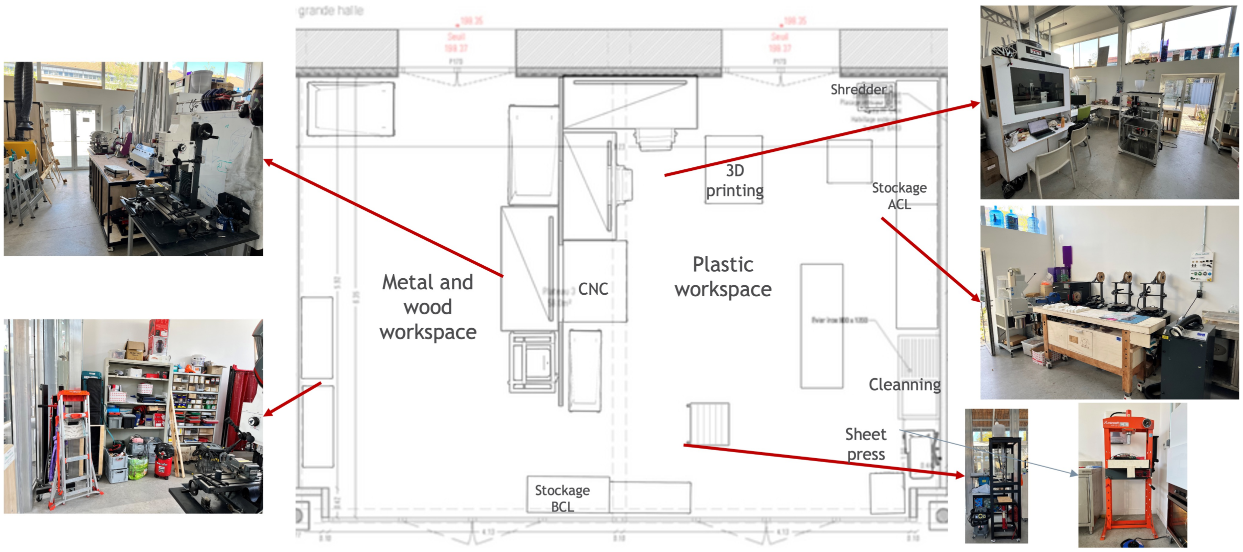


Figure 9: **Adequation spaces for the preparation of the waste material**

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

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

4.4.3 Compounding III

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

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 study.

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

4.4.4 Feedstock IV

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

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

Figure 10 present the technical characteristics of the material equipment:

Technology 1 – Filament extrusion 3D (3DEVO)

Type of techno:

3Devo's extrusion machine transforms plastic pellets (new or recycled) into a quality **filament** for 3D printing.

Operating mode :

1. Turn on the machine
2. Download the 3DEVO software
3. Connect the connector of the machine to the computer
4. Set up the extrusion according to the type of material
5. Empty the material
6. Place the new material Extruder et unpack the filament

Production capacity:
Practical information:

- PLA 1 hour of extrusion = 340 g
- HDPE 2 hours of extrusion = 200 g

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:

Plastic	°C 1	°C 2	°C 3	°C 4	Extruder speed	Fan
PLA	170	185	190	170	3,5 rpm	40%
HDPE	200	215	230	240	3,5 rpm	40%

Safety Rules:

Wear gloves when emptying and winding the filament.

Advantages :

- 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 :

- 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**

Filament is produced at 0.4 kg/h using 0.24 kWh/kg with a diameter ±4.6%.

4.4.5 Manufacturing process – Technological mix to valorize the recycled material

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

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

4.4.5.1 Desktop injection moulding Injection moulding is one of the most used technique to form plastic materials.
Figure 11 present the major technologies in the 'Green Fablab' case to propose a manual recycled aspect to possible reuse the plastic waste into small and medium plastics sheets.

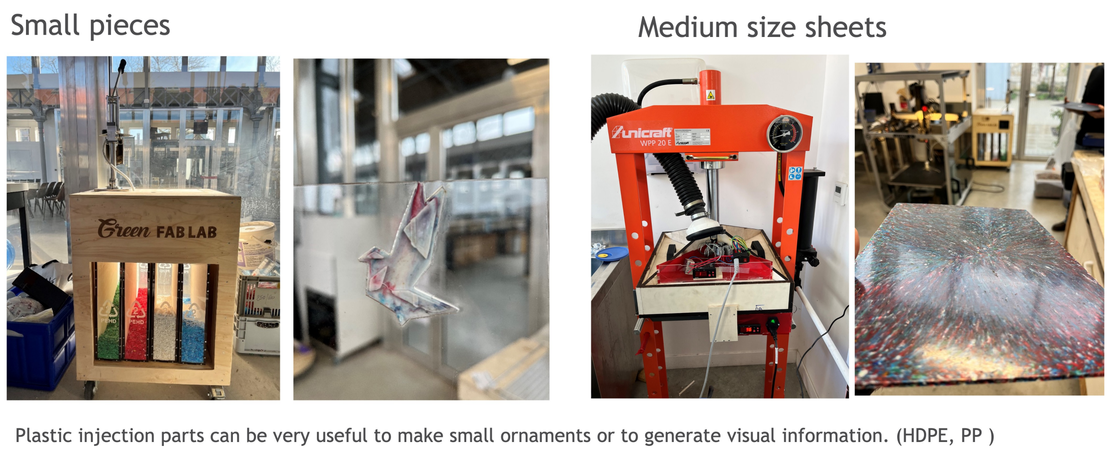


Figure 11: **Manual injection in small and medium sizes**

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

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

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

Type of techno:
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:
Product of
•Width: 200 mm
•High: 250 mm
•Length: 200 mm
Size nozzle: 0.4 mm

Operating mode :
1. Machine cleaning (bed and nozzle)
2. Turn on
3. Home the machine
4. Check the level of the nozzles in relation to the bed.
5. Pre-heat the machine
6. Put the filament
7. Upload the G-code file in the machine.
8. Pre-feeding test
9. Start the printing.
10. Waiting the printing process
11. Remove the object from the bed
12. Turn of the machine

Parameters - type of material:

Type of material	rHDPE	vPLA	rPLA
T1	240	190	200
Bed T°	85	60	60
Speed printing mm/s	60	60	50

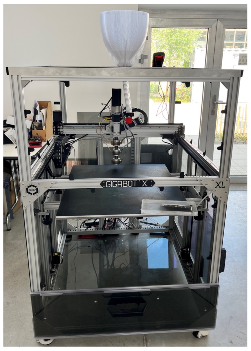
Safety Rules:
•Don't handing while the machine printing
•Be careful with heating and electronic elements.

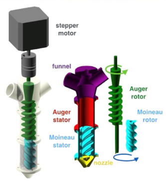
Constraints :
• The print size is relatively small

Advantages :
•Very easy to use
• Quality impression
•Easy to move and adaptable to different environments
•Recyclability (feed recycled filament plastic)

Figure 12: **Fused filament fabrication -FFF- principle**

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





Principle

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.

Production capacity:
Product of
•Width: 500 mm
•High: 450 mm
•Length: 650 mm
Size nozzle: 1.75 mm

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 of the machine

Parameters - type of material:

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

Safety Rules:
•Don't handing while the machine printing
•Be careful with heating and electronic elements.

Constraints :
- Feeding issues for high size pellets
- High skills required for its upgrading

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)

Figure 13: **Fused granular fabrication -FGF- principle**

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

5 Operationalization of DIT process for the Use Case

5.1 Integration of the 3D Printing Recycled Plastic

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

5.2 Step 1 – Receive Design and Specification

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

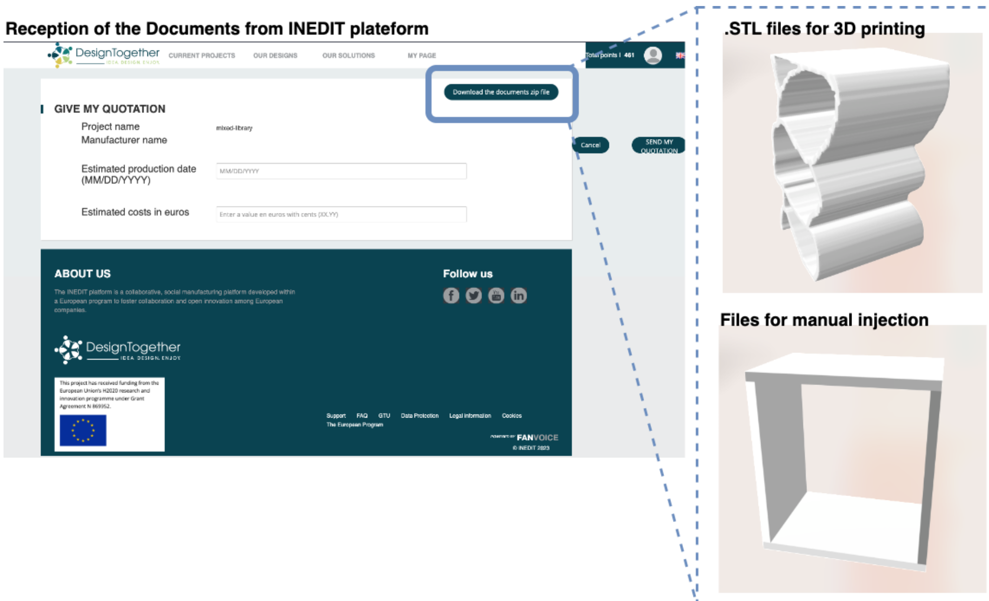


Figure 14: **Reception of the exploitable documents for the fabrication process**

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

5.3 Step 2 – Validation of the technical specifications of model to fabricate

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

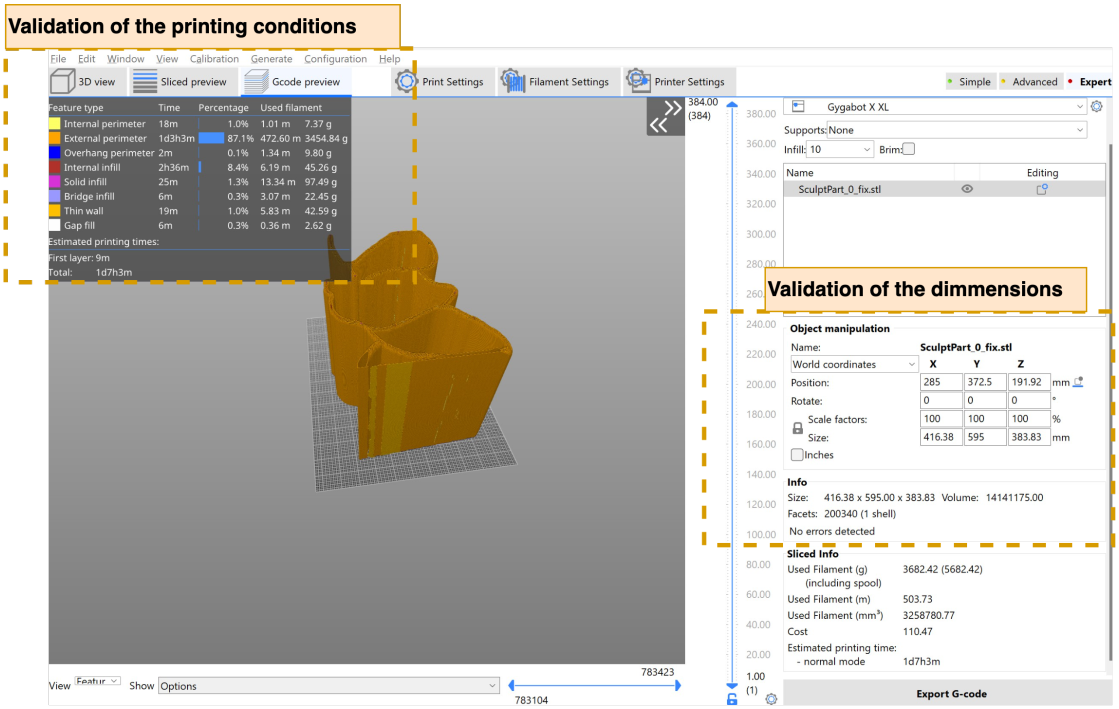


Figure 15: Validation of the printing conditions

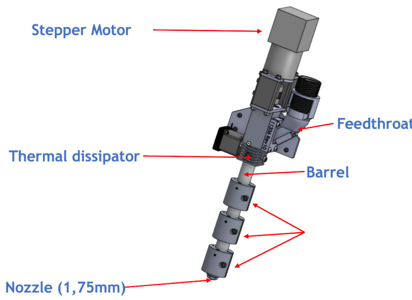
1. the dimensions of the part
2. the orientation and quality of the STL
3. the printability of the material

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

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

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

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

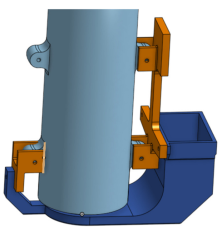


Extruder system

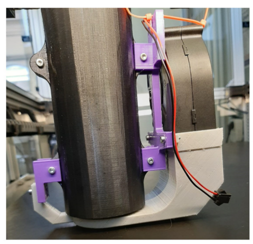
Sr No.	DOE				
	print speed	extrusion	temperature	layer height	Cooling system
1	-1	-1	-1	-1	-1
2	1	-1	-1	-1	-1
3	-1	1	-1	-1	-1
4	1	1	-1	-1	-1
5	-1	-1	1	-1	-1
6	1	-1	1	-1	-1
7	-1	1	1	-1	-1
8	1	1	1	-1	-1
9	-1	-1	-1	1	-1
10	1	-1	-1	1	-1
11	-1	1	-1	1	-1
12	1	1	-1	1	-1
13	-1	-1	1	1	-1
14	1	-1	1	1	-1
15	-1	1	1	1	-1
16	1	1	1	1	-1
17	-1	-1	-1	-1	1
18	1	-1	-1	-1	1
19	-1	1	-1	-1	1
20	1	1	-1	-1	1
21	-1	-1	1	-1	1
22	1	-1	1	-1	1
23	-1	1	1	-1	1
24	1	1	1	-1	1
25	-1	-1	-1	1	1
26	1	-1	-1	1	1
27	-1	1	-1	1	1
28	1	1	-1	1	1
29	-1	-1	1	1	1
30	1	-1	1	1	1
31	-1	1	1	1	1
32	1	1	1	1	1

Table 8 Design of experiments design matrix

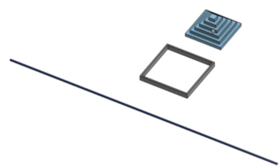
Improvements



CAD of cooling system on Onshape



3D printed Cooling system by FDM using DfAM principles



CAD of benchmarking models

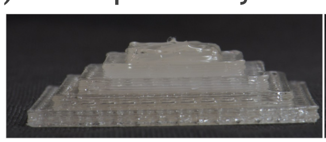
(a) Test of printability

Visual Inspection

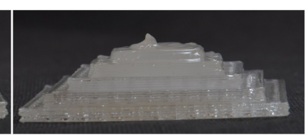
Print quality - colour unevenness.

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

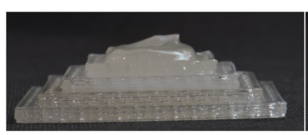
T1 heating block temperature and print speed at higher limit results in early colour uneveness.



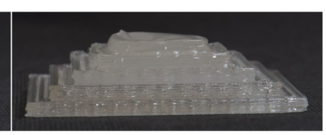
DoE 1



DoE 2



DoE 5



DoE 6

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

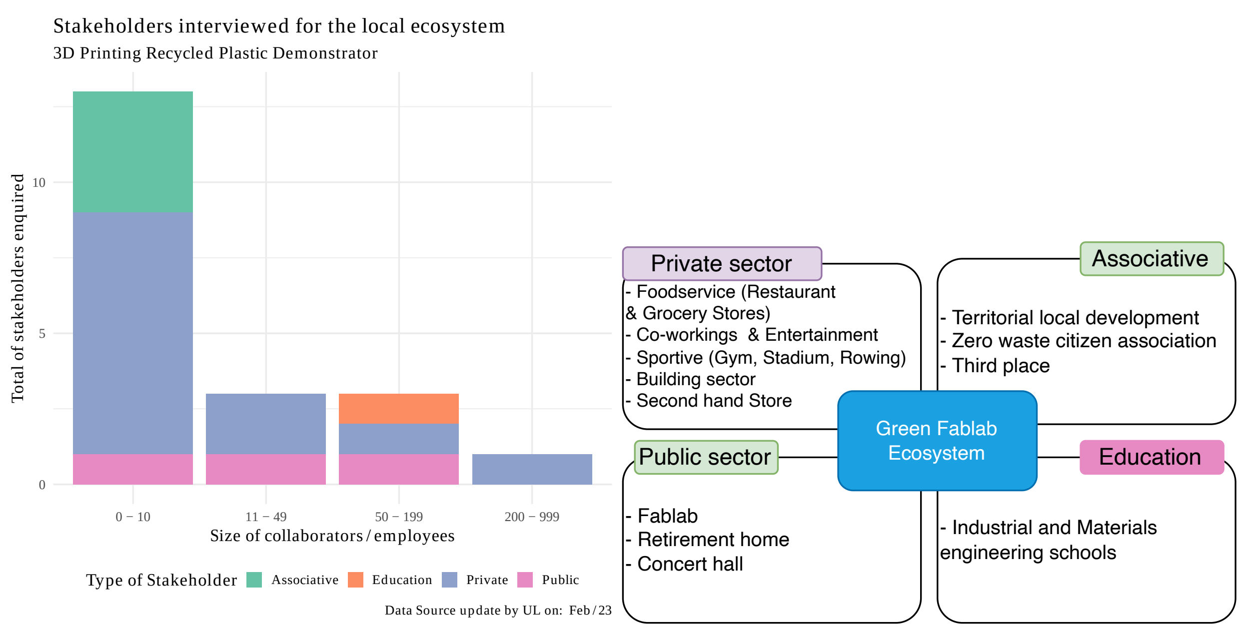
(b) Validation of the printability

Figure 16: Experimental protocol to validate the printability tests.

5.4 Step 3 - Identify local source of plastic waste

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

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

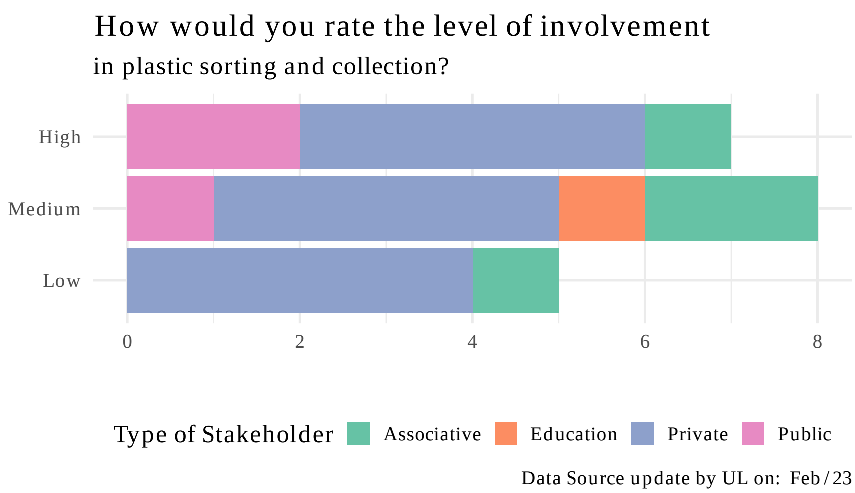


(a) **Total of stakeholders** *(b)* **Type of stakeholders addressed**

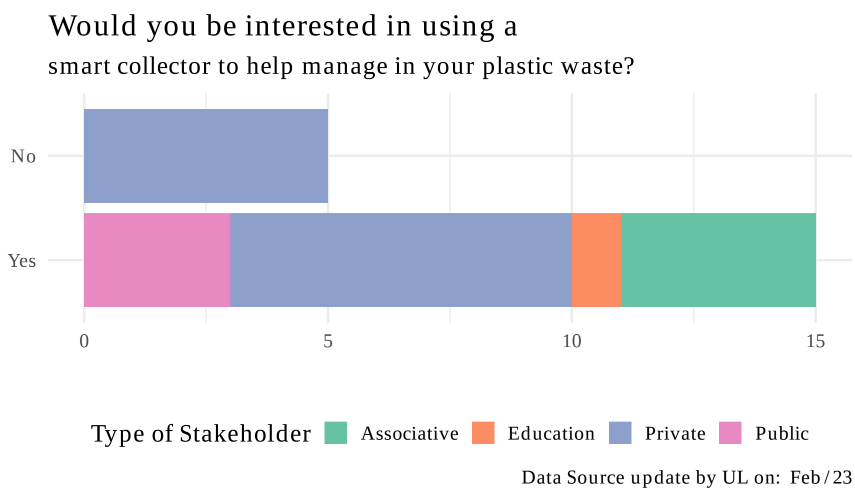
Figure 17: **Local ecosystem interviewed about the implementation of 3D printing recycled demonstrator**

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

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



(a) **Local ecosystem interviewed about the implementation ofa 3D printing recycled demostrator**



(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**

First, an inventory of their plastic waste practices was carried out.

The majority of the establishments surveyed generate plastic waste which is mainly food waste (bottles and packaging). However, they do not all have a specific system for the management of this waste, but above all they sort glass and cardboard/paper. This can be explained by a lack of internal resources, such as the absence of suitable materials for sorting plastic, or the lack of dedicated skills (only 5 establishments have staff in charge of waste management). In some cases, the sorting process is not complete, as the sorted waste is mixed with other types of waste at the time of collection due to a lack of awareness. Other establishments depend on the system of public or private collection companies, which limits their involvement in the management of this plastic, and sometimes leads to a lack of information on what happens to this waste after collection. The majority of respondents confirm that they were favorable to participate in civic initiatives, to commit to environmental protection and to participate in the dissemination of these good practices to their local ecosystem.

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

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

5.5 Step 4: Put in place smart collectors

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

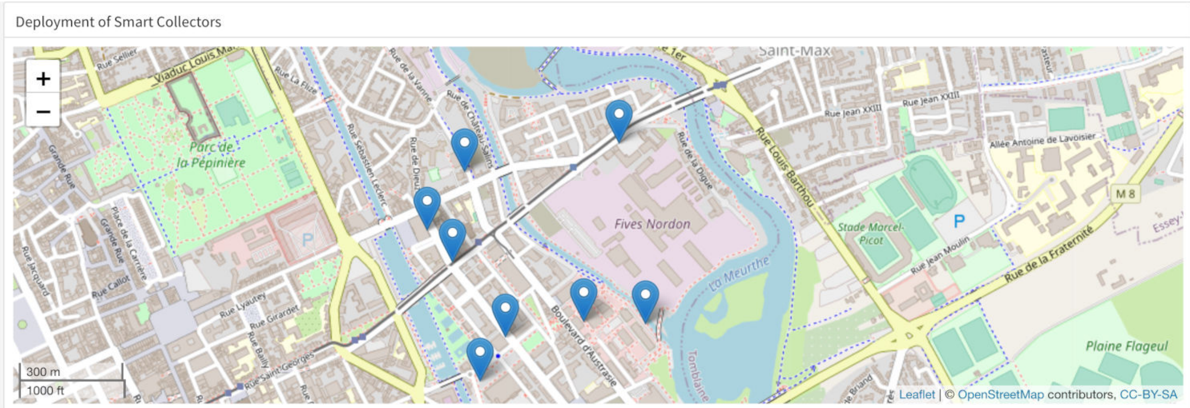


Figure 19: **Deployment of the Smart Collectors.**

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

Table 1: **Selected points of deployment of the smart collector in the neighboorhood 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 Entreprise	+100	Sport Gym
4	University	300	Engineering school
5	Private Enterprise	50	Mutual Insurance
6	University	500	Engineering school
7	Public Entreprise	50	Management of waterrways network
8	Association	+100	Sports club (Rowing)

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

Then, a system activation is putted in place to begin the collection gate. Once the smart collector is online, it is necessary to survey the online dashboard to control the waste plastic quantity. In the moment that the dashboard present a weight more than 3 kg, we mapped the collection point in the stage of *'to collect'* and we plan the recovery. The distance of the collection place is less than $2\ km$ so is carried out by bicycle or on foot to avoid the possible impact produced for a combustion or electric vehicle. Once the recovery process is made, at 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**

FabaLab before posterior treatment and adequation.
we have build a central collector where the material is stored before it is treated.

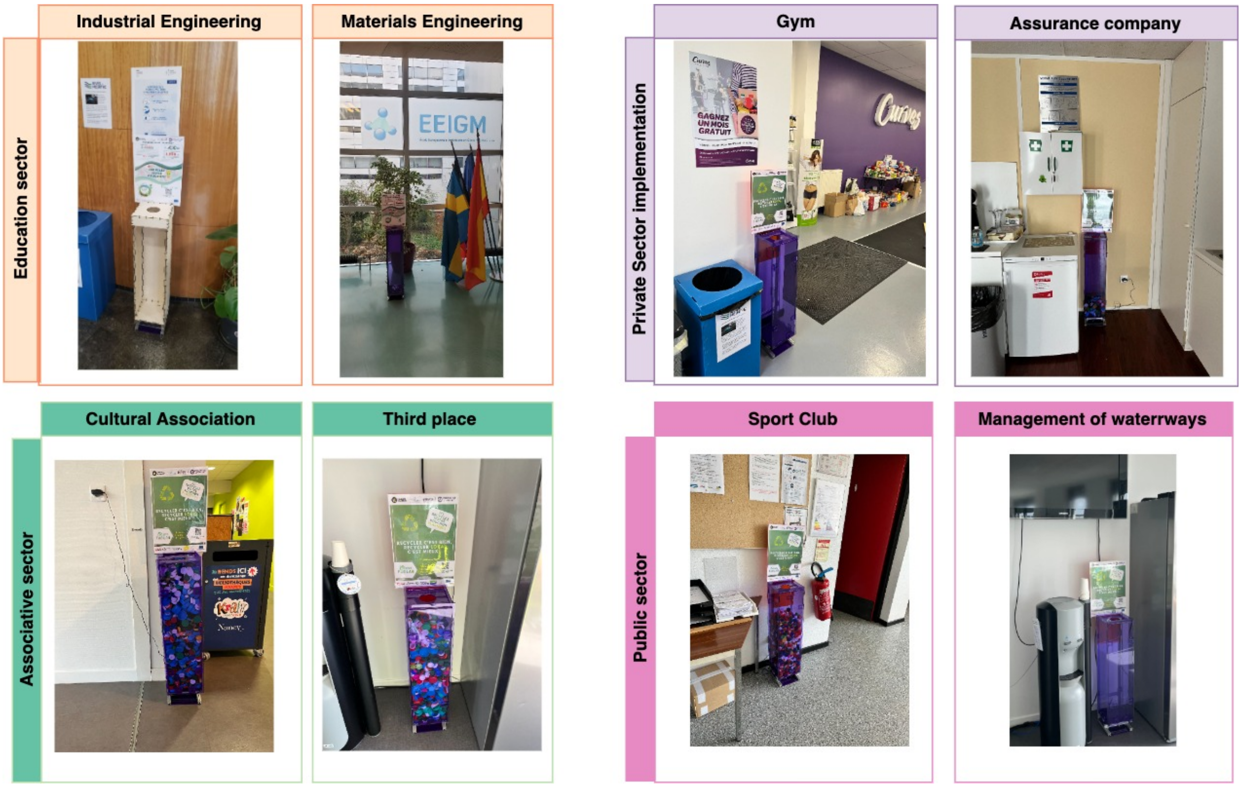


Figure 21: Smart collectors deployed in the territory

5.6 Step 5: Transport waste material to the recycling facilities

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

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

(a) Central storage of plastic waste

(b) Communication flyer for the smart collector

Figure 22: Smart collector

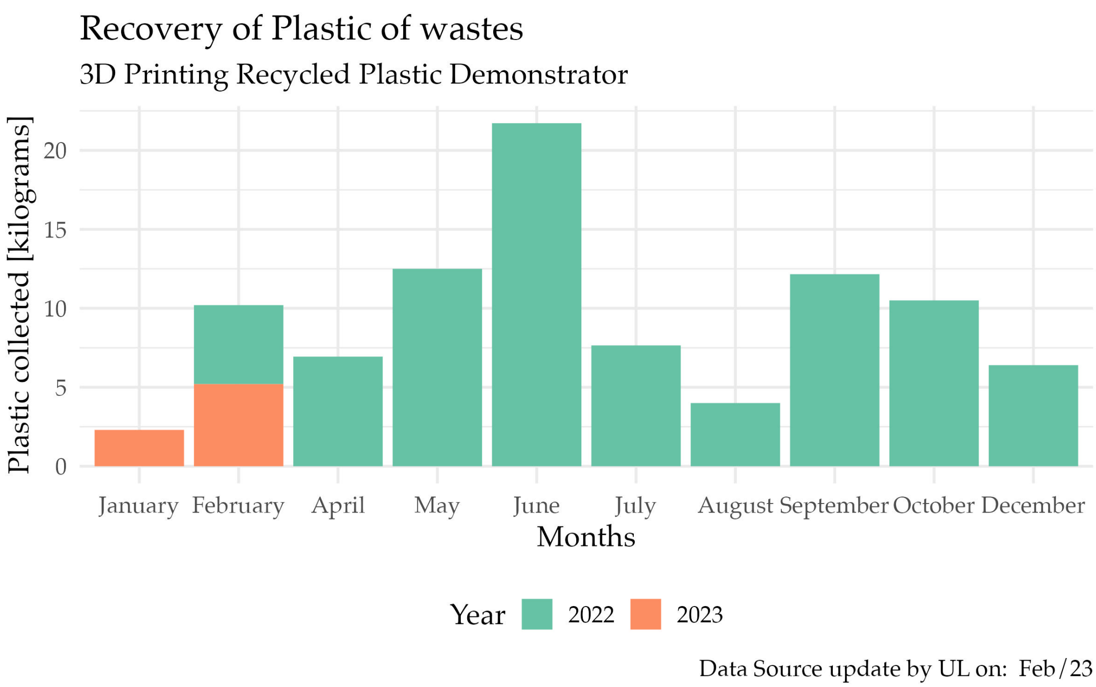


Figure 23: Recovery profile of plastic

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 techno:
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 optimun size.

Type of techno:
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

rPET 1.5mm rPET 3mm rPET 5mm

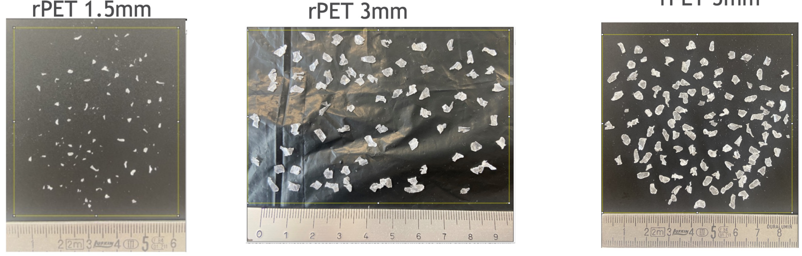


Figure 27: Photo of the Shredding process

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

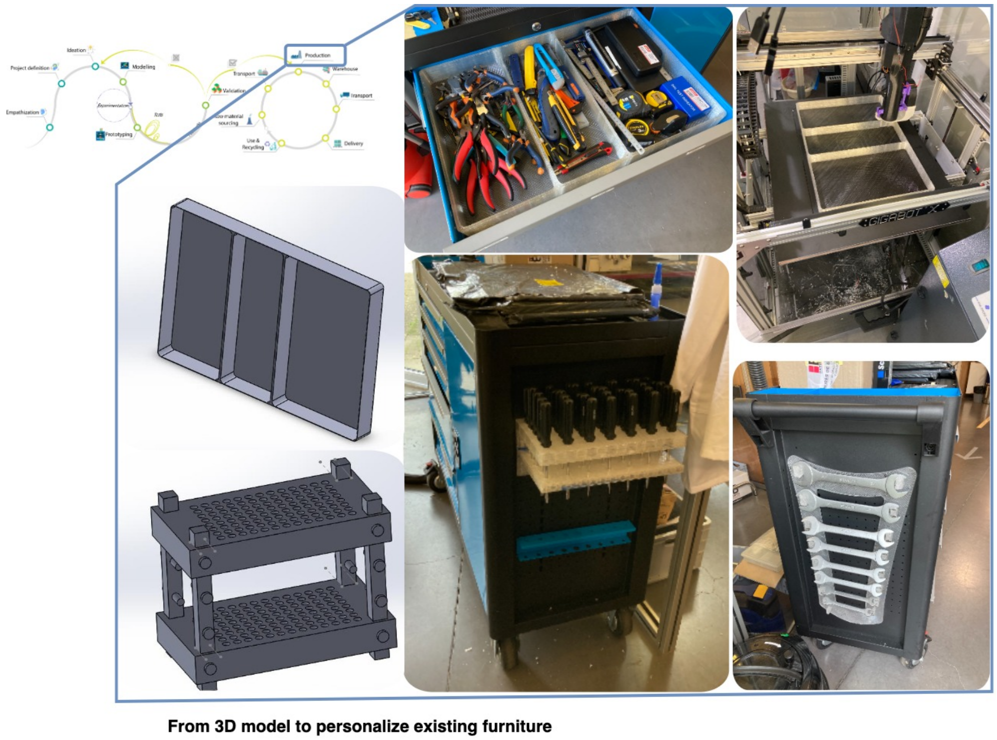


Figure 30: **Personlizing a existing furniture**

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

5.10.2 Refurbishing of the an old furniture

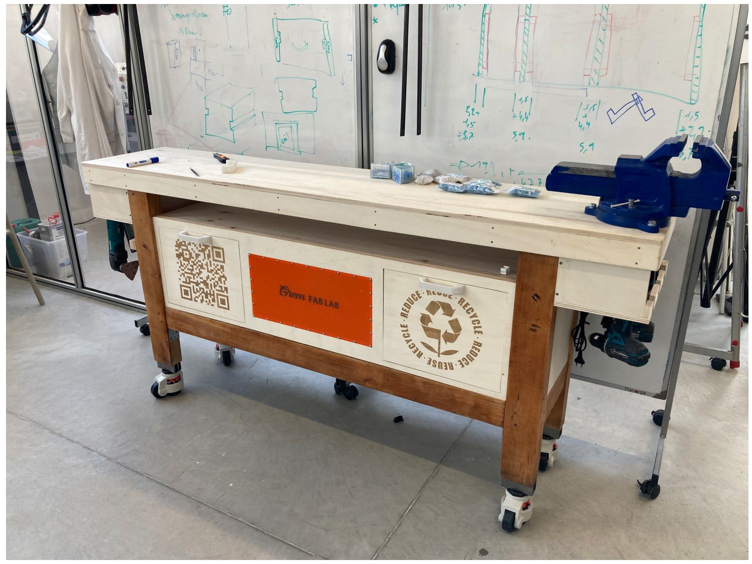
In this case, the experimentation was a step further. The main idea was to refurbishing of the an old wood workbench, connecting the tools of INEDIT. Therefore, the idea was to use the scanner and the sketch features of the DesignTogether tool developed by the colleges of ENSAM / TTPS. Based on that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

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

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

Afterwards, the model enables a first materialization of the of the proposition that could be 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

5.10.3 Connecting the Recycling part and the Smartification

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

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

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

Figure 34: **Smartification of a kitchen**

5.10.4 Collaborative Desk building

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

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

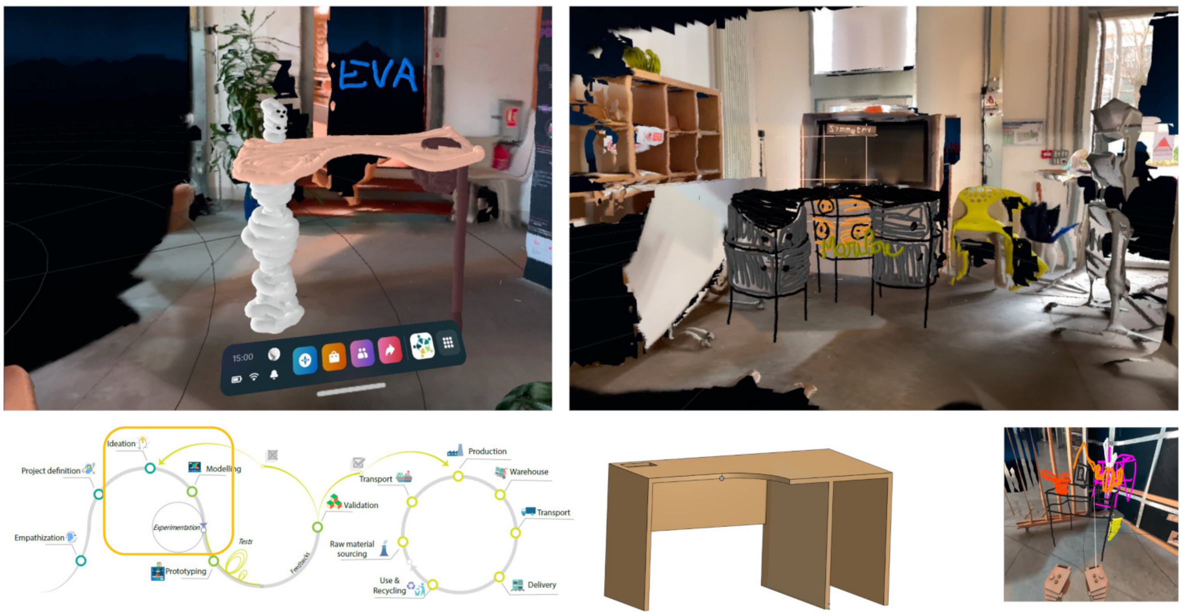


Figure 35: **Co-creation stage on the personalization for the**

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

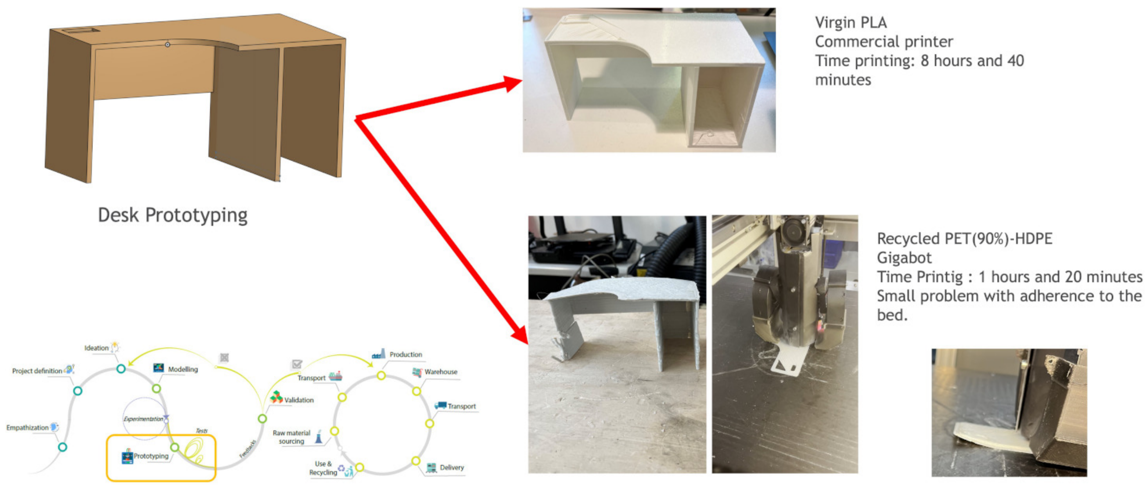


Figure 36: **Prototype of the desk**

The prototype enabled to identify three main customization object, namely 1) PC monitor support, 2) an ajustable folder separation and 3) the drawer handler. as displayed in the Figure 37. The PC monitor support was built entirely using the manual injection molding. The drawer handler was completly 3D printed. On finnaly, the ajustable folder was a combination of injection and 3D printed processes

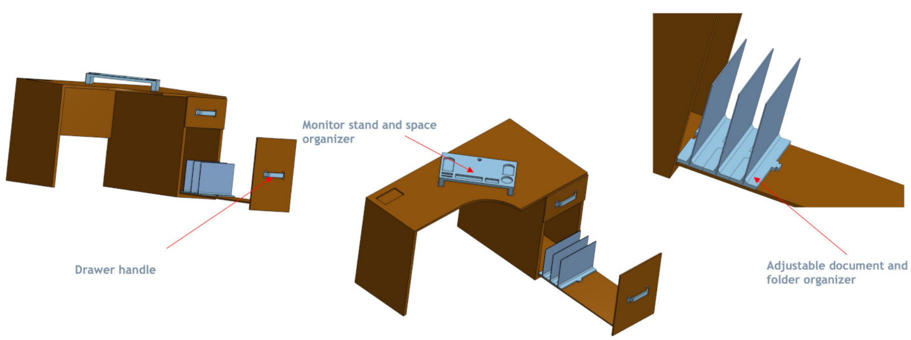


Figure 37: **3D model of the recycled pieces to be made**

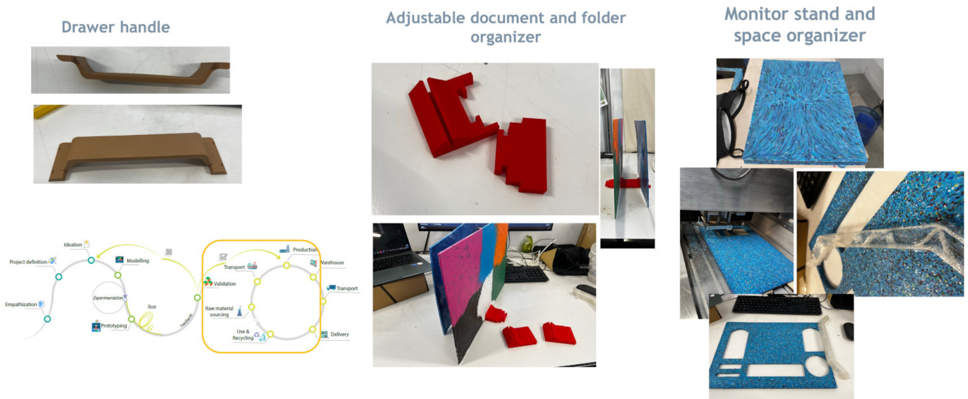


Figure 38: **Manufacturing of the recycled parts (PC support, adjustable folder separation and drawer handler)**

This experimentation was then confronted with the consortium to obtain a feedback about the possible improvements in the echnicall level. But more importantly, to identify the possible 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**

5.10.5 Bookshelf

Working on….

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

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

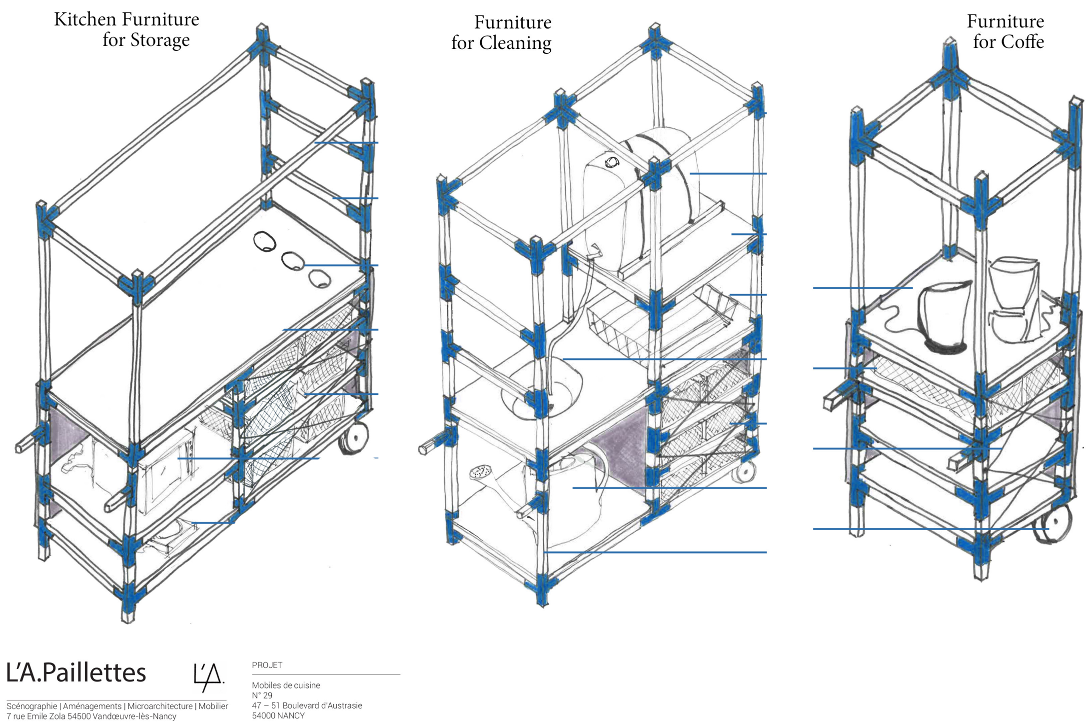


Figure 40: **Sketch models designed by the local actor L’A.Paillette**

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

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

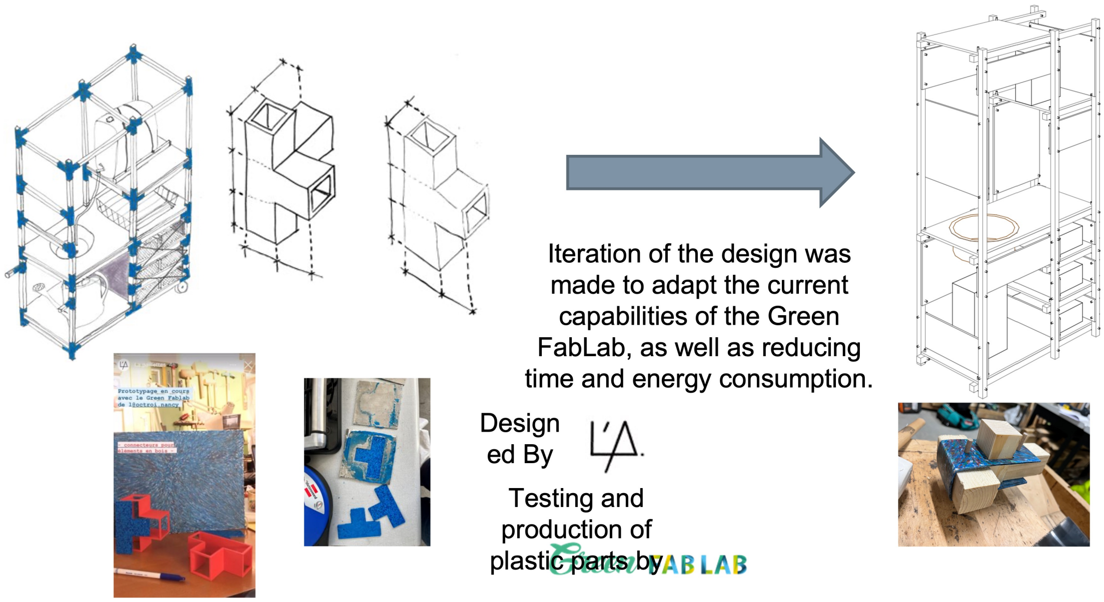


Figure 41: **Iteration and re-design of the proposed recycled parts**

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

Finally, the production consisted on 3 sheet in rAfter several attemps, a version of recycled wheets, pins were decided to fabricate. This final model was fabricated using 400g per sheet, 96 plastic pin joints (20g per pin), having a total recycled plastic used about 3,1 kg aprox. (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

In this report, we described the research and development work developedin the task Task 6.4: The major results of the were:

- The methodlogical proposition of a distributed recycling via additive manufacturing approach.
- The implementation of the Green
- • The mechanical and process characterization of composite materials with a high percentage of wood or cellulose and their validation as appropriate materials for furniture making.
- The manufacturing of 8 demonstrators to validate this technology within INEDIT framework. The work developed in this task opens a new technology for the flexible manufacturing of customized furniture. Such tools can act as enablers in a Social Manufacturing platform like INEDIT, creating new business models and markets in the furniture sector.

More examples neeed it in the recycling for education purposes

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