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Research article

Preliminary assessment of solid waste in Philippine Fabrication Laboratories

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Abstract: Solid waste management is seen as a response to the increase in waste generation due to the rising number of industrial facilities. This includes digital manufacturing facilities such as Fabrication Laboratories (FAB LAB) which acts as innovation centers that generates prototypes using a common set of digital fabrication equipment. Previous studies have tackled with the environmental impacts of FAB LABs in a macro-level scale; however, there has been a lack of research specifically assessing the solid waste of laboratories, more so on Philippine FAB LABs. A baseline assessment study on FAB LABs of the Philippines could be applicable in future implementations of solid waste management systems through the crafting of institutional policies and guidelines for environmental sustainability. Using data gathered from 11 respondent FAB LABs, this study quantified percentage compositions of the waste according to waste type as well as the relative waste generated by each respondent FAB LAB. Machine availability was seen as a factor in waste generation resulting in the high generation of wood and plastic waste. Moreover, it was observed that earlier established laboratories generally had more active makers than recently established ones, hence the older FAB LABs statistically produced more waste. Approximately 53% of the overall waste produced was considered recyclable by Philippine standards but the actual recyclability of the waste was still undetermined due to the ambiguous criteria for recyclables and the lack of feedback data from recycling facilities. The initial findings suggest that an implementation of continuous waste monitoring, sufficient in-laboratory protocols, and coordination between FAB LABs and recycling facilities could improve actual waste recyclability and—by extension—the environmental sustainability of Philippine FAB LABs.

Keywords: Fabrication Laboratories; environmental sustainability; solid waste management; digital manufacturing; solid waste assessment

1. Introduction

Fabrication Laboratories (FAB LABs) are small-scale laboratories that enable invention and innovation by providing access to tools for digital fabrication to the general public. Operating in varying managerial configurations, these FAB LABs are being operated in key locations around the world either as a private entity, a government project or as a public-private partnership. This is achieved using equipment capable of producing tangible prototypes from both three-dimensional and two-dimensional digital designs [1,2]. Computer Numerical Control (CNC) milling machines, laser cutters, and 3D printers are some of the many tools that are integral to the fabrication of the said designs [3]. FAB LABs often operate under the culture of the 'Maker Movement'—where individuals are encouraged to not only be a consumer but also a maker of creative products. This promotes Do-It-Yourself (DIY) tinkering and invention by providing interested makers with the capability of digital manufacturing [4]. Raw materials are the base resources in any kind of manufacturing and fabrication [5]. FAB LAB machines, in particular, utilize materials of plastic, paper, metal, and wood in their production processes [3,6]. A portion of these materials inevitably get turned into solid waste, and this results in waste becoming a by-product of the entire process [7]. Solid waste constitutes any non-liquid and non-gaseous garbage from facilities with industrial, commercial, mining, agricultural, and community activities [8]. Its rate of generation has been increasing due to the continuous rise of urbanization and industrialization around the globe [9]. Hence, solid waste management is seen as a response to ensure environmental sustainability despite an increase in industrial facilities [10]. The regulation systems involve the control of the generation, storage, collection, processing, and disposal of solid waste [11].

For FAB LABs, waste generation is influenced primarily by the involvement of the maker. In a greater scale, material suppliers, technology developers, and product investors have an indirect impact on the laboratories' waste production and recycling [12]. Since all kinds of manufacturing operations generate solid waste [13], there is a need for digital fabrication makerspaces such as FAB LABs to assess their waste outputs to implement solid waste management systems [14]. Proper solid waste management systems initially focus on the classification and assessment of the generated solid waste [15]. The waste of a particular establishment is classified into different types such as organic, paper, plastic, glass, metal, etc. [16]. The collected data is then assessed based on the efficiency of waste generation and waste recyclability ratio [17]. This, in turn, can then be utilized for developing a sufficient solid waste management practice for a particular facility. In other systems, the subsequent steps following waste classification vary due to differences in available technology, and resources at hand [16]. The economic category of a facility's country can also influence its waste management practices [18–20]. Developing countries, in particular, tend to neglect proper waste management [10]; often times due to profit maximization, workplace culture, institutional issues, and improper choice of technology [20,21]. If inappropriately handled, solid waste could result in environmental and public health risks; polluting the locality's air, soil, and water [22,23]. A common example of this would be the indiscriminate dumping of solid waste which contaminates surface supplies, stagnates water for insect breeding, and clogs drains resulting to flood [16,24]. Continued improper handling would eventually cascade into a population increase of disease-propagating organisms (e.g. mosquitos and rats), heightening the risk of potential disease in the local population [25–27].Conversely, the uncontrolled burning of solid waste and improper incineration practices could contribute significantly to urban air pollution [24]; further causing health and safety issues. These situations could be avoided through the appropriate use of solid waste management practices [28,29].

In the case of the Philippines, currently, currently there are 23 Fabrication Laboratories operating nationwide, where a portion of these labs focus not only on innovation and invention but on local entrepreneurship as well [30–32]. As with other Fabrication Laboratories, solid waste is a necessary by-product of their operations [2]. Although there have been several studies on the macro-environmental impacts of FAB LABs as a whole [2,6,33], research on the solid waste assessment of digital fabrication facilities of Fabrication Laboratories in the Philippines, is yet to be established. This paper aims to initially assess the generated waste from the Philippine FAB LABs where the waste data will be classified and quantified accordingly. Being preliminary in nature, this assessment study is limited to providing a more general picture of solid waste generation among selected Philippine FAB LABs. Implications of the results from this study could be used in establishing a waste monitoring scheme and create applicable solid waste management systems in the future, apt for improving the environmental sustainability of Philippine FAB LABs. In addition, long-term implications could include the ability to promote more sustainable operational models for other FAB LABs in the country.

2. Methods

2.1. Online survey

The study was conducted between March and May, 2019. Eleven FAB LABs were assessed from the original 23 operating laboratories in the country. A social media-based messaging platform was used in disseminating the overview of the current research to the project managers. The researchers created a questionnaire as a survey instrument derived from previous studies' waste assessment survey tools [34,35]. The instrument comprised of questions regarding an estimate weight (Kilogram was used as the base unit of the mass) of the different types of solid wastes generated daily, and other supplementary information of the FAB LABs (i.e. available machines, starting date of operation, and affiliated institution). A pretest of the questionnaire was conducted in order to ensure that the questions were comprehensible and unambiguous. The data gathered through the online survey were accumulated and analyzed with the use of the Microsoft Excel program.

2.2. Classifying solid waste

The classification of the accumulated solid wastes was primarily based on previous studies of solid waste management systems [15,17,36,37]. Only a few categories of the reference guide were included in the current study as other types (e.g. medical waste, junk vehicles) were deemed inapplicable for FAB LAB production processes. The types of solid wastes included in this study are paper, metal, wood, plastic, embroidery and electronic waste. Furthermore, the only recyclable waste materials in the Philippines are: paper, plastic, iron, metal, glass, and aluminum waste [38]. The listed items in Table 1 are common waste by-products of FAB LAB production processes.

Table 1. Classification of Philippine FAB LAB waste by-products.

Recyclable	Paper	Photo paper	Waxed cardboards
		Tissue paper	Sticker paper
		Bond Paper	Newsprint
		Waste paper	Packing boxes
		Laminated paper, Magazines/Catalog	
	Metal	Metal shading	Permanent marker containers
		Broken end mills or bits	Paint cans
		Whiteboard marker containers	Scrap metal
	Plastic	Damaged tarpaulin	Adhesive tapes
		Polylactic acid (PLA)	Plastic acrylic
		Elastic Polyurethane (EPU)	Alcohol containers
		Styrofoam	Glue bottles
		Ethylene vinyl acetate (EVA	Paint gallon
		UV resin	Ink bottles
		Plastic gloves	Filament spools container
		Face mask	Acrylonitrile Butadiene Styrene (ABS)
		Disposable spoon/fork/cups	Thermoplastic elastomer (TPE)
		Packed lunch containers	
Non-recyclable	Embroidery waste	Cloth, Threads	Needle container
		Thread spools	Tracing materials (Pellon)
		Unused needles	
	Wood	Small pieces of medium density fiberboard (MDF)	
		Saw dust	
		Big pieces of medium density fiberboard (MDF)	
	Electronic waste	Unused electronic boards	Damaged soldering led
		Unused wires	Unused resistors

2.3. Quantifying solid waste

In quantifying the wastes of each FAB LAB, this study employed the percentage-based computation of waste composition. The weight of a solid waste type generated in a given month was divided by the total weight of the solid waste generated by the FAB LAB. Multiplying this with 100% yields a solid waste type percentage. This formula was used for determining the percentage composition of each respondent FAB LAB.

$$\text{Percentage of Solid Waste Type} = \frac{\text{Weight of waste type}}{\text{Total waste generated by FAB LAB}} \text{x}100\% \qquad (1)$$

Where the Weight of waste type *is the weight of a solid waste type (e.g. paper, wood, etc.) produced by the particular FAB LAB.* The total waste generated by a particular FAB LAB was divided by the overall weight of waste generated of all the respondent Philippine FAB LABs. Multiplying this by 100% yields a percentage value for a particular FAB LAB's waste contribution.

$$\text{FAB LAB Waste Contribution} = \frac{\text{Total waste generated by a FAB LAB}}{\text{Overall waste generated by all FAB LABs}} \text{x}100\% \qquad (2)$$

3. Results and discussion

3.1. Waste composition

The wastes generated from different FAB LABs were categorized into 6 types, namely: paper, plastic, wood, metal, embroidery, and electronic waste, respectively. These wastes are the result of the common raw materials that are being processed by the common set of FAB LAB equipment. Figure 1 depicts the percentage composition of the overall waste generated by all Philippine FAB LABs according to waste type. From this composition, wood by-products dominated the production of 43.36%, followed by paper wastes (25.57%) and 20.59% of plastics. Other waste contributors are composed of 6.63% metals and 2.03% electronic wastes; while embroidery wastes account for only 1.82% of the total production.

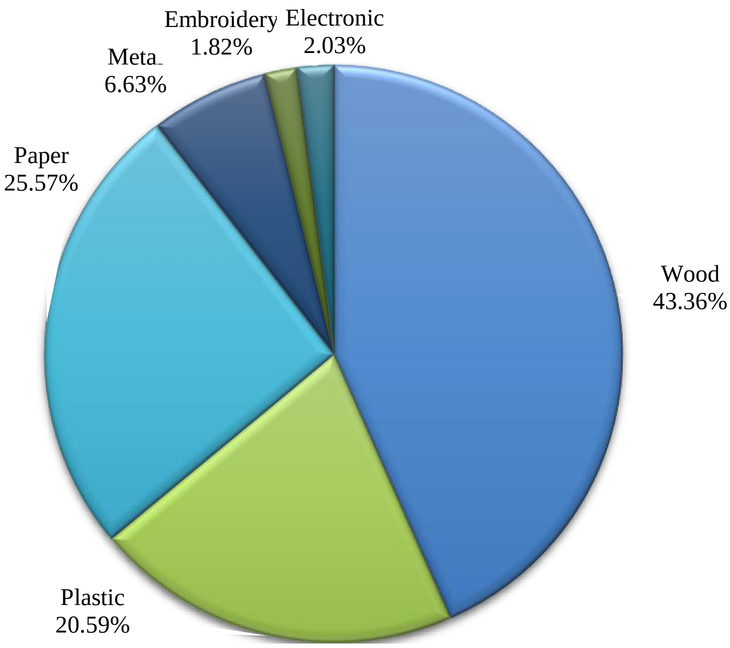

Figure 1. Composition of waste by-products produced by Philippine FAB LABs.

Based on actual weight composition, Table 2 summarizes the waste production according to monthly average weight. In a given month, a respondent Philippine FAB LAB generates 7.30 kg of wood, 4.30 kg of paper waste, 3.47 kg of plastic, 1.12 kg of metal, 0.34 kg of electronic waste, and 0.31 kg of embroidery waste, respectively.

Table 2. Monthly average waste production of each Philippine FAB LAB according to composition.

Waste Composition	Monthly Average Production (kg)
Wood	7.30
Plastic	3.47
Paper	4.30
Metal	1.12
Embroidery	0.31
Electronic	0.34

Wood constituted for the highest quantity of waste produced by Philippine FAB LABs in contrast to the waste produced by embroidery operations. This disparity of wood waste relative to other solid waste types could be attributed to machine availability and inefficiency of material usage. All respondents had machines that utilize wood as a base resource. Wood manufacturing processes are also prone to varying results due to their naturally inhomogeneous material composition [39]. This leads to repetitive production process until a sufficient quality of the product output is met. Such problem is prevalent in other production facilities that utilize wooden material as well [40]. Medium-density fiberboards are the primary wood material used in the laser cutter and CNC milling machine operations of the respondent FAB LABs [41]. Despite having a more consistent composition relative to other wood materials [42], makers are still inefficient to optimize spacing of the cut-out designs [43], thus the high volume of waste generation.

Paper and plastic follow after the wood waste in terms of the average weight percentage; (25.6% and 20.6%, respectively). A major portion of the overall paper waste was composed of paper products (e.g. bond paper) that have been discarded after an initial use for administrative and ideation functions of the FAB LAB being an innovation center. As with previous studies on solid waste assessment, paper generally constitutes a major portion of the generated solid waste [24,37,44]. Hence, it is unsurprising for FAB LABs to have a high paper waste generation. Meanwhile, some of the processes and machines of FAB LABs use plastic as their medium of model production. This is especially true in the case of the 3D Printers' plastic polymer spools and the laser cutters' plastic acrylic sheets. Small excess portions of plastic materials from production processes become unused and ultimately end up as waste [43]. Metal waste, embroidery waste, and electronic waste constitute a small portion of a FAB LAB's average solid waste generated. One reason for this is the minimal use of metal and electronic materials in the production processes. Moreover, the use of metal sheets in milling is relatively more hazardous than other materials [45]; hence, it is not commonly used. Embroidery waste constitutes the lowest average weight percentage. On equal volume, its material is lighter than wood, plastic, or metal. Additionally, this can be attributed to the fact that not all the respondent FAB LABs have embroidery machines available for use. The machine activities of the FAB LABs which in turn generate waste will be dependent on the expected varying outputs that will require specific kinds of raw materials to be processed by the available FAB LAB machines. Waste composition, therefore, is also influenced by the machine availability of the respondent FAB LABs.

Figure 2 shows the available and operational machines of each respondent FAB LAB. All of the FAB LABs have 3D Printers, Wood CNC milling machines, and laser cutters. The latter two machines generally use wood as their raw material. This can be seen as a cause for wood waste constituting the largest portion of the total waste generated. The combined 48 3D printers of the respondents generate plastic filament waste; contributing to the overall plastic waste output. Laser cutters have also contributed to the total plastic waste since they can use acrylic plastic sheets as raw materials. Therefore, potential waste generation rises with machine availability. Conversely, the absence of machines can become cause for low waste generation. Only 5 out of 11 FAB LABs have digital sewing machine. This—coupled with embroidery waste being generally lighter—can be seen as a reason for embroidery waste garnering the lowest percentage of the total waste composition. In a similar manner, only 4 out of 11 FAB LABs have Metal CNC milling. The lack of available machines, as well as the inherent hazard of milling metal, has resulted to a low 6.6% waste percentage of metal in the total waste composition.

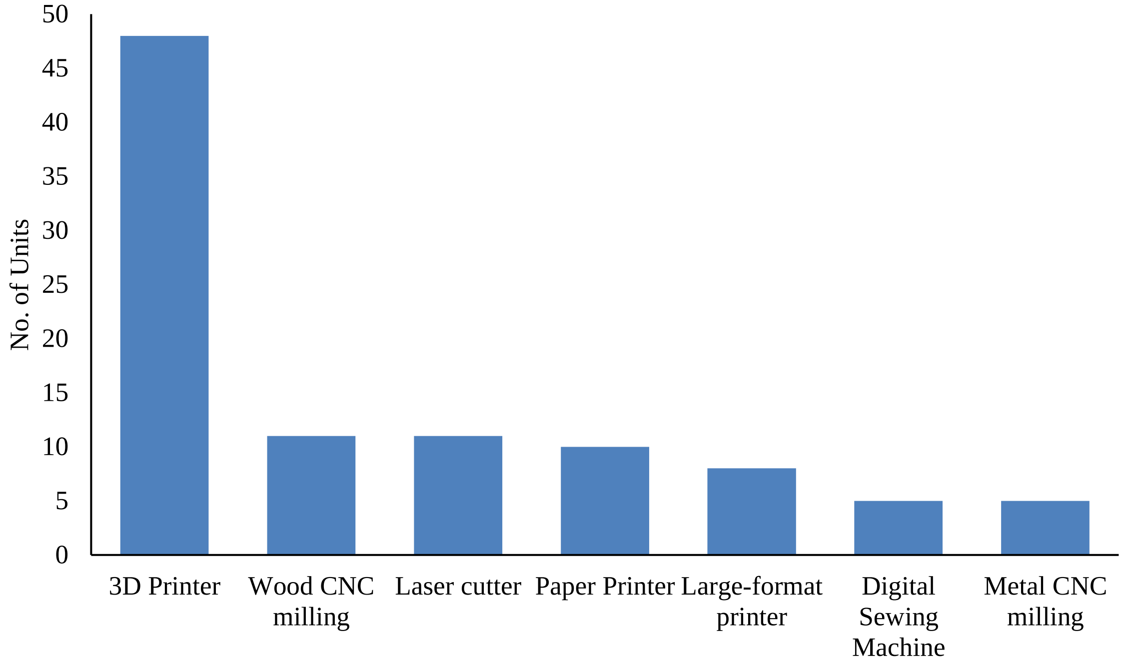

Figure 2. Summary of available machines and equipment in different Philippine FAB LABs.

3.2. Waste production

The 11 Philippine FAB LAB respondents produced an overall weight of 185.10 kg of solid wastes; comprising of paper, plastic, wood, metal, embroidery, and electronic waste. During the survey period, a respondent FAB LAB generated an average of 16.83 kg of waste. Based on Figure 3, it is shown that FAB LAB 'C' had the highest quantity of waste followed by FAB LAB 'J' while FAB LAB 'G' garnered the lowest waste quantity.

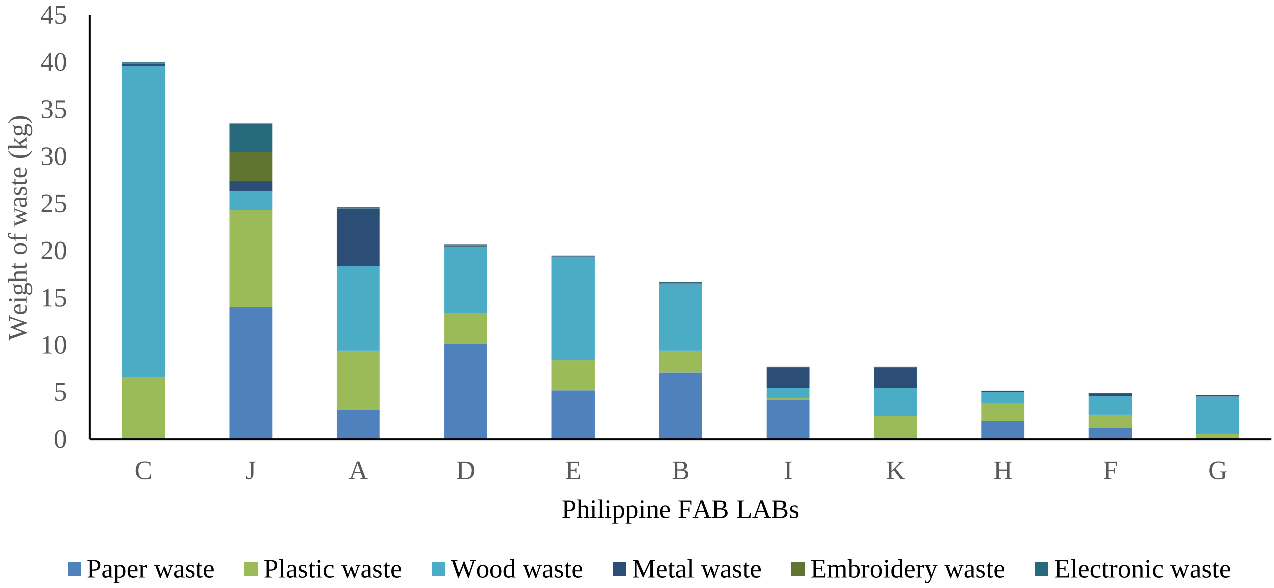

Figure 3. Distribution of overall solid wastes from different Philippine FAB LABs.

This disparity in waste generation could be due to the lack of active makers in their respective FAB LABs. Less usage of the machines consequentially leads to less generated waste [46]. As of this study's data collection, FAB LAB G has only been operational for a year. FAB LABs 'C' and 'J', conversely, have been operating for three years. Clearly, earlier established FAB LABs have had more time to develop their local maker community than later established FAB LABs. A common problem of Philippine FAB LABs is the difficulty in enticing new makers due to the superficially intimidating nature of the machines [47]. It takes a considerable amount of time and effort for Philippine FAB LABs to acclimate to their local communities and increase the number of makers. Hence, older FAB LABs tend to have more makers than younger FAB LABs. An increase in the number of active makers can lead to more projects which potentially generate more solid waste. This presents the need for earlier established FAB LABs to implement pro-environment practices as they are potentially generating more solid waste than later established laboratories.

3.3. Waste Recyclability and Solid Waste Management in Philippine FAB LABs

Based on previous studies on recyclable materials in the Philippines [38,48,49], only paper, plastic, iron, metal, glass, aluminum wastes are usually recycled [38]. As shown in Figure 4, 52.79% of the overall waste produced by the FAB LABs are considered as recyclable.

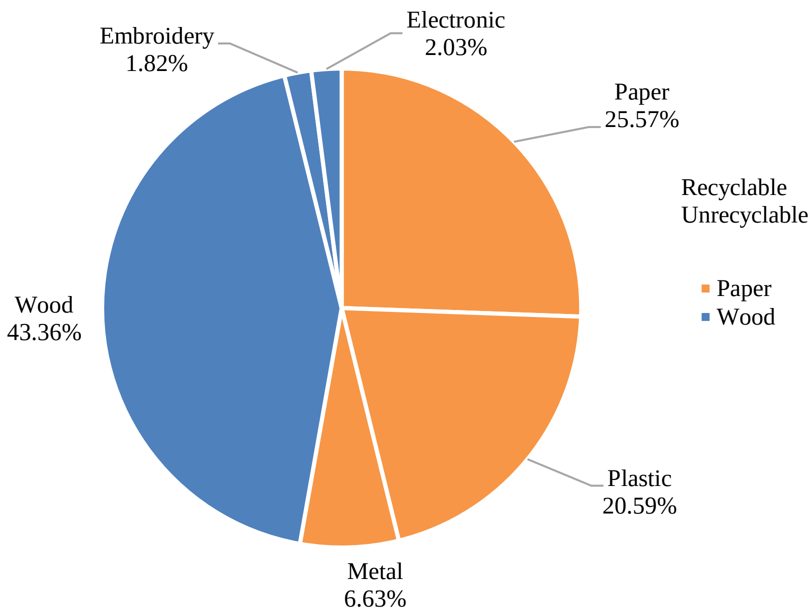

Figure 4. Recyclability of wastes generated by Philippine FAB LABs.

On initial assessment, this suggests that with efficient waste management practices, more than half of the waste production of FAB LABs could be sent to recycling centers for processing. These base guidelines, however, have been previously regarded as ambiguous and unclear by past studies [49]. Hence it cannot be concluded yet that FAB LAB operations are environmentally sound. In addition, all respondent FAB LABs were not aware if their generated waste was indeed recycled by their respective waste collectors. Although there exists a reasonable system of waste collection, segregation, and recycling in certain Philippine localities; some materials that pass the initial screening for recyclability, still ultimately end up in landfills. These rejections are often due to impurities and quality degradation of the solid wastes themselves [48]. One study regards the lack of proper segregation as a possible cause for the refusing of recyclables, citing paper and plastic waste products as usual offenders [48]. This is a probable occurrence of the solid waste of the respondents. In the same paper, it was proposed that there should be a sense of accountability of the waste producers; where waste generators could coordinate with local waste management efforts of segregation and recycling facilities [48]. This could optimize the collection and recycling system for both the waste producer and recycler.

There are several ways on alleviating this problem from the side of the industrial waste producers. As previously suggested, FAB LABs could coordinate directly with the local recycling facilities in order to ensure that at least a portion of their generated waste was recycled. This was applied in a larger scale in FAB LAB Bohol Philippines, wherein the collaboration with local micro recycling facilities has led to a production of sellable bags using recycled plastic waste from the FAB LAB and the local community. The environmental benefit of the system was incentivized by the income it provided to the recyclers [31].Since the lack of segregation is a prime reason for refusal of recyclables, FAB LABs could also implement in-lab waste segregation policies for paper and plastic waste that could improve the chance for recyclability of the generated wastes.

From the unrecyclable wastes, wood accounts for almost 92% of the composition. This subset is primarily comprised of medium-density fiberboards (MDF). Although easy to decompose [50], wood is still a space- inefficient fire hazard. As such, recycling facilities are disinclined to include wood in their recycling processes [48]. Makers primarily utilize MDFs due to their ease of use, material-consistency, and cost-efficiency [42]; but, they also are environmentally- friendly since MDFs are partially composed of recycled materials [51]. Such aspects of the MDF allow for environmental sustainability without much compromise on the quality of the product. Barring previously mentioned suggestions, FAB LABs in localities with limited waste management facilities can still minimize their environmental footprint by lessening unnecessary machine usage in both the production and prototyping process. These initial steps are imperative in developing a sufficient management waste system for digital manufacturing facilities such as FAB LABs.

4. Conclusion and recommendations

In general, manufacturing processes—such as the digital fabrication of FAB LABs— have contributed to the generation of solid waste in their respective communities. In order to solve this problem, proper solid waste assessment must first be implemented in the process of achieving environmental sustainability. Through the established procedures on waste categorization, the solid waste generation of 11 respondent Philippine FAB LABs was assessed and analyzed. From the most generated waste to the least, they are ordered as follows: wood, paper, plastic, metal, electronic, and embroidery. The availability of machines was seen as a factor in solid waste generation. Wood and plastic waste contributed approximately 64% of the total waste and these were largely due to the availability of laser cutters and 3D printers in these respondent facilities. Additionally, it was observed that there is an apparent correlation between the amount of waste generated by a FAB LAB and the age of the laboratory; as earlier established laboratories had more active makers that could potentially generate more solid waste. Fifty-three percent of the overall waste generated was considered recyclable but actual recyclability remains inconclusive due to the vague criteria of Philippine recycling facilities. Furthermore, FAB LAB managers were uncertain if a portion of their waste was recycled. In addition to lessening the unnecessary usage of machines, the coordination with local respective recycling facilities, and the implementation of proper segregation practices could ensure the recyclability of generated waste.

Being a preliminary study, a year-long waste monitoring in Philippine FAB LABs is encouraged to capture a more comprehensive assessment of the laboratories' waste production. Furthermore, as the present results are based on the observations and data of a subset of Philippine FAB LABs, it is recommended that these findings be used as baseline references in creating a solid waste monitoring and management system fit for a Philippine FAB LAB. Solid waste assessment is only the initial step into taking initiatives toward environmental sustainability. Ultimately, digital manufacturing facilities such as FAB LABs must advocate not only for efficiency in product fabrication but also for the preservation and sustainability of the environment.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Blikstein P, Krannich D (2013) The makers' movement and FabLabs in education: experiences, technologies, and research. In Proceedings of the 12th International Conference on Interaction Design and Children (IDC '13). Association for Computing Machinery, New York, NY, USA, 613–616.
2. Kohtala C (2016) Making sustainability: how Fab Labs address environmental issues, Aalto University.
3. Bohne R (2014) Machines for Personal Fabrication, In: Walter-Herrmann J, Büching C (Eds.), *FabLab: Of Machines, Makers and Inventors*, transcript Verlag.
4. Ferdinand J, Petschow U, Dickel S (2016) The Decentralized and Networked Future of Value Creation: 3D Printing and its Implications for Society, Industry, and Sustainable Development.
5. El-Haggar SM (2007) Sustainable Industrial Design and Waste Management, Elsevier.
6. Knips C, Bertling J, Blömer J, et al. (2014) FabLabs, 3D-printing and degrowth – Democratisation and deceleration of production or a new consumptive boom producing more waste? Fourth International Conference on Degrowth for Ecological Sustainability and Social Equity. 2014
7. Chandrappa R, Brown J (2012) Solid Waste Management: Principles and Practice, Berlin Heidelberg, Springer-Verlag.
8. US Enviromental Protection Agency (2016) Criteria for the Definition of Solid Waste and Solid and Hazardous Waste Exclusions.
9. Doble M, Kumar A (2005) Biotreatment of Industrial Effluents, Oxford, United Kingdom, Butterworth-Heinemann.

10. Marshall RE, Farahbakhsh K (2013) Systems approaches to integrated solid waste management in developing countries. *Waste Manage* 33: 988–1003.
11. Mishra A, Mishra S, Tiwari A (2013) Solid Waste Management— Case Study. *Int J Res Adv Technol* 2: 396–399.
12. Fleischmann K, Hielscher S, Merritt T (2016) Making things in Fab Labs: a case study on sustainability and co-creation. *Digit Creat* 27: 113–131.
13. US Congress. Office of Technology Assessment (1995) Managing Industrial Solid Wastes from Manufacturing, Mining, Oil and Gas Production and Utility Coal Combustion, Washington, DC, DIANE Publishing.
14. Byard DJ, Woern AL, Oakley RB, et al. (2019) Green fab lab applications of large-area waste polymer-based additive manufacturing. *Addit Man* 27: 515–525.
15. Alabi RA, Wohlmuth K (2019) The Case of Sustainable Management of Waste in Germany (and Bremen) and Practical Lessons for Nigeria (and Lagos), Bremen, Germany, Institute for World Economics and International Management (IWIM).
16. Hoornweg D, Perinaz BT (2012) What a waste: A Global Review of Solid Waste Management. *Urban Dev Ser Knowl Pap* 15: 87–88.
17. Tun MM, Juchelková D (2018) Assessment of solid waste generation and greenhouse gas emission potential in Yangon city, Myanmar. *J Mater Cycles Waste Manag* 20: 1397–1408.
18. Achankeng E (2003) Globalization, Urbanization and Municipal Solid Waste Management in Africa, *African Studies Association of Australasia and the Pacific 2003 Conference Proceedings*, Adelaide, South Australia.
19. Palczynski R (2002) Study on Solid Waste Management Options For Africa, African Development Bank.
20. Abarca-Guerrero L, Maas G, Hogland W (2012) Solid waste management challenges for cities in developing countries. *Waste Manag* 33: 220–232.
21. Khajuria A, Yamamoto Y, Morioka T (2008) Solid waste management in Asian countries: Problems and issues, 643–653.
22. World Resources Institute, United Nations Environment Programme, United Nations Development Programme, et al. (1996) World Resources 1996–97, New York ; Oxford, Oxford University Press.
23. Gomez G, Meneses M, Ballinas L, et al. (2008) Characterization of urban solid waste in Chihuahua, Mexico. *Waste Manag* 28: 2465–2471.
24. Alam P, Ahmade K (2013) Impact of Solid Waste on Health and The Environment. *Int J Sust Dev Green Econ* 2: 165–168.
25. Ivers LC, Ryan ET (2006) Infectious diseases of severe weather-related and flood-related natural disasters. *Curr Opin Infect Dis* 19: 408–414.
26. Beigl P, Lebersorger S, Salhofer S (2008) Modelling municipal solid waste generation: a review. *Waste Manag* 28: 200–214.
27. United States Environmental Protection Agency (USEPA) (2002) Solid Waste Management: A Local Challenge with Global Impacts.
28. McDougall F, White P, Franke M, et al. (2001) Integrated Solid Waste Management: A Life Cycle Inventory. *Int J LCA* 6: 320.
29. Zeng Y, Trauth KM, Peyton RL, et al. (2005) Characterization of solid waste disposed at Columbia Sanitary Landfill in Missouri. *Waste Manag Res* 23: 62–71.

30. Fab City Research Lab, Fab Foundation (2020) FabLabs.io - The Fab Lab Network, Labs | FabLabs, 2020. Available from: https://www.fablabs.io/labs?utf8=%E2%9C%93&q%5Bcountry_code_eq%5D=ph&q%5Bactivity_status_eq%5D=&per=25&commit=Filter.
31. Tokushima Y (2016) Creating an Innovative Environment with FabLab – Case study: Bohol, the Philippines. *New Breeze, Quarterly of the ITU Association of Japan* 28: 18–21.
32. Velasco LC (2017) Making the FAB LAB Fabulous - A Project Scope Management Challenge.
33. Cruz Sanchez F, Lanza S, Boudaoud H, et al. (2015) Polymer Recycling and Additive Manufacturing in an Open Source context : Optimization of processes and methods, *Proceedings: 26th Annual International Solid Freeform Fabrication Symposium - an Additive Manufacturing Conference*, Austin,Texas,USA, University of Texas, 1591–1600.
34. Allesch A, Brunner PH (2014) Assessment methods for solid waste management: A literature review. *Waste Manag Res* 32: 461–473.
35. Moser H (2016) Transformative Innovation for International Development: Operationalizing Innovation Ecosystems and Smart Cities for Sustainable Development and Poverty Reduction, Washington, DC, Center for Strategic & International Studies.
36. Zender Environmental Engineering Services (2001) A Guide to Closing Solid Waste Disposal Sites in Alaska Villages, Rural Alaska, Institute for Tribal Environmental Professionals and Zender Environmental Engineering Services.
37. Saeed MO, Hassan MN, Mujeebu MA (2009) Assessment of municipal solid waste generation and recyclable materials potential in Kuala Lumpur, Malaysia. *Waste Manag* 29: 2209–2213.
38. Atienza V (2011) Review of the Waste Management System in the Philippines: Initiatives to Promote Waste Segregation and Recycling through Good Governance, Chiba, Japan, Institute of Developing Economies, Japan External Trade Organization.
39. Bates-Green K, Howie T (2018) Materials for Laser Cutter Machines, Lynnwood, Washington, National Resource Center for Materials Technology Education.
40. Feil A, de Quevedo DM, Schreiber D (2015) Selection and identification of the indicators for quickly measuring sustainability in micro and small furniture industries. *Sus Prod Consum* 3: 34–44.
41. Kamberg ML (2016) Creating with Laser Cutters and Engravers, New York, The Rosen Publishing Group, Inc.
42. Gerhards P (1997) Entertainment Centers You Can Make: Complete Plans and Instructions for Freestanding and Built-In Modules, Stackpole Books.
43. Lopera DK (2019) FAB LAB Mindanao: Machine Operations and Internal Management Systems.
44. Babayemi J, Dauda K (2009) Evaluation of Solid Waste Generation, Categories and Disposal Options in Developing Countries: A Case Study of Nigeria. *J Appl Sci Environ Manag* 13: 83–88.
45. University of Washington: Environmental Health & Safety (2017) Milling Machines and CNC Mills: Safety Precautions, Washington, DC, University of Washington.
46. Aliverti P, Maietta A (2015) The Maker's Manual: A Practical Guide to the New Industrial Revolution, San Francisco, USA, Maker Media, Inc.
47. Brun J, Cheng E, Alcudia M (2018) The challenges of managing a Fablab in a developing country: the Philippines, *Proceedings from the Fab14 'Fabricating Resilience' Research Papers Stream*, Toulouse, France, Creating 010, Rotterdam University of Applied Sciences, 75–83.

48. Rebullida MLG (2008) Stakeholders' Relationships in Recycling Systems: Experiences in the Philippines and Japan, *Promoting 3Rs in Developing Countries - Lessons from the Japanese Experience*, Chiba, Japan, Institute of Developing Economies, Japan External Trade Organization, 80–106.
49. Antonio LC (2010) Study on Recyclables Collection Trends and Best Practices in the Philippines, Jakarta, Indonesia, Economic Research Institute for ASEAN and East Asia.
50. Callister, Jr. WD, Rethwisch DG (2012) Fundamentals of Materials Science and Engineering: An Integrated Approach, New Jersey, USA, John Wiley & Sons.
51. Birkeland J (2012) Design for Sustainability: A Sourcebook of Integrated Ecological Solutions, *Design for Sustainability: A Sourcebook of Integrated Ecological Solutions*, Oxfordshire, England, Earthscan Publications Ltd., 205.