Waste Minimisation through Sustainable Manufacturing

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Abstract

Waste management is a challenge, especially in developing countries. The rapid economic and population growth has further exacerbated the consumption rate, the main driver behind massive waste generation. Recent studies have indicated that residents in urban areas generate waste that is roughly 1.2 kg per person, which is an estimated 1.3 million tons per year. Statistically, this is likely to increase by 1.42 kg per person and 2.2 billion tons in 2025. Therefore, to counteract the impact and consequences of spiralling waste generation, it is essential to do away with unsuitable and flawed means of production and adopt sustainable manufacturing. The emerging concept of 6R-based sustainable manufacturing with its technological elements has given light to new ways of production that can be adopted to achieve environmental protection and material efficiency. Material efficiency reduces industrial waste volumes of virgin raw materials, extraction and consumption, increasing waste segregation, decreasing energy demand, reducing extraction and consumption of virgin raw materials, increasing waste segregation, and decreasing carbon emissions thereby, reducing the environmental impact of waste generated by the manufacturing industry. However, the concept of 6R and material efficiency are poorly researched, with minimal information on their role in waste minimisation, especially at manufacturing levels. Waste generation can only be reduced if material consumption and material flow are monitored at the early stages of production; this can be done by emphasising material efficiency at the industrial level.

Keywords
Sustainable manufacturing, waste management, 6R, Optimisation, Material efficiency

1. Introduction
Waste management continues to be a global challenge, especially in urban areas of the rapidly growing cities in developing countries. Rapid industrialisation and urbanisation have changed the nature of produced waste. This calls for evaluating and updating the current solid waste management systems to develop better sustainable waste quality, quantity, and composition (Manaf, 2009). According to a study conducted by Hoornweg and Bhada-Tata (2012), it was estimated that residents in urban areas generated waste that is roughly 1.2 kg per person, which is estimated to be 1.3 million tons per year. Statistically, this is likely to increase by 1.42 kg per person and 2.2 billion tons in 2025. Several studies have been conducted by scholars such as Mokebe (2018); Nkosi (2014); Snyman and Vorster (2011) and Worku (2014), focusing on waste management within the City of Tshwane, and have all indicated that over the years, there has been an increase in waste generation, which is associated with the rapid population growth and urbanisation. Waste generation is the subsequent product of manufacturing; any manufacturing process that involves input for product creation generates an output and the by-product (Waste).

Manufacturing industries are still using traditional manufacturing flows of making products, where material consumption is the only significant phase without careful consideration of ways of introducing used up material into a new cycle for continued material flow. Consequently, material efficiency is under-researched (Allwood et al., 2013). Therefore, there is a need for knowledge on the integration of reverse logistics, material efficiency, circular economy, and the development of sustainable infrastructure for waste management and recycling. Integration of these aspects will allow for careful evaluation -of a product life cycle from the initial stages of design to the final stages of recycling, subsequently improving waste generation and disposal. The effects of manufacturing and by-product on the environment have gained attention. The manufacturing industries have gradually introduced improved production and profit generation strategies while maintaining environmental sustainability.

1.1 Objectives

This paper aims at evaluating waste minimisation through sustainable manufacturing, based on an adaptation of the 6R sustainable manufacturing processes and system and material efficiency and evaluate the current state of waste production and disposal, specifically recyclable products (plastic and cardboard, and paper) and how they can be introduced into new manufacturing cycles.

The following section unpacks the key concepts of the paper-based on what has been covered by other authors. The literature review explains what is meant by sustainable manufacturing and how it is linked to waste production, and ways in which sustainable manufacturing can be adopted to reduce waste production, focusing on applying the 6R model and material efficiency.

2. Literature Review

2.1 Sustainable Manufacturing

According to The U.S. Department of Commerce in Jayal et al. (2010), the creation of manufactured products that use processes that minimise negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers are economically sound. The Lowell Center has given a similar definition of sustainable production as the creation of goods and services using processes and systems that are: non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for workers, communities, and consumers; and, socially and creatively rewarding for all working people (Veleva et al. 2001). These definitions emphasise the conservation of natural resources by reducing the material consumption rate and adopting the reduction, reuse and recycle principle. This can be achieved by integrating material efficiency in sustainable manufacturing for waste reduction.

Sustainable manufacturing advocates for production by using minimal/minimised energy, non-renewable resources and reduced waste emission. This is achieved by using advanced technological processes and systems for production. Although the concept of sustainable manufacturing is well established and widely used by scholars, it is essential to note that there is no universally accepted definition for the term sustainable manufacturing Jayal et al. (2010: 144). Sustainable manufacturing offers alternative ways of manufacturing products using sustainable methods and advanced technological means. However, it is essential to note that for these products to be functional and serve the purposes of sustainability, producers need to apply a holistic and integrated approach when designing, producing, supplying and managing the product (Jawahir and Bradley 2016). Sustainability is concerned about balancing the currently exploitative relationship between humans and the environment, looking at the three primary pillars, i.e. economic, environmental and social aspects of development.

2.2 Waste Management Cycle

Waste management is not a simple task involving many stages from generation to separation, collection and transportation, recovery and disposal. Thus, an integrated approach should optimise a waste management system that minimises generated waste, collection, transfer, and treatment to prevent landfill disposal of untreated municipal solid waste (Snyman and Vorster, 2011). To achieve effective execution of these stages of waste management, one needs to understand the waste management hierarchy that serves as a guideline in waste management. This indicates that waste minimisation should be the foundation of any management strategy, followed by reuse, recycling, incineration and land disposal as a last resort (Bagchi 2004). The waste management hierarchy looks at the overall process from waste production to the final stages of waste treatment. According to the waste hierarchy, there are three important aspects that one needs to understand, and those are consumption rate, production rate and waste generation, hence the Cradle to the grave concept, which emphasises the importance of understanding the root cause or source of waste production (Gertsakis 2003).

Separation at source, reuse, and recycling are essential in the waste management hierarchy. Waste prevention is the most desirable attribute at the top of the waste management hierarchy. Its primary goal is waste reduction at the source, followed by the three steps that emphasise waste generation reduction through adopting the 3R's model, with waste disposal as the least desirable outcome. According to Gertsakis and Lewis (2003), Victorian Environment Protection Act, is specifically stating that waste should be managed under the following order of preference: avoidance, reuse, recycling, recovery of energy, treatment, containment and disposal. According to Mukhtar et al. (2015) a detailed understanding of how waste management systems evolve can provide new perspectives and insights; this is important in the current era as waste management is undergoing a paradigm shift, refocusing on sustainable resource management rather than sustainable waste management. The authors further argue that to facilitate the improvement of future systems, it is necessary to compare the simultaneous evolution of waste management systems between developed and developing cities in a comprehensive manner, particularly the relationship between socio-economic developments. Wilson (2007) and McDougall et al. (2001) argue that the difference between waste management systems in developed and developing countries is their optimisation strategies. Developed countries are grounded on resource conservation, while developing countries are characterised by inadequate management and operational inefficiency.

2.3 Principles of 6R-based Closed-loop Sustainable Manufacturing

The 6R concept stands for (Reduce, Reuse, Recover, Redesign, Remanufacture and recycle); it is the cornerstone for sustainable manufacturing. The 6R methodology involves several sustainability metrics and has often been used in many studies (Worrel et al. 2012; Allwood 2013; and Jayal et al. 2010) to evaluate a product's sustainability life cycle processes. This methodology focuses mainly on environmental impacts of manufacturing, energy consumption during manufacturing processes, waste generation and management, consumption of natural resources and manufacturing cost. Reduce emphases reduced use of natural resources and energy in the manufacturing stage and reduction of waste produced during the use stage of a product. At the same time, reuse focuses on the multiple uses of a product in a continued life cycle after its first life cycle to reduce the need to extract new raw materials to produce the same product. Converting material at its end-use stage, where it would generally be regarded as waste, is referred to as recycling and contributes relatively to reducing waste disposal. Private companies and waste pickers engage in this activity for profit generation and environmental conservation. Redesigning involves redesigning a product to make it more environmentally friendly and sustainable. At the same time, re-manufacturing refers to restoring products to their original state through re-processing already used products to make a new product that is fully functional Jayal et al. (2010). Studies have proven, through careful evaluation, the application of this methodology in waste reduction. They have proven that using the 6R methodology reduces the mass of waste generated throughout the life cycle and the mass disposed at the end of life stage of a product. Successful application of the 6R methodology in manufacturing prolongs a product's life span, thereby reducing the need for excessive use of natural resources and reducing the volume of waste in landfills.

2.4 Industrial Waste Minimization through Sustainable Manufacturing

Godfrey and Oelofse (2008) argue that waste management challenges in South Africa are contributed by issues of insufficient budget, capacity, equipment and lack of law enforcement. These challenges form part of why this study is carried out, highlighting the per capita cost of the waste management sector areas at a city-wide level and the financial trends concerning the capital and operating costs. However, financial capacity has been outlined as a constraint to service delivery, very little attention is given to poor policy implementation. Solid waste management is a challenge for cities in developing countries, mainly due to the increasing generation of waste, the burden posed on the municipal budget. As a result of the high costs associated with its management, the lack of understanding of a diversity of factors that affect the different stages of waste management and linkages necessary to enable the entire handling system to function. The increased production of domestic, industrial, and municipal waste poses a threat to the environment and human lives exposed to unbearable odour and unsanitary conditions of disposed waste. Patterns of resource consumption have shown a high rise which correlates with buying power. Over the years, waste management systems have evolved to address the adverse impact of inadequate waste management on environmental degradation and public health (Emery et al. 2003). However, formulating localised waste management strategies remains the primary concern due to underlying issues such as costs, social adaptation and environmental effectiveness of various strategies (Mc Dougall et al. 2001).

According to Ellen MacArthur Foundation (2012), the generation of industrial waste poses a grave threat to sustainability given its impact on the environment. The manufacturing industry and dominated by the traditional manufacturing practices that result in the Cradle grave process. Extracted resources and raw materials result in waste in dumping sites, landfills and water bodies. Applying the 6R at the end of life stages to reduce waste generation and material consumption has remained a challenge in the industrial system. Ideally, industrial waste could be utilised directly in another process or be reused within its loop, thereby reducing the demand for virgin material. Best practice waste management reduces the environmental burden generated throughout a product's life cycle. This is to decrease the effect of waste on health and the environment, increase environmentally friendly material consumption, avoid hazardous and toxic material, and use processes and technologies with lower emissions to minimise waste. Also, it is to correct waste segregation and disposal via reuse and recycling and to avoid landfills and incineration. Tshwane is currently landfilling all of its MSW with no pre-processing or minimisation efforts. This is due to the impression that there is capacity in the availability of unused space within existing landfills. They believe that they can satisfy the city's needs for at least the next ten years (Snyman and Vorster 2011).

Reduce, reuse, recycle, and re-manufacture are all associated with environmental benefits in manufacturing operations. The production system is an industrial ecosystem in zero-emission (closed-loop) manufacturing, requiring the reuse of waste or by-products. As a result, zero-emission manufacturing necessitates pollution avoidance (for example, waste substitution) and waste reuses capabilities. Manufacturing equipment that can accept fluctuations in material flows can help to improve sustainability while maintaining competitiveness. Packaging may be made more sustainable by using more efficient and recyclable designs. Thus, material efficiency is required to reduce industrial waste volumes, resource extraction and consumption, waste segregation, energy demand, carbon emissions, and the global economy's overall environmental effect.

2.5 Material efficiency for sustainable manufacturing

According to (Shahbazi 2018) material efficiency in manufacturing implies any activities to reduce the amount of material used for manufacturing a product in a factory through different options such as process improvement or in-house recycling/reusing, generating less waste per product regardless of end-of-life scenarios, and achieve better waste segregation and management to move up the waste hierarchy steps. Material efficiency like the 6R model is the cornerstone for sustainable manufacturing. It results in the prevention and reduction of volumes of industrial waste generation and waste disposal and increased recycling and reuse of waste products for the re-manufacturing of new products. Material efficiency allows for manufacturing the same fully functional product only with reduced virgin raw material, reduced energy demand, and reduced carbon emission in a cost and energy effective way (Worrell et al. 2016), thereby reducing environmental impacts associated with manufacturing while enhancing profit generation. Furthermore, Rashid et al. (2008) describes material efficiency as reducing the consumption of primary materials without substantially affecting the service or function, without affecting the level of human activities qualitatively. Thus, improved material efficiency is a key to improving the circular economy and capturing value in the industry (Shahbazi et al. 2016). Material efficiency in manufacturing directly results in cost and energy savings in fabrication, transformation, transportation and disposal and reduced greenhouse gas emissions through better waste segregation and a higher recycling rate. It increases the success rate of waste management initiatives (Allwood et al. 2012). During the manufacturing phase of a product, raw material is consumed, and waste is generated during the process; in order to enhance the potential life span of a product, correct waste segregation can improve the recycling and reuse rate significantly. Waste segregation allows for the reuse of residual material in re-manufacturing. However, this also depends on other factors, such as the value and type of material used in the initial manufacturing stage. Remanufacturing is also essential for material efficiency in manufacturing. Material efficiency can also be achieved through innovative technological advances, such as eliminating paperwork to digital paperless functions and using degradable packaging material.

The following segments elaborate on the methodology used to conduct the study, giving a summary of the tools and methods that were utilised to collect secondary and primary data that meets the objectives of the paper while providing a clear picture of the nature of the paper whether it is qualitative or quantitative).

3. Methods

This paper reports on the application of sustainable manufacturing mean to achieve waste minimisation, specifically looking at integrating the 6R approach and material efficiency in planning, designing and product manufacturing. This paper aims to provide insight into the current state of waste management (Production and handling) within the city Of Tshwane and evaluate sustainable manufacturing tools/ approaches that can be applied to address waste management challenges in the city. This paper is mainly based on literature studies as well as empirical findings. The City of Tshwane was studied, a detailed description of the empirical and literature studies is presented in the findings. This study adopted a descriptive research design as it seeks to evaluate the applicability of sustainable manufacturing in waste minimisation in the City of Tshwane. Adopting this design is fitting for investigating a multifaceted social phenomenon such as waste management/ waste reduction to understand the dynamics and the implications of this social phenomenon. A descriptive research design helps understand the deep-rooted causes of a phenomenon. In n this case, factors that hinder the effective implementation of sustainable measures in the manufacturing industry are poor monitoring of the product life cycle from manufacturing to its end-life phase for improved recycling, reuse and re-manufacturing. The rationale of this approach is that the qualitative data and results provide a general picture of the research problem and more analysis by addressing questions, such as what and why to understand underlying factors.

3.1 Data Collection

Secondary data was used to provide background information based on existing literature about sustainable manufacturing, looking at the application of 6R to achieve sustainable manufacturing and minimise waste production in integration with material efficiency. The literature review provides an understanding of the theoretical context of the study. The secondary data sources include; books, articles, seminar reports, theses and government reports, which provide relevant information that would have required more time for the researcher to gather. To find relevant literature, keywords including "material efficiency, 6R methodology, sustainable manufacturing, waste minimisation were used to search for existing literature. After reviewing the secondary data, the researcher identified gaps and deficiencies and strived to cover them through primary data collection as additional information. Primary data based on the current state of waste management in Tshwane was collected from a small sample of participants that were selected using purposive sampling to serve the study's objective. Interviews were then conducted using semi-structured questionnaires. The researcher also visited the landfill sites for observation. The sample of participants is presented in the below table, indicating the number of participants, field of work and their ranking (Table 1).

Table 1. Respondents' roles in waste management

Institution	Rank	Number of Respondents
City of Tshwane municipality	Management andAdmin	2
Recycling facilities	Management and Admin	2
Landfill	Management and Admin	2

Participants were chosen based on their field of expertise and relevance to the study, specifically their involvement in waste handling and management. The above table indicates that six participants were chosen overall. Two participants represented the City of Tshwane municipality (waste management division), two representing recycling facilities, and two landfill managers.

The next part of the paper is the presentation and discussion of the result obtained during primary data collection. This section addresses the objectives of the study through careful evaluation of primary data and existing literature to conclude the current state of waste management and how sustainable manufacturing can be applied to achieve sustainable waste management in the city of Tshwane.

4. Results and Discussion

This section provides results based on primary data collected during the study. The data presented in this chapter is based on three different questionnaires set up for different stakeholders in waste management, namely, municipal officials, landfill managers, and recycling facilities. Data is presented with the aid of tables, graphs, and descriptions. This paper aims to evaluate the current state of waste production and disposal, specifically recyclable products (plastic and cardboard, and paper) and how they can be introduced into new manufacturing cycles. While presenting sustainable ways in which waste minimisation can the achieved through sustainable manufacturing, look at two dominant approaches: the 6R model and material efficiency. The first part of this section provides statistics on waste composition in landfills and further breaks down the lifecycle of plastic contents from the production phase, end-of-life phase, and re-manufacturing phase. The second part covers waste treatment options and mitigation strategies adopted by the municipality to ensure the recovery, reuse and recycling of material

4.1 Waste composition

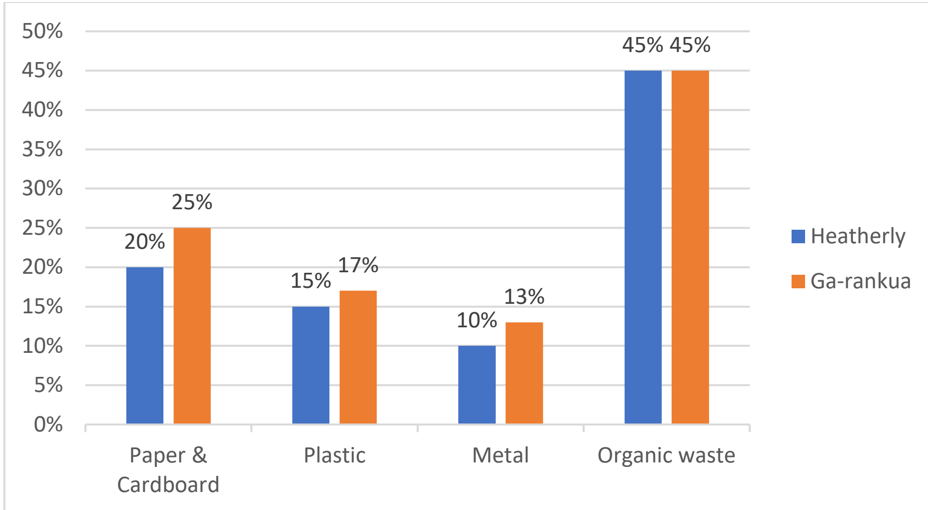

Figure 1. Waste composition in landfills

The graph (Figure 1) above presents the distribution of waste within the studied waste handling facilities i.e., the landfills and recycling facilities. The most predominant form of waste composition is identified during disposal since there is no separation in landfills. Figure 3 below presents the distribution of waste within the studied waste handling facilities. Based on the below data, an average of 20% to 25% of paper and cupboards end up in landfills, with 15% to 17% making up the waste composition in a landfill. Waste pickers contribute an implacable role in reducing the amount of recyclable material in landfills. There would be a great reduction in the percentage of disposed of material if industries enforced material efficiency at the designing and packaging stages of products by introducing packaging using degradable and environmentally friendly material (Shahbazi et al., 2016). Furthermore, collection of products in the end-of-life phase for re-manufacturing or reusing products can reduce the need for new resources or raw material, subsequently mitigating environmental degradation and reducing the amount of disposed of material. However, the reuse of by-products for re-manufacturing relies heavily on waste segregation; waste sorting of materials such as plastics, metal, glass provides great environmental and economic benefits. Correctly separating recyclable material at the source, at the manufacturing stage and at the after use stage before disposal can enhance manufacturing material efficiency, reduce the use and extraction of raw material, and ultimately reduce the volume of waste that results in landfills. Therefore, this means that materials such as plastics need not be mixed with combustible material for successful segregation. The Manufacturing industry is one of the industries that use the rawest materials for manufacturing and packaging purposes. Therefore, they must ensure that their waste packaging is recyclable.

4.2 Plastic life cycle: Recovery, recycling and reuse

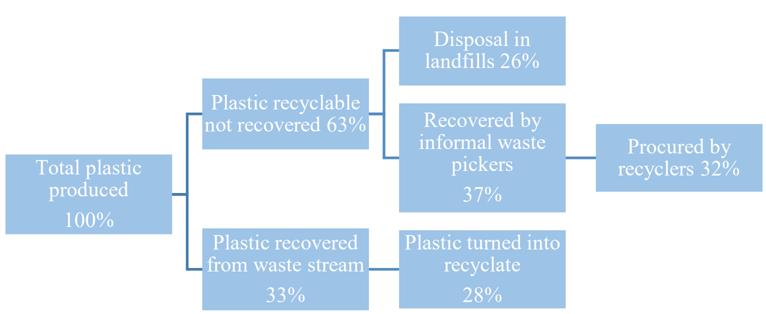

Figure 2. Schematic representation of plastic recycling

The above figure is a schematic presentation of plastic waste and the recovery stages. It is a breakdown of how plastic waste is channelled from the point of production as waste to the final stages of disposal and recycling. Based on the findings, it is evident that plastic materials recovered from the point of collection (residential and industrial) account for 33%, while waste that is not recovered accounts for 63%. Of the unrecovered waste, 26% reaches its end-life stage through disposal at the landfill if unrecovered by waste pickers, while waste pickers collect 37% from bins and landfills. The 33% recovered material accounts for 28% of recycled waste, with the remaining percentage counted as a loss due to the quality of the material.

4.3 Materials Recovery Facility (MRF)

The city of Tshwane has partnered with the private sector to develop a Materials Recovery Facility (MRF), and buy-back centres that serve as the service point between supplies (informal waste pickers) and private recycling companies. In partnership with the Department of Environmental Affairs, the City of Tshwane launched three buy-back centres in Atteridgeville, Stinkwater and Hammanskraal on 7 June 2016. The municipality's establishment of these buy-back centres aims to address the current challenges in waste management by providing safe operating space for waste pickers and communities to engage in material recovery and exchange with recycling facilities. This is a sustainable way of diverting recyclable material away from landfilling and ensuring reuse after the end-of-life phase of a product.

4.4 Waste treatment

Based on the waste distribution and treatment findings in the City of Tshwane from various waste handlers, i.e., landfills, recyclers and waste pickers, the researcher drew up the average percentage of waste diverted towards landfill disposal, recycling, open dumping and other. However, the findings are inconclusive due to inconsistency in recorded waste received by the landfill, especially the heartedly, due to recurring load shedding. The results indicate that the majority of the generated waste is diverted towards landfill disposal, which accounts for 53%, while recycled waste is at 15%, waste used for compost at 5%, open dumping burning/ dumping is at 17% and other forms of waste treatment at 10%. The city of Tshwane needs to adopt Closed-loop manufacturing in order to extend the lifespans of what were previously considered to be waste materials, reintroducing them into the manufacturing lifecycle through system innovations. Similarly, it also means utilising recycled products instead of virgin materials to lessen environmental impact. By utilising your waste for something other than the landfill, you can adequately satisfy looking to reduce your manufacturing waste.

4.5 Waste minimisation through separation at the source

The separation at the sourcing initiative is the city's waste minimisation plan to enhance recycling by recovering recyclable materials at the source to divert 93% of the generated away from landfills by 2040 (CoT, 2014). In October 2020, the city launched its second phase of separation at the source project. The municipality encourages the community to separate recyclable material at a household level and actively participate in waste management through waste prevention and minimisation. According to CoT (2014), the city is experiencing rapid depletion of landfill space. If their waste disposal rate continues to grow, the city is estimated to run out of landfill airspace by 2023. Therefore, the separation of the sourcing initiative is a way of enforcing and encouraging communities to work with the municipality to divert waste away from landfills toward recovery and recycling.

4.6 Challenges in the implementation of waste separation initiatives

The interviews conducted with landfill managers, municipal waste managers, and waste handling companies indicated several challenges in implementing waste separation initiatives. The table 2 is a summary of the challenges and their ratings on a scale of 1-3 with; (i) 1: least persistent; (ii) 2: average, and (iv) 3: most persistent.

Table 2. Sector related waste management challenges

Sector	Challenges	Rating (0-5)	Opportunities
Municipality	• Growing informal settlements with poor infrastructure for accessibility • Expertise Knowledge and skill resulting in the independence of the municipality to private companies • Poor monitoring of separation at the source (pick-it-up) program	• 3 • 2 • 2	• steady improvement, enforcement is still needed
Landfill	• Insufficient waste minimisation and recycling initiatives	• 2	• Material hub for

	• lack of waste information • lack of regulation, maintenance and enforcement of policies • Nature of environmental and health risks	• 3 • 3 • 3	waste pickers and waste re-claimers. • Job creation for informal waste picker
Recycling facilities	• Quality of recyclables • Poor separation of waste at the source • Intensive energy use • Supply fluctuation • Establishing own collection networks	• 2 • 3 • 2 • 2 • 2	• Job creation, • Economic development • Cleaner environments

During the interviews with municipal officials, they were asked if any initiatives deal with recycling and waste material recovery. They responded that the city currently relies on the pick-it up systems and is responsible for waste picking in residential and industrial areas. They have provided waste bins in residential areas to encourage recycling through separation at the source. The table above indicates several challenges encountered by the municipality in their step towards recycling and recovery. The most persistent challenge that the municipality is facing is the growing informal settlements with poor infrastructure for accessibility at (3), followed by the lack of expertise, knowledge and skill, resulting in the dependence of the municipality on private companies at an average scale of (2) and lastly the poor monitoring of separation at the source (pick-it-up) program at an average scale of (2).

Interviews were also conducted with landfill managers to establish the challenges they face in their work environment and to establish their role in waste recycling; based on the observation, it was clear that the Heatherly landfill is a harbour for waste pickers who engage in material recovery and recycling. The landfill managers had these three most common challenges; Lack of reliable waste information due to poor record-keeping at a scale of (3); lack of regulation, maintenance and enforcement of policies at (3), insufficient waste minimisation and recycling resulting in disposal of recyclable material (2) and lastly the unsafe nature of environmental and health risks posed on the waste pickers who engage in material recovery in the site at a scale of (3).

Lastly, interviews were conducted with managers from two recycling facilities. They outlined the following challenges; quality of recyclables at the scale of (2) for the average state due to the poor separation of waste at the source, either household or industries at the scale of (3). The most waste from business units is found in an average state compared to residential areas. Another challenge faced by recyclers is the establishment of a collection and supply fluctuation bot at a scale of (2)

5. Proposed Improvements

To determine the environmental impact, sustainable manufacturing and waste minimisation can be achieved by integrating 6R elements in the current existing methodologies. The 6R metrics and indicators can be used to assess existing methodologies and be used in redesigning and improving the sustainability value of products. Developing a combination of these mechanisms and assessments is the primary approach to implementing the 6R elements as the technological basis for the circular economy. This integration will bring light to designers' and manufacturers' decision-making through an overall assessment of sustainable value creation using the 6R indicators to determine manufacturing processes' social, economic, and environmental impacts. This would give the manufacturing world the ultimate tool for designing sustainable products, processes, and systems.

There is a need for technical training programs and formal university education for industrial manufacturing that is innovative and in line with sustainability principles; proper training will yield the next generation of manufacturing. There is a need for qualitative and quantitative methodologies that continuously evaluate the effectiveness of current strategies and enhance sustainable value creation.

5.1 Validation

According to Saunders et al. (2009), construct validity is defined as "the extent to which your measurement questions measure the presence of those constructs you intended them to measure". Mohajan (2017) suggested that using multiple sources of evidence can support construct validity and ensure that the collected information is correct (Meredith, 1998). As highlighted in the methodology, this research is qualitative; therefore, the results are based on primary data and case studies reviewed in the literature review. Evidence for this study was collected from multiple sources, including content analysis of journals, documents, observations, and interviews. This information was further triangulated to pick up patterns, similarities and to provide solid information based on existing literature.

6. Conclusion

Although sustainable development and sustainable manufacturing are developed concepts, putting them into practice remains a challenge due to their broad scope, including several factors that need careful evaluation to ensure balance within the environmental, economic, political, and social aspects. Given the diverse interests of all involved stakeholders, it is essential to ensure balance in the trade-offs by integrating all objectives and observing the mandatory policies and procedures (Rosen and Kishawy, 2012). Sentime (2014) also argues that the application of policies and legislation has proven inconsistent. The lack of favourable and comprehensive policies hinders the possibility of sustainable socio-economic service delivery and cost-effective waste management systems; there are fragmented strategies instead of integrated approaches.

There is a need for Tshwane municipalities to integrate material efficiency and the 6R model into their existing Integrated waste management plan; this would help address the existing challenges in waste management. The emphasis on waste reduction at the production and end-use phase from the two approaches is exactly what the city needs to reduce the amount of waste diverted into landfills, mainly because their existing landfills are reaching their life span. This paper emphasises prevention and reduction of waste generation, thereby advocating for waste segregation at the source for effective recycling and recovery and as a step toward material efficiency. The paper highlights the need to develop a shared understanding of material efficiency in manufacturing and links existing performance measurements to this shared understanding through material-efficient operations.

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Biography

Anelisa Kanyisa Nokele is currently a registered student at the University of Johannesburg for Masters in Sustainable Urban Planning and Development (MSUPD). She obtained her bachelor's degree in Geography and Environmental management at the University of KwaZulu Natal in 2015. She later completed her honors in Political Sciences specialising in International relation at the University of KwaZulu Natal in 2016. She has conducted research on Post-Colonial Economic growth in the developing region, a comparison study between Asia and Africa.

Dr Jackson Sebola-Samanyanga possesses a Baccalaureus Technologiae Degree (BTRP) in Town and Regional Planning from the University of Johannesburg; a Master's Degree (MTRP) in Town and Regional Planning, and a Doctorate (PhD) in Development Studies from the University of Pretoria. He is a Registered Professional Planner with the South African Council for Planners (SACPLAN) and a South African Planning Institute (SAPI) member. He has more than ten years of working experience in the Urban and Rural Planning fraternity. His experience is wide-ranged, consisting of the private, public and academic sectors – specifically including expertise from the Makhado Local Municipality; the City of Ekurhuleni; the Department of Rural Development and Land Reform; Isibuko Development Planners; University of the Witwatersrand; the University of Johannesburg and GoldenGrey Consortium (Pty) Lt.