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Analysis of MEP Work Waste Management Efforts in Building Construction Projects in Jakarta Greater Area

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ABSTRACT

Construction projects are among the sectors that are growing rapidly in Indonesia and have an impact on the environment from the resulting construction waste. The purpose of this study is to analyze the highest type and quantity of construction waste generated from Mechanical Electrical Plumbing (MEP) work from the difference in the amount of material from the BOQ with the amount attached to the as-built drawings, evaluate the economic value by calculating the ratio of the amount of waste generated to the amount of material at BOQ (waste level) × the scope of work percentage (waste cost), selling value of waste (the quantity of waste × the local selling price), and costs of disposal of construction waste based on the agreement of each project management. This study uses a descriptive quantitative method. The results showed that most of the construction waste generated was based on its type, consisting of copper-based cables, steel and plastic pipes, and polyurethane ducts. The highest quantity of construction waste came from the office project, which was 2 × 1.5 mm^2 NYA cables (216,515 m). The highest waste level value came from office, condotel, and factory projects using several types of cables (> 94%). The highest waste cost value came from the condotel project is polyurethane duct (IDR 5,727,267,000.00). The metal waste produced is sold by contractors to collectors for recycling. Non-metal waste is disposed by paying a civil contractor. Construction waste management policies must be implemented to reduce the amount and impact of construction waste generated.

Introduction

Construction projects are a sector that has been growing rapidly in Indonesia since the last few years in line with its economic growth [1]. The construction sector has a major influence on the environment, utilization of natural resources, processing, and waste it produces. Development in the construction sector will cause environmental problems if not managed properly [2]. Waste that has not been reused ends up in landfills. The increasing amount of construction waste that was simply dumped into landfills without any management processes led to an increase in land use [3]. Problems arise when the landfill is full, resulting in the manager having to find a new location to replace the old landfill. The existence of this landfill is often rejected by the community because it is considered to disturb the condition of the surrounding environment, thereby affecting quality of life [4].

The construction process consumes the majority of materials. However, the production of construction materials requires extensive natural resource exploration. Based on the amount of material consumed, the construction process requires approximately 40% of the material globally or 3 billion tons per year [5]. In the United States, an estimated 250 million tons of municipal solid waste are generated annually [6]. Approximately 170 million tons of waste are related to construction and demolition, with 39% coming from

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residential sources and 61% from non-residential sources [7]. The metal content of construction waste can contaminate soil and water bodies via surface water runoff, thereby endangering the environment. These impacts include decreasing the pH value and increasing the total distribution of heavy metals in the soil [8]. Construction waste generates large amounts of waste. Based on Law No. 18 of 2008 concerning Waste Management in Indonesia, this waste is included in the category of "specific waste", which requires special rules [9]. Owing to its large volume and non-decomposing nature, it can cause problems in waste management.

Currently, the construction industry must apply the concept of sustainable construction. Responsibility in the sustainable aspect must exist in the design, construction, and post-construction stages [10]. This demand is reinforced by the existence of targets from Sustainable Development Goals (SDGs) regarding responsible consumption and production (12) [11]. Therefore, efforts are needed to overcome the impact of this waste on maintaining environmental conditions [12]. The concept of sustainable construction, which is a part of sustainable development, has various parameters, one of which is the effort to implement 3R (reduce, reuse, and recycle) [13]. Waste management has great potential for overcoming the impact of construction waste. Reducing waste using a more adequate design to reduce the resulting concrete debris is considered more effective. However, reuse and recycling of construction waste must also be pursued. Concrete debris can be reused as an aggregate to produce new concrete.

Other materials such as asphalt, wood, and metal have the potential to be reused or significantly recycled, namely, by selling them to third parties for recycling [14]. There is no systematic review of research progress in the literature on sustainable construction waste management, making strong processes, strategies, management systems and policies, and efficient waste management urgently needed [15]. Construction waste management must be conducted to conserve resources and to prevent environmental degradation. For effective construction-waste management, two important parameters must be implemented and integrated. Construction waste management hierarchy and review the factors that contribute to construction waste management [16]. Metal-based construction waste (scrap) is often used in the steel smelting industry to produce machine components and new metallic materials [17]. The purpose of this study is to analyze the highest type and quantity of construction waste generated and evaluate the economic value, selling value of waste, and costs for disposal of construction waste.

Materials and Methods

The methods used in this study were descriptive and quantitative. This method was carried out by first identifying the type of construction waste that was produced. The 3R concept was used to determine the types of waste that could be further processed. Furthermore, data collection was performed based on the economic value obtained from waste utilization. This information is used to determine the potential economic value and solutions for the sustainability of the carrying capacity and carrying capacity of the environment. The steps of the research are as follows: identify the dominant material types by calculating the quantity of construction materials needed based on data from the Bill of Quantity (BOQ) minus the installed materials based on the as-built drawings [18]; analyze the economic value of waste generated by calculating the waste level by dividing the amount of waste generated by the amount of material in the BOQ [19]; calculate the waste cost by multiplying the waste level by workload and total contract value [19]; calculate the waste index by estimating the ratio between the volume of construction waste disposed of and the project area [20]; calculate the value of waste that can be sold by multiplying the quantity of waste by the local selling price (IDR/kg); and calculate the cost for disposing construction waste and calculating the cost for disposal of construction waste every month based on the agreement of each project management.

Results and Discussion

The Dominant Material Types

According to Government Regulation No. 101 of 2014 [21], waste is a residual result of operations and activities. Construction waste can be reused with the same function and form as before. Therefore, waste that is referred to as residual activity in construction is not always disposed. The remaining material can be sorted for use in other construction projects or removed for recycling [22]. The materials used in Mechanical Electrical Plumbing (MEP) work vary widely, and include cable trays, lighting, conduit pipes, water pipes, valves, sprinkler pipes, and ducting. These materials have the potential to generate construction waste from the work performed [23]. Based on these results, several types of materials were used in this project. The basic materials that are widely used are metal-based and plastic. Metal-based materials are often used to manufacture firefighting pipes, air-conditioning pipes, ducts, cable trays, and cables. Plastic-based materials are generally used for manufacturing plumbing (plumbing) and ducting. The data on the types of construction waste generated from each construction project are presented in Table 1.

Table 1. The three largest quantity of construction waste.

Rank	Materials					
	Office	Waste quantity (m)	Condotel	Waste quantity	Factory	Waste quantity (m)
1	NYA 2 × 1.5 mm^2	216,515	CPVC Ø 15 mm	6,918 m	NYM 3 × 2.5 mm^2 + metal conduit	3,505
2	NYM 3 × 2.5 mm^2	20,177	PU duct	5,195 m^2	NYY 3 × 2.5 mm^2 + in metal conduit Ø 20 mm	1,160
3	HI PVC conduit Ø 20 mm	18,105	NYY 3 × 4 mm^2 + PVC conduit	5,007 m	NYY 4 × 4 mm^2 + BC 4 mm^2	654

CPVC = chlorinated polyvinylchloride, N = copper core, Y = PVC insulation, M = more than one core, A = single cable, HI = high impact, PU = polyurethane, BC = bare copper.

Based on Table 1, in the Office project, there is a NYA 2 × 1.5 mm2 cable as the material with the highest amount of construction waste (216,515 m). Followed by NYM cable 3 × 2.5 mm2 (20,177 m) and HI PVC conduit Ø 20 mm pipe (18,105 m). The NYA 2 × 1.5 mm^2 cable material ranks highest with the most remaining material owing to differences in the calculation of the amount of material in the BOQ and what has been installed in the as-built drawings. The calculation of material requirements in the BOQ uses a unit of 14 to 38 m/point of installation of the electronic unit material, while the material installed turns out to be a series circuit with electronic unit materials, such as heat detectors, smoke detectors, and manual push buttons. Therefore, the actual required 2 × 1.5 mm^2 NYA cable material is much less than that stated in the BOQ. Similarly, with NYM cables of 3 × 2.5 mm^2 and HI PVC conduit pipes Ø 20 mm. The two materials are used to complement each other because the NYM cable (3 × 2.5 mm^2) is wrapped in an HI PVC conduit Ø 20 mm pipe; thus, the amount of waste generated is not significantly different.

In concrete projects, the CPVC pipe Ø 15 mm is the material with the largest amount of construction waste (6,918 m). The PU duct ranks next, with a total waste area of 5,195 m^2. Third, the NYY cable 3 × 4 mm^2 + PVC conduit contains 5,007.5 m of construction waste. The CPVC pipe material Ø 15 mm occupies the largest amount of construction waste because it is a branch pipe with the smallest size, which often experiences changes in the installation path during the construction process, thereby affecting the amount of material needed. In this study, it was also found that the smaller the diameter of the pipe, the more often there is a change in the installation path compared to a larger pipe of the same type. The main-line pipe is the least likely to change the installation path compared with pipes with smaller sizes. PU duct material with construction waste of 5,194.8 m^2 due to changes in the ducting path, and the large quantity of the ducting surface causes a difference in the remaining material. The ducting fabrication process, which is also conducted in the project area, affects the amount of remaining raw materials that can become waste. The next material is an NYY cable 3 × 4 mm^2 + PVC conduit with a total construction waste of 5,007.5 m. The difference between the amount of material in the BOQ and that installed is often caused by a change in the installation path and number of installed units.

In the Factory project, the same phenomenon was observed for the amount of cable material left. In this project, there are three rankings for the type of material with the largest amount of construction waste, all of which are types of cables, successively including NYM cable 3 × 2.5 mm^2 + metal conduit (3,505 m), NYY cable 3 × 2.5 mm^2 + metal conduit Ø 20 mm (1,160 m) and cable NYY 4 × 4 mm^2 + BC 4 mm^2 (654 m). As shown in Table 1, cable material dominates the other types of materials. This is because the scope of electrical and electronic work is larger than that of mechanical work, which requires the installation of more types of cables. In general, the amount of cable waste generated is due to differences in the method of calculating cable requirements compared with those that have been installed based on as-built drawings. When an electronic installation unit and an electrical installation unit have been installed, the project owner or consultant only reviews how many installation units have been installed but does not measure the length of installation of the cable has been installed.

Compared to structural work during construction, MEP work can produce much construction waste, ranging from 40 to 60% of the total construction cost. This is because there is often uncertainty in design changes [24]. Overestimation in calculating the material required is one factor affecting the amount of construction waste produced [25]. Based on government regulations in the Republic of Indonesia no 101 in 2014, cable waste was classified as hazardous waste [21]. This waste harms the environment and humans owing to its chronic impact on human health [26]. Cable waste can endanger health because of the heavy metal mixture used in the manufacture of raw materials [27].

Analysis of the Economic Value of Waste

The highest value of waste level based on the amount of waste generated is shown in Table 2. The largest level of waste in office projects comes from FRC cables 4 × 1 × 35 mm^2 + NYA 16 mm^2 (95%), ITC cable 2 × (1 × 1.5 mm^2) + PVC conduit ¾" (98%), and the factory projects are NYY cable 4 × 4 mm^2 + BC 4 mm^2 (95%). Large waste-level values are derived from the type of cable material. The cables used are generally of the copper core type; therefore, copper is a construction waste that should be considered to be economically sufficient. The large number of remaining cables, both unplugged and intact, was owing to the difference between the calculation method during the bidding process based on the BOQ document and the actual number installed based on the as-built drawings. In addition, project owners and consultants often see only the number of units installed, overlooking the number of remaining cables. The high level of waste indicates that this material requires special attention for handling construction waste because it will have a negative impact in the future. In East and Southeast Asia, high levels of untreated waste are predicted to increase this problem in the next few years [28].

Table 2. The largest waste level of each project.

Project	Material	Waste quantity	Waste level
Office	FRC 4 × 1 × 35 mm^2 + NYA 16 mm^2	185.3 m	95%
Condotel	ITC 2 × (1 × 1.5 mm^2), in PVC conduit 3/4	37 m	98%
Factory	NYY 4 × 4 mm^2 + BC 4 mm^2	654 m	95%

FRC = fire resistant cable, N = copper core, Y = PVC insulation, A = single cable, ITC = indoor telephone cable, PVC = polyvinylchloride, BC = bare copper.

In general, the high waste level calculation results, which are above 50% for several types of materials, are also influenced by other factors, namely the type of formula used. In this study, the waste level was calculated using the difference between the amount of material in the BOQ and the amount installed in the as-built drawing. Therefore, there is a possibility of bias because the amount of material that arrives at the project is not as high as stated in the BOQ and the as-built drawings are not very detailed. The use of this formula is due to the availability of BOQ data and as-built drawings, which are available and complete. A more accurate waste level formula can also be used to match the incoming material and material collection data from the warehouse. However, this is not possible because much of the data are incomplete, and the recording of data on the amount of material taken from the warehouse is not always up to date. From the amount of waste generated, waste cost calculations were also performed to determine the product of the amount of waste by workload and contract value. The highest waste cost values are listed in Table 3.

Table 3. The largest waste cost of each project.

Project	Material	Waste quantity	Waste cost
Office	NYA 2 × 1.5 mm^2	216,515 m	IDR 3,897,270,000.00
Condotel	PU Duct	5,194.8 m^2	IDR 5,727,267,000.00
Factory	Copper busduct 5,000 A	24 m	IDR 522,516,000.00

N = copper core, Y = PVC insulation, A = single cable, PU = polyurethane.

Based on Table 3, the biggest waste cost value from the resulting office project is NYA cable 2 × 1.5 mm^2 (IDR 3,897,270,000.00). This is because this type of cable is widely used for the installation of fire protection electronic accessories such as smoke detectors, heat detectors, manual push buttons, and flow switches. Therefore, the need for BOQ calculations and their installation in the field is significant. PU duct is the material with the highest waste cost from the condotel project (IDR 5,727,267,000.00). Even though the waste level is low (38.5%), the average unit price of the material per m2 is quite high, which (IDR 1,102,500.00). In the factory project, the material with the largest waste cost value is found in the copper busduct 5,000 A (IDR 522,516,000.00). Even though the waste level was relatively low (33%), the unit price of the material for the Copper busduct 5,000 A was quite high (IDR 21,771,500.00/m). As shown in Table 3, the most common types of waste materials are metals and plastics. There is a close relationship between the types of waste made of metal and plastic and the waste cost per ton [29].

The high value of the waste cost is influenced by the amount of waste and the unit price of the material. The large amount of MEP work waste generated also affects the value of the waste level in the previous discussion. One of the causes of the high waste level in the previous discussion is that it only uses the complete available data types (BOQ documents and as-built drawings), so the waste cost is high. To estimate the ratio between the volume of construction waste disposed and project area, the waste index value was calculated. The results of the waste index calculations are presented in Table 4.

Table 4. Waste index value of construction waste.

No	Factors	Office	Condotel	Factory
1	Frequency of transportation of construction waste per month	8 times	3 times	2 times
2	Transport truck volume	12 m^3	12 m^3	7.7 m^3
3	The duration of the project	12 months	36 months	12 months
4	Project area	39,300 m^2	32,393 m^2	11,900 m^2
5	Waste Index	0.029	0.040	0.016

Based on Table 4, the waste index values obtained from Office, Condotel, and Factory projects were 0.029, 0.04, and 0.016, respectively. The largest waste index value is in the Condotel project, whereas the smallest waste index value is in the factory project. The Condotel project obtained the largest waste index value because it lasted the longest compared to other projects, thus affecting the amount of waste released to the greatest extent. The smallest waste index in the factory project was caused by the smallest project area and smaller number of transport trucks compared to the other two projects. The waste indices resulting from the construction of the Credit Agricole Bank office building project in New Cairo and Dar el Handassa New Headquarter Smart Village in Giza were 0.025 and 0.026 [30]. Similar research has also been conducted in the high-rise building of the Thamrin Nine project in Jakarta, where iron occupies the largest waste level with a project waste index of 0.078 [31]. The construction waste that could be sold in this study was metal waste-based waste (scrap). The types of waste that could be sold in this study were scrap, including iron, copper, and zinc-coated steel. Based on the interviews, the sales results for metal materials are listed in Table 5.

Table 5. Selling price of construction waste.

No	Type of metal	Office		Condotel		Factory	
		Quantity	Selling price/Kg*	Quantity	Selling price/Kg*	Quantity	Selling price/Kg*
1	Steel	2,000 Kg	IDR 3,500.00	1,000 Kg	IDR 4,500.00	3,000 Kg	IDR 2,000.00**
2	Copper	500 Kg	IDR 55,000.00	(NA)***	-	100 Kg	IDR 70,000.00
3	Zinc-coated steel	500 Kg	IDR 500.00	-	-	50 Kg	IDR 500.00

*Selling price based on interview; **selling price below standard; ***NA: Not available data.

Based on the Table 5, the highest selling price of scrap is found in copper (IDR 55,000.00–IDR 70,000.00). Scrap copper has a higher selling value than other metals, such as iron and zinc, because copper can be recycled into goods that have a high selling value [32]. Based on the amount of scrap waste generated, iron scrap occupies the highest amount of all samples compared to copper and zinc-coated steel scrap. This is because, in terms of quantity in kilograms, this type of iron material is more widely used in all scopes of work, both mechanical, electrical, and electronic, compared to copper, which is often used only in electrical and electronic work scopes.

Zinc-coated steel accounts for the smallest amount of scrap sales because its use is limited to the scope of air conditioning work, and not all air conditioning work in the project uses zinc-coated steel as a raw material for ducting. Zinc-coated steel for ducting installation is used only in office and factory projects. Condotel projects use far more ducting made from polyurethane (PU) than zinc-coated steel; thus, the zinc-coated steel waste generated from condotel projects is practically zero. The metal waste that is sold can be processed into new goods by metal smelting companies to provide economic benefits. Recycled metals can provide economic benefits when available mineral resources are limited [33]. The result of metal waste recycling is a high-quality product. One of the recycled products produced is wear-resistant welding hardfacing material [34].

Analysis of the Cost for Disposing of Construction Waste

Construction waste that cannot be reused in projects is often disposed of outside the area. However, the disposal of construction waste is expensive. Table 6 lists the costs incurred for each project. Based on the disposal costs in Table 6, in a month, the office, condotel and factory projects cost IDR. 2,000,000.00, IDR. 1,200,000.00 and IDR. 600,000.00. The disposal of MEP construction waste is an action taken when there is activity residue or material resulting from construction activities that cannot be reused. The disposal of construction waste is costly. The construction costs for the projects in this study were determined during a meeting between the project owners, consultants, and contractors involved. Of the three projects sampled, civil contractors handled all construction waste that could not be utilized. The costs incurred when disposing of waste in the three projects were only purchased once per month, regardless of the quantity or number of trucks transporting it.

Table 6. MEP waste disposal cost.

No.	Project	Waste disposal cost (per month)
1	Office	IDR 2,000,000.00
2	Condotel	IDR 1,200,000.00
3	Factory	IDR 600,000.00

Costs incurred on 5 (five) apartment building development projects in Malaysia. The amount of costs incurred to dispose of construction waste in a span of 15 to 17 months ranges from RM 72,000 to RM 192,000 [35]. Based on government regulations that construction waste is "specific waste", which requires special handling, there should be specific regulations, including strict sanctions. In fact, there is a lack of clarity regarding the proper management of construction waste and sanctions imposed by the government. Contractors and landfill managers, who often come from the private sector, perform technical construction waste management without specific instructions from the regulations issued by the government. The contractor was limited to paying construction waste disposal costs to the landfill manager. However, cooperation between the government and private sector in managing construction waste is expected to reduce the costs of its disposal [36].

Conclusions

The largest quantity of construction waste from office projects is 2 × 1.5 mm^2 NYA cables (216,515 m). The highest waste level value came from office, condotel, and factory projects, and came from several types of cables with a value of > 94%. When utilizing construction waste, scrap waste is often sold to collectors by contractors at a certain price. Scrap is resold by collectors to metal smelting companies for use in new goods. Meanwhile, non-metal construction waste is disposed of by contractors outside the project by paying civil contractors. It is hoped that a review of materials other than the installed units and the application of certain policies in project management for the management of construction waste can reduce the amount of construction waste generated.

Author Contributions

EA: Conceptualization, Methodology, Data Curation, Software, Investigation, Writing - Review & Editing; **LK**: Methodology, Writing - Review & Editing, Supervision; **E**: Methodology, Writing - Review & Editing, Supervision.

References

1. Lukiyanto, K. *Mandor, Model Kepemimpinan Tradisional Jawa pada Proyek Konstruksi Era Modern*; Gramedia Pustaka Utama: Jakarta, ID, 2016;
2. Kementerian Pekerjaan Umum dan Perumahan Rakyat. *Peraturan Menteri Nomor 05/PRT/M/2015 tentang Pedoman Umum Implementasi Konstruksi Berkelanjutan Pada Penyelenggaraan Infrastruktur Bidang Pekerjaan Umum dan Permukiman*; KemenPUPR: Jakarta, ID, 2015;
3. Wang, T.; Wang, J.; Dong, W. Dynamic Assessment on Environmental Impacts of Construction Waste Disposal by Landfill in Shenzhen. *Constr Econ*. **2016**, *37*, 100–103, doi:10.14181/j.cnki.1002-851x.201602100.

4. Lumbangaol, P.H.; Sihombing, M.M. Pengelolaan Limbah Konstruksi di Medan. *Jurnal Teknik Nommensen* **2016**, *2*, 83–96.
5. U.S. Green Building Council. Green Building Research Funding: An Assessment of Current Activity in the United States. 2007. Available online: https://s3.amazonaws.com/legacy.usgbc.org/usgbc/docs/Archive/General/Docs2465.pdf (accessed on 22 October 2020).
6. EPA (Environmental Protection Agency. Municipal Solid Waste Generation, Recycling, and Disposal in the United States. 2008. Available online:https://archive.epa.gov/epawaste/nonhaz/municipal/web/pdf/msw2008data.pdf (accessed on 22 October 2020).
7. EPA (Environmental Protection Agency). Estimating 2003 Building-Related Construction dan Demolition Material Amounts. 2009. Available online: https://archive.epa.gov/region9/buildingreuse/web/pdf/cd-meas.pdf (accessed on 22 October 2020).
8. Wu, G.; Wang, L.; Yang, R.; Hou, W.; Zhang, S.; Guo, X.; Zhao, W. Pollution characteristics and risk assessment of heavy metals in the soil of a construction waste landfill site. *Ecological Informatics* **2022**, *70*, doi:10.1016/j.ecoinf.2022.101700.
9. Indonesian Government. *Undang-Undang Republik Indonesia Nomor 18 Tahun 2008 tentang Pengelolaan Sampah*; State Secretariat of the Republic of Indonesia: Jakarta, ID, 2008;
10. Hansen, S. *Quantity Surveying: Pengantar Manajemen Biaya dan Kontrak Konstruksi*; Gramedia Pustaka Utama: Jakarta, ID, 2017; pp. 242–243.
11. United Nations. The 17 Goals. 2015. Available online: https://sdgs.un.org/goals (accessed on 2 August 2023).
12. Santoso, E.B.; Umilia, E. Kajian Indikator Daya Tampung Lingkungan Binaan dan Sosial di Jawa Timur. *Jurnal Penataan Ruang* **2016**, *11*, 7–15, doi:10.12962/j2716179X.v11i2.5215.
13. Surjono. *Bumi yang Lestari: Kajian Literatur dan Empiris tentang Perencanaan Pembangunan Berkelanjutan Skala Makro – Mikro*; Universitas Brawijaya Press: Malang, ID, 2018;
14. Turkiyilmaz, A.; Guney, M.; Karaca, F.; Bagdatkyzy, Z.; Sandybayeva, A.; Sirenova, G. A Comprehensive Construction and Demolition Waste Management Model using PESTEL and 3R for Construction Companies Operating in Central Asia. *Sustainability* **2019**, *11*, 1–16, doi:10.3390/su11061593.
15. Mohammed, M.; Shafiq, N.; Abdallah, N.A.W.; Ayoub, M.; Haruna, A. A review on achieving sustainable construction waste management through application of 3R (reduction, reuse, recycling): A lifecycle approach. *IOP Conference Series Earth and Environmental Science* **2020**, *476*, 012010, doi:10.1088/1755-1315/476/1/012010.
16. Kabirifar, K.; Mojtahedi, M.; Wang, C.; Tam, V.W. Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. *Journal of Cleaner Production* **2020**, *263*, 1–16, doi:10.1016/j.jclepro.2020.121265.
17. Suyanto; Wibowo, R.; Pramono, S. Pemanfaatan Besi Scrap Sebagai Bahan Dasar Industri Peleburan Baja. *Marine Science and Technology Journal* **2021**, *1*, 51–57, doi:https://doi.org/10.31331/maristec.v1i2.1557.
18. Pertiwi, I.G.A.I.M.; Herlambang, F.S.; Kristinayanti, W.S. Analisis Waste Material Konstruksi Pada Proyek Gedung (Studi kasus pada proyek gedung di Kabupaten Badung). *Jurnal Simetrik* **2019**, *9*, 185–190, doi:10.31959/js.v9i1.204.
19. BRANZ (Building Research Association of New Zealand). Easy Guide to Reducing Construction Waste – A Practical Guide to Reducing Waste from Buiulding Sites. 2002. Available online: http://www.branz.co.nz/cms_show_download.php?id=5da3dc419c35372152668af7ac0776b6d9b43cfc (accessed on 08 July 2019).
20. Poon, C.S.; Yu, A.T.W.; See, S.C.; Cheung, E. Minimizing Demolition Wastes in Hong Kong Public Housing Projects. *Construction Management and Economics* **2004**, *22*, 799–805, doi:10.1080/0144619042000213283.
21. Indonesian Government. Peraturan Pemerintah Nomor 101 Tahun 2014 Tentang Pengelolaan Limbah Bahan Berbahaya dan Beracun; State Secretariat of the Republic of Indonesia: Jakarta, ID, 2014;
22. Ahmad, S.N.; Hanafie, I.M.; Sriwati, M.; Kamba, C.; Lapian, F.E.P.; Risfawany, L.D., Mansyur; Syam, A.; Mustika, W.; Tumpu, M.; et al. *Pemanfaatan Material Alternatif (Sebagai Bahan Penyusun Konstruksi)*; Tohar Media: Makassar, ID, 2021;

23. Wang, J.; Wang, X.; Shou, W.; Chong, H.Y.; Guo, J. Building Information Modeling-based Integration of MEP Layout Design and Constructability. *Automation in Construction* **2016**, *61*, 134–146, doi:10.1016/j.autcon.2015.10.003.
24. Samarasinghe, T.; Mendis, P.; Aye, L.; Gunawardena, T.; Fernando, S.; Karunaratne, R. BIM and Modular MEP Systems for Super-Tall and Mega-Tall Buildings. In 8th International Conference on Structural Engineering and Construction Management, Kandy, Sri Lanka, 7–9 December 2017.
25. Widhiawati, I.A.R.; Astana, N.Y.; Indrayani, N.L.A. Kajian Pengelolaan Limbah Konstruksi pada Proyek Pembangunan Gedung di Bali. *Jurnal Imiah Teknik Sipil* **2019**, *23*, 55–61, doi:10.24843/JITS.2019.v23.i01.p07.
26. Nisa, A.S.; Trihadiningrum, Y. Pengelolaan Limbah Elektronik di Kantor Pemerintah Kota Surabaya. Thesis, Institut Teknologi Sepuluh Nopember, Surabaya, ID, 2018.
27. Iswanto; Sudarmadji; Wahyuni, E.T.; Sutomo. Timbulan Sampah B3 Rumahtangga dan Potensi Dampak Kesehatan Lingkungan di Kabupaten Sleman, Yogyakarta. *Jurnal Manusia dan Lingkungan* **2016**, *23*, 179–188, doi:10.22146/jml.18789.
28. Jebaranjitham, J.N.; Chistyraj, J.D.S.; Prasannan, A.; Rajagopalan, K.; Chelladurai, K.S.; Gnanaraja, J.K.J.S. Current scenario of solid waste management techniques and challenges in Covid-19 – A review. *Heliyon* **2022**, *8*, 1–19, doi:10.1016/j.heliyon.2022.e09855.
29. Foggia, G.D.; Beccarello, M. Drivers of municipal solid waste management cost based on cost models inherent to sorted and unsorted waste. *Waste Management* **2020**, *114*, 202–214, doi:10.1016/j.wasman.2020.07.012.
30. Elgizawy, S.M. A framework for sustainable slum development based on zero waste concept: "Learn to Earn Model". Dissertation, AUC Knowledge Fountain, Egypt, 2019.
31. Hara, D.F.M. Analisis Waste Besi Beton Dan Penanganannya Pada Proyek High Rise Building (Studi Kasus: Proyek Thamrin Nine, Jakarta Pusat). Thesis, Mercu Buana University, Jakarta, ID, 2019.
32. Dewi, L.; Hanik, U.; Habibah, A.; Candra. Determinan Harga dan Potensi Sampah sebagai Sumber Modal Ekonomi di Bank Sampah Syariah UINSA Surabaya. *Nomicpedia: Journal of Economics and Business Innovation* **2021**, *1*, 14–26.
33. Corder, G.D.; Golev, A.; Giurco, D. ‘‘Wealth from metal waste’’: Translating global knowledge on industrial ecology to metals recycling in Australia. *Minerals Engineering* **2015**, *76*, 2–9.
34. Bendikiene, R.; Antanas, C.; Kavaliauskiene, L. Circular economy practice: From industrial metal waste to production of high wear resistant coatings. *Journal of Cleaner Production* **2019**, *229*, 1225–1232, doi:10.1016/j.jclepro.2019.05.068.
35. Arumugam, S.K.; Muhamad, R.; Yahya, K. Implementation of eco-costs per value ratio (EVR) on construction waste management in Shah Alam, Malaysia. *IOP Conf. Ser.: Mater. Sci. Eng.* **2019**, *513*, 012037, doi:10.1088/1757-899X/513/1/012037.
36. Wang, H.; Pan, X.; Zhang, S.; Zhang, P. Simulation analysis of implementation effects of construction and demolition waste disposal policies. *Waste Management* **2021**, *126*, 684–693, doi:10.1016/j.wasman.2021.03.056.