Development of a mobile unit for the recovery of packaging glass

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Abstract

With the imposition of ambitious goals by the European Union for glass recycling, Sociedade Ponto Verde advanced with a project to design a unit for the recovery of packaging glass present in the waste of mechanical, biological, and energetic valorization treatment plants. Previously developed research has resulted in a mobile recovery unit that integrates part of a Glass Recovery Diagram, formerly tested and validated. To be adopted by companies, it is essential for this unit to have a good performance in terms of its waste processing capacity and implementation costs. The present work aims to analyze the drawbacks and points of improvement of the previous mobile unit, and develop a new mobile unit that improves upon the identified limitations. The verification of the new support structures concerning their structural safety is carried out, and a prototype in a reduced scale of the new unit was produced by a 3D printer. The new mobile unit consists of two optical sorters that separate contaminants from glass by opacity, and several conveyor belts that transfer the residues from one optical sorter to the other and that perform the extraction of the sorting products to the exterior. The unit has a processing capacity of 41891 t/year and has two modes of operation, one in which the optical sorters work serially and the other in which they work in parallel. The prototype was produced in Polylactic acid (PLA) on a scale of 1:20, having a dimension of 610 x 122 x 145 mm and has sliding inserts that illustrate the movement of the extraction conveyor belts of the sorting products between two characteristic positions of its operation.

Keywords: Mobile unit; Glass recovery; Rapid prototyping; Additive manufacturing.

1. Introduction

The rapid economic growth at a worldwide scale has increased the amount of solid urban waste (SUW) produced [1]. The deposition of this waste in a landfill prevents it from being processed and reintroduced into the economy.

In order to reuse the glass present in SUW, the MOBILE-PRO-U project was started by the “Associação para o Desenvolvimento do Instituto Superior Técnico” in partnership with Maltha (glass recycling company), the objective was to develop a mobile glass recovery unit that extracts this material from the SUW in an economically viable way so that it can be adopted by public and private companies.

1.1. Solid Urban Waste in Portugal

According to the Agência Portuguesa do Ambiente (APA), 5.281 million tons of SUW were produced in Portugal in 2019, which translates into 513 kg / (citizen.year), which is far from the goal defined by the Planeamento Estratégico de Resíduos Sólidos Urbanos (PERSU), which corresponds to 410 kg / (citizen.year) for the year 2020 [1].

In 2019, 178,941 tonnes of packaging glass were recycled, a value that decreased considerably when compared to the 210,422 tonnes recycled in 2011. The non-recycled packaging glass is directed to the various Urban Waste Management Systems (UWMS) that do not have capacity to recover this material, which results in rejects of mechanical and biological treatment (MBTr) and incineration slag (IS), which are deposited in landfills [1].

1.2. Glass recovery diagram

The Glass Recovery Diagram (GRD) was developed by Nilmara Dias [2], with the purpose of extracting the glass contained in MBTr and IS.

The GRD is divided into two stages, the first one is the pre-processing, which includes drying operations, ferromagnetic separation, the removal of particles with a granulometry lower than 5.6 mm via a 5.6 mm mesh sieve, and the separation of the MBTr into two portions via a 16 mm mesh sieve. Processing is the second stage of the GRD, where the MBTr of the fraction between 5.6 and 16 mm is refined two times by the RecGlass equipment, removing contaminants with a sub-spherical geometry through a process of separation by form, and later together with the fraction greater than 16 mm, is refined three times by optical sorters, removing contaminants by opacity through the use of light sensors, with the vacuuming of light contaminants at the entrances of each of these processes [2]. A scheme of the GRD is illustrated in Figure 1.

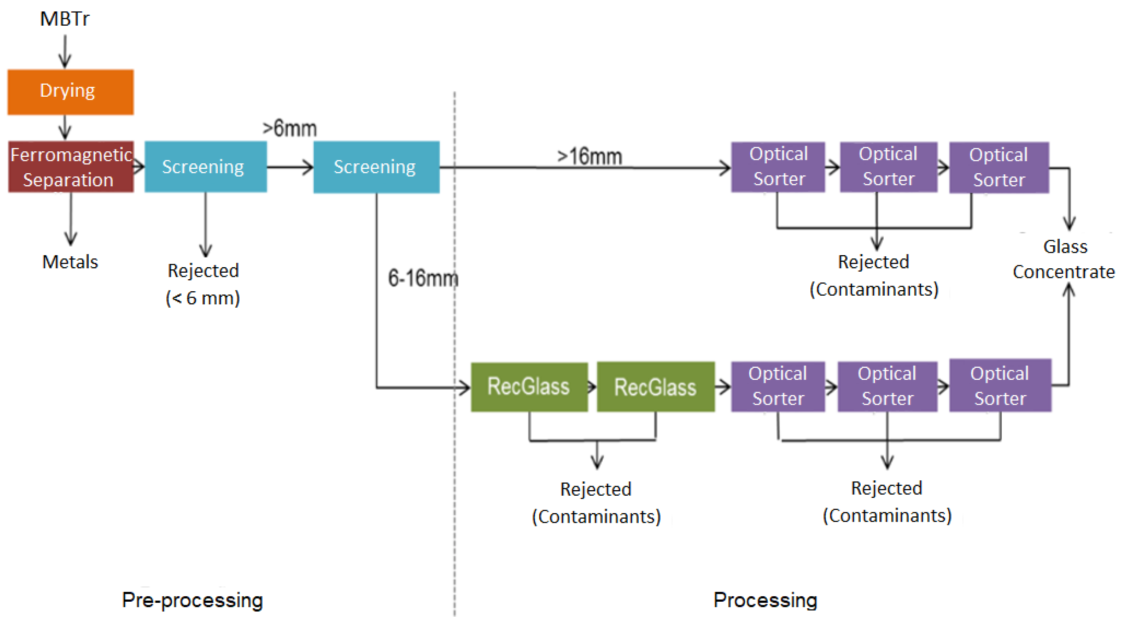

Fig. 1: GRD developed by Nilmara Dias, modified from [2]

1.3. Mobile glass separation unit developed by Arrais

In the mobile glass separation unit (MPU) developed by João Arrais [3], the author partially applied the GRD within the limited space of a 40-foot ISO container (approximately 12 meters) with a side opening. This unit contains all the equipment used in the processing stage (optical sorters, RecGlass, and light contaminant suction hoods), while the responsibility of the equipment that makes up the pre-processing stage belongs to the UWMS [3]. Figure 2 shows the 3D model of the MPU, which includes exterior equipment such as the hopper and the z-profile conveyor belt that feeds the unit, as well as the packaging glass and contaminant deposition containers that are present in the UWMS.

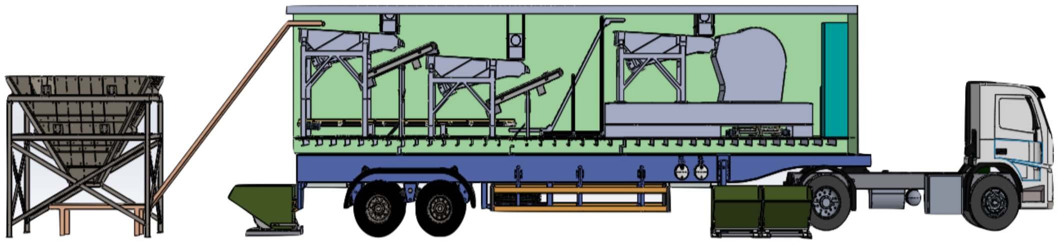

Fig. 2: 3D model of the MPU developed by Arrais [3]

The MBTr and IS decontamination process requires 3 phases, with differences in the first phase between the two fractions. Fractions between 6 and 16 mm are processed by two RecGlass and an optical sorter during the first phase of processing, while fractions over 16 mm are processed only by the optical sorter. The second and third phases is the same for the two fractions, consisting of a processing stage in the optical sorter for each phase.

2. Development of the new mobile recovery unit

2.1. Analysis of the previously proposed MPU model

The previously proposed MPU was analyzed with the objective of identifying its limitations, and producing criteria for the conceptualization of a new MPU that rectifies the identified limitations.

The bottleneck of the MPU identified is the optical sorter, which has a processing capacity of 16 ton/h. The MBTr and IS are processed three times by the unit [2], and assuming that MPU works 247 days a year during two work shifts (16 hours), a period that corresponds to the working hours of the UWMS used by Bernardo [4] in his dissertation, the MPU has an annual processing capacity of:

$$C_p = \frac{16\ (ton/h)}{3} \times 16 \left(\frac{h}{day}\right) \times\ 247 \left(\frac{day}{year}\right) \approx 20946\ ton/year \tag{1}$$

Therefore, the number of units required to process the annual production of MBTr and IS with a granulometry greater than 5.6 mm (127401 ton/year [5]) is given by the following equation:

$$N = \frac{127401\ \text{ton/year}}{20946\ ton/year} = 6{,}08 \rightarrow 7\ MPU \tag{2}$$

Notably, the processing capacity of this MPU is lower than the annual IS production of Valorsul (45045 ton/year [5]), which means that three MPU will be needed to process all of IS of Valorsul. The development of a new MPU with a greater processing capacity than the current one, aims at solving the above exposed problem, as well as reduce the total number of units needed to compose the MPU network, simplifying the planning and logistics system, taking into account economic and environmental factors.

The RecGlass equipment present in the MPU, is used in the first phase of processing of the fraction between 5.6 and 16 mm, remaining inactive in all other phases. To analyze the amount of time the RecGlass is inactive in relation to the total operating time of the MPU, the usage rate of this equipment was calculated.

Taking into account the total annual production of MBTr and IS between 5.6 and 16 mm (94774 ton / year [5]), the usage rate is calculated using equation 3:

$$t_{oc_g} = \frac{(Fraction > 5{,}6\ mm\ a < 16\ mm)}{(Fraction > 5{,}6\ mm) \times 3} \times 100 = \frac{94774}{127401 \times 3} \times 100 = 24{,}8\ \% \qquad (3)$$

With a usage rate of 24.8%, it is possible to conclude that, on average, the RecGlass only works during a small proportion of the entire process. The optical sorter, by comparison, has an occupancy rate of 100%, as this equipment is used in all passages and for all particles of any size.

2.2. Conceptualization of the new MPU

After the analysis of the previously proposed mobile unit, a new proposal was developed, with the main objective being the maximization of processing capacity.

The equipment that constitutes the MPU is installed inside a 40 feet intermodal container with rear and side openings, from Cleveland Containers (40ft Side Opening High Cube model) [6].

Since the RecGlass is the cheapest equipment of the GRD, its implementation in the various UWMS does not present a significant increase in the GRD implementation costs. With the previous considerations, this equipment was excluded from the new MPU. This scenario will allow the RecGlass to work at maximum processing potential, as there is no concern to adjust its processing speed to ensure compliance with the lower permissible flow rate of the optical sorter.

The optical sorter is an essential equipment of the MPU, not only because the processing of MBTr and IS in this equipment is the last step to obtain the glass concentrate as defined in the GRD, but also due to the fact that the cost of an optical sorter is at least an order of magnitude greater than the cost of any other equipment that constitutes GRD, which consequently makes its implementation in the UWMS unfeasible, according to Dias [2].

The MPU developed in this dissertation consists of two optical sorters, two light contaminant suction hoods installed directly above the output of the vibration feeders of each optical sorter, two z-profile conveyor belts, model KFG-P 2000 AS, and four conveyor belts, model GUF-P 2000 AS, both from MK Technology Group [7].

The conveyor belts, model GUF-P 2000 AS, are installed directly under the outlets of both optical sorters, these carry out the extraction of contaminants and the processed product to the exterior of the MPU through the open side of the container. For this to happen, the output of these conveyors must be located outside the MPU during the processing of MBTr and IS, and inside in order to close the side doors to allow the transportation of the MPU. To solve these two situations, these conveyors are mounted on a linear guidance system that allows movement and fixation during processing and transportation positions.

The MPU must have the capacity to perform three stages of optical sorting as described in the GRD, for this, the optical sorter will have to work in series during the first phase of processing, and in parallel during the second phase. For this purpose, the support structure of the glass concentrate extraction, the conveyor belt under the first optical sorter is mounted on a second linear guidance system that allows the lateral movement of this structure (Figure 3).

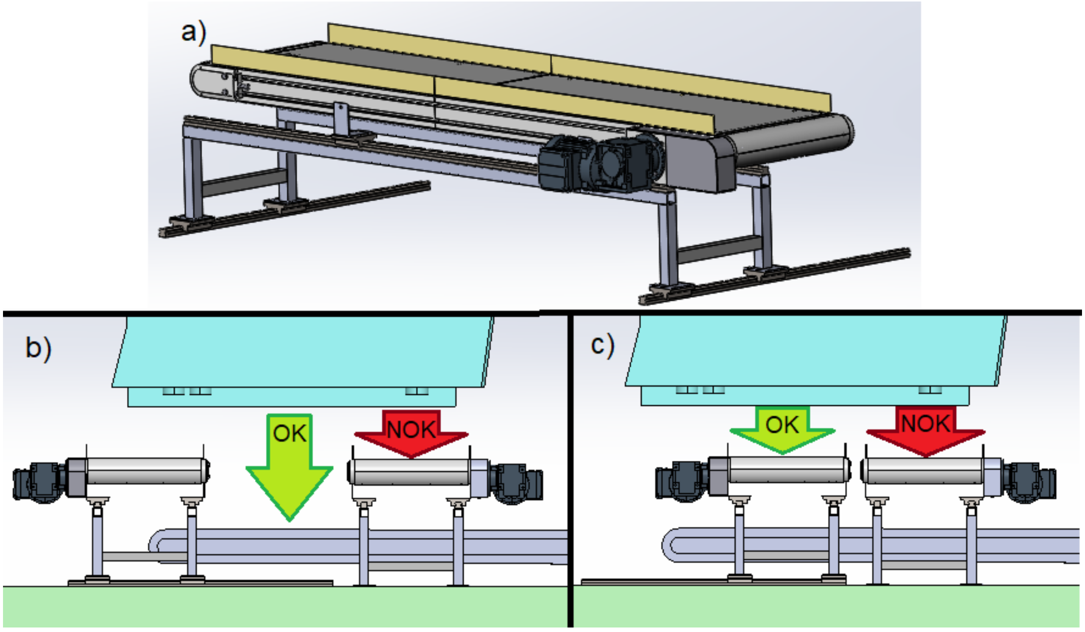

Fig. 3: Operation of the conveyor belt with lateral locomotion: a) Conveyor belt mounted on a support structure and on two linear guidance systems, allowing for movement in two directions; b) Position of the conveyor during the first phase of processing; c) Position of the conveyor during the second phase of processing (OK is the glass concentrate, NOK are the contaminants)

2.3. Operation of the new MPU

The MPU is transported on a semi-trailer to a UWMS, after its arrival, the rear and side doors of the container are opened, and then the equipment present in the UWMS, shown in figure 4, will be installed next to the MPU.

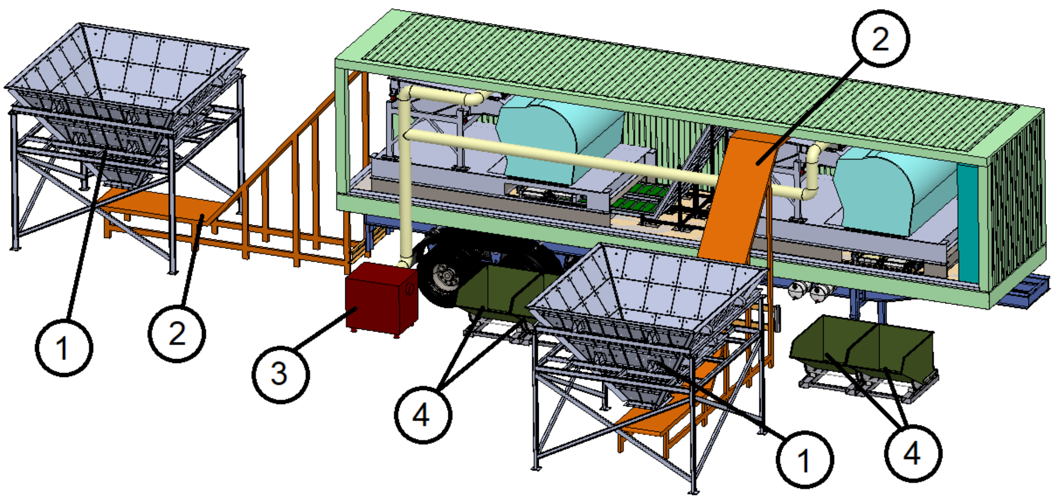

Fig. 4: MPU connected to the equipment present in an UWMS: two Hoppers (1); two feed conveyor belts (2); Vacuum system (3); four collection containers (4).

First phase: The hopper connected to the conveyor belt that carries the material through the rear entrance is loaded with MBTr or IS, feeding the first optical sorter. The waste passes through a light contaminant vacuuming stage and is then processed by the first optical sorter. Contaminants are extracted out of the container, while the glass concentrate falls on the z-profile conveyor belt, which transports it to the second optical sorter. After processing by the second optical sorter, both contaminants and the glass concentrate are extracted out of the unit, with this last step, the first phase is concluded.

Second phase: The conveyor belt that extracts the glass concentrate under the first optical sorter, is positioned under the glass concentrate outlet of this equipment. Both hoppers are then loaded with MBTr or IS which deposit these on the feed conveyors connected to its respective optical sorter. In this phase, both optical sorters work in parallel.

The MBTr or IS undergo a light contaminant vacuuming stage and are then processed by the respective optical sorter. After processing, both contaminants and the glass concentrate are extracted out of the unit. The final product corresponds to the packaging glass concentrate that is ready for recycling, as described in the GRD.

2.4. Comparison of the proposed models for the MPU

The annual processing capacity of the new MPU is calculated taking into account that in the second phase, both optical sorters work in parallel, which translates into the following equation:

$$C_p = \frac{16\ (ton/h)}{1{,}5} \times 16 \left(\frac{h}{day}\right) \times\ 247 \left(\frac{day}{year}\right) \approx 41891\ ton/year \quad (4)$$

Like the previously proposed MPU, the processing capacity of the new MPU is lower than the annual IS production of Valorsul (45045 ton/year), requiring two of the new MPU to process this flow, i.e. a reduction of one unit compared to previously proposed MPU.

The estimated number of units required to process the entire annual production of MBTr and IS of fraction greater than 5.6 mm, of all the facilities analyzed in the context of the Mobile-Pro-U project will be:

$$N = \frac{127401\ \text{ton/year}}{41891\ \text{ton/year}} = 3{,}04 \rightarrow 4\ UMP \quad (5)$$

Despite the increased cost of the new MPU, the difference between the processing capacities of the two MPU implies a different number of units needed to process the annual flow of MBTr and IS, making it important to compare the total costs for the production of the MPU network:

Table 1: Comparison of estimated costs between the two proposals

Unit	Cost per unit	Quantity	Total Cost
Previously proposed MPU	412 700 €	7	2 888 900 €
New MPU	584 500 €	4	2 338 000 €

With the results present in Table 1, it is concluded that although cost per unit of the new MPU is higher, it requires three units less to form the Mobile-Pro-U network when compared to the previously proposed MPU due to the increase in waste processing capacity, which results in an estimated total cost reduction of 550 900 €.

3. MPU prototype

The transmission of ideas is more understandable through a physical object rather than by virtual means, making it important to produce a physical prototype in a reduced scale to facilitate the communication of the operation of the new MPU.

For the realization of this prototype, the 3D printing technology "Fused Deposition Modeling" (FDM) was chosen, as it is a commercially well-established technology and widely used in rapid prototyping.

A scale of 1:20 was selected to manufacture the prototype, which presents acceptable dimensions for a good representation of the various components of the MPU. It is expected that certain components will have profiles that are too small to be produced with precision and structural integrity, as FDM technology has limitations regarding the minimum size of the printed parts, so certain details of the components in the CAD model will have to be adapted, slightly increasing its dimensions.

3.1. Printing material

The base material selected for part printing was the biodegradable thermoplastic PLA, it has a relatively low printing temperature, which reduces the stresses resulting from the cooling of the part that can induce warping on its surfaces.

As the printed parts are produced layer by layer, a previous layer is required for the deposition of the next layer. FDM printing allows overhangs up to 45º of inclination, but for larger overhangs, it will be necessary to use a support material. For this, PVA was chosen as the support material, which is compatible with PLA and soluble in water, facilitating its removal from the part.

3.2. Printing considerations

The layer height influences the printing speed, the mechanical properties of the part, and the water absorption by the PLA, an important parameter since the parts will be submerged in water to remove the support material. A layer height of 0.2 mm was chosen, as it provides good mechanical properties, and low water absorption [8].

Due to the orientation of the layers, the pieces produced have inherent anisotropic properties, being much more resistant in directions parallel to the surface of layer deposition than in the direction perpendicular to it. For narrow and long components, it is then more appropriate to orient the layers along the length of the part [9].

It is advisable that all profiles produced have a minimum dimension of 2 mm, profiles smaller than this limit tend to have an amorphous structure with poorly defined edges and low mechanical resistance. For movable inserts, a gap of 0.5 mm should be left between parts. These limitations were verified and concluded with the production of test parts.

3.3. CAD preparation

The MPU components have profiles with very small dimensions in the 1:20 scale, making it impossible to print these parts. Therefore, the CAD model was adapted, increasing the thickness of certain sections. The beam profile of the optical sorter's support structure is an example of the modifications made, these beams have a thickness of 6 mm, applying the scale 1:20, the thickness becomes 0.3 mm, this was then changed to 2 mm (see figure 5).

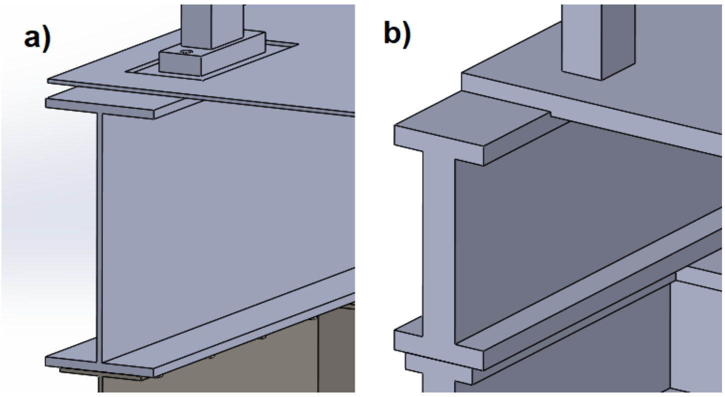

Fig. 5: The beam profile supporting the optical sorter: a) original CAD; b) CAD adapted for printing

The CAD model was divided into parts that will be printed separately (Figure 6). This process aims to reduce the necessary support material and respect the limits of the available construction volume. In order to join the parts, fittings were developed, and were verified by means of small test prints, to avoid material waste.

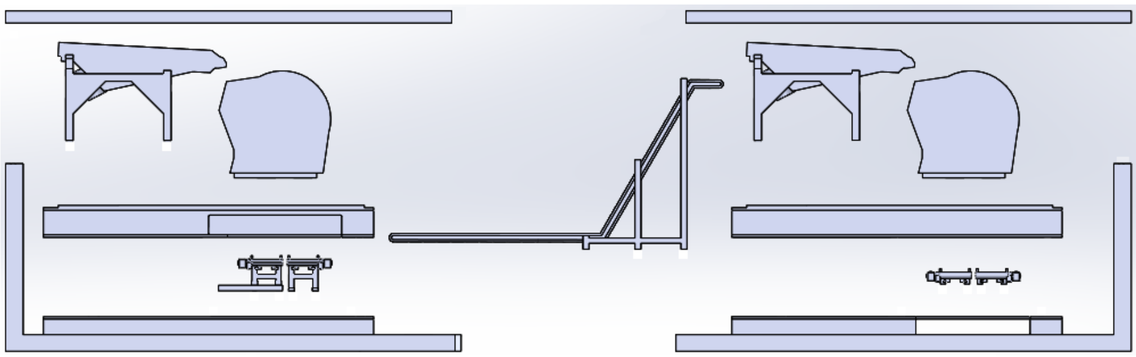

Fig. 6: Componentes separados para impressão individual

3.4. Prototype production

With all connections tested and verified, the printing of the MPU components takes into account printing orientations that minimize the amount of support material needed, and the orientation of the long thin profiles along the same direction as the print layers, to improve their mechanical properties. Figure 7 shows the printed parts, before and after assembly.

Fig. 7: The MPU prototype: a) Separate components; b) MPU assembled

4. Conclusions

The newly developed MPU consists of two optical sorters and has two processing modes, in series and in parallel, used in the first and second phases of waste processing, respectively. The cost per unit was estimated at 584 k€. It has an estimated annual processing capacity of approximately 41 thousand ton/year, which is still not enough to process the annual IS production of Valorsul using one MPU, but it reduces the total number of MPU needed from three to two. Regarding the annual production of MBTr and IS of all UWMS, four units are required, a reduction of three units when compared to the previously proposed MPU, which results in an estimated total cost reduction of 550 k€.

The UWMS will have to provide various equipment to accommodate an MPU, namely two hoppers, two feed conveyor belts, four containers for the collection of optical sorting products, a light contaminant vacuuming system, and at least one loader.

The MPU prototype was produced on a 1:20 scale, with a dimension of 610 x 122 x 145 mm. It was possible to produce parts with sliding fittings, representative of the linear guidance systems connected to the extraction conveyor belts of the sorting products. This prototype can therefore be used to demonstrate the two modes of operation of the new MPU (series and parallel), as well as the flow of waste during its operation.

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