

GMIT and the systematic environmental assessment of secondary materials

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Abstract. This article reviews the development of a digital inventory tool developed specifically for secondary material markets. Unlike other available inventory tools, this tool aimed at including environmental assessment features, that would allow warehouse managers to have an estimation of their environmental contribution associated to their sales performance without having to engage environmental experts regularly. The resulting open source software allows to keep an inventory of items available at the warehouse, export to an online shop and generate reports of the sales and environmental benefits of reusing some of the secondary materials sold. This article explains how the tool was developed, how the simplified LCA calculations were done and integrated to the tool, the difficulties encountered when compromising ease of use with the need for reliable data to do the environmental calculations, and reflects on the reliability and scalability of the developed tool.

Keywords. Secondary materials, Urban Resource Centres, simplified LCA integrated to a digital inventory tool, open source, Idemat, online catalogue

1. Introduction

Secondary materials (i.e. scrap, residues and/or products recovered at the end of their useful life [1]) are largely available in cities, but are usually discarded before reaching new users. The push for Circular Economy (CE) in current European regulation suggests to promote waste prevention practices, keeping materials in society through reuse, repair, re-manufacture and recycling before finally discarding them [2]. The concept of Urban Resource Centres was developed by the Partnership on CE, of the Urban Agenda for the EU, to name the physical locations and network of actors that currently enable waste prevention through preparation for reuse, repair and relocation of discarded materials [3]. Such centres help facilitate sustainable consumption practices and make secondary material available at a reduced price, but also have a capacity building role, by helping to develop and share knowledge that is necessary for material recirculation [4]. Two studies that reviewed organizations that could be considered Urban Resource Centres, covering in total 25 different initiatives, concluded that even though there are several



different approaches to enable waste prevention, the cases reviewed had similarities that allowed to draw a common framework and identify shared barriers and success factors. One thing that was clear in all the reviewed initiatives, was that they lacked the means to measure and demonstrate the impact of their operations in a effective way [3], [4].

The [Haus der Materialisierung](#) (HdM) in Berlin can be considered an urban resource centre. There, more than 20 pioneer organizations collaborate to provide access to secondary materials, shared tools and products, open workshops and teaching sessions [5]. Three of the HdM pioneers are secondary material warehouses (i.e. [Material Mafia](#), [Kunst-Stoffe](#) and [Berliner Stadtmission](#) [6]–[8]) with diverse materials and products on offer. Each of them uses their own inventory system and, just as in many other secondary material markets, these inventories have been developed on-the-go, in parallel to their activities. Also, several examples of online secondary materials catalogues exist (e.g. [Genbyg](#), [RotorDC](#), [Restado](#) [9]–[11]). However, they all have yet to include a systematic environmental assessment of their activities and materials.

While large companies are widely using digital solutions for warehouse management systems as part of their Enterprise Resourcing Planning-Systems (ERP), smaller CE actors like the pioneer organizations in the HdM are lacking resources and knowledge to use digital support tools to monitor material flows and measure their impact. To support the professionalization and communication of such pioneers, the project “Practical implementation of Circular Economy in an Urban Context” (Reallabor Zirkuläres Wirtschaften im urbanen Raum) was done. The project is a collaboration between Circular Berlin, Zusammenkunft Berlin, Material Mafia, and TU-Berlin. It was funded by the German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt – DBU), and aims to support and document the establishment of the HdM during its first three years of operation [12]. One of the core deliverables of the project is a digital inventory tool specialized in secondary material markets. The main requirements for this digital inventory tool, were that it would be simple to use daily at a material warehouse, allow to connect to an online web-shop, and be able to provide an estimated environmental assessment of recirculating secondary materials, rather than tapping into a virgin source. To estimate the environmental contribution of secondary material recirculation, simplified Life Cycle Assessments (LCA) were done for a list of ten secondary materials recurrently available through the HdM pioneer Material Mafia. The environmental effects of selling these items were estimated, providing an environmental indicator per sale unit. The results of these estimations were then integrated to the secondary warehouse inventory tool (GMIT for its acronym in German – *Gebraucht Material Inventar Tool*), thus allowing to aggregate the environmental effects of sales over periods of time.

This article discusses the challenges encountered developing the GMIT, the lessons learned and the results obtain so far. The article is structured as follows: Section 2 describes the development of the GMIT, accounting in section 2.1 for the warehouse inventory needs and the categorization possibilities, in 2.2. for the connection to an online-shop and in 2.3 how the simplified environmental assessments were made. Section 3, discusses the results obtained, describing the current state of the tool (3.1), its reliability (3.2) and potential for scalability (3.3).

2. Developing the GMIT

The development of the GMIT started with the project partners collecting their ideas and requests for the tool in a software requirement specification (SRS) document. The SRS defines the three core functions of GMIT to be: an inventory system, an online shop, and an environmental assessment feature for secondary material warehouse management [13]. The project partners involved had different roles in the development of the GMIT: Material Mafia, as the secondary material warehouse manager would provide input regarding warehouse processes, Circular Berlin was involved to do the back end and front end programming, while TU Berlin would provide help with the data model and environmental assessment aspects. The GMIT development process started in May 2020 and started to be used by Material Mafia for keeping the warehouse inventory in November 2021.

2.1 Secondary warehouse inventory needs, data collection possibilities and relevant categories

To understand the warehouse management needs, the management practices of Material Mafia were described and used as a starting point. The process flow was described as structured into four main phases: Getting offers from material suppliers, transporting and receiving goods, offering the materials to clients, and finally selling materials. The individual phases of this process were described in the SRS with special attention given to describe who provided information and how it would be collected. The information provided by the supplier determines if the material will get accepted, while more information about the material might be needed at the moment of offering and selling the material. A distinction was made as to whether this information could be generated by the warehouse manager, if it is provided by the material supplier or if a database would be needed. The idea behind using a database was to bundle all relevant material information and convert it into a warehouse-specific material database, so that the warehouse manager would not need to input all the known information of a material, each time it was received. This material database (also referred to here as the knowledge database) would be the basis for the inventory of recurrent materials in GMIT, and would collect available market information and additional properties of those specific materials. In addition to facilitating inventory creation, the environmental information associated to those materials would be pre-filled into the knowledge database, making it available through the inventory to the online store and eventual reporting.

2.1.1 Data model with relevant categories for the material database. The development of the data model started in June 2020. The original intention was to design these code lists and categories in such a way that they could be used to establish a link between existing product and material categories of the EU market statistics to the EU waste categories. This was expected to make processes at the secondary material warehouse trackable into the current statistics, and therefore more easily communicated. So, it was expected to have a material categorization (related to waste categories) and a product or article categorization (related to market or production categories). Both classifications would be done in two levels to facilitate assignability in the GMIT.

To find an adequate and transferable material classification, the European Waste Catalogue [14] and the Idemat database [15] were considered. The data sets of the existing inventory lists from Material Mafia, Kunststoffe e.V. and Restado were used to select what categories were most relevant. This approach initially resulted in long lists of redundant categories that did not make much sense for the practitioners, given that the existing inventory lists were inconsistent in how they described the elements (e.g. door, wood, indoor flooring).

Given the inconsistency in how secondary materials were described by the different warehouse actors, it became necessary to define some terminology: Anything coming into a warehouse was named an item and a conceptual framework was used to provide a hierarchical understanding for potential secondary items. This framework, developed by a previous research project establishes the relation between: flows > products > components > materials > elements [16]. It was important to note that some materials might be uni-materials (having only one type of material component, e.g. PVC pipes) or multi-materials (with more than one material component, e.g. composite materials such as Aluminium Composite Panels). From this conceptual framework, the most relevant elements for the case of secondary warehouses was the distinction between products and materials, therefore the data model would provide categories for product and materials independently, making it possible to define an item as a product, with some materials.

However, to define the product categories a harmonization with EU market categories for products proved to be challenging, and not make much practical sense. Market statistics categorize elements by their economic branch or industry. While some products are very specific to an economic sector (e.g. concrete used for construction, electronic equipment for film), others are used in many ways across several sectors (e.g. textiles, furniture, containers). This economic sector differentiation was deemed to have no practical implications for secondary warehouse management, and provided little ease in categorizing the elements to be recirculated.

After several iterations, some product categories were determined, that made sense for Material Mafia, so that they could be used to pilot test the GMIT. Specifically, items can be defined as products for construction, props and decoration, lamps and lights or furniture, based primarily on their potential future areas of application. These categories were defined by Material Mafia, since they make sense to offer the available items to new customers grouped in this manner. Then items can be associated to the material categories plastic, paper, metal, glass, wood, paint, and textiles. Each of these material categories have sub-categories to distinguish for example what type of wood or textile it refers to. In practical terms, both product and material categories are used to organize the items on the Material Mafia website, with the only difference that if a material category is selected in the GMIT, the tool prompts the sub-category list for further specification if desired. Each item can have associated several categories at once, for example, a chair would be categorized as a furniture product, with the materials wood, sub-category pinewood, and textile, subcategory upholstery fabric. It was concluded that in the case that other initiatives would want to use the GMIT, they would have to adapt the category lists to their requirements during an initial set-up phase. To facilitate the calculation of the environmental impacts for other initiatives, it is recommended that the material sub-categories they choose from are based on the material lists available on the Idemat database for environmental impacts (more information about this can be found in section 2.3). Currently the GMIT allows users to create new items inputting only a title and description, all other information fields can be left empty if desired, to facilitate quick inventory creation. In practice Material Mafia tends to use as many information fields as possible, meaning that the items are normally associated to at least one category.

2.2 *Online store*

Since online stores for secondary materials already exist, the first strategic consideration was how to generate sufficient visibility and reach for the materials in the HdM. The project group therefore agreed to collaborate with the existing online store Restado [11]. Restado is a company (founded in 2016) that specializes in brokering used building materials in Germany, with a big portion of their offers in the Berlin area. The cooperation between the project partners and Restado offers many advantages and synergies for all parties involved, such as the use of an existing trade structure, the additional exposition for the material offer and the potential of reaching new customers. The cooperation was defined so that a specific interface to the online store Restado was integrated into the program architecture of GMIT through an application programming interface (API) specification, making it possible to offer materials directly to the online store. The GMIT allows to publish items to the Material Mafia website, as well as to the Restado store. The Material Mafia website uses the categories defined in the tool to generate the online catalogue, however, the Restado store uses different categories, so the option was to publish the items uncategorised on Restado, but including in the description the relevant available information about the items. The implementation to the online store was recently deployed in the beginning of May 2022.

2.3 *Simplified Life Cycle Assessments with Idemat*

To estimate the environmental contribution of secondary material recirculation, simplified LCA calculations were performed for a list of ten items recurrently available through Material Mafia. The detailed explanations for the environmental calculations used in the GMIT are described in a project report available through the TU-Berlin repository [17]. This section will provide some of the main takeaways from that report.

The environmental estimations done were calculated using a simplified or “Fast-Track LCA” procedure. Such simplified LCAs do not comply with the ISO 14040-44 standards, but are commonly used by designers and companies to orient themselves regarding decisions made early in the design stage, allowing them to improve designs to reduce environmental impact [18]. These simplified LCAs are also known as the Phillips method, or a screening LCA, and it is indeed the first step into performing a full LCA [19]. The simplified LCA for the GMIT was done using the Idemat 2021 database for environmental impacts. This database is made openly available, with yearly updates, at the Eco Cost

Value website [15]. It was decided to present the environmental assessment results using both eco-costs and carbon footprints for each item included in the study. Carbon footprint (measured in kg of CO₂eq emissions) because it is the most commonly used single issue indicator, widely popularized by the climate change mitigation discussion. And eco-costs, because it is an aggregated environmental indicator calculated using the marginal prevention costs for mitigating environmental impacts in the EU, resulting in a single environmental cost measured in euros [20]. Because it is measured in euros, it can be related to the sale price of items and highlight the additional contribution that reuse activities bring in terms of mitigated externalities.

The system used to describe the secondary material warehouse operations is shown in **Figure 1**. Material reuse, facilitated by secondary material warehouse services, prevents waste generation of the items donated for reuse, but does so only at that moment. Eventually the items will be discarded, so this avoided waste generation is considered more precisely as a postponed waste generation. What is considered the environmental contribution of secondary material reuse, is the avoided production of these materials from virgin sources, for them to be used in their second application.

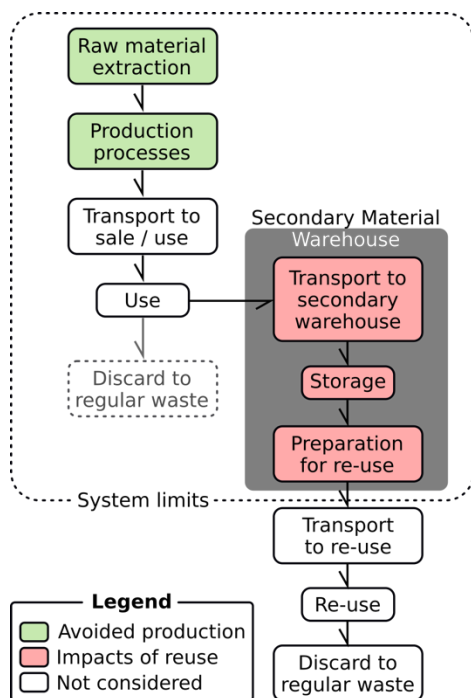


Figure 1. System diagram used in the simplified LCA of a secondary material warehouse. The foreground processes that incur in environmental impacts are considered to be the operations at the Secondary Material Warehouse (over grey background). The background processes are the environmental impacts embedded in each item, which in this model are considered as avoided impacts since the items are reused. Source [17].

The environmental impacts of facilitating for reuse are considered to be the transport to the warehouse, storage and any preparation for reuse operations that may be needed. Storage expenses were considered to be electricity and water use, and it was estimated to obtain an average impact factor per item sold, allocating the resource use for storing evenly among 800 stored items. In the case of transport, a maximum transport distance was used to provide an impact factor, that then could be multiplied by each items' weight, while the preparation for reuse estimations were done uniquely as estimations of cutting items (with their corresponding tools) in the case that these were made of metal, wood and plastics. This estimation means that it is assumed that all items made from those materials would be cut, even if the case might be that they can be sold as is, with no cutting needed.

The idea was to integrate environmental estimations to the GMIT using the warehouse specific knowledge database (as mentioned in section 2.1). This knowledge database is basically a list of items for which most of the information and characteristics have been pre-filled (including their eco-cost and carbon footprint) before defining if there is an available quantity at the warehouse. When the warehouse manager creates a new item on to the GMIT they can choose to select an item already existing in the

knowledge database, and import all the related information. To test the knowledge database idea, a list of ten recurrent secondary items were chosen as a starting point for the assessments. These items are all available to Material Mafia on a regular basis (meaning that they can basically be picked up on demand), so they are constantly available in the stock of items that the warehouse has for sale. Of the ten items four came in a range of sizes, so the calculations were done to include all the sizes available at the warehouse. The estimations were done for a sale unit of each item, allowing to associate the reported sales of the recurrent items, to the respective environmental effect of reusing these items. **Table 1** shows the resulting data inputted to the GMIT.

Table 1. Recurrent items analysed, their sales unit, weight and the resulting eco-cost and carbon footprint estimations.

Item name	Unit	kg	Eco-cost (euros)	Carbon Footprint (kgCO ₂ eq.)
Pine wood wall	m ²	10.40	-2.58E-01	-8.27E-01
Molton fabric	m ²	0.30	-2.50E+00	-9.05E+00
Molton w/eyelets	m ²	0.34	-3.20E+00	-9.44E+00
Nessel	m ²	0.20	-1.65E+00	-5.93E+00
Foam 60mm	m ²	1.20	-1.60E+00	-3.20E+00
Foam 80mm	m ²	1.60	-2.14E+00	-4.37E+00
Foam 100mm	m ²	2.00	-2.69E+00	-5.53E+00
Acrylic glass 3mm	m ²	3.57	-4.09E+00	-1.31E+01
Acrylic glass 4mm	m ²	4.76	-5.47E+00	-1.76E+01
Acrylic glass 5mm	m ²	5.95	-6.85E+00	-2.20E+01
Acrylic glass 9mm	m ²	10.71	-1.24E+01	-3.99E+01
Alu Dibond 2mm	m ²	2.90	-3.33E+00	-6.52E+00
Alu Dibond 3mm	m ²	3.80	-4.38E+00	-8.64E+00
Alu Dibond 4mm	m ²	4.75	-5.49E+00	-1.09E+01
Alu Dibond 6mm	m ²	6.60	-7.65E+00	-1.53E+01
Offset printing mat	unit	2.00	-4.56E+00	-1.07E+01
Plastic barrel, 30L	unit	2.20	-2.57E+00	-5.45E+00
Plastic barrel, 60L	unit	2.20	-2.57E+00	-5.45E+00
Plastic barrel, 120L	unit	4.30	-5.28E+00	-1.13E+01
Plastic barrel, 150L	unit	5.40	-6.70E+00	-1.43E+01
Plastic barrel, 220L	unit	7.60	-9.54E+00	-2.04E+01
Metalic barrel, 210L	unit	17.30	-3.93E+00	-1.77E+01

The possibility of automating the environmental calculations to all items inputted to the GMIT was evaluated, but deemed unviable, given the amount of detailed information that the warehouse managers would have to input for each item. If this was desired, for each item it is necessary to define the materials it is made of, the production processes it endured and the associated weight per material type. Depending on the production processes, it might be necessary to know other dimensions of the item, such as its size or surface area. The time needed to gather and input this data was deemed unrealistic for the everyday context of a warehouse. Therefore, to build a knowledge database with all the available information for the recurrent items was considered a better option. Currently the GMIT does not automate any environmental estimation. Once the calculations were done by the research team for the recurrent items, these were inputted to the tool as a new material including all available item information, and were marked to be included in the knowledge database. Then, when creating a new material, the warehouse manager can import recurrent items from that database, and have the associated environmental estimations.

If one would still contemplate the possibility of automating this process for the best case scenario, in which the item to be imputed is a uni-material that corresponds to a material listed in the Idemat database, the weight of the item, or its sale unit, would still be needed. The GMIT would need to be developed to identify this particular case, to then multiply the corresponding environmental indicators by the weight of the sale unit to generate the indicators associated to the item on the inventory. In such a case, the researchers suggests that the environmental estimations done should be based solely on the material extraction avoided, not including the production processes associated to it, to minimize the amount of data needed. If calculations have been done for a warehouse specific knowledge database, the environmental costs of warehouse operations and preparation for reuse could be also included to potential automated estimations. None of these suggestions for automation have been done in the current version of the GMIT and they were deemed beyond the initial scope of this project.

Nonetheless, it is recommended that other initiatives that wish to use the GMIT database use the material categories and material types available on the Idemat database, in order to facilitate doing the environmental calculations for the recurrent items they define, when building their own material database.

3. Discussion of the lessons learned and results so far

The first takeaway lesson, is that it is extremely difficult to develop software by a multidisciplinary team that has little or no knowledge in software development. Initial ideas of what the software could or should do varied greatly, even among the project team, including conflicts between what would be useful in a everyday use situation at a warehouse, and what information would be needed to relate to readily available statistics and provide an environmental assessment. Additionally, because warehouse users are not often familiarized with the information needed to provide environmental assessments, it is difficult to ensure that they follow the steps needed to guarantee input data quality. That said, despite the difficulties and delays the GMIT development has had, it is completed according to the initial requirements.

3.1 *Current state of the tool*

The GMIT is currently released under the MIT open source licence, and published on the Circular Berlin GitHub account [21]. The GMIT can therefore be used, adapted and appropriated by other reuse actors as they see fit, with the condition of preserving the license and copyright notice.

Since November 2021 the GMIT has been used internally by the Material Mafia to do the inventory, and register sales. shows how warehouse managers see the inventory list on the GMIT. A first environmental reporting on the activities of the Material Mafia was presented in March at the DGAW conference in Dresden. The contribution reported on the results after using the GMIT for two months, collecting data on 426 sold items, resulting in a total environmental saving of 745 € eco-costs, or 1,810 Kg CO₂eq. through the sale of the defined recurrent items [22].

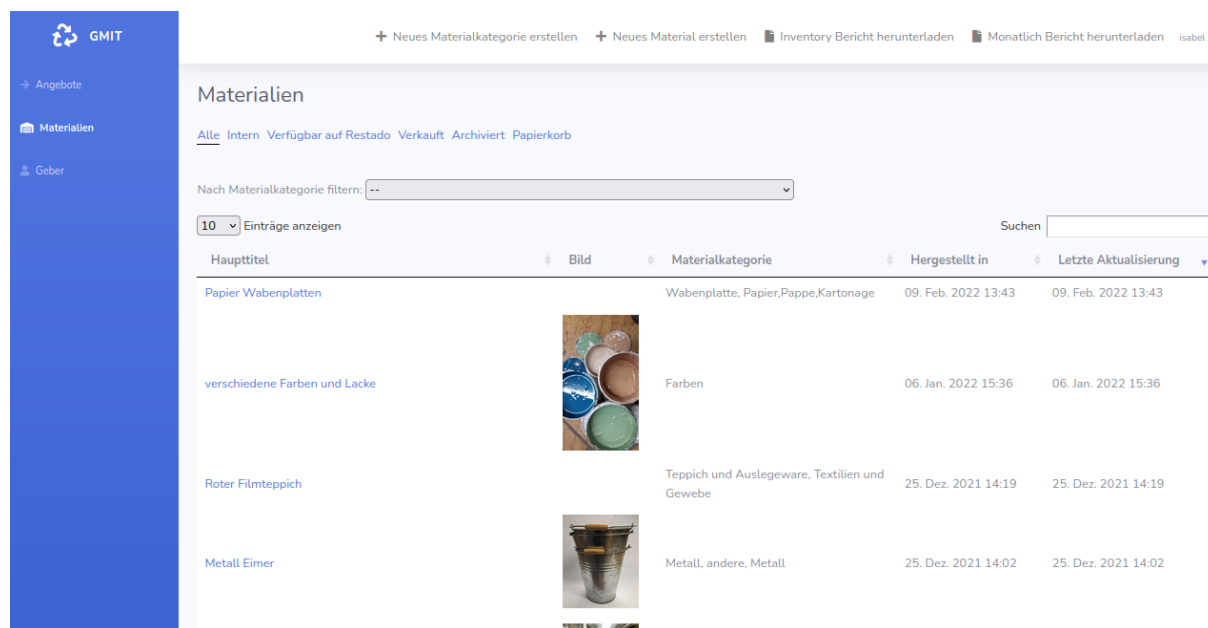


Figure 2: Screenshot of the Inventory catalogue on the GMIT, as seen by a warehouse administrator. A user can filter by material category if desired, and all the listed items are organized in those that are only for internal used, those which are available on Restado, those that have been sold, archived or deleted. On the left frame, users can navigate to the material offers that have come in, and information list from material providers. On the top-right menu, users can choose to make a new material category, make a new item, download the inventory list or a monthly report.

Given the delays that the final deployment from the GMIT to the web-page and online-shop Restado, these features have only recently started to be used, with some initial discrepancies in the material lists from the GMIT and the open portals. These issues are being addressed at the moment of writing. The use of the eco-cost information has up until now only been used internally in the GMIT and to generate performance reports. This has not been made public to consumers or potential buyers, nor it has been actively communicated by the initiative. Mainly this is due to the project team and the initiative still resolving final inconsistencies to start using the tool to its full capacities. It is expected that once that is clear, Material Mafia will take advantage of the environmental information it has of its activities, and communicate it to clients and other interested actors.

3.2 Reliability

Simplified LCA estimations are not a thorough calculation of the environmental effects of any process. Neither are professional LCAs for that matter, always being a systemic abstraction of the phenomena they wish to assess. Professional LCAs do however reduce the uncertainties related to the calculations, by careful iteration and reliable data gathering. However, given the heterogeneity of secondary materials streams, their sources, how they are used and their conditions, it is most likely unpractical and uneconomical to do professional LCAs on such streams, given that the assumptions that will have to be made are already quite significant. Therefore, it was always beyond the scope of this project to provide full LCAs for secondary material warehouse activities, considering that simplified LCAs could provide a good enough estimation to for the purposes of reporting on these activities.

The reliability of a tool will always be defined by the rigour that the user of the tool has when working with it. In this case, the people working with the GMIT everyday are the warehouse managers, that have been part of the development of the tool and have an understanding of how it should be used to provide a good inventory overview that they can work with. They are however, less familiar with the requirements for the environmental estimations to be correctly estimated and registered in external

reporting. The GMIT includes eco-cost and carbon footprint estimations for recurrent items, but for them to appear on an item indexed on the tool, the item should be created by cloning a material from the knowledge database, which has this and other useful data already calculated and associated to the specific types of items. If the warehouse manager, in a rush inputs one of the recurrent materials by creating a new material and adding the information needed, then that indexed item will not have the environmental estimations associated to it.

During a quick review of the items on the tool at the moment of writing, it is clear that the process of registering items into the tool has been done with irregularities (e.g. not all indexed aluminium composite panels have associated environmental estimates). Unfortunately, when starting to use the tool, the managers were not completely aware of this step and have created regular items without importing the pre-calculated estimations. Therefore, the data of the current inventory, had to be reviewed once exported and harmonized to provide a more realistic estimation. The reporting that can be done based on irregular data will always be limited to the additional input errors. This input error should be handled, by teaching the warehouse personnel how to use the tool so that they minimize input errors for the environmental estimations, and/or by changing something in the graphic user interface (GUI) that may help prevent this double creation for recurrent items from happening. Unfortunately the project did not contemplate either of the above measures in the application, meaning that for the moment it is a known problem that needs to be assumed.

3.3 Potential for scalability

Given that the GMIT software has been developed open source, the hope is that it is adopted by other actors, that would tailor it to their specific needs. The categories available to define the items to be listed can be edited by a software manager in bulk, so that an initial set-up phase would also include defining the categories and items to be listed at the given warehouse. To benefit from the environmental assessment features, similar simplified LCAs would have to be done for the recurrent items other organizations define as relevant for them. All the information needed to do this has been developed and documented during this project and is available open source for people to use. However, understanding that these are quite specific requirements for the potential adoption of the GMIT tool, the project team envisions to promote the tool through a capacity building module, or by offering consultancy services to do the environmental calculations required for each institution.

The capacity building module would be a full day (or two half day) seminar. The project participants would help the organizations define the product categories that are relevant for them, identify the material categories from the Idemat database that they work with, and teach them how to do simplified environmental estimations, assisting them in this process for some of their recurrent items. With such a capacity building session, the participants would then be able to estimate the environmental effects of all of the items they would deem relevant, building with time their own material knowledge database. Such a capacity building module is to be developed based on the project results as future work.

Despite the project team's efforts of providing a user friendly easy to use tool, the environmental estimation requirements provide a complexity that cannot be avoided. The only feasible option found to conciliate these opposing requirements was to separate the environmental estimations as a process that has to be done, but optimize it so that it is done for the recurrent items warehouses sell, so that they can provide regular environmental overviews based only on the flow of their recurrent items. The simplified LCA calculations is a process that can be taught to warehouse managers, if they wish. That would enable them to be able to expand their database when possible, so they could overtime cover a larger proportion of their total inventory. On the other hand, if it is provided as a consulting service by people with this knowledge, the warehouse managers do not have to spend the time to learn simplified LCAs, but will be limited to the recurrent item list they request from the consultants.

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