D6.4 3D Printing of recycled plastic demonstrator

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1 Executive Summary

This report describes the open manufacturing demonstration facility of "*3D printing of recycled plastic demonstrator*' developed in the INEDIT project. The main goal is to validate the logistical and technical feasibility of recycled assets to be used in the Do-It-Together (DIT) approach. Therefore, a complete technical description is presented to transform certain plastic wastes into functional objects using 3D printing and desktop plastic injections through multiple experimentations. The activities were oriented to produce objects for the purpose of 1) manufacturing prototypes for validation prior to production stage, 2) personalization of furniture and 3) spare parts for reparability to enlarge the life of discarded furniture.

These technical and logistical elements were implemented in a recycling pilot platform known locally as the *'Green FabLab'* at the city of Nancy, France. The technical development was based on an open design approach in order to be replicable to other countries. The integration was validated according to Key Performance Indicators.

There are two majors outcomes of the work done within task 6.4 and documented in this report:

1. Describe the methodological concept of the distributed recycling via additive manufacturing (DRAM) system oriented to the revaluation of plastic.
2. Demonstrate in a relevant environment to prove the integration of a distributed and local plastic recycling with the INEDIT process.

The development of open-source technologies that enable the main stages for plastic recycling constitute a first chain validation. Moreover, the implementation and development of Use Case 3 proved to validate the technology maturity level from TRL4 to TRL6 and market readiness level from MRL 1 to 3/4 for technologies used such as the smart collector and fused granular fabrication. In addition, the creation of a local and distributed plastic recycling chain at a territorial level constitutes an important output for the impact of the project given the high level objectives of INEDIT.

1.1 Outline

The report is structured into three main parts. The section Section **??** provides a baseline introduction regarding the plastic recycling issues in European Union. Then, section Section **??** gives an overview of the context where the 3D printing of recycled plastic demonstrator have been developed, characterizing its main methodological and technical features. After, the section Section **??** presents in detail the operationalization of the demonstrator in the DIT approach. This is illustrated the step-by-step technical elements to consider each element and the illustrative experimentations made to validate each of the DIT process. The rapport finish with a conclusion section.

2 Introduction

INEDIT develops a multi-sided platform pursuing the goal of new sustainable manufacturing processes integrated in agile manufacturing networks to simplify personalization of furniture. To do that, a numeric platform is devoted to connecting consumers, designers, makers, and manufacturers in order to push further the access to production means improving the creativity and design in open innovation ecosystems. This trend is enframed in the concept of mass customization, identified as a key major trend by the EU for 2030. In fact, the on-demand production capacity (all around Europe) enabled by the DIT approach seeks to be environmentally responsible.

The Université de Lorraine developed a pilot platform called locally as the 'Green Fablab' with the aim to describe and implement a 3D printing of recycled plastic demonstrator. 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. The technical feasibility of the plastic recycling via additive manufacturing was based on an open design approach that could facilitate the replicability and appropriation in different countries.

Therefore, 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 a relevant environment. More precisely in a cultural and citizen third place at Nancy, France.

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

- 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 democratize 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.

3 Plastic Issues for the European Union

Since 1950', our society has 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 is 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.

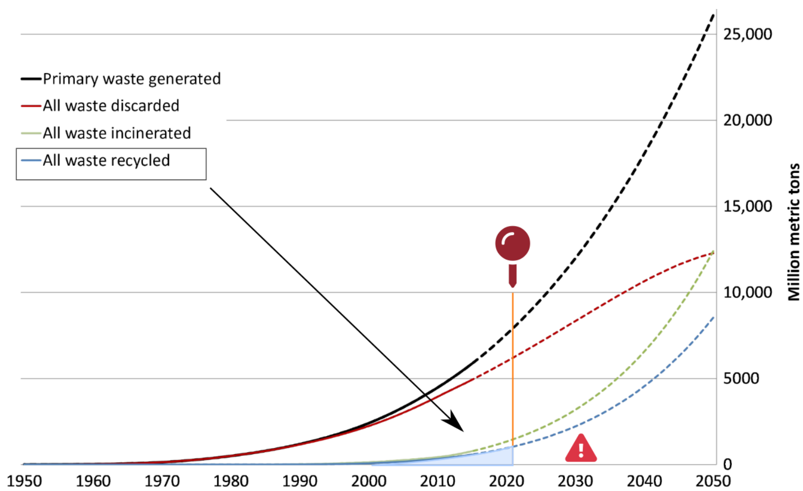


Figure 1: **Cumulative plastic waste generation and disposal (in million metric tonnes). Source: adapted from Geyer et al (2017)**

Globally, only about 9% of all plastics were recycled since 1950's up to 2015 (Geyer et al., 2017) as displayed by the Figure **??**. The share of plastic in municipal solid waste (by mass) increased from less than 1% in 1960 to more than 10% by 2005 in middle- and high-income countries being a packaging field, the largest market (Geyer et al., 2017). Therefore, single–used plastic materials are hardly recycled worldwide and therefore they end up on the waste disposal sites, nature and oceans. Over 300 million tons of plastic materials are annually produced worldwide and from this amount, approximately 6300 Teragrams of plastic waste had been generated considering estimations of 2015 (Geyer et al., 2017; Wang et al., 2020).

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

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 as a demonstration of the INEDIT project called '3D Printing of Recycling Plastic' that was developed and implemented.

4 Context of the 3D Printing of Recycled Plastic Demostrator

4.1 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 **??**. 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.

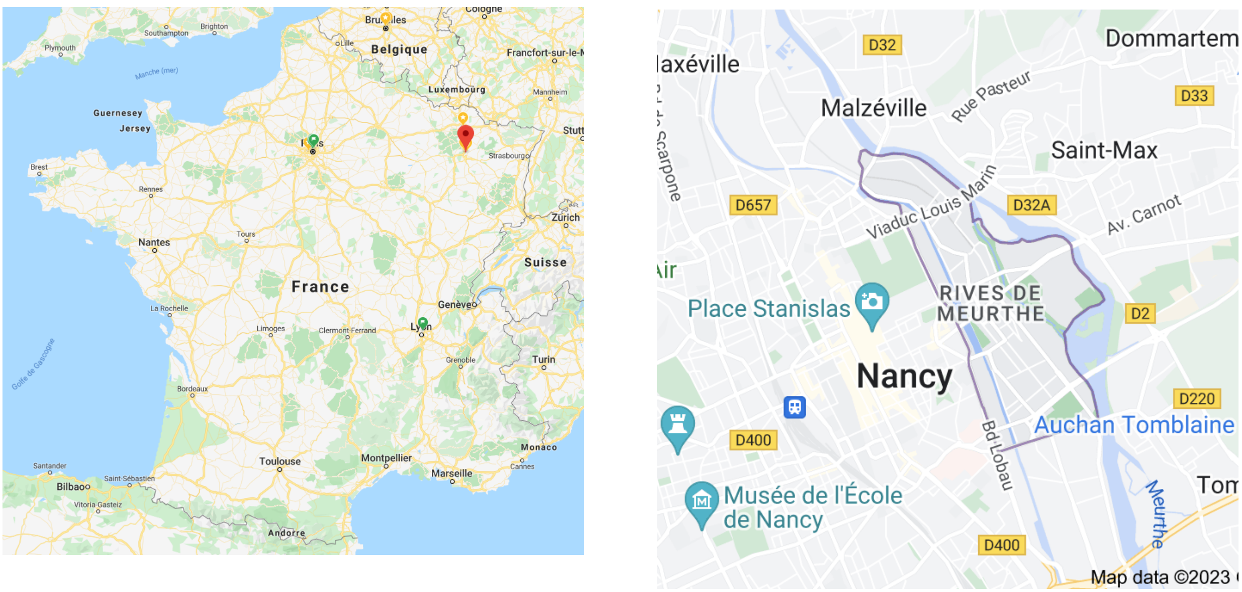


Figure 2: **Localization of the Rives the Meurthe district at Nancy, France.**

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 the 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 peri-central space of the city.

Among the multiple choices, one of the strategic actions taken by the government has 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 consultation to create exemplary actions in terms 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 beginning on 2020, the end of works was only finished in 2021.

4.2 Third place Octroi Nancy

The third place Octroi Nancy is an 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.

Four large buildings (Figure **??**) 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 a 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 building (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 intermittent cultural activities mostly in the summer holidays.

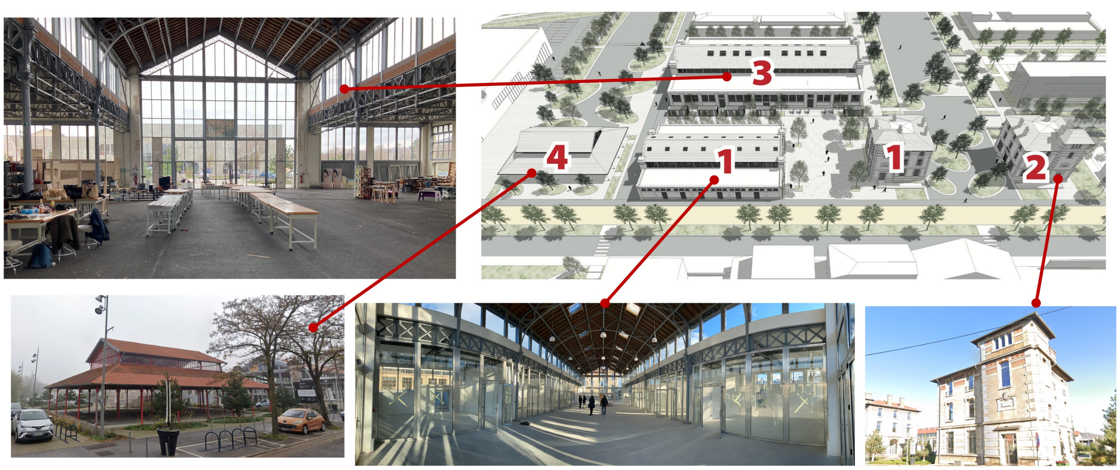


Figure 3: **Overview of the Octroi facilities at the Rives of Meurthe district**

In summary, these types of third places are open ecosystems that will bring together artists, researchers and creative people with the public, the city's inhabitants and businesses. These initiatives can be framed as 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

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

initiatives can give an opportunity for socially inclusive and environmentally responsible new roles of the local actors regarding the city development.

4.3 Lorraine Fab Living Lab®

Connected to the Octroi ecosystem, the **Lorraine Smart Cities Living Lab (LSCLL)** is a trans-disciplinary 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 a 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 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 cooperation in engineering design with different stakeholders in order to create new 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 a 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 **??**:

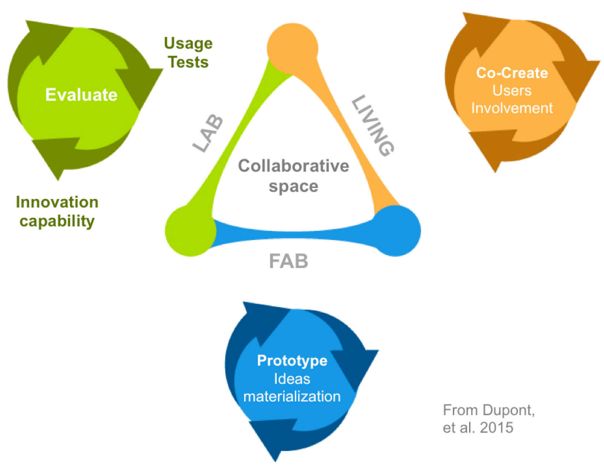


Figure 4: **The Lorraine Fab Living Lab methodology.**

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.

[2] 4^{th} wave of labellisation

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 allow 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.

5 3D Printing of recycled plastic demonstrator: the "Green FabLab"

5.1 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 **??**, 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 as a Open Manufacturing Demonstration Facilities (OMDF). The *Green Fablab* is the recycling pilot platform based on an 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 5: **Initial overview of the Green Fablab at November 2021**

Initially, the initial technical equipment of the Green fablab was first incubated at 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 in 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 possibly establish a secondary raw material market. Likewise, it was required the study of technical parameters for the technological diversity to possibly 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.

5.2 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, the 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 **??** illustrates the conceptual model of DRAM.

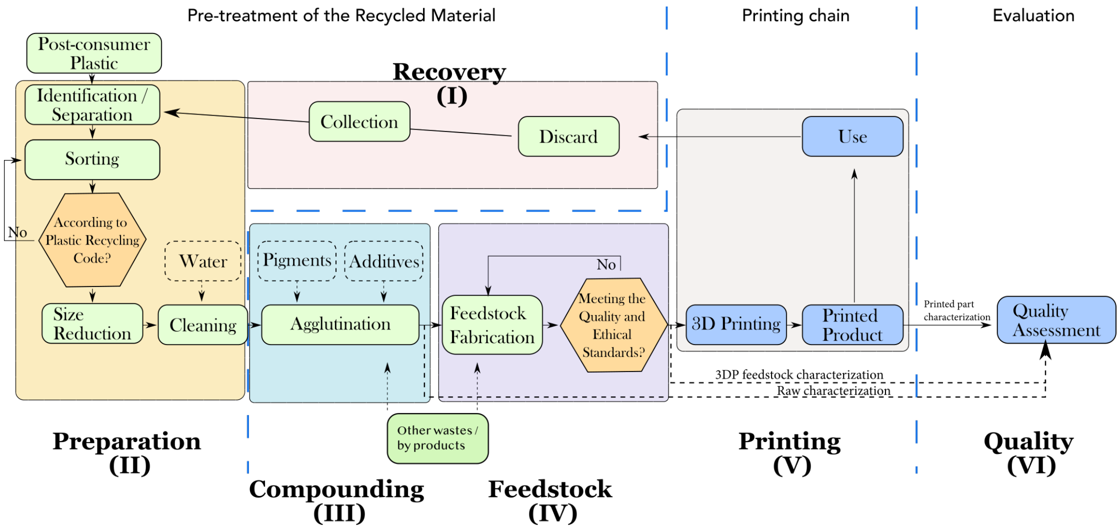


Figure 6: **Distributed recycling via additive manufacturing (DRAM) approach (Cruz Sanchez et al., 2020)**

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.

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). 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.

5.3 Positioning of Use case in the DIT approach.

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 **??**.

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

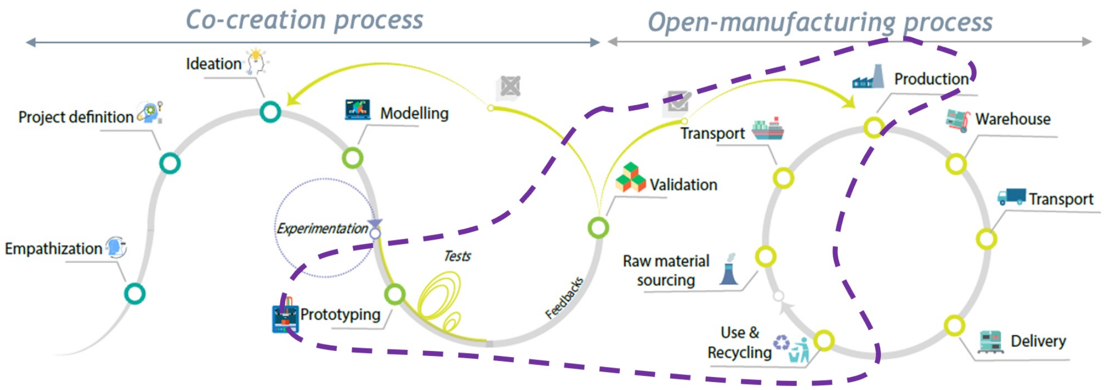


Figure 7: **Connection of the 3D printing Recycled Plastic demonstrator in the Do-It-Together approach of INEDIT**

In 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.

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.

5.4 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 a plastic waste source, PLA waste can be found from printed prototypes or 3D printed parts discarded.
  - HDPE is a thermoplastic widely used in 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 recycling. Therefore, to make technical experimentation, the source waste niches need to be with a non/low contaminated 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 minimal viable option to possibly control the input of material on the Green fablab facilities.

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

5.5 Technical characterization of the 3D printing of recycled demonstrator

5.5.1 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 operation 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 distributed manufacturing.

The collection task 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 difficulty relies on 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 **??**. 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 repositories with the purpose that open communities to take advantage of the experiences developed at the Université de Lorraine. Eventually, the open communities can propose improvements and better versions.

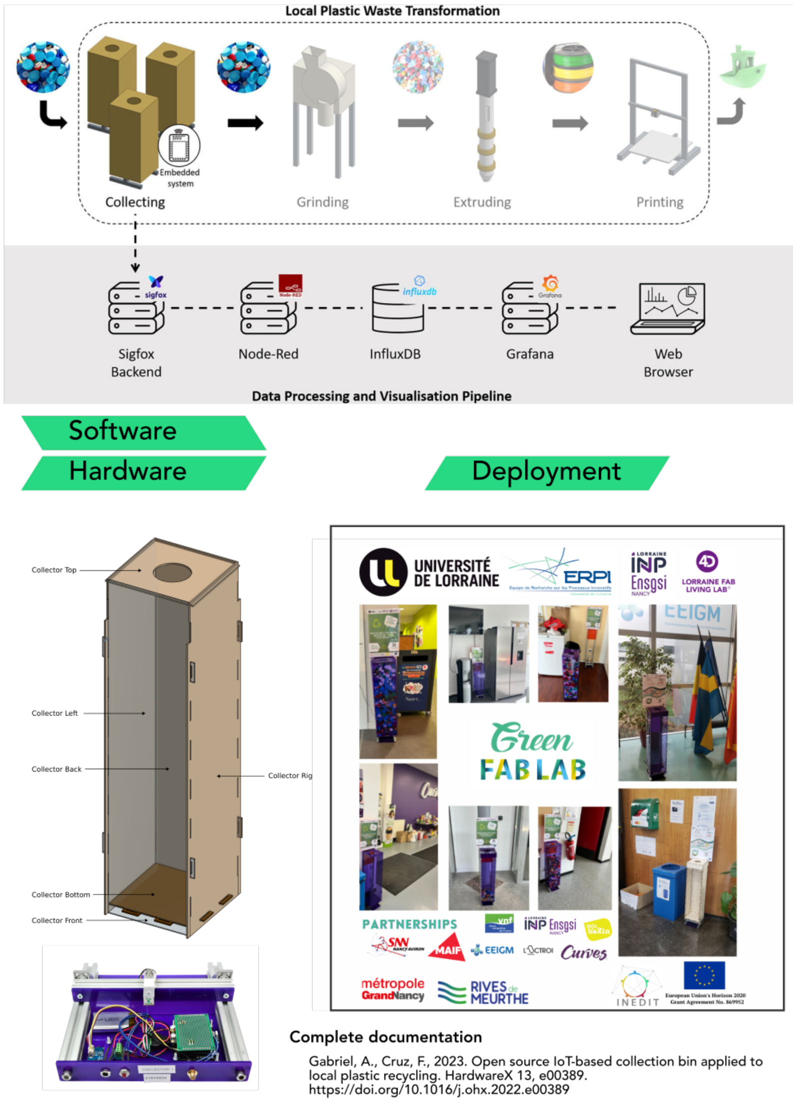


Figure 8: **Description of the developed Smart collector**

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 uses 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 **??** 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 guarantee a constant supply chain of raw material that can be used inside the recycling facilities

5.5.2 Preparation II

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

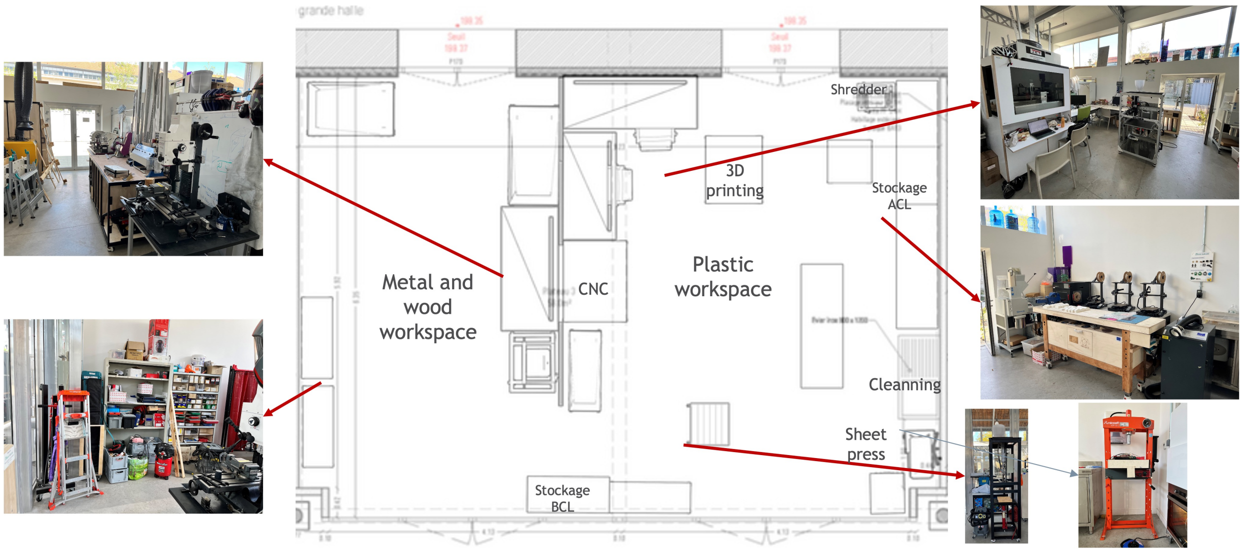


Figure 9: **Adequation spaces for the preparation of the waste material**

The plastic waste preparation process aims to adequate the collected plastic to the requirements of 3D printing and manual injection molding. 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 us to separate the plastics that can be used as raw material for further production processes.
- **Cleaning**: This process 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 obtain an adequate granulometry. This process allows 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 prevents hydrolytic decomposition of the molecular chains during the melting or plasticization, so that the treated material has to be as dry as possible.

5.5.3 Compounding III

The *Compounding* III phase is related to the operation, strategies in the development of composite materials using recycled feedstock intended for the 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. However, it has to be highlighted that one major assumption of the scientific studies relies in that the material used is already sorted, cleaned and using the same type of discarded product.

In INEDIT, 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.

5.5.4 Feedstock IV

The *Feedstock* IV phase refers to the processes in order to transform the plastic waste into usable material for the fabrication stage. Two outputs are seen here: 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.

The filament production is made using a semi-open source commercial desktop extruder. Figure **??** 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.

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%

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

Safety Rules:

Wear gloves when emptying and winding the filament.

Production capacity:
Practical information:

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

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**

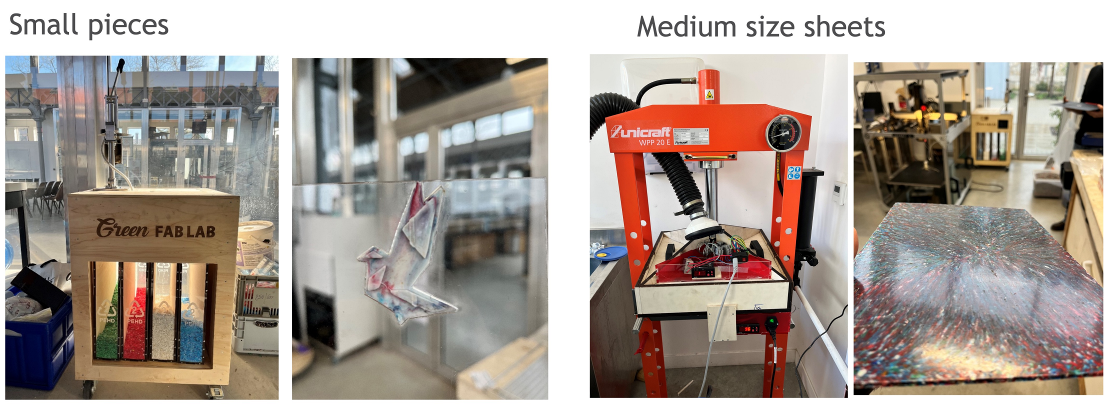
Filament is produced at 0.4 kg/h using 0.24 kWh/kg with a diameter ±4.6%.

5.5.5 Printing process V (and desktop injection molding)

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.

5.5.5.1 Desktop injection molding Injection molding is one of the most used techniques to form plastic materials.
Figure **??** presents the major technologies in the 'Green Fablab' case to propose a manual recycled aspect to reuse the plastic waste into small and medium plastics sheets.

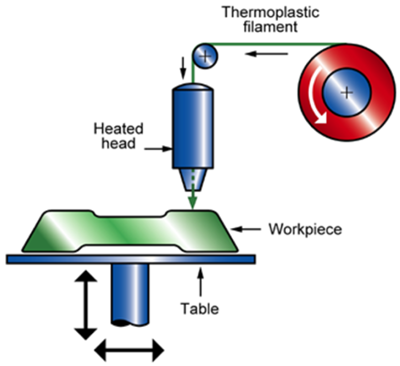


Plastic injection parts can be very useful to make small ornaments or to generate visual information. (HDPE, PP)

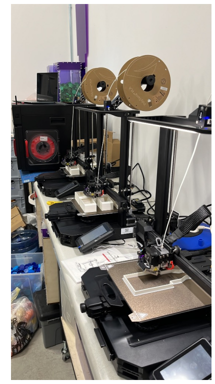
Figure 11: **Manual injection in small and medium sizes**

5.5.5.2 3D printing process: Fused Filament & Granular Fabrication (FFF & FGF) In the era of 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).

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



(a) **Fused filament fabrication -FFF- principle**



(b) **3D printinter machines**

Figure 12: **Fused filament fabrication machines**

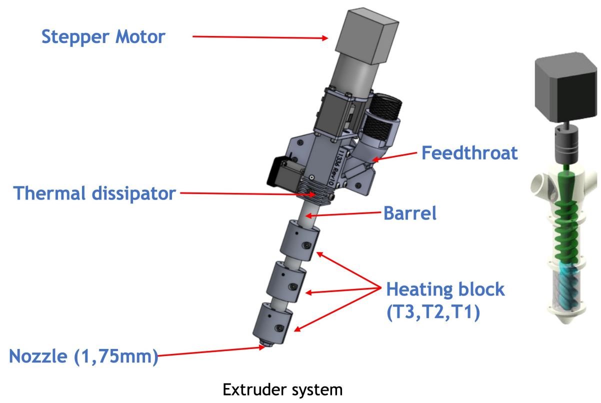
The principle of the filament fabrication was developed and patented in 1989 by Scott Crump as *Fused Deposition Modeling*, and since 2009, the technology became open source, known as Fused Filament Fabrication, to establish the difference between the registered mark. A schematic representation of this technology is presented in Figure **??**. 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).

On the other hand, Fused granular fabrication –FGF- is a polymeric additive manufacturing process which make use of pellets rather than traditional filaments as feedstock material The FGF is a new key additive manufacturing process and it is a key technical advancement to facilitate the use of recycled material in the printing process. Figure **??** presents the Gigabot X XL machine used in the experimentation.

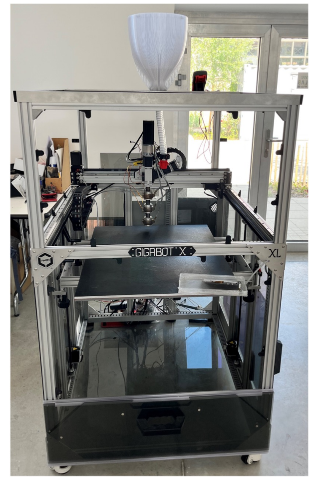
Heating blocks provide sufficient heat energy to change the pellets from solid stated to liquid state and the compression screw helps in providing enough pressure to push the liquefied thermoplastic. This machine has a long barrel with 3 heating elements or zones which helps in the melting of the thermoplastic. 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 a nozzle of 1.75mm diameter that influences the deposition rate.

The design of compression screw is also important for efficient melting of the material and to create back pressure to remove the trapped air inside the barrel. Convectional extruder screw has 3 section – feeding section, melting section, and metering section.

The quality of the extruded material or print quality depends on process parameters of the machine. The print quality is distinguished into two parts visual inspection and quantitative measurements. Visual inspection is the direct inspection of the 3D printed part however quantitative inspection is the measurements of the dimension of the 3D printed part. The resolution of 3D printer is causally related to the size of the nozzle. Small sized nozzles produce small details accurately as the smallest



(a) **Fused Granular fabrication -FFF- principle**



(b) **Gigaboot X XL printer**

Figure 13: **Fused Granular Fabrication fabrication**

feature size is reduced to the diameter of the nozzle. The smallest nozzle size diameter ranges from 0.15 – 0.7 mm. While small nozzle size provides good print resolution big nozzle diameters increase mass flowrate which reduce the production time. Large nozzle diameter ranges (from 5 – 7.62 mm) provides a decent print resolution and good mass flowrate. A detailed description is presented in the annex A to present the technology.

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

6 Operationalization of DIT process for the Use Case

6.1 Integration of the 3D Printing Recycled Plastic

The following table presents an explanation of the implementation steps for the use case. In the next subsections each step will be detailed.

Steps ID	Steps Description
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.
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.
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.
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.
STEP 5 - TRANSPORT WASTE MATERIAL TO THE RECYCLING FACILITIES	All the recycled plastic waste is collected and transported to the recycling facilities
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).
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.
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.
STEP 9 – Implementation Examples	The DIT innovation space enables the designer to test the just realized prototype, to ensure proper functioning in real conditions. 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).
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).

6.2 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 downloading the respective documents that contain the 3D model to be manufactured by the use case as presented in the Figure ??.

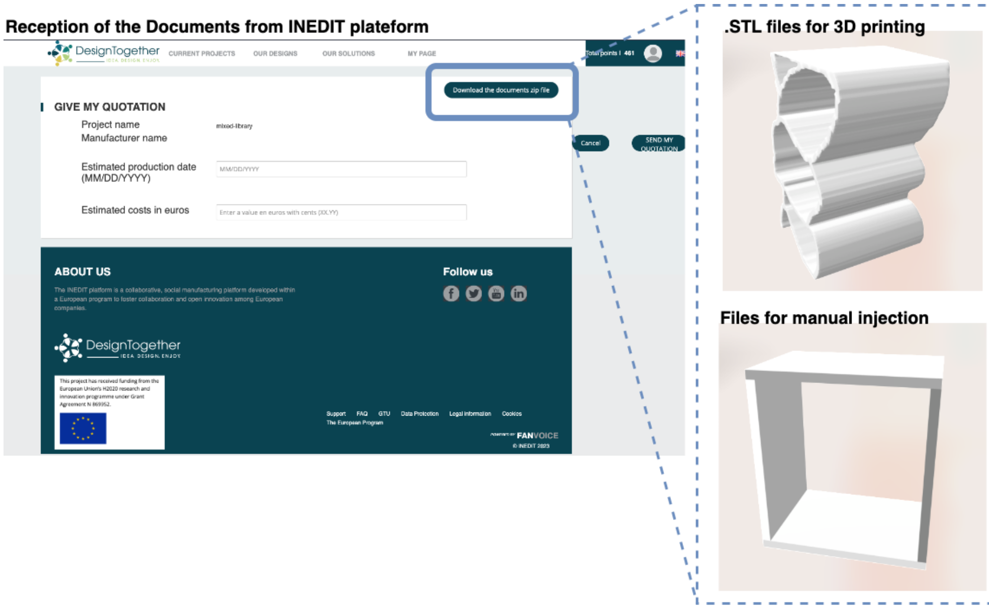


Figure 14: **Reception of the exploitable documents for the fabrication process**

One of the outputs of the co-creation phase of INEDIT platform 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 demonstration 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.

6.3 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 concerning:

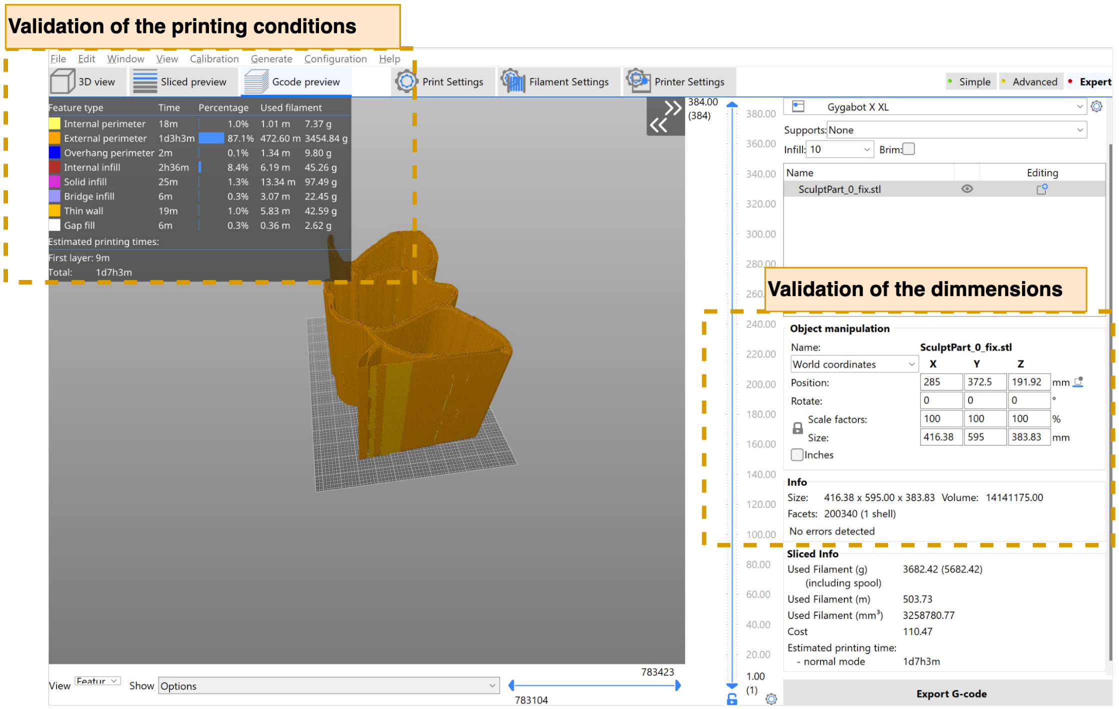
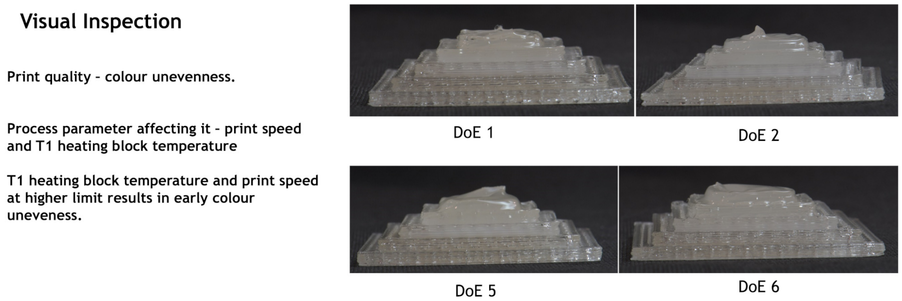


Figure 15: **Validation of the printing conditions**

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 tests 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 ??.



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

Figure 16: **Experimental protocol to validate the printability tests**

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

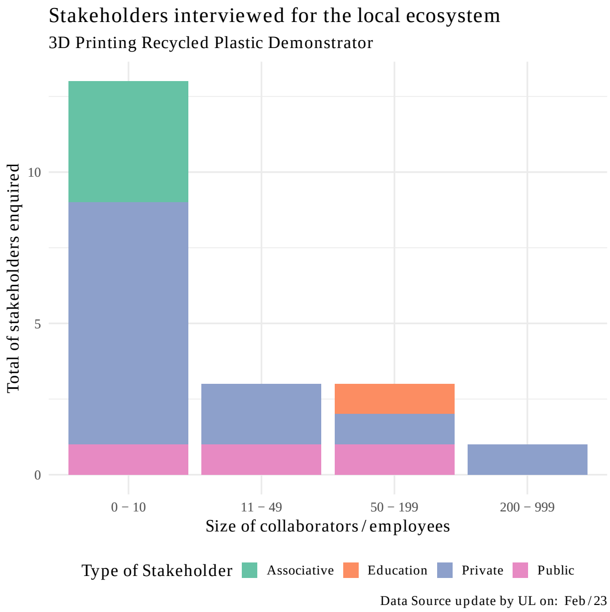
A technical paper to describe in more detail the results of this printability approach is being prepared at the time of writing this final rapport.

6.4 Step 3 – Identify local source of plastic waste

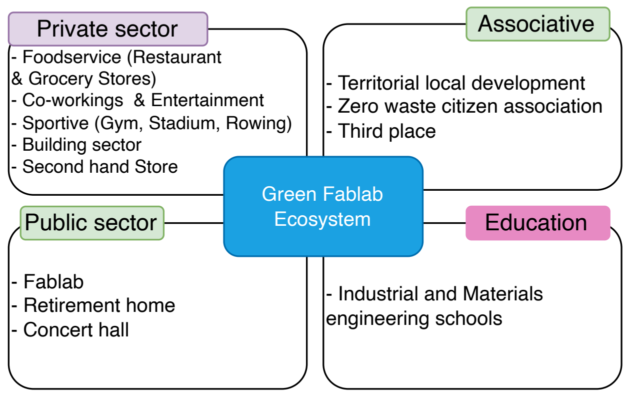
This step seeks to establish a first network of plastic wastes source from the local ecosystem. The task of the identification of local sources of plastic wastes is fundamental as the first stage in the recovery process. Therefore, an exchange with local key actors was necessary in order to achieve this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

The first step was to identify relevant stakeholders in the local ecosystems to inquire on the issue of plastic wastes sources. Firstly, they needed to belong to 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. Secondly, it was necessary to consider the diversification of the profile of actors that can be sensitized to the participation of the collection (general public, employees, students) and/or the status of the actors (Public, Private, Associative) where our 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 awareness of plastic management by the general public.

A total of 23 actors were interviewed, of which 21 by physical or telephone interview and 2 by electronic questionnaire. They were mainly companies (47% small and 26% medium size), associative entities, and the academic sector as displayed in the Figure **??**. 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



(a) **Total of stakeholders**



(b) **Type of stakeholders addressed**

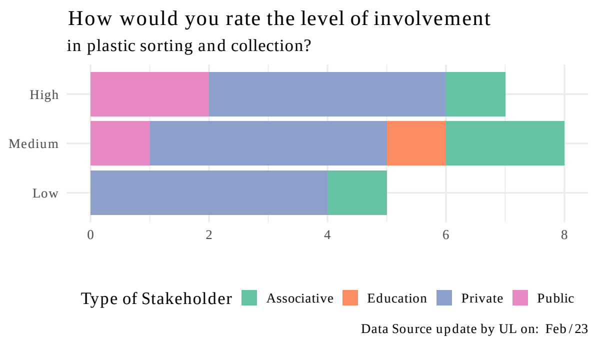
Figure 17: **Local ecosystem interviewed about the implementation of 3D printing recycled demonstrator**

the territory were paped in the Figure **??**

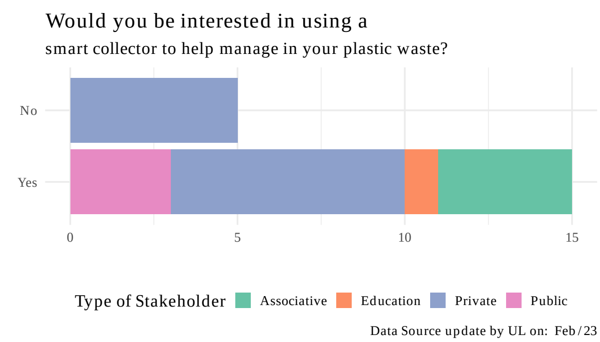
The scope of activity of most of the respondents is local (at the level of the neighborhood or city) which may reflect a strong territorial anchoring and a commitment to local concerns and issues (waste management, social welfare, local job creation). The majority of their business decisions are made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

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



(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**

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 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 refused 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 make 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 identified the sources of 3D printing and potential synergies with the Green Fablab.

6.5 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 **??** 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).

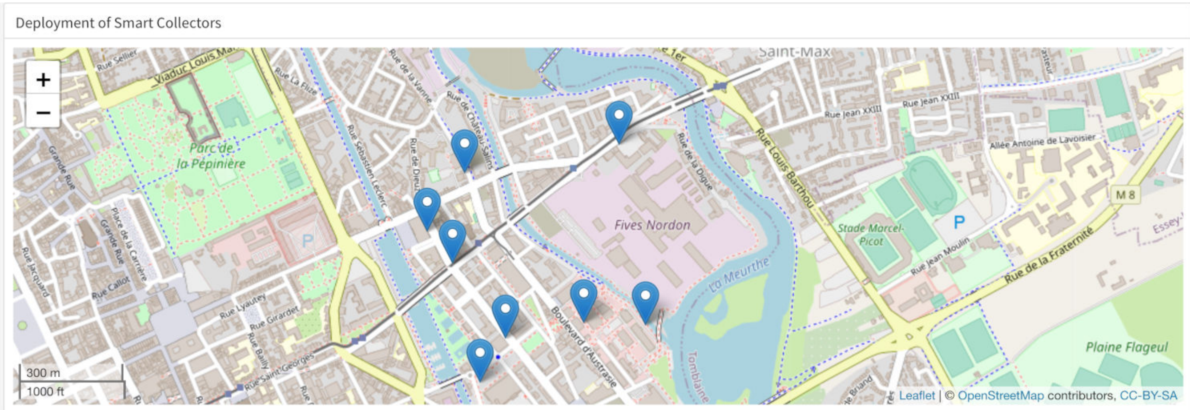


Figure 19: **Deployment of the Smart Collectors.**

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 **??**.

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 **??**)

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.

(a) Smart collector at the collection point

(b) Communication strategy of the device

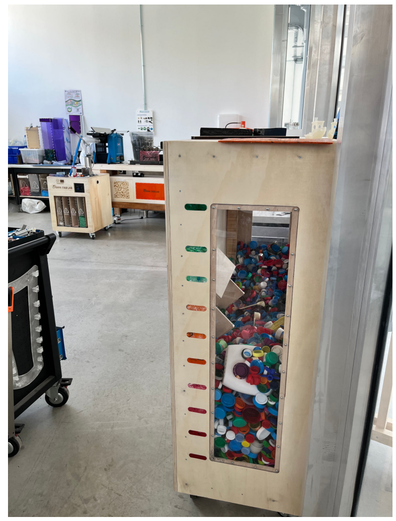
Figure 20: Deployment example of the smart collector at the collection point

Figure 21: Smart collectors deployed in the territory

6.6 Step 5: Transport waste material to the recycling facilities

The recovery process took place once a week on average. When the waste plastic is collected, it is stored at the facilities of the Green FabaLab before posterior treatment and adequation.
We have build a central collector as illustrated by the figure Figure **??** where the material is stored before it is treated.

(a) **Central storage of plastic waste**



(b) **Communication flyer for the smart collector**

Figure 22: **Central storage of the collected plastic waste.**

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

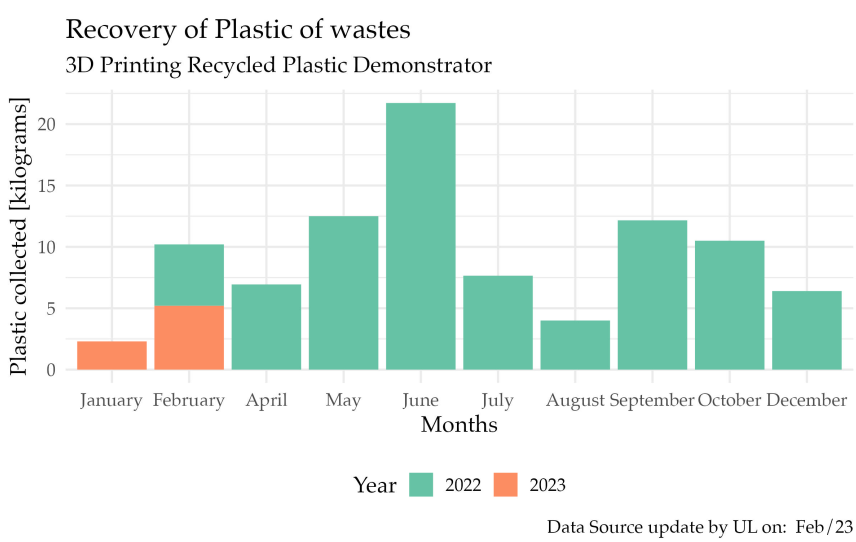


Figure 23: **Recovery profile of plastic**

Key Performance Indicator of the Recovery process

In terms of *KPI* of the recovery, from February 2022 to February 2023, we have collected a total of 94.37 *kg* of plastic waste using 8 collectors in the territory of Rives de Meurthe, Nancy-France.

6.7 Step 6: Adequation and preparation of the material

This is the first stage carried out inside the Green Fablab. This stage corresponds to the set of activities required for the plastic waste to be adapted for further use. The Green Fablab works mainly with 4 types of plastic at the moment. The most common are high density polyethylene (HDPE) and polypropylene (PP), which are the main plastics used in the production of bottle caps and they are collected in the smart collector. The plastic waste from unused/damaged 3D printing parts mainly of polylactic acid (PLA) are collected mainly from the Lorraine Fab Living Lab. And finally, the plastic bottles also are collected which are polyethylene terephthalate (PET).

The preparation process begins with the separation and identification of each plastic collected. As already mentioned, the plastics used in the Green FabLab are 4 (HDPE, PP, PET and PLA) and are separated by type of plastic and color. This process is carried out manually.

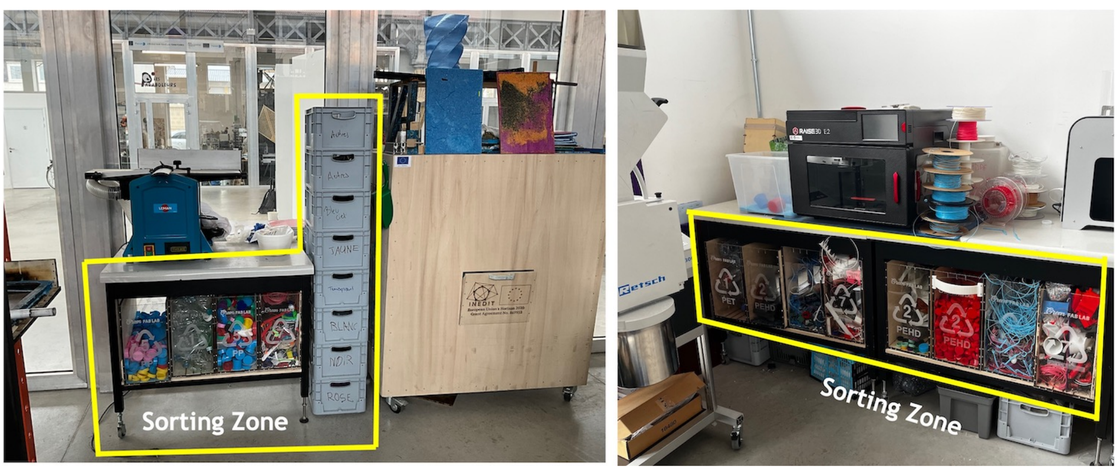


Figure 24: **Sorting process of the plastic cups in function of the type of plastic accordig to the standard identification**

The second step is the cleaning phase. Cleaning and washing plastic cups and bottles is a crucial step for effective recycling. Plastics are mainly post-consumer waste, thus they are not in an adequate state of cleanliness to be introduced in the technical machines. It is required to ensure the plastic is as clean as possible because dirty material can affect the quality of the extrusion / printing process, which at the end affects the recycled product. Therefore, we aim to remove adhesives, leftover waste, and labels. HDPE and PP are mainly used in the plastic injection molding process, while PLA and PET (Mixed with 9% HDPE) are used in 3D printing.

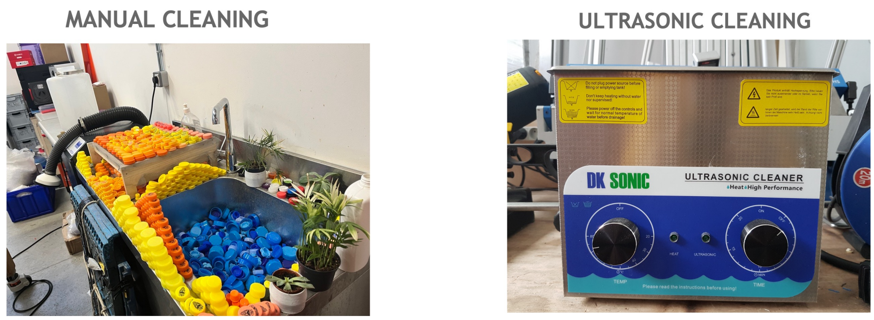


Figure 25: **Manual and ultrasonic cleaning processes**

In the first moment, the manual cleaning is used to remove most of the major contaminants present in the material. For plastic injection molding, where mainly PP and HDPE are used, the plastic is washed in a sink with hot water.
The water consumption per gram is approximately 4 liters per kilogram. The drying of the plastic is done by natural convection in the open air.

For additive manufacturing, where mainly PLA, HDPE and PET blends are used, the cleaning 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 washes 200 gr of plastic with 1 L of water.. This process takes 20 mins with a consumption of 2kWh.

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 a shredding machine where it is grounded into smaller pieces of plastic. A critical parameter in the control of the granulometry. The purpose of the size reduction is to obtain plastic waste where the granulometry corresponds to the extrusion / printing. The plastic waste needs to be 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 identify the optimum size.

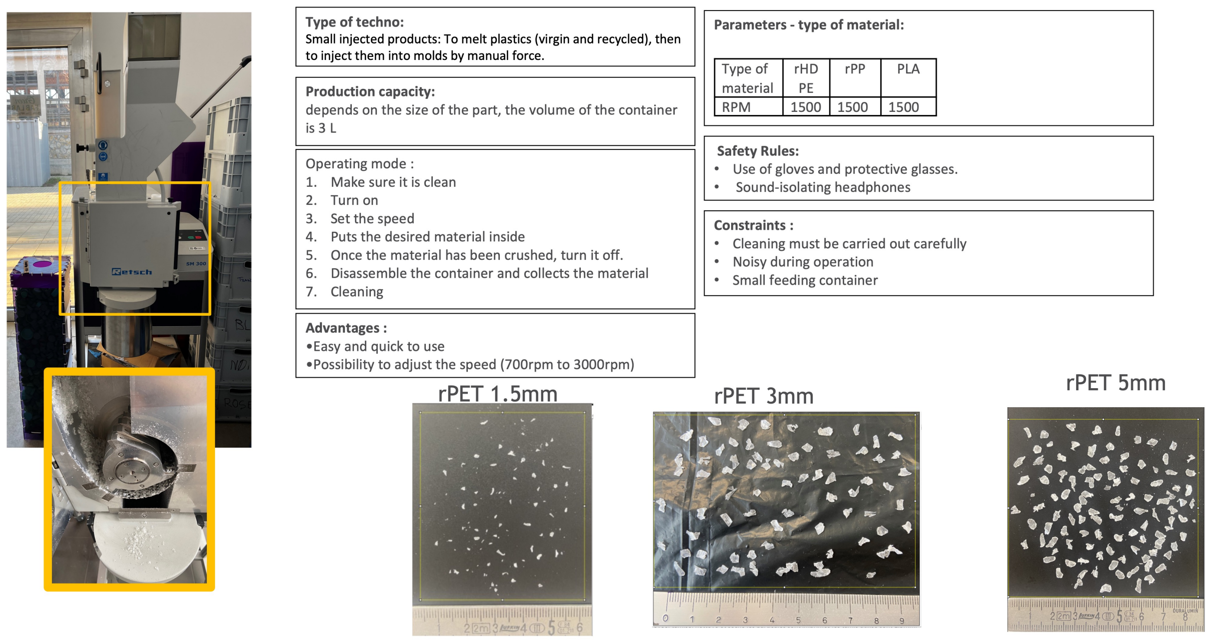


Figure 26: **Photo of the Shredding process**

> **ℹ Key Performance Indicator of the FGF**
>
> For fused granular fabrication technology, the optimum size for the granulometry for printing is between 3 and 5mm. In terms of plastic injection molding, the plastic flakes can be slightly larger than those required for 3D printing.

Finally, the drying process is the last step to prepare the material. To remove all the moisture from the plastic it is necessary to carry out a drying process in a conventional oven. In the drying phase, the plastic is put in the oven at 60°C during 15h with a consumption of 0,061 Kwh.

6.8 Step 7: Path planning - 3D Printing

In this step, the main purpose is to use the open source SuperSlicer software, to establish the printing parameters considered for the pieces. An experimental work needs to be made in order to adapt the adequate configuration of the slicer with hardware of the Gigabot X and FFF machines. Figure **??** gives an overview of the characteristics and basic parameters configurations considered in the process.

6.9 Step 8 : Post-processing

Post-processing relies on the treatment of the injected and/or printed part. Regarding the injection part, the post-processing refers to the surface treatment of the injected part

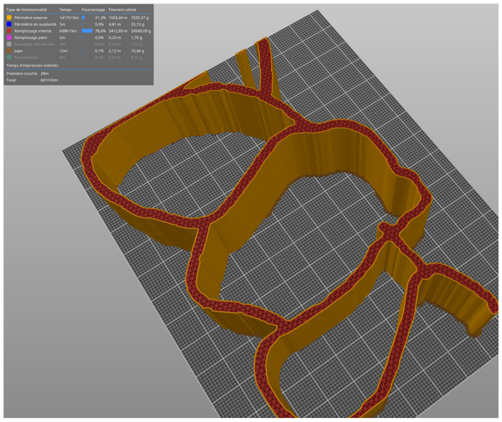


Figure 27: **Programmation of the printing process using the OS SuperSlicer software**

Main parameters	Value
Material	PET recycled
Bed temperature	84 °C
Extrusion factor	1.32
Nozzle temperature	264 °C
Number of perimeters	2
Top solid layers	2
Bottom solid layers	2
Fill density	30%
Travel speed	20 mm/S
Nozzle Diameter	1.75 mm
Support	No

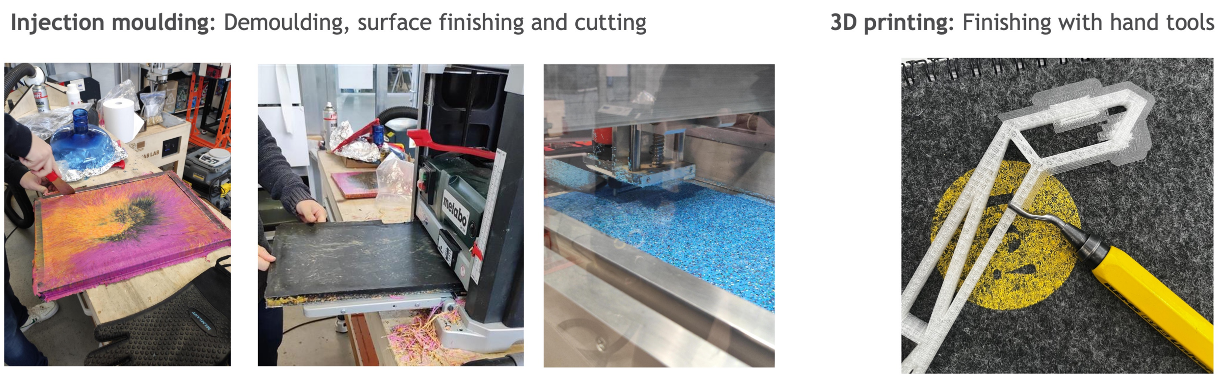


Figure 28: **Post-processing activities for the injection molding and 3D printing processes**

On the other hand, post-processing on the printing part is related to the removal of excess backing material and the support material used. These two activities are made manually.

6.10 Step 9: Implementation Examples

The different examples of implementation of the use case are presented in the following sections. Each example aims to tackle step by step the complexity of the implementation of the DIT process at a TRL6 level. We specified in each example the step of the DIT process that aims to test.

6.10.1 Personalization of existing furniture

This first experimentation aimed to prove the design of a customized product. Based on the 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 ??, several printed parts were manufactured to evaluate the technical pertinence of the results as part of existing furniture.

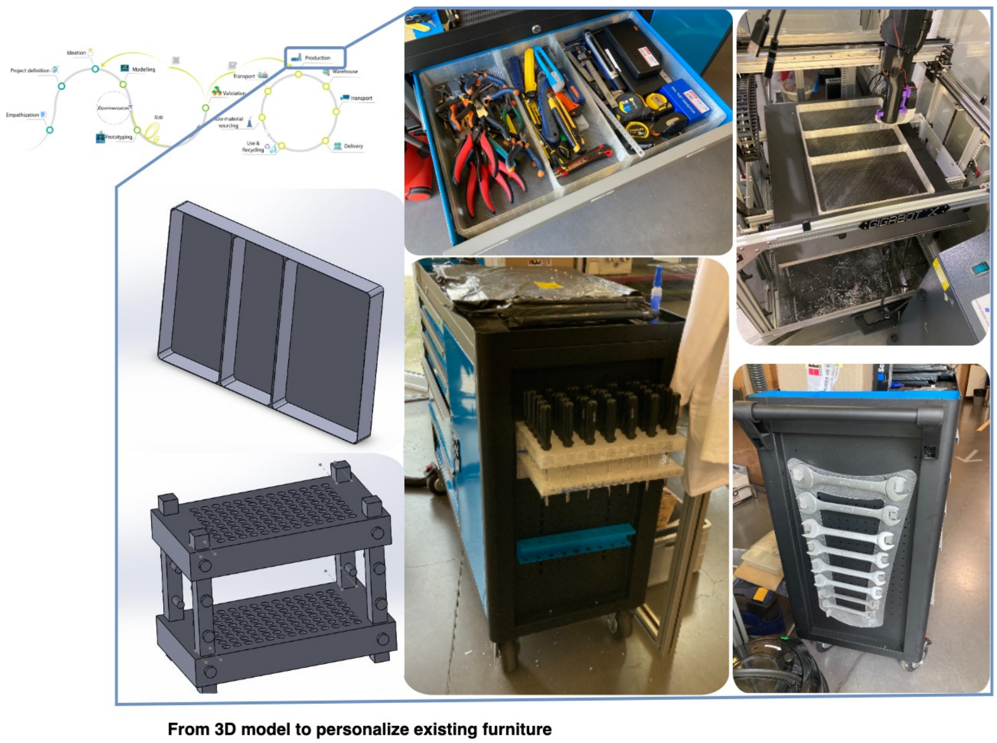


Figure 29: **Personalizing a existing furniture**

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

6.10.2 Refurbishing of the an old furniture

In this case, the experimentation was a step further. The main idea was to refurbish 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 INEDIT. Based on those inputs, the manufacturing tools at the Green fablab including the 3D printing were mobilized.

Figure 30: **Refurbishing an old wood workbench using the INEDIT technologies**

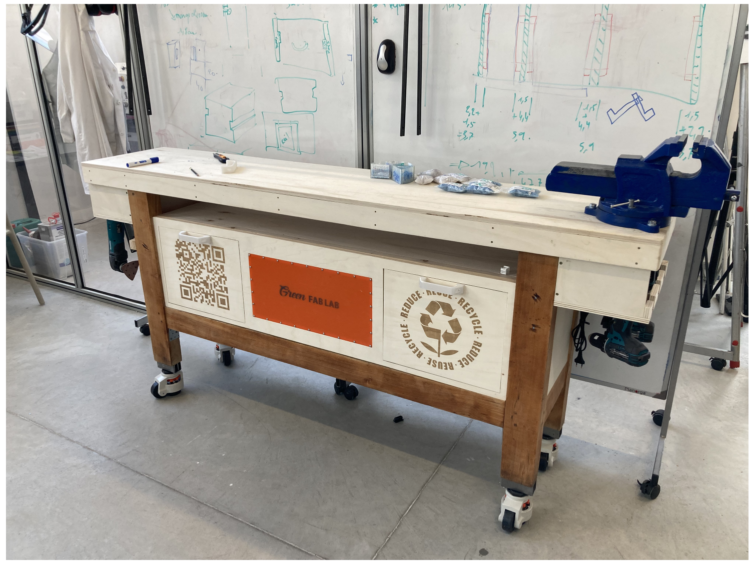
Figure **??** presents the processes entailed in the experimentation. First, once the workbench was dismantled, it was scanned using an Ipad Pro considering the technical characteristics needed for the application. Then, the model was uploaded in the DesignTogether application in order to brainstorm 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 proposition that could be made. So, the different manual task started in function

6.10.3 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 build a piece of furniture to test the integration of the plastic and smartification technologies. In this case, Figure **??** illustrates the manufacturing of a recycled plastic bar specifically made to be part of the entire furniture.

(a) **Initial recovered workbench**



(b) **Refurbished workbench**

Figure 31: **Experimentation on refurbishing a wood workbench model**

Figure 32: **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 **??**. 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 33: **Smartification of a kitchen**

6.10.4 Collaborative Desk and Bookshelf

At the INEDIT consortium, it was decided to build a collaborative desk and a bookshelf. 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 **??** 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 of Industrial Systems Engineering (ENSGSI) was organized to create several ideas on the same object.

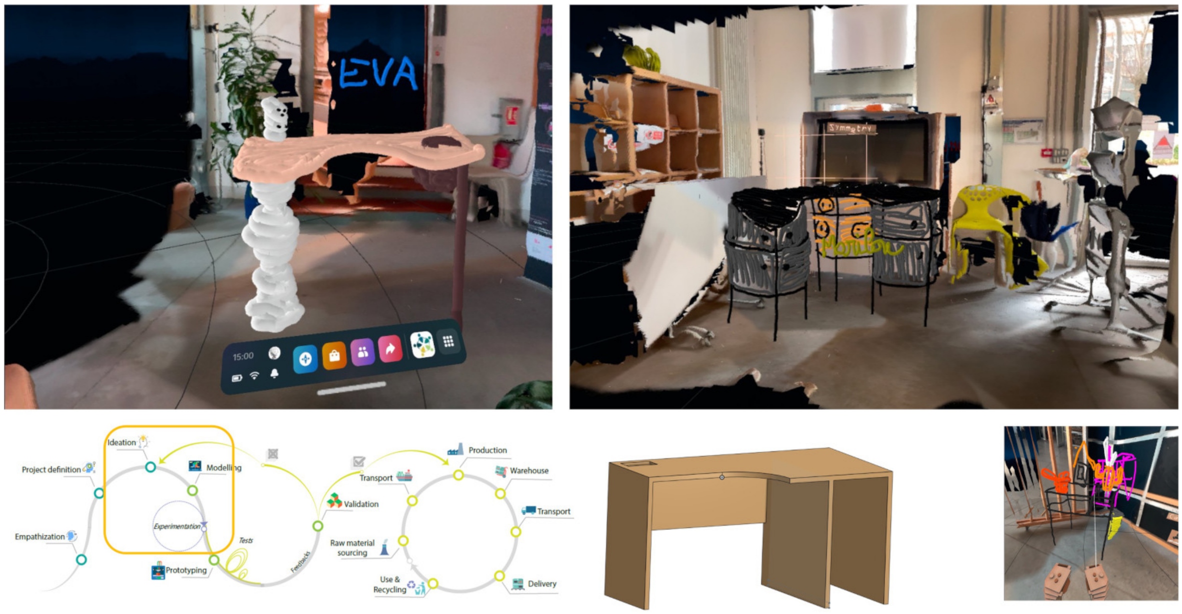


Figure 34: **Co-creation stage on the personalization for the**

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 **??**. This made it possible to define the components that were manufactured at real scale.

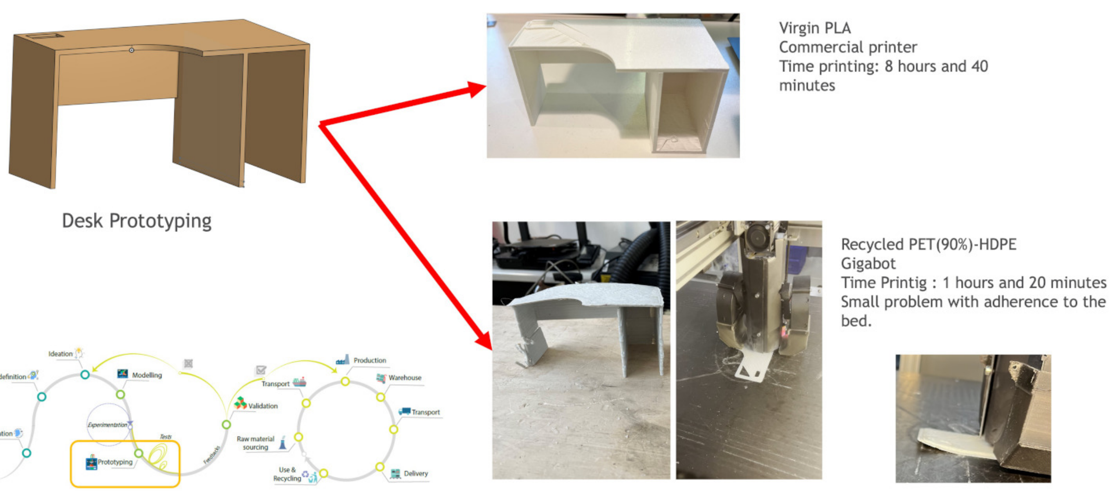


Figure 35: **Prototype of the desk**

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

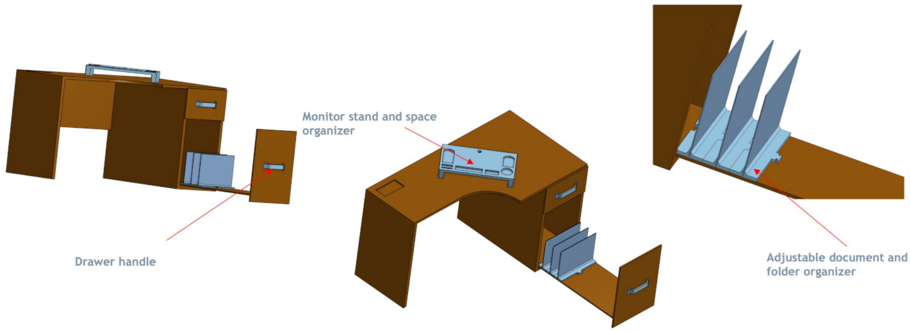


Figure 36: **3D model of the recycled pieces to be made**

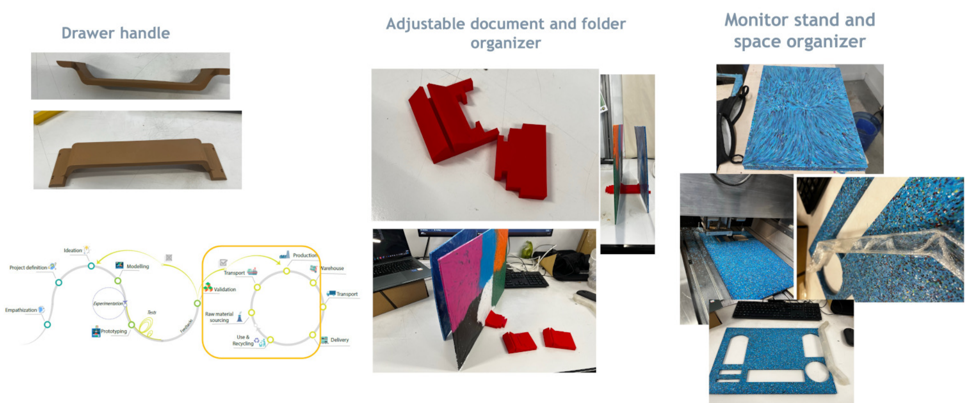


Figure 37: **Manufacturing of the recycled parts (PC support, adjustable folder separation and drawer handler)**

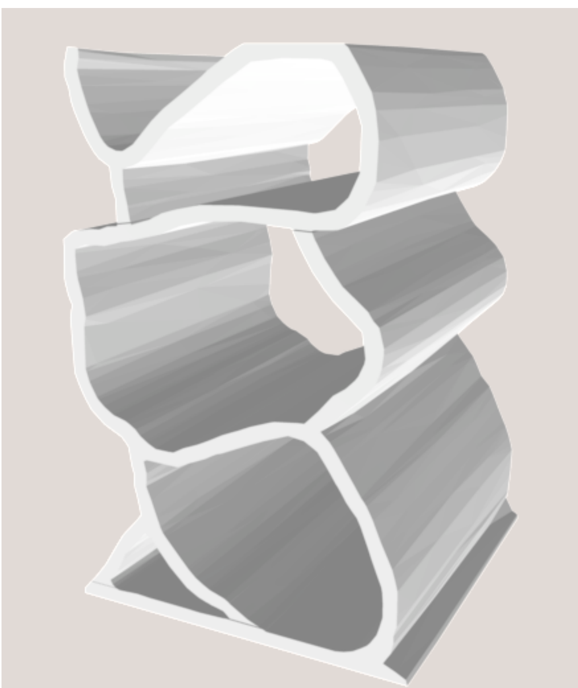
This experimentation was then confronted with the consortium to obtain feedback about the possible improvements in the technical level as presented in the Figure **??**. But more importantly, to identify the possible continuum and interaction between the different technologies and models.

Regarding the bookshelf, we could printed a prototype version of the STL model that was generated in the co-creation phase of the platform as displayed in the Figure **??** and Figure **??**.

(a) **Final assembling of the desk**

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

Figure 38: **Feedbacks on the improvement of the recycled printed and injected parts**



(a) **Bookshelf 3D model**

(b) **Printed Bookshelf as a prototype**

Figure 39: **Bookshelf demonstration with the STL model and the 3D printed prototype.**

6.11 Local collaboration with the Green fablab: the case of the "Le Spationef & L'appaillet"

One important element of the INEDIT project is the interaction with external designers and the local ecosystem. The implementation of the Green Fablab inside the Octroi ecosystem makes 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.

For instance, Figure **??** displays a collaboration with a local micro-architecture collective of called Le Spationef, where the main objet was to make a prototype of a concept of furniture.

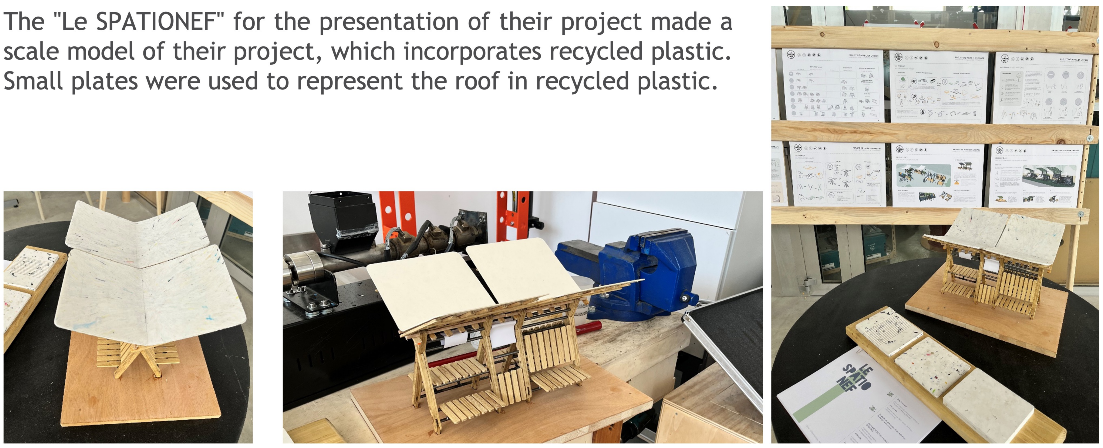


Figure 40: **Sketch models designed by the local actor Le Spationef**

The prototype of the roof was made using the desktop plastic machine tested in the Green Fablab. THe interaction with this local architect enable us to see the pertinence of have the plastic recycling capabilities for sheet plastic part. They pointed out that this type of prototyping aspects can be useful in particular furniture where the wood furniture is adequate.

Based on these insgths, in another example, we made an experimentation project with the local association of designers called **L'A.Paillette**[4]. The purpose was to not only create a prototype part but a fonctional part that can be used by the Octroi community. Thus, the project was to design and build 3 mobile modules and movable for a kitchen. These modules will allow heating equipment, preparation equipment and cleaning equipment to be placed and moved.

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

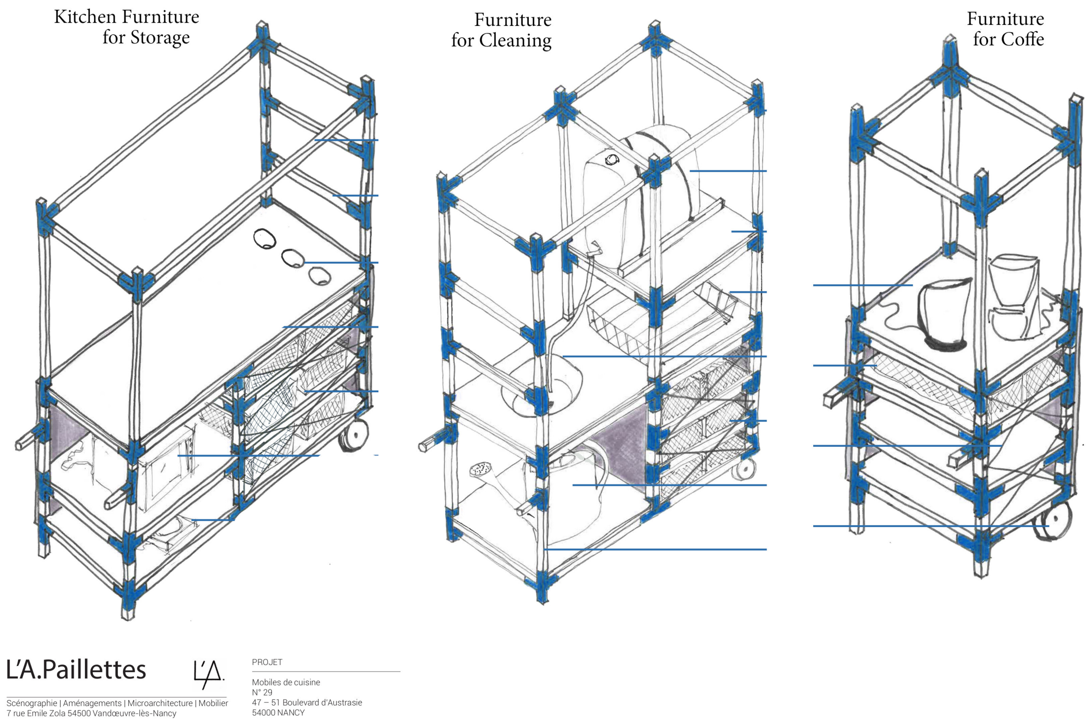


Figure 41: **Sketch models designed by the local actor L'A.Paillette**

The first proposition of the models are presented in the Figure **??**.

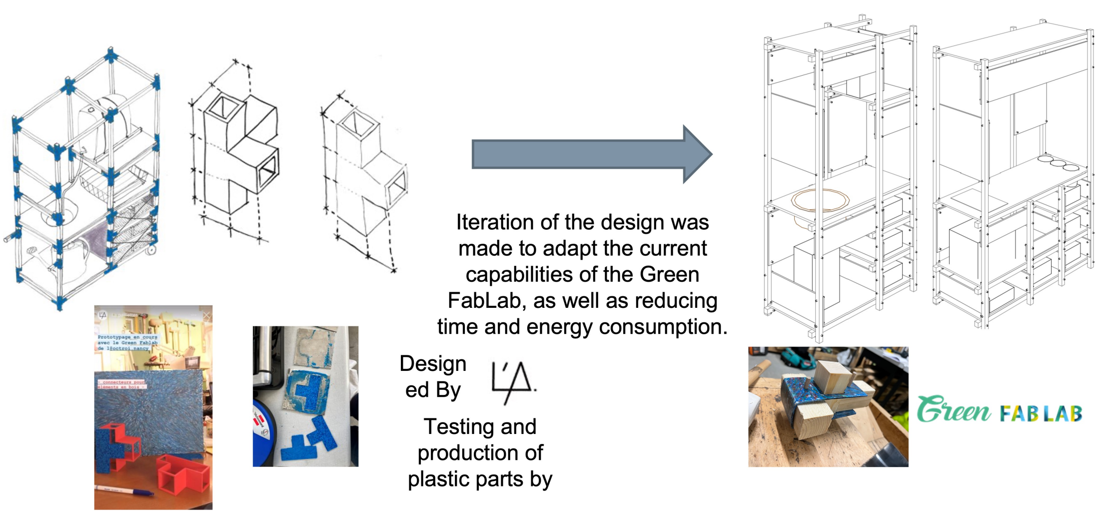


Figure 42: **Iteration and re-design of the proposed recycled parts**

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

(a) **Final overview of the kitchen**

(b) **Recycled plastic parts implemented**

Figure 43: **Final furniture made in collaboration with the local designers at Octroi.**

The production consisted on 3 sheets. After several attempts, 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 approx. (around 800 bottle taps). The final furniture made is presented in the Figure **??**.

Finally, given the local establishment of the the team of the Green Fablab demonstrator at the Octroi ecosystem, the local mayor's office of Nancy organized a "Zero Waste Market" on December 2022. Figure **??** illustrates the participation of the Green Fablab team, an it was an excellent opportunity to make a communication and dissemination with general public on the INEDIT projet and the importance of plastic recycling issues

Figure 44: **Participation of Green Fablab to the Zero Waste Market organized by the mayor city at December 2022**

7 Conclusions

In this report, we described the research and development work developed in the task Task 6.4. Mainly, the open manufacturing demonstration facility of "3D printing of recycled plastic demonstrator' (also known as 'Green Fablab') developed in the INEDIT project. The main goal was the validation of the logistical and technical feasibility of recycled assets to be used in the Do-It-Together (DIT) approach.

This rapport showed:

- a conceptual and a technical implementation of the distributed recycling via additive manufacturing (DRAM) approach for the INEDIT. This conceptual approach is a major scientific output of the INEDIT project.
- A step-by-step process was shown to illustrate the materialization of the 3D printing of plastic recycling demonstrator.
- Several implementation examples were presented in order to validate technical advancement, but more importantly, to highlith the territorial impact that this type of initiatives can have.

The work developed in this task explores new and responsible tools that can act as drivers in a social manufacturing platform like INEDIT. The results of this example can create new business models and markets in the furniture sector and also establish new technology for the flexible manufacturing of customized furniture.

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.

Nevertheless, more examples are needed in the DRAM for education, prototyping and semi-industrial purposes. There are complexities in the recycling aspect given the variability and the plastic waste contamination. However, given that the AM technology makes it possible to reduce market entry barriers, reduce capital requirements, major research and development experimentation can be made to achieve an efficient minimum scale of production to promote distributed, flexible forms of production (Despeisse et al., 2017).
Taking this into account, the DRAM system presents significant potential in the future as an option to address the environmental problems linked to plastic waste, where increased quantity and use of 3D printing allows more recycled plastic assets to be produced and utilized.

Also, the stages of distributed model factories and decentralized production types are emerging 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). This is a relevant future path for the European union.

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A Annex of the technolgical description of the machines

TECHNOLOGY 3 - EXTRUDER

Type of techno:
Injection products: Extrusion is a continuous process. As with injection molding, the pellet enters a heated tube equipped with an endless screw. The homogenized soft material is pushed, compressed, and then passed through a die to be shaped into the desired form

Production capacity:

mould	Tube	Tube	Tube
Size of mould	L 53 cm ; Diameter 14	L 26 cm ; Diameter 14	L 15 cm ; Diameter 14

Operating mode :
1.Place the mold on the material outlet
2.Plug in and turn on the extruder
3.Wait for the temperature to rise according to the settings
4.Press the start button to start the extrusion
5.Heat the mold with the heat gun.
6.Wait for the material to fill the mold
7.Turn off the extruder
8.Cool the mould with compressed air
9.Remove the mold
10.Cool the mold in a container of water
11.Turn out

Advantages :
•Easy to understand operation
•Large tank for material supply

Parameters - type of material:
•In the Green Fab-Lab, the extruder made bars and pins. To achieve this production, the machine is programmed at 3 temperatures of 120°C, 160°C and 210°C.

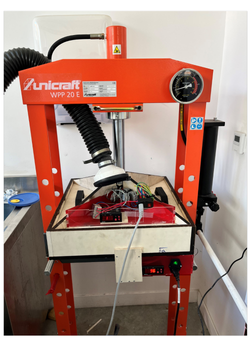
•The manufacture was carried out with HDPE.

Safety Rules:
•Thermal gloves
•Always unplug the power cable when handling it
•Wear goggles
•Ensure space for a water tank for cooling

Constraints :
•Slow extrusion time
•No homogeneous extrusion output
•Difficult to clean
•Minimum 2 people to use
•Difficult to fix the mould at the exit of the machine
•Low motor rotation (39 rpm)
•Need to shake the filling pipe at times to ensure the material is fed

Figure 45: Extruder machine

MINI SHEETS PRESS



Type of techno:
Sheet production Hot pressing is a material processing method that compresses materials by simultaneously applying high temperatures and isostatic pressing.

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%

Production capacity:
•Inside the wooden structure there are 470mm x 480mm x 800mm
•The heating plates have a surface of 470 m x 300 mm (limiting the size of the plates)

Operating mode :
1. Check the condition of the mold and press
2. Setting up a mold
    a. BBQ paper x2
    b. Mould frame
    c. Material
    d. Sheet metal x2
3. Connect the cable and turn on the machine
4. Set the temperature to 190°.
5. Wait for the set temperature
6. Press between 1 and 2 T
7. Wait for the plastic melting phase (15min to 1h depending on the mould used)
8. Unplug and induction of the mold
9. Remove the mobile part from the press
10. Remove and place the mold on the cooling press
11. Wait for cooling and unmold

Advantages :
•Can be used with different types of material
•Easy to move press
•Easy to design the heating system

Safety Rules:
•Thermal gloves
•Vacuuming during and after use
•Always unplug the power cable when handling the machine
•Eyeglass door
•Ensure a space to put the hot part above in all safety

Constraints :
•Maintenance and cleaning of the mould
•Cooling time of the plate too long
•Complexity in demolding
•Risk of burning during the cooling process
•Complexity to remove the mold

Figure 46: Sheet Injection Machime

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

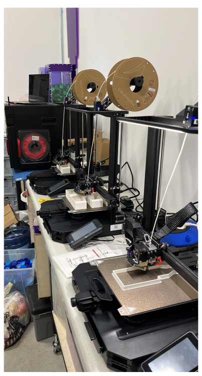
Parameters - type of material:

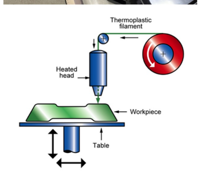
Type of material	rPet-rHDPE	vPLA	vPET
T1	264	190	240
	230	185	200
	220	170	185
Bed T°	85	60	80

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 47: **Technical characterization of the ultrasonic cleaning**





Principle

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:

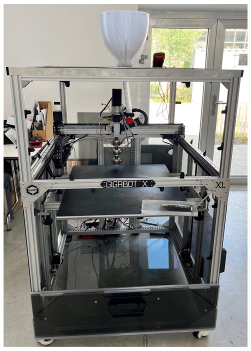
Type of material	rHDPE	vPLA	rPLA
T1	240	190	200
Bed T°	85	60	60
Speed printing mm/s	60	60	50

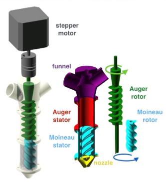
Safety Rules:
•Don't handing while the machine printing
•Be careful with heating and electronic elements.

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 48: **Fused filament fabrication -FFF- principle**





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 49: **Fused granular fabrication -FGF- principle**