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RECYCLED EPS INSULATION PLATES: CRITICAL FACTORS AND POTENTIALITIES FOR THE PRODUCTIVE FEASIBILITY OF A VENTURE IN THE DISTRICT OF LA PLATA[1]

PLACAS AISLANTES DE EPS RECICLADO: FACTORES CRÍTICOS Y POTENCIALIDADES PARA LA VIABILIDAD PRODUCTIVA DE UN EMPRENDIMIENTO EN EL PARTIDO DE LA PLATA

PLACAS ISOLANTES DE EPS RECICLADO: FATORES POTENCIAIS E CRÍTICOS PARA A VIABILIDADE PRODUTIVA DE UM EMPREENDIMENTO NO DISTRITO DE LA PLATA

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RESUMEN

Investigaciones previas han permitido desarrollar y caracterizar un material aislante a partir de descartes de poliestireno expandido (EPS) que puede utilizarse para la fabricación de placas, brindando oportunidades laborales a grupos sociales desocupados o vulnerables. Trabajando en articulación con una cooperativa de recicladores local, se determinaron los procesos productivos necesarios para su fabricación en una escala apta para su comercialización. El objetivo de esta investigación es analizar estos procesos productivos e identificar los aspectos críticos para la viabilidad de ejecución y gestión de esta tecnología. La metodología utilizada implica: i. la adecuación del producto; ii. la determinación de los insumos y recursos para su viabilidad; iii. la detección de los procesos productivos con mayor criticidad; y iv. la adecuación al caso particular de aplicación. Se obtiene un conjunto de requerimientos considerados mínimos para el desarrollo de un emprendimiento productivo. Además, se identifican en el contexto local los procesos de mayor criticidad, relativos a la separación y la obtención del EPS y su provisión continua en el tiempo. Los resultados condensan aportes para contribuir a la replicación y la sostenibilidad de esta experiencia.

Palabras clave
aislamiento térmico, materiales alternativos, ingeniería de la producción.

ABSTRACT

Previous research has allowed developing and characterizing an expanded polystyrene waste (EPS) based insulation material that can be used to manufacture plates, providing job opportunities to unemployed or vulnerable social groups. By working together with a local recycling cooperative, the production processes needed for their manufacture on a scale suitable for commercialization were determined. The goal of this research is to analyze these production processes and identify the critical aspects that make the technology's implementation and management viable. The methodology used involves i. the product's adaptation; ii. determining supplies and resources for its feasibility; iii. detecting the most critical production processes; and, iv. adapting to the particular case of application. A set of minimum requirements is obtained to develop a productive venture. In addition, the most critical processes related to the separation and obtaining of the EPS and its continuous supply over time, are identified. The results summarize contributions to replicate and make this experience sustainable.

Keywords
thermal insulation, alternative materials, production engineering

RESUMO

Pesquisas anteriores desta equipe permitiram desenvolver e caracterizar um material isolante a partir de poliestireno expandido (EPS) descartado que pode ser utilizado na fabricação de placas, oferecendo oportunidades de trabalho a grupos sociais desempregados ou vulneráveis. Trabalhando em coordenação com uma cooperativa local de recicladores, foram determinados os processos de produção necessários para sua fabricação em escala adequada para a comercialização. O objetivo desta pesquisa é analisar os processos produtivos envolvidos e os aspectos críticos que tornam viável a execução e gestão desta tecnologia. A metodologia utilizada implica: i. a adequação do produto; ii. a determinação dos insumos e recursos para sua viabilidade; iii. a detecção dos processos com maior criticidade; e iv. a adaptação ao caso particular de aplicação. Obtém-se um conjunto de requisitos considerados mínimos para o desenvolvimento de um empreendimento produtivo. Além disso, são identificados no contexto local os processos mais críticos relacionados à separação e obtenção do EPS e seu fornecimento contínuo ao longo do tempo. Os resultados condensam contribuições que têm por objetivo a replicação e sustentabilidade desta experiência.

Palavras-chave
isolamento térmico, materiais alternativos, engenharia de produção.

INTRODUCTION

In Latin America, one out of every three families lives in inadequate housing, be it because of construction with precarious materials or the lack of basic services (Bouillon, 2012). In 2010, in Argentina, about 35% of houses were recoverable, needing improvements in terms of material quality (INDEC, 2010). It is well known that the use of inappropriate or insufficient materials for the enclosure and insulation of housing affects habitability and thermal comfort, as well as when it comes to taking advantage of and rationally using energy (Abu-Jdayil, Mourad, Hittini, Hassan & Hameedi, 2019). This problem is particularly accentuated in working-class neighborhoods[2], where homes are usually made with simple wooden walls and sheet roofs (di Virgilio & Rodríguez, 2018). At a local level, this qualitative housing deficit was revealed in the Social Council of the National University of La Plata[3], a space for interaction between different public sectors and the community to debate and propose responses to the region's main social problems. The working group from which this article is from has made contributions on this issue, one of them referring to the development of thermal insulation materials.

The materials used for thermal insulation are characterized by having low thermal conductivity, a coefficient that expresses their ability to allow heat flow. While traditional materials such as mineral wool and plastics are efficient in these terms (Abu-Jdayil *et al.*, 2019; Aditya *et al.*, 2017), the use of alternative recycled or natural materials have shown thermal performances with the potential to be used in housing (Durakovic, Yildiz & Yahia, 2020; Kumar, Alam, Zou, Sanjayan & Memon, 2020; Hasan, Khan, Akhtar & Kirmani, 2021; Zhao, Zheng, Tang, Sun & Wang, 2022; Meng, Ling & Mo, 2018; Li, Saberian & Kirmani, 2021; Hasan, Khan, Akhtar & Kirmani, 2021; Nguyen, 2018; Flores-Alés, Jiménez-Bayarri & Pérez-Fargallo, 2018; Steyn, Babafemi, Fataar & Combrinck, 2020). In this context, the use of natural fibers from harvest by-products and recycled materials from high-demand industrial products stand out, both for their inclusion in cement mortars and for insulating applications. In this sense, the aforementioned working group has proposed and characterized an alternative thermal insulation material based on the recycling of expanded polystyrene (EPS) waste that currently does not have a post-consumption destination at a local level (Viegas, Walsh & Barros, 2016; San Juan, Viegas & Jodra, 2018; Reynoso, Carrizo, Viegas & San Juan, 2021). Considering the needs expressed by the social groups involved in this research, arose the need to look for alternatives that would add value to such waste.

Expanded polystyrene is a material used widely as an insulator and as a packaging to protect fragile products. It is characterized by being extremely light, mainly comprising air with just 2% polystyrene. Due to its low weight and large volume, it is an unprofitable material for recycling, and hence mostly ends up in landfills (Marten & Hicks, 2018; Oliveira, Luna & Campos, 2019). In 2011, global EPS consumption was around 5.8 Mt (Jang, Shim, Han, Song & Hong, 2018). According to the Argentine Petrochemical Institute, more than 25,000 tons of EPS were consumed in 2018, meaning an annual consumption of around 570 gr/inhab. in the country (IPA, 2018).

For recyclers, selling raw materials is not a profitable option, thus the material needs to be processed to reintegrate it into the market and use circuit. From this perspective, two alternatives for processing expanded polystyrene waste in Argentina have been identified. Some cooperatives shred the packaging for use as a lightweight filler for construction or as a filling for cushions and similar items. These cooperatives develop, in certain cases, finished products such as bricks or blocks for construction. In this area, the NGO, PuntoVerde, and the cooperative, Reciclando Conciencia, stand out in the country. Some other cooperatives or companies reduce EPS to polystyrene and produce "finished products" from the material -

2 Working-class neighborhoods, where at least 8 families live and more than half the population does not own the land or have regular access to two or more of the basic services (running water, electricity, and/or sewage network) (RENABAP, 2020).

3 The Social Council of the National University of La Plata is composed of Government departments of the Province of Buenos Aires, representatives of legislative chambers, municipalities of the Capital Region, trade union centers, territorial organizations, cooperatives, science and technology organizations, and different actors of the university community. Among its objectives, it proposes to bring together all the region's actors to analyze the main socio-economic, political, cultural, and environmental problems, and jointly discuss possible strategies to address them through local and national policies.

school supplies, and cutlery, among others-, such as the company, Sirplast, and the Creando Conciencia cooperative. Sirplast recycles EPS at an industrial level, recovering 1.2% of the total EPS consumed in 2018. These figures lay out what is clear in the streets themselves, namely, the great availability of the material and its potential for projects that involve its reuse.

Different research projects have evaluated the use of mechanically crushed or recycled EPS in construction mixtures. Some studies propose its use as a lightweight aggregate in concrete mixtures, for load-bearing or enclosure panels (Fernando, Jayasinghe & Jayasinghe, 2017; Dissanayake, Jayasinghe & Jayasinghe, 2017; Dixit, Dai Pang, Kang & Moon, 2019; Maaroufi, Belarbi, Abahri & Benmahiddine, 2021). Suggested mixtures for mortars, insulating fillers, or insulation panels have also been analyzed (Laukaitis, Žurauskas & Kerien, 2005; Madariaga & Macia, 2008; Aciu, Manea, Molnar & Jumate, 2015). The material developed, the result of this working group's research, is distinguished by using simple materials and methods for its manufacture, which allows for meeting a specific need of social economy sectors and developing a product technically evaluated through different standardized tests. The project in question was chosen in 2020 by the INVAP Foundation, due to its economic, social, and environmental impact, in the preparation of responses that bring science and technology closer to the real needs of the population. The mixture developed and characterized uses crushed EPS in sizes between 4 and 10 mm that are bonded with a cementitious mixture (San Juan *et al.*, 2018). The insulation is characterized by having a thermal conductivity of between 0.0603 and 0.0706 W/m·K, no small flame propagation risks, resisting electrical overheating at high temperatures, and being able to be stored outdoors without great changes in its insulating capacity. In addition, it can be easily cut to adapt to the surfaces being insulated and its mechanical properties are suitable for non-load-bearing applications (Reynoso *et al.*, 2021).

This determines the feasibility of the material for wall insulation plates and interior cavities for housing. The processes involved in the material's manufacture, make both its self-production and production on a larger scale for sale, feasible. This setup is based on the concept of a social and solidarity economy, which seeks to form societies united and guided by care for the environment and the generation of decent jobs (Coraggio, 2009). Likewise, the project involves the reintroduction of EPS waste in the use stages, which seeks to avoid the generation of new raw material for this purpose and promote the generation of new employment from its reuse. These logics differ from the linear economy based on the "take-make-waste" principle and are linked to the circular economy. The circular economy considers each stage of the product's life cycle, before and after it reaches the consumer, and privileges restoration over the expiration of products and materials (Buren, Demmers, Van der Heijden & Witlox, 2016; Kirchherr, Reike & Hekkert, 2017).

The research, for a larger-scale productive experience, has worked together with the Sol-Plat recyclers cooperative, located in La Plata. The cooperative's task falls within the local government management program for differentiated collection by type of waste. The management of the urban solid waste generated is a priority environmental problem at a global level. At a local level, the problem mainly affects working-class neighborhoods or settlements, mostly devoid of optimal infrastructure for waste collection, among other key aspects for proper habitability (Esparza, 2021). In this context, the cooperative is dedicated to the classification and sale of dry waste separated at its origin. using green bags provided by the local government. The classified materials are plastics (PET, LDPE, HDPE, and PS), cellulose materials (paper and cardboard), tetra brik, glass, aluminum, and ferrous metals, among others. The facilities comprise two 600 m^2 production spaces, one where the incoming waste is classified into *big bags*. In the second production space, the waste is compacted using a hydraulic machine, and part of the classified materials are also stored.

The experience of working in the cooperative meant the transition from laboratory tests and the production of unique samples, to a more specific dimension: thinking about which adjustments the product needs, which processes are involved, and what requirements are needed to set up a production enterprise at scale. In this framework, the research information mainly refers to the quantitative analysis of products and/or mixtures with crushed EPS, but few investigations address the study of the production processes involved in large-scale production. Thus, the need to address, not just the technical aspects of the new materials' design, but also the socio-productive factors that can make this type of study a success or a failure, is detected. Specifically, the research presented here proposes to determine, describe, and analyze, from the definition of the product, the production processes involved in its manufacture, as well as identify the critical aspects in terms of production viability and management of this technology on a suitable scale for its commercialization. The aim is to condense the knowledge generated from the experience at a local level, so that it can be used as the basis for its replication in other contexts. The contribution lies in the efforts to make an enterprise based on scientific-technological research, with social, environmental, and economic impact, viable, in co-construction with the social actors involved. The hypothesis is that the analysis of productive processes allows addressing viable solutions that meet the needs of a social sector with structural deficiencies in terms of housing conditions and generate genuine work.

METHODOLOGY

This work seeks to bring together technology, understood as a product and the knowledge involved (Thomas, Juárez & Picabea, 2015), and society, to generate employment for vulnerable or unemployed social sectors. It proposes, from the basis of participatory action research, to involve different actors from the working-class economy (de Sousa Santos, 2012). Specifically, members of the Sol-Plat recyclers cooperative are involved to collaborate, with the responsible research group, in creating a productive venture based on the production of alternative thermal insulation plates. The cooperative's tasks mainly include the classification and processing of materials to collect and sell raw materials. This proposed venture looks to manufacture end-use products, covering the final links of the waste value chain, to valorize raw EPS waste (Caló, 2009). The aim is to strengthen the self-management and co-management capacities of organized groups to improve their economic conditions and, at the same time, promote improvements in the environment and habitat (Enet, Romero & Olivera, 2008).

The production process flow diagram presented in Figure 1 was designed, considering the minimum technical specifications required for insulating plates and the reduction of direct manufacturing costs. Designing the processes implies deciding how resources are transformed into goods and services (Carro Paz & González Gómez, 2013), whereby the input materials, the sequence of operations and their connection, the working methods and times, as well as the quality of the product obtained, are taken into account.

The process begins outside the production facility, with the separation of the expanded polystyrene waste. This considers as separation and collection options: a. the household collection green bag; b. clean points; and c. large waste generators. In the production facility, the initial processes are the reception or collection of raw materials, namely, the cement and the raw EPS packaging. If necessary, the EPS waste is revised, removing labels or tape. Then, the packages are pre-crushed into pieces to facilitate their processing in the following stages. Next, fine crushing is done using grinding machinery to obtain granules that are between 4 and 10 mm. Once the recycled raw material is ready, the mixture is made that will allow the plates' molding. The binding mixture consists of cement and water, which are placed first, before then gradually adding the ground EPS. Once a uniform mixture is achieved, the casting is done in the previously prepared molds, which can be 1 m x 0.50 cm x 0.07 cm, or other measurements, depending on the project. The wet mixture is compressed and stored for drying at room temperature for between 7 and 10 days. After that period, the molds are removed and, if the plates do not have any breaks or surface defects, they are identified by their production batch and stored on pallets. Depending on the specific orders, the plates are prepared and cut into special sizes for distribution.

The research methodology is organized into the following stages:

1. Adaptation of the product. Using the insulating material developed and characterized by the working group (Reynoso *et al.*, 2021), adjustments are made for its scale production and commercialization, analyzing the following aspects:

a. The direct costs of the product (Cdir) per square meter, are calculated considering: the costs from the transfer of raw EPS needed for a month, from its origin to the production facility; the cost of commercial raw materials involved and consumed during a month; the labor required for the product's manufacture; and the square meters of insulating plates produced monthly (equation 1).

$$C_{dir} = \frac{Traslado\ EPS + Materias\ primas\ comerciales + Mano\ de\ obra}{Metros\ cuadrados\ de\ material\ aislante/mes} \quad (1)$$

b. The required technical requirements, considering the desirable specifications for thermal insulation applications.

2. Determination of supplies and resources for the viability of the production processes. At this stage, the machinery, tools, and services considered for two possible cases of EPS availability are analyzed in the context where the experience is inserted. The proposed supplies and resources have a close relationship with the production times and the available labor.

3. Identification of the most critical processes. This implies ranking the processes to establish priorities in decision-making (Mendoza, 2000). Each one is analyzed using the following variables:

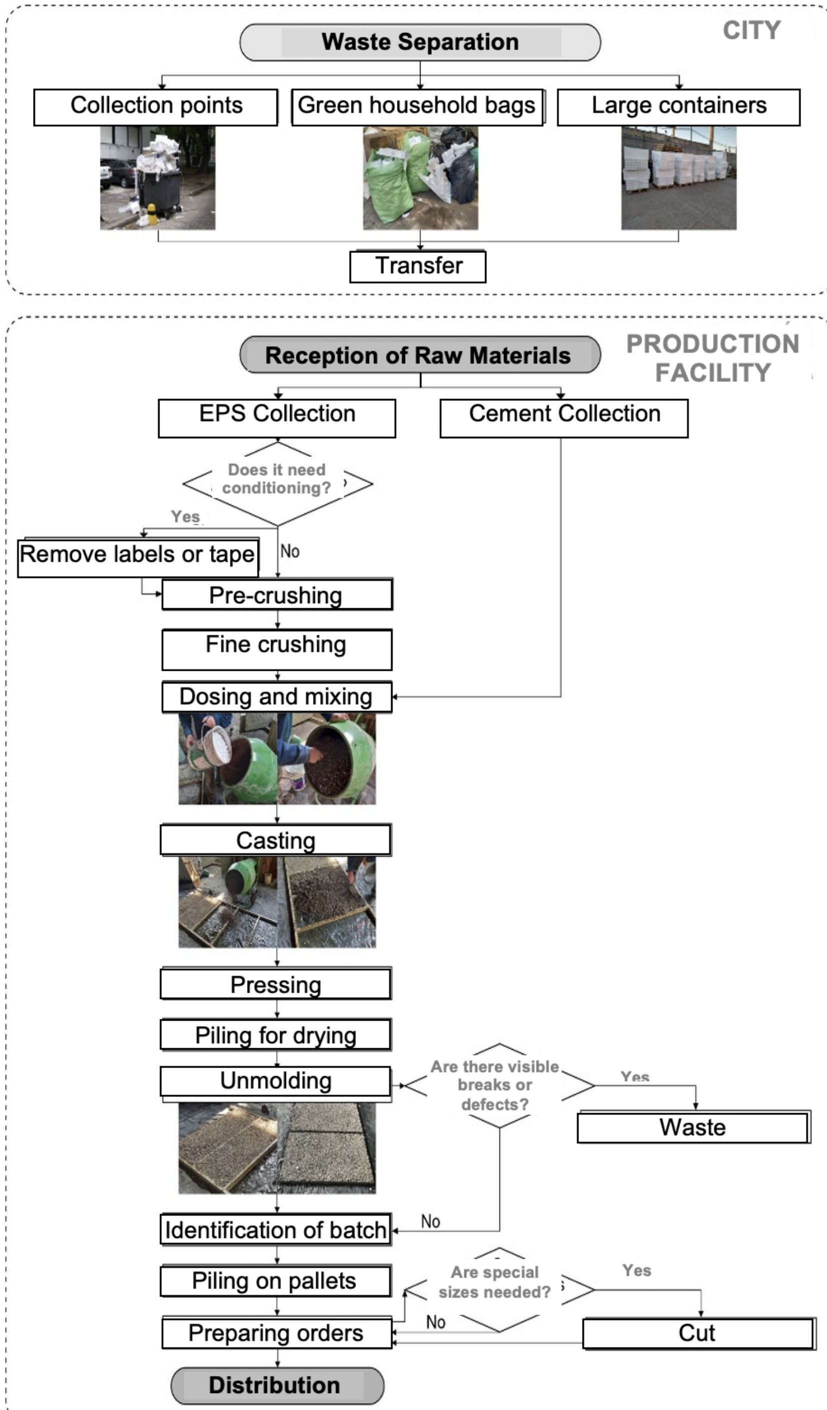

Figure 1. Flow diagram of the alternative thermal insulation board production process. Source: Preparation by the authors.

a. Dependence on end products' technical characteristics - This evaluates to what extent the process is linked to the final features of the end product, considering market requirements.
b. Dependence on external factors - Evaluates to what extent those responsible for the process are external to the venture.
c. Probability of setbacks, caused by delays or faults: Evaluates to what extent setbacks are possible, considering different reasons (machine faults, late deliveries by third parties, setbacks due to human error, among others).
d. Impact of setbacks on subsequent processes: Evaluates the degree to which setbacks can affect the continuity of the production chain and the product's materialization, considering the expected technical characteristics.

	High	Medium	Low
Dependence on the technical characteristics of the end product	The process and its proper execution are directly related to obtaining the appropriate technical characteristics of the product for its sale.	The process and its proper execution affect to some extent obtaining the appropriate technical characteristics of the product for its sale.	The process and its proper execution do not affect obtaining the appropriate technical characteristics of the product for its sale.
Dependence on external factors	The process depends entirely on third parties and management and engagement activities, for its execution.	The process depends on both third parties and the work team for its execution.	The realization of the process depends exclusively on the work team.
Probability of setbacks, delays, or faults	The process regularly has setbacks or delays.	The process may occasionally have setbacks or delays.	The process may exceptionally have setbacks or delays.
Impact of delays or faults	Delays or faults in the process prevent the continuity of the production chain and/or regularly affect the technical characteristics of the end product.	Delays or faults in the process affect certain processes in the production chain and/or occasionally affect the technical characteristics of the product.	Delays or faults do not affect the continuity of the production chain and/ or exceptionally affect the technical characteristics of the product.

Table 1. Variables used to analyze the criticality level of the processes. Source: Preparation by the authors.

Each of these variables was classified for each production process into high, medium, and low, as described in Table 1. The criticality level from the process was determined by taking the most frequent levels obtained in the four variables.

4. Adaptation to the particular case of application. The experience initiated at the local level, its starting point, as well as the requirements to make progress in its development are described here.

RESULTS AND DISCUSSION

ADAPTATION OF THE PRODUCT

In coordination with the local recyclers' cooperative, work was carried out to adapt previously developed material to make a product with scale production feasibility. This material had shown, in previous research, good performance in terms of insulation: a thermal conductivity of between 0.0603 and 0.0706 W/m·K, measured based on the ISO 8990 standard (Reynoso *et al.*, 2021). Additionally, it evidenced the ability to preserve these insulating properties after being stored outdoors. Regarding its combustibility, the tests carried out based on the ISO 11925-2 standard revealed that cement acts as a flame retardant, meaning the material does not generate risks due to the propagation of a small flame. Likewise, the glow wire flammability tests, based on the IEC 60695-2-11 standard, showed that the material could withstand overheating up to 960°C without generating risks. The behavior of the samples with compression and flexion tests was also determined following the guidelines of the ISO 844 and ISO 1209-1 standards, respectively. In this sense, the material was suitable for applications that do not bear loads following the minimum requirements defined by the ISO 4898 standard. Finally, it was determined that the material can be easily cut by machines and tools to adapt to the surfaces being insulated. This characterization of the material (Figure 2 Point a) defined the feasibility of the material for the production of insulating plates.

Considering the cost variables and the technical requirements, certain changes were made in the composition of the previously described material and in the processes involved in its manufacture, since:

a. Direct cost analysis showed that the vinyl additive used in the binder was about 35% of the manufacturing costs. Consequently, the need to replace or eliminate this component was carried out to reduce the total cost of the product.
b. The plates manufactured in sizes of 0.5 x 1 x 0.05 m had a certain fragility during handling, so it was required to increase the mechanical strength of the product.

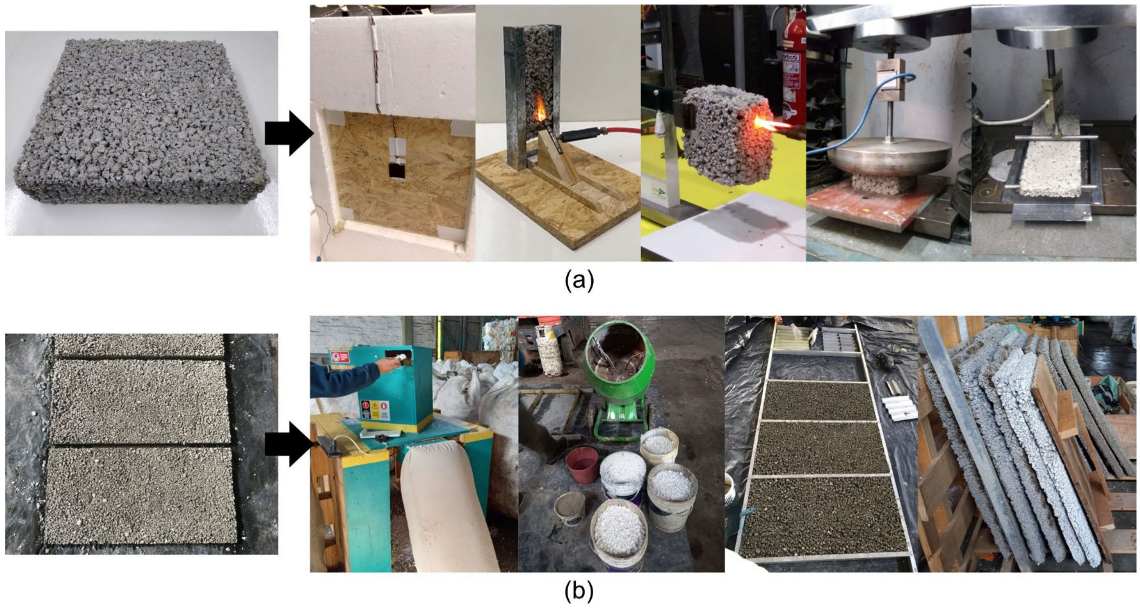

Figure 2. Developments and activities carried out in the laboratory and the cooperative: (a) Insulating material and technical tests based on international regulations; (b) Insulating plate product and production processes on a larger scale. Source: Preparation by the authors.

Processes	Machinery/ Tools	Services
Transportation/reception of raw materials	Light transport (own or outsourced)	-
EPS collection	Manual or hydraulic lifter	-
Cement collection	Manual or hydraulic lifter	
EPS conditioning and pre-crushing	Hot wire cutter or multiple copper wire cutter	Electricity
Fine crushed EPS	Crushing machine: self-built model (200kg), or commercial mill (1000kg) Big bags	Electricity
Dosing of components and mixing	Electric concrete mixer 120 l (200 kg) and 400 or 600 l (1000 kg) Mold Polythene Buckets	Water Electricity
Casting	Flat masonry trowel	Water
Pressing	Hydraulic press	-
Piling for drying	Stands	-
Piling on pallets	Pallets Manual or hydraulic lifter	-
Preparation of orders	Manual or hydraulic lifter Circular saw	Electricity
Distribution	Light transport (own or outsourced)	-

Table 2. Machinery/tools and services needed to process 200 kg and 1000 kg of raw EPS per month. Source: Preparation by the authors.

In the tests to improve the mechanical strength of the final plates, the compression process of the mixture was incorporated after casting. Together with members of the Sol-Plat cooperative, it was determined that compaction of the material with a weight greater than 100 kg increases its resistance, while only cement and water are used as binding materials. Different degrees of compression were also evaluated, obtaining that the compression ratio (Rc) needed to be between 1.3 and 1.5. is understood as the quotient between the final and the initial volume occupied by the material in the mold. As a result, insulating plates were obtained (Figure 2 Point b) that consider relevant aspects for their insertion in the current market. These have suitable thermal insulation, appropriate fire behavior, and improved performance in terms of mechanical resistance.

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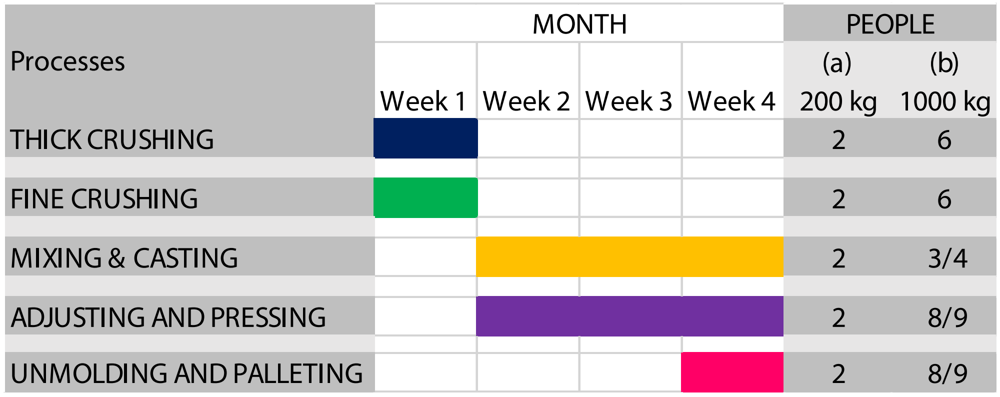

Figure 3. Distribution diagram of the production processes during a month. The number of people in charge of each process for case 1 (a) and case 2 (b). Source: Preparation by the authors.

DETERMINATION OF SUPPLIES AND RESOURCES FOR PRODUCTIVE VIABILITY

The supplies and resources needed are described based on two possible cases of EPS availability in the context where the experience is found. The first one (case 1) is proposed based on the entry of 200 kg of gross EPS per month, considering smaller scale or automation processes. The second (case 2), is based on the processing of 1000 kg of gross EPS per month. It is important to consider that the machinery and tools described in each case may vary depending on investment possibilities and the potential demands of the final plates. Table 2 presents the machinery, tools, and services required to process the raw material, identifying specific modifications considering the volume of EPS available monthly.

As a result of case 1, it is highlighted that for that amount of waste it is possible to produce approximately 200 m^2 of 5cm thick plates, and that about 1300 kg of cement would be required. regarding crushing machines, a low-cost self-built model can be used, proposed by the NGO, Punto Verde de Tandil (2018), Argentina. Under this grinding mode, 120 l is generated in approximately 20 minutes. To increase the crushing volume, multiple self-built machines can be considered with a low investment. As for the mixing machinery, 120 l electric mixers can be used, which can mix the insulating material needed to produce one square meter of 5 cm thick plates per cycle. Regarding the workforce, at least 4 people dedicated to production are required.

For case 2, based on the availability of 1000 kg of gross EPS per month, about 1000 m^2 of 5 cm thick plates would be produced and about 6500 kg of cement would be required. These volumes entail the need to use industrial mills for crushing and incorporating 400 or 600 l concrete mixers. In this sense, it is seen that there are commercial machinery options that allow increasing the mixing volume with a moderate investment, while the incorporation of industrial mills for crushing, demands a greater investment. However, increasing production capacity also means reducing execution times and the necessary manpower. For production, it is estimated that 12 people would be necessary, between 3 and 4 people to carry out the mixing and dosing, and between 8 and 9 people to handle casting in molds and pressing.

In both cases, a hydraulic press is also required, designed to compress the wet mixture evenly. A multiple hot wire cutter is also required to fragment the raw waste, and a circular bench saw to cut the plates, according to specific demands.

Regarding the time distribution of the production activities, in both cases, they are proposed in such a way that the EPS grinding process and the plate production take place non-simultaneously. That is, of the 20 working days considered in a month, it is estimated that the EPS grinding will take place during the initial 5 days of the month and in the remaining 15 days the assembly of the plates will be carried out, which includes the mixing, casting, pressing, and storage processes. The plates are unmolded approximately 10 days after the casting is done. Figure 3 presents the process distribution diagram for a month, assigning several people for each process and considering a total of 4 people for case 1 and 12 people for case 2.

DETECTION OF THE MOST CRITICAL PROCESSES

The criticality level of each process was analyzed using the following variables: (a) dependence on the technical characteristics of the final plates; (b) dependence on external factors; (c) probability of setbacks, due to delays or faults; and (d) impact of these setbacks on subsequent processes. Figure 4 summarizes the results of each process and its corresponding level of criticality.

The analysis shows that the most critical processes are the separation of EPS waste in the city and obtaining or receiving of raw materials. Both processes can be

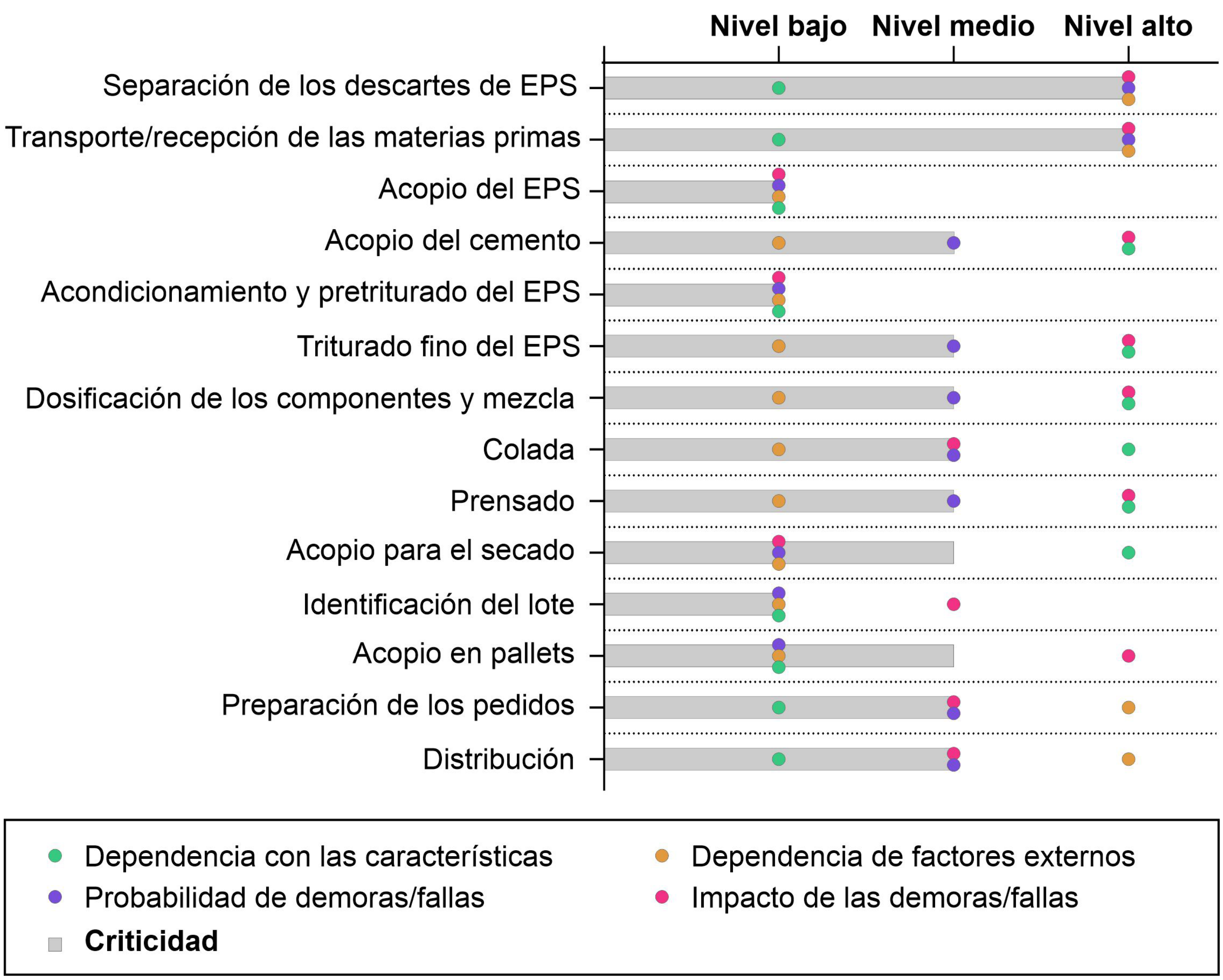

Figure 4. Level of criticality of the processes involved in the manufacture of alternative thermal insulation plates. Source: Preparation by the authors.

affected by external factors and depend to a large extent on the management needed to carry them out. The separation of the EPS, if done by collection in the green bag, requires handling with the city government under analysis. For the installation of clean points, engagement with private or public institutions is essential. It is possible that obtaining the raw material by the two previous modalities requires a classification process to separate the materials that are not of interest. The third option for obtaining EPS is contact with large waste generators, from the pharmaceutical industry, laboratories, and the household appliance industry, among others. This last way simplifies efforts, allowing obtaining a large volume of clean raw material in a single load.

The medium criticality processes are cement collection; fine crushing of EPS; dosing of components and their mixture; casting; pressing; piling for drying; piling on pallets; preparation of orders; and the distribution of the plates. These processes can lead to delays capable of interrupting later processes or generating the production of final plates that do not meet the required specifications. Therefore, the cement for the binder must be properly stored inside to ensure its durability, as well as the quality of the resulting plates. Another important aspect is the fine grinding size of the EPS used, which determines the technical characteristics of the plates. It is essential to regularly check the output granulometry of the crushing machines used, especially if self-built models are used. Regarding the dosage of the material's components and its mixture, these must be weighed or measured and added in order: water, cement, and very gradually the EPS grains. It is necessary that the mixing is done suitably so that each of the grains is completely covered by the binder and the correct cohesion and final strength are ensured. When casting, it must be taken into account that the volume placed in each of the molds is constant. In addition, a mold release agent (reused oil) must be applied to the molds, prepared in profiling, and placed on a plastic film. The plates are finished by forming with wet pressing; an aspect where it is very important that the compression ratio (final volume/initial volume)

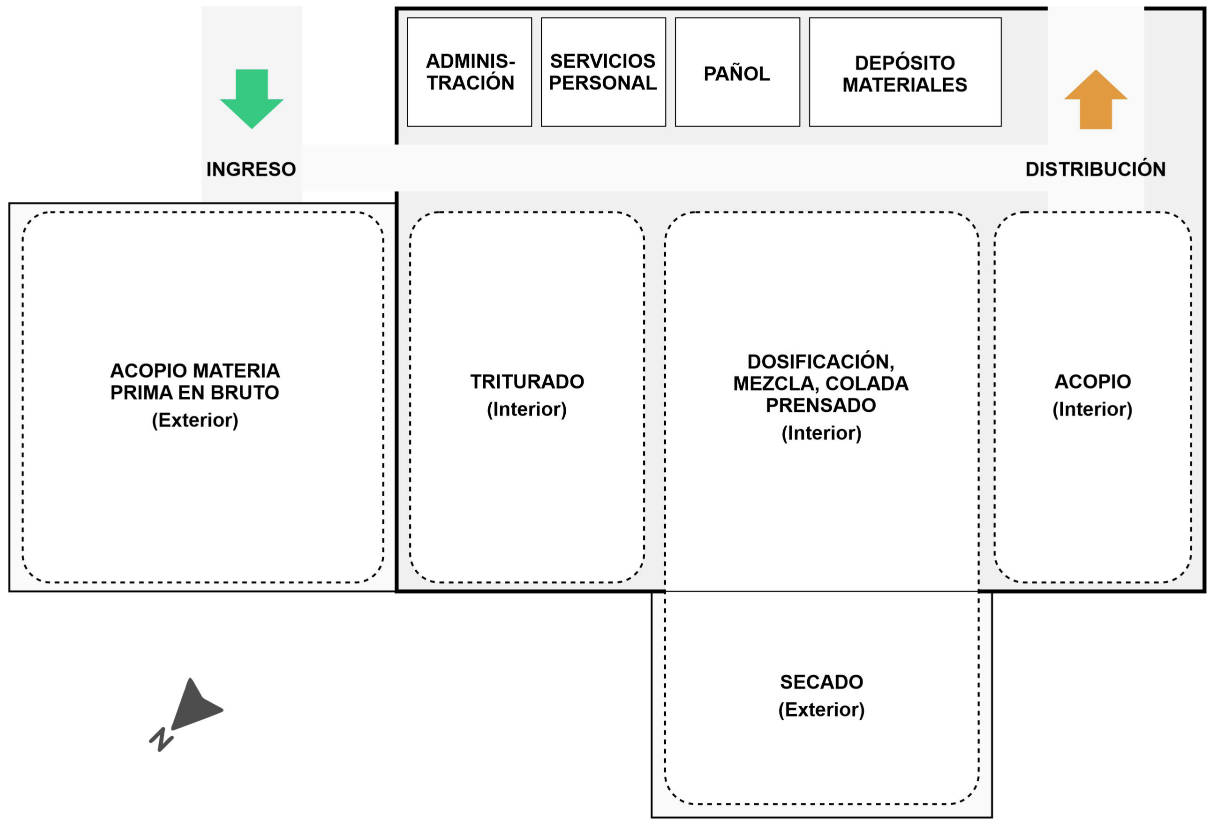

Figure 5. The organizational layout of the production facility. Source: Preparation by the authors.

is as indicated and is kept constant. The piling of the plates for drying, as well as their arrangement on pallets, also requires special attention. The plates must be placed horizontally and it is advisable to avoid large stacks. Finally, the preparation of the orders and their distribution imply adaptation for each order and its piling, which must be done properly to guarantee that the plates arrive in the best condition to the end user.

The processes with the lowest criticality are the storage of raw EPS waste, its revision and pre-crushing, and the identification of the batches. In fact, if these procedures are delayed or not performed properly, there are very low or no impacts on the process and the end product.

ADAPTATION TO THE PARTICULAR CASE OF APPLICATION

At a local level, the venture has been launched at the Sol-Plat recyclers cooperative located in the city of La Plata, Buenos Aires, Argentina. The plate production activity is in one of the cooperative's productive spaces, where the compaction of the waste is also done. At the end of 2020, the production layout was started by having: a) a low-cost crushing machine, which replicates the model mentioned by the NGO, Punto Verde de Tandil; b) a serially manufactured aluminum molding system of 1 m x 0.5 m x 0.05 m; c) a 120 l electric concrete mixer; and d) the raw EPS, which comes from a laboratory located in Greater Buenos Aires, a large waste generator, which provides about 270 kg of waste. At present, there is no workforce dedicating itself exclusively and sustainably to production tasks, especially because the income of the cooperative's members depends on the sale of waste that has traditionally arrived processed. This is why progress in the execution tasks is gradual, both by the research group and by the cooperative group. This is a key factor in the venture's management because the cooperative's members are social actors in a state of vulnerability, who require state support. Due to the characteristics of the production process, the potential that the venture can be developed by organized groups of women is considered, thereby generating ventures with a gender perspective.

So far, it has been possible to start the production of plates on a small scale, determining a minimum viable product, and the raw material that has been received on various occasions, from the large generator, has begun to be crushed. Based on the gross raw material obtained so far and the current investment possibilities, it was defined that to continue with the development of the venture, the following is required: i) the participation of 4 people responsible for the production tasks; ii) the use of 2 low-cost crushing machines; and, iii) the use of a press for compressing the mixtures. Under these conditions, it is estimated that 270 m^2 of plates will be produced per month, considering the task distribution, and the production facility diagram presented in Figure 5. The diagram includes performing certain activities inside and outside the facilities, to maximize the use of space.

CONCLUSIONS

This research presents an original contribution in terms of the analytical study of the production processes, the critical factors, and the relationships between actors needed to generate a production venture arising from a scientific-technical technological development with social and environmental impact in an Argentine locality. The results have been presented considering the suitability of the product for its scale production and the activities and processes required for the formation of an enterprise based on the manufacture of alternative thermal insulation plates. The design of the production processes was the result of the participatory action research method that involved members of a local recyclers cooperative. In the exchange, improvements and contributions were generated in the developed product and, therefore, in the production process. This research in coordination with local actors allowed reaching the conclusions set out below.

First of all, it was possible to make the adaptations of the product for its manufacturing at scale and commercialization considering economic, technical, and technological aspects. This meant making modifications to the previously developed material, replacing used components, and modifying production processes to improve performance at a lower cost.

Secondly, the supplies, services, and resources for the viability of the venture were described, considering the availability of raw EPS, raising two possible waste supply cases. In each case, the key machinery, related to crushing and mixing, was identified in particular to achieve the required production capacity. It was also observed that, although the required labor increases depending on the waste supply, the monthly planning of production processes could be kept. It is important to emphasize that both this production layout and the aforementioned resources are understood as a way to materialize the project, rather than as exclusive recommendations for the venture.

On the other hand, a methodology was proposed to determine the criticality levels of production processes, which can be applied to other cases and regions. In the local context, and according to the study and classification of each of the productive processes, the provision of raw material and its sustainability over time are the most critical processes for the venture. In this sense, it is considered that the best way to provide raw materials is the contact with large waste generators. At the same time, it is advisable to store an excess amount of raw material to mitigate the impacts of periods when less waste is received.

The work done in the local cooperative can be considered one of the ways to start the productive experience on a larger scale. The instances of progress achieved were established, as well as aspects that will have to be worked on and resources that will be required for the experience's growth. In this context, the organization of the production facilities was outlined and the necessary human and material resources needed for this venture were proposed.

The venture being developed at the local level proposes a way of reusing EPS that generates job opportunities for vulnerable and unemployed sectors through the social and solidarity economy. From this approach, it is understood that, although the product seeks an innovative solution that reaches the paradigm of the circular economy, the substitution or elimination of certain components and processes is desirable to maximize the reduction of environmental impacts.

What is presented in this research implies a series of inputs to replicate the experience, as well as providing relevant contributions for the organization and generation of production facilities in other contexts. Replicating the experience in other contexts, regions, or countries where these problems are considerable, means the generation of employment, the contribution towards improving the habitat quality, the reuse of EPS waste, and, ultimately, the reduction of environmental impacts.

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