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Zero-waste toilet a sensor-operated urine diverting toilet for sustainable sanitation and fertilizer production

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Abstract

This research introduces an innovative zero-waste toilet, a sensor-operated urine-diverting system designed to overcome limitations in current sanitation methods. The toilet directly converts human feces into organic fertilizer while segregating urine from solid waste. Its walls are constructed using repurposed plastic PET bottles filled with local soil, enhancing strength and durability through steel wire interconnection and cement plaster reinforcement. Touchless sensors facilitate automatic flushing upon user entry and after a predetermined duration, with a gesture sensor for post-use cleaning. A front-mounted urine basin ensures proper waste separation. Feces are directed to a specialized tank via a trap system, while urine is directed to the sewer line. The tank features two meshes for effective filtration. Solar energy and sensors power the process, enabling atomization for efficient fertilizer production, followed by composting in a blending tank. The zero-waste toilet offers a key advantage: fertilizer production without manual waste handling, aligning with scavenger act regulations. It minimizes waste generation, conserves water, and enhances sanitation. Repurposed plastic bottles reduce plastic pollution, and the system is comfortable, durable, and resource-efficient. Challenges include specialized expertise, initial costs, and user adaptation to automated systems. Further research is needed to optimize fertilizer production from waste compost. Nonetheless, the zero-waste toilet holds promise for sustainable sanitation, improved hygiene, and resource conservation.

*Keywords: zero-waste toilet, urine diverting toilet, organic fertilizer, sensor-operated, sustainable sanitation, PET bottles, w*ater conservation, waste management, hygiene, resource utilization, composting.

1. Introduction

Currently, a global sanitation crisis persists, with staggering numbers highlighting the magnitude of the issue. Approximately one billion individuals resort to open defecation, while a staggering 2.5 billion people lack access to even the most basic sanitation facilities. In 2012 alone, it is estimated that 1.5 million lives were claimed by diarrheal diseases resulting from poor sanitation (Garcia-Fine, 2015). Diarrhea, one of the world's most prevalent diseases, is primarily caused by inadequate sanitation and accounts for over 846,000 deaths each year. Although progress has been made in providing improved sanitation facilities to a growing portion of the global population, extending access to better sanitation remains challenging for the 2.3 billion individuals residing in rural areas (Ignacio et al., 2018).

The dire state of sanitation in rural communities of India often goes unnoticed by urban residents. Alarmingly, out of the planet's 1.3 billion inhabitants, nearly 800 million lack access to toilet facilities. Open defecation continues to be a pressing issue associated with poor sanitation and inadequate toilet infrastructure. Diseases like cholera, diarrhea, and E. coli infections are transmitted through water contamination caused by open defecation. To address this pressing concern and achieve comprehensive sanitation nationwide, innovative approaches and strategies are imperative. Access to sanitary facilities should be a universal right, accessible in all regions of the country. It is essential to raise awareness among the rural population in India about the urgent need to improve their physical well-being. Expanding sanitation coverage to unprecedented levels within this population is crucial to realizing this vision (Shah et al., 2020).

Discharging excrement or fecal matter through sewer lines into rivers and lakes poses a significant threat to water supplies and human life. However, fecal waste contains valuable nutrients that can enhance soil fertility. Instead of polluting water bodies, it makes more sense to utilize fecal matter to enrich the soil and harness its nutrient content. This project proposes a novel sanitation technique that minimizes human involvement while upholding established sanitation standards.

Ensuring hygienic conditions after toilet usage is of utmost importance. Introducing sensors into the project plays a pivotal role in maintaining cleanliness. Restroom sensors are employed to automate toilet flushing and fragrance spraying. To address the issue of misuse of flushing systems by toilet users, sensors are incorporated to maintain consistent automated flushing, effectively cleaning the toilets. Additionally, sensors are employed for regular fragrance sprays, ensuring a pleasant smell in the facilities and mitigating any unpleasant odors caused by improper flushing practices.

The inclusion of PET (Polyethylene Terephthalate) bottles in this project represents a significant step towards environmental protection and the development of eco-friendly toilets. With the increasing population, PET bottle production has surged, but inadequate disposal practices have resulted in their widespread presence, littering the environment. When these bottles mix with the soil, they adversely affect soil fertility as they take around 450 years to decompose. Furthermore, plastic waste, including PET bottles, has become a pervasive problem in water bodies, causing harm to aquatic life and contributing to the deaths of over 1.1 million seabirds and other animals annually. By utilizing PET bottles, this project contributes to the preservation of nature.

Compared to other household tasks, toilet usage consumes significantly less electricity. A sustainable alternative to relying on generated electricity is harnessing solar energy. Solar power can generate ample electricity to meet most electrical needs, such as lighting and sensor operations. Utilizing freely available solar energy requires thoughtful consideration. Solar panels have been installed at top the toilet to provide the necessary electricity, effectively addressing the pressing issue of carbon emissions. The lighting system, flushing system, and odor removal system rely on this solar-powered sensor-based automation, which eliminates issues arising from user negligence and ensures efficient utilization of water and light while safeguarding the environment.

The global sanitation crisis is an ongoing challenge that demands innovative solutions to provide sustainable and efficient sanitation systems for communities worldwide. One such solution is the development of zero-waste toilets, which aim to address the issues of poor sanitation, water contamination, and environmental degradation. This chapter introduces an zero-waste toilet design known as the Sensor-Operated Urine Diverting Toilet that not only promotes sustainable sanitation practices but also facilitates fertilizer production through the recycling of waste materials. The incorporation of sensor technology and solar power in this design enhances its efficiency and reduces the environmental impact associated with traditional sanitation methods.

Access to proper sanitation facilities is a fundamental human right and a critical factor in promoting public health and well-being. However, the current global sanitation situation is alarming, with millions of people lacking access to safe and hygienic sanitation facilities (UNICEG ＆ ＷＨＯ , 2019). Inadequate sanitation contributes to the spread of diseases, particularly in low-income communities where open defecation is prevalent. Diarrheal diseases, for instance, claim the lives of hundreds of thousands of people annually, mainly due to poor sanitation and lack of access to clean water (Prüss-Ustün et al., 2014). Furthermore, the disposal of untreated human waste poses significant environmental risks, such as water pollution and soil degradation (Tilley et al., 2014).

Zero-waste toilets offer a promising solution to address the challenges of traditional sanitation systems. These toilets integrate environmentally friendly practices, resource conservation, and waste recycling, making them an effective and sustainable option for communities in need. By implementing zero-waste toilets, several benefits can be achieved, including improved public health, reduced water pollution, and the production of valuable resources, such as fertilizers (Crume, 2018).

The incorporation of sensor technology in the current toilet enables automated flushing, odor control, and maintenance functions. Sensors detect the presence of users and initiate the flushing process, reducing water consumption and promoting water conservation (Ray, 2017). Furthermore, sensors can be used to monitor the cleanliness of the toilet and automatically dispense cleaning agents or fragrances, ensuring a hygienic and pleasant environment for users (Aryza et al., 2022).

A key feature of the current toilet is the separation of urine from solid waste. Urine, rich in nitrogen, phosphorus, and potassium, can be collected separately and processed into a nutrient-rich liquid fertilizer through appropriate treatment methods (Simha and Ganesapillai, 2017). This process not only prevents the contamination of water sources but also offers a valuable resource for agricultural purposes, contributing to sustainable farming practices (Angeletti and Bjørseth, 2013).

The implementation of the current toilet brings numerous environmental benefits. Firstly, the diversion of urine reduces the load on wastewater treatment systems, decreasing energy requirements and treatment costs (Wilderer and Schreff, 2000). Secondly, the recycling of urine into fertilizer reduces the demand for synthetic fertilizers, which are often produced through energy-intensive processes and contribute to greenhouse gas emissions (Cordell et al., 2009). Furthermore, the utilization of solar power as the primary energy source minimizes the reliance on fossil fuels, mitigating carbon emissions and combating climate change (Shafiee and Topal, 2009).

The primary objective of this research is to explore the feasibility, efficiency, and effectiveness of the Sensor-Operated Urine Diverting Toilet as a sustainable sanitation solution. Specific research objectives include:

1. Investigating the performance and functionality of the toilet in terms of user satisfaction, water conservation, and waste management efficiency.
2. Assessing the environmental impact of the toilet, including its potential for reducing water pollution, carbon emissions, and reliance on synthetic fertilizers.
3. Examining the economic viability and cost-effectiveness of implementing the toilet in different contexts.
4. Identifying potential barriers to adoption and strategies for promoting the widespread use of zero-waste toilets in communities worldwide.

The following are the important parameters of the zero-waste toilet.

Fecal Waste: Human feces contain pathogens such as bacteria and viruses that can cause diseases (Prüss-Ustün et al., 2014). Unfortunately, access to proper sanitation, especially in low-income urban areas, is severely limited. Less than 10% of urban areas in low-income nations have access to sewer systems, and a significant portion of fecal waste is left untreated, posing serious health risks to the public and the environment (2019). Lack of funding, inadequate infrastructure, and limited space contribute to the absence of piped networks for sewage disposal and wastewater management (Tilley et al., 2014). When onsite sanitation facilities like pit latrines become full, fecal waste, known as fecal sludge, needs to be physically removed and transported to treatment facilities. However, there is potential to utilize treated fecal sludge as fertilizer in agriculture, improving soil health (Simha and Ganesapillai, 2017). Overcoming societal prejudice and lack of awareness is crucial in promoting the beneficial use of human waste, as it enhances soil fertility and reduces the negative impact of chemical fertilizers on soil acidification and salinization.

PET Bottles: The production of PET (Polyethylene Terephthalate) bottles amounts to 56 million tons annually, with approximately 30% of the global demand fulfilled by bottle production, primarily for beverages (Crume, 2018). Unfortunately, used PET bottles contribute significantly to plastic pollution, ranking high among the plastic debris found during beach clean-ups. Improper disposal of plastic bottles can exacerbate flooding issues in developing nations lacking proper waste management systems (Shafiee and Topal, 2009). PET's durability is both a strength and a weakness, as it takes around 450 years to fully degrade, occupying valuable landfill space. This project aims to reduce waste generated by reusing PET bottles and minimizing their disposal.

Sensors: In this project, sensors play a vital role in maintaining hygienic conditions and optimizing resource usage. Motion sensors installed in toilets detect human presence and trigger automatic flushing, resulting in increased water efficiency and reduced cleaning costs. Smart toilets equipped with sensors can reduce water usage by up to 80% by automatically flushing and cleaning after each use. These sensor-based systems not only improve cleanliness and hygiene but also contribute to energy efficiency and environmental sustainability through smart lighting features (Ray, 2016). Additionally, sensors are employed to ensure a pleasant odor in the restroom area, with regular spraying to maintain a fresh and comfortable environment (Aryza et al., 2022).

Nutrient Recovery: Rather than considering waste materials like feces and urine as pollutants, this project recognizes their potential as valuable resources. These waste materials contain essential nutrients that can be effectively recovered and utilized to enhance the agricultural sector. By combining fecal waste with organic waste, organic chemicals, wheat bran, and sawdust to reduce moisture, and utilizing a composter to accelerate the composting process, a finished product can be obtained. This nutrient-rich compost can be used as fertilizer when exposed to a temperature of 35-40 degrees Celsius. By utilizing this recovered nutrient from waste as fertilizer, farmers can reduce their reliance on chemical fertilizers, which often have negative effects on human health and the environment (Simha and Ganesapillai, 2017).

Societal Benefits: By efficiently utilizing waste discharged from toilets and recovering its nutrients for fertilizer production, the project promotes sustainable farming practices. This reduces reliance on artificial fertilizers and harmful chemicals, resulting in more effective and environmentally friendly fertilizers. Additionally, farmers can potentially generate income by selling these nutrient-rich fertilizers (Simha and Ganesapillai, 2017).

The following raw materials have been used to manufacture Zero-waste toilet.

Mild Steel: Mild steel is a type of carbon steel with low carbon content. It is popular due to its weldability and machinability, making it suitable for various applications. Mild steel is often used in the construction of steel frames and in manufacturing roofing materials like M.S. Sheets.

Plaster of Paris (POP): Plaster of Paris is a white powder that, when mixed with water, forms a solid mass called gypsum. It is used to improve the smoothness of surfaces and is commonly used for creating molds and casts. In the context of the proposed toilet, gypsum plaster (POP) is used for finishing toilet pan mold.

PVC: PVC stands for polyvinyl chloride, and it is a widely used polymer known for its versatility. PVC has many applications in various industries. It is durable and long-lasting, making it a popular choice for construction purposes.

PET Bottles: PET (Polyethylene Terephthalate) bottles are a type of plastic bottle commonly used for packaging beverages and other products. However, the excessive use of plastic bottles has become an environmental concern. In the context of the toilet project, PET bottles are reused as building material, specifically for constructing walls. These bottles, known as ECO-BRICKS, are eco-friendly and help reduce pollution.

Bricks: Bricks are one of the oldest and most common building materials. They are typically made from burnt clay and have properties such as durability, strength, and resistance to moisture and erosion. Bricks are used for various construction purposes, including walls, septic tanks, foundations, and flooring.

Cement: Cement is a binder used in construction to bind other materials together. It is mainly used in concrete and mortar. Cement is manufactured through a chemical process that combines calcium, silicon, aluminum, iron, and other ingredients. Ordinary Portland cement is a commonly used type of cement in construction.

Aggregate: Aggregates are natural particles obtained through mining processes. They make up a significant portion of concrete, providing bulk and compressive strength. Coarse aggregates, such as gravel and crushed stone, are used for making concrete, while fine aggregates, such as sand, are used for both concrete and filtration purposes.

Nylon Mesh: Nylon mesh is a type of plastic-based fiber that is extruded into strands of various sizes and thicknesses. It is known for its filtration properties. In the context of the toilet project, 120-micron nylon mesh is used to separate flush water and feces and purify the flush water.

Charcoal: Charcoal is a black carbon residue produced by heating wood or other organic materials in the absence of oxygen. Activated charcoal, in particular, has a high adsorption capacity and is used for filtration purposes. In the toilet project, activated charcoal is used to enhance the rate of filtration.

Water: Water is an essential component in construction activities. It is used for various purposes such as preparing mortar, mixing cement concrete, curing work, and creating a water-cement paste. The quality of water used in construction affects the quality of mortar or concrete.

Industrial Sand: Industrial sand is high-purity silica sand with uniform grain size. It is used for filling PET bottles in the toilet project. The use of industrial sand helps reduce industrial waste and provides additional strength to the walls of PET bottles.

Tiles: Tiles are thin coverings made from materials such as ceramic, stone, metal, clay, or glass. They are commonly used for covering internal walls and flooring in construction.

Fiber Glass Resin: Fiberglass resin is a synthetic material that is created by combining alcohols and organic acids. It can be prepared in various forms, including gels, films, and liquids. When used in the manufacturing process of a toilet pan, the resin is typically in liquid form and is catalyzed before being applied to the fiberglass mold. Once applied, it undergoes a chemical reaction known as thermosetting, which involves curing and bonding to the fiberglass. During this process, a significant amount of heat is generated. The resin gradually cures, starting as a jelly-like consistency within 10-20 minutes and becoming hard within 30-40 minutes at room temperature.

Special Wax (Releasing Agent): A releasing agent, such as special wax, is a critical component used in the manufacturing process of molds. It creates a barrier between the mold surface and the substrate, facilitating the separation of the cured part from the mold. Without a releasing agent, the substrate would adhere to the mold surface, resulting in difficulties during clean-up and a loss in production efficiency.

Hardener: In certain mixtures, a hardener is added to increase the resilience of the material once it sets. In other cases, a hardener serves as a curing component. A hardener can function as either a reactant or a catalyst during the chemical reaction that occurs when the mixture is mixed. It may also be referred to as an accelerator, as it speeds up the curing process.

Marble Powder: Marble powder is a fine powder obtained as a by-product during the sawing and shaping of marble. It has been studied from a chemical and physical perspective to determine its potential use as a mineral addition in mortars and concretes, particularly for self-compacting concrete. Marble powder exhibits a high Blaine fineness value, indicating its fineness, with a significant portion of particles being smaller than 50 μm. Various cement pastes were prepared using marble powder, with and without the addition of an acrylic-based superplasticizer, to evaluate its effects on mechanical behavior. The substitution of sand with 10% marble powder showed maximum compressive strength while maintaining similar workability compared to mixtures without marble powder.

Fiber Mat: A fiber mat is a type of biodegradable fibrous material that is woven into mats of different sizes and thicknesses. It is commonly composed of coconut fiber and possesses certain characteristics such as uniform fiber dispersion, a smooth surface, a soft hand-feeling, low binder content, fast resin impregnation, and good mold obedience. Fiber mats are often used in various applications, including construction, as reinforcement, or for providing added strength and durability to materials.

Motion Sensor: Motion sensors in toilets detect movement and enable touchless operations. They automate flushing by detecting when a person approaches or moves away, triggering an automatic flush mechanism. Motion sensors can also control toilet seats, lifting them when someone approaches and lowering them when they move away. Additionally, they facilitate touchless handwashing by activating water

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flow and soap dispensers when hands are detected beneath the sensors. These sensors enhance hygiene by eliminating the need for manual interaction with toilet fixtures, reducing the spread of germs, and providing a convenient and sanitary experience for users.

Heating system: To accelerate the early decomposition of fertilizer, a heating system can be employed. This system typically consists of heating elements or a heat source that raises the temperature within the fertilizer storage or decomposition area. The heat promotes microbial activity, which speeds up the breakdown of organic matter in the fertilizer. The heating system may utilize electric heaters, steam coils, or hot air blowers to generate the necessary warmth. By maintaining an optimal temperature range, the heating system creates favorable conditions for microbial activity, enhancing the decomposition process and ensuring the fertilizer becomes readily available for plant uptake in a shorter time frame.

2. Materials and methodology:

2.1Toilet pan (urine diverting pan):

Figure 1: Toilet Pan

Figure 1 depicts a toilet pan. A urine diverting toilet pan, commonly used for compost production and safe sanitation, is made from Fiber Glass Resin due to limitations in ceramic manufacturing requirements and material availability. The manufacturing process involves several steps:

Figure 2: Crafting toilet pan

The process of crafting the toilet pan involves several steps to ensure its quality and functionality. Figure 2 depicts the making toilet pan. First, the selection of the appropriate size for the toilet pan is crucial to fit the intended space and purpose. Following this, a layer of special wax is applied to the pan, acting as a releasing agent to provide surface smoothness and facilitate easy removal. This wax layer requires about 30 minutes to dry. Next, a solution of Fiber Glass Resin is prepared, and mixed with cobide to provide strength to the pan while achieving the desired white color. The addition of marble powder is an option to fine-tune the solution's density. To control the setting time, a hardener is added to the solution, and the quantity can be adjusted as needed.

The entire solution is then carefully poured into the mold, ensuring precision in the manufacturing process. To enhance the pan's strength and durability, a layer of fiber mat is applied. The pan is allowed to set for approximately 30 to 40 minutes, ensuring that it takes on the desired form. A finishing layer of plaster of Paris (POP) is then applied to the pan, further contributing to its surface smoothness. Finally, the pan is painted white to achieve its final aesthetic appearance, resulting in a well-crafted and functional toilet pan ready for use.

3. Sensor technology:

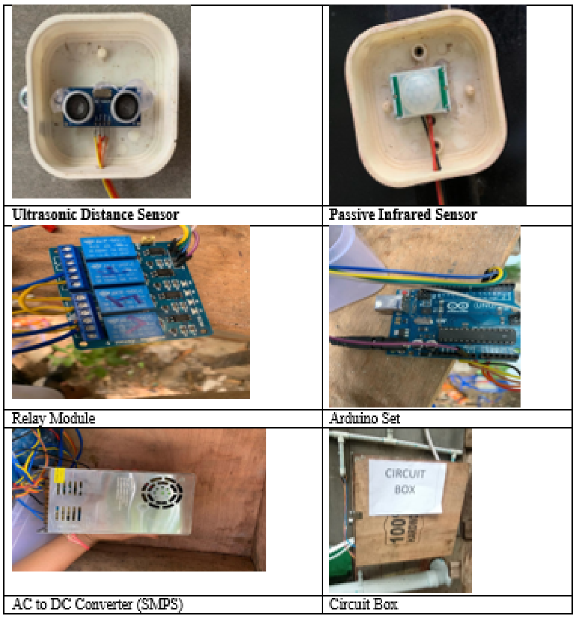

Figure 3: Toilet pan sensor configuration

When a person enters the toilet, a sophisticated system of sensors comes into play to ensure a

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convenient and efficient experience. Figure 3 demonstrations Toilet pan sensor configuration. As soon as someone steps inside, motion sensors detect their presence and trigger a series of actions. First and foremost, the light illuminates automatically, ensuring adequate visibility within the restroom.

Now, let's consider the flushing mechanism. If the person finishes toilet activity and leaves the toilet within three minutes, the flush system activates without any additional input. This helps conserve water, as a single flush utilizes six liters of water. However, if the individual needs more time in the restroom and stays beyond three minutes, a unique feature comes into play. To initiate the flush, they simply need to place their hand in front of an ultrasonic distance sensor for a mere five seconds. This ensures that water is used judiciously, aligning with modern efforts to save water resources. Moreover, for added convenience, the system not only triggers the flush but also starts the jet function simultaneously. This ensures a thorough and hygienic cleaning experience for the user.

In summary, this system seamlessly integrates motion sensors, lighting control, and water-saving features to enhance both convenience and sustainability. Whether you're in and out quickly or require a bit more time, this system ensures a comfortable and eco-friendly visit to the toilet.

3.1 Operational units of sensor:

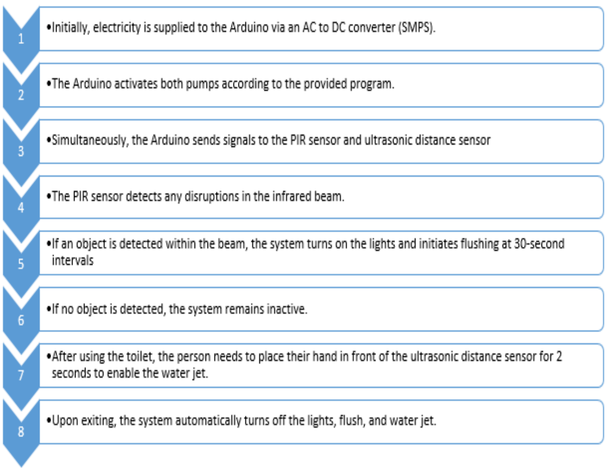

Figure 4: Operation of sensor

In this automated toilet project, ultrasonic sensors detect user presence and proximity, triggering the flushing mechanism when someone approaches or leaves the toilet. When a user enters, the ultrasonic sensor measures distance; if the user moves away, it triggers a flush. PIR sensors are employed for intelligent lighting control, illuminating the area when motion is detected. Furthermore, a separate PIR sensor is used to activate a light switch, ensuring convenient hands-free operation. This integrated system enhances hygiene and convenience, conserving water through precise flushing and promoting energy efficiency with responsive lighting control. Figure 4 depicts sensor operation.

In the model, sensors are incorporated to enhance functionality and reliability while reducing physical contact and potential bacterial infections. Various sensors are utilized for different purposes, including automatic flushing and occupancy detection. The flushing sensor automatically flushes the human waste. Another sensor is responsible for determining the amount of water to be dispensed based on the duration of toilet usage. If the person spends more time, a larger amount of water will be dispensed, while less water will be used for shorter durations. Additionally, sensors are employed to maintain cleanliness by periodically spraying water on the floor for disinfection. This sensor-based approach improves energy efficiency and sanitation in the toilet. Table 1 lists the sensor's technical parameters.

Table 1: Technical specifications of sensor

Technical specifications of ultrasonic distance sensor (HC SR04)		Technical specifications of Passive Infrared Sensor	
Parameter	Value	Parameter	Value
Operating Voltage	DC 5V	Operating Voltage	DC 5V – 12V
Operating Current	15mA	Operating Current	40mA
Operating Frequency	40KHz	Operating Frequency	8-14 KHz
Max Range	4m	Max Range	5m
Min Range	2cm	Min Range	0.5m
Ranging Accuracy	3mm	Measuring Angle	110-180 degrees
Measuring Angle	15 degrees	Dimension	50 x 50 x 25mm
Dimension	45 x 20 x 15mm	-	-

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3.2 Separation & collection unit:

The separation unit consists of a tank with two compartments for separating flush water and feces. One compartment collects the filtered flush water, while the other compartment holds the feces. The collected feces are then transferred to a drying tank, where they undergo a 15-day drying process facilitated by a heater. The heater maintains a temperature between 40 to 45 degrees Celsius. The PCC tank is constructed using regular burnt clay bricks and PCC materials, and polyurethane waterproofing chemicals are applied inside the tank to prevent water penetration and ensure its integrity.

Before the collection tank, there is an additional tank called the M.S. (Mild Steel) tank, which is positioned above the PCC tank and beneath the outlet of toilet pipes. The M.S. tank is installed on an M.S. stand in such a way that it tilts towards the side with more weight when feces fall into it. Inside the M.S. tank, both nylon mesh and M.S. mesh are fitted inclined at a 45-degree angle. The M.S. mesh provides support to the nylon mesh. The purpose of the M.S. tank is to filter the flush water and feces, with the bottom of the tank remaining open to collect the flush water separately.

The dimensions of the M.S. tank are as follows in **Figure 5**.

- Size: 1'6" x 1'6" x 1'6"

Figure 5. Dimension of M.S tank

4. Filtration unit

The filtration unit is a complex system comprising various integral components and layers, each playing a crucial role in the water purification process. At its base lies the large gravel layer, characterized by gravel sizes ranging from 16mm to 32mm. Positioned above this layer is the fine gravel layer, featuring smaller gravel sizes in the range of 4mm to 8mm. Further up the filtration hierarchy is the fine sand layer, which consists of sand particles with sizes ranging from 0.4mm to 0.6mm. At the very top of this intricate setup is the layer of anthracite coal grains, comprising coal particles ranging from 0.5mm to 1.2mm in size.

Collectively, these layers work in concert to create the filter bed, a composite structure vital for water treatment. The filter bed, spanning a size range from 0.6m to 3m, ensures that the water undergoes a comprehensive purification process. To facilitate the flow of water, the filtration unit is equipped with inlet and outlet points. At the top, an inlet serves as the entry point for unfiltered water, while an outlet is positioned for the removal of backflush water. Simultaneously, at the bottom, an outlet facilitates the extraction of filtered water, while an inlet is designated for the passage of backflush water. This multifaceted design allows the filtration unit to effectively and efficiently purify water, making it an indispensable component in water treatment systems. **Figure 6** shows the filtration unit.

Figure 6. Filtration unit

4.1 Process of manufacturing & assembling of zero-waste toilet

The process of creating a zero-waste toilet involves several essential steps aimed at sustainability and functionality. To start, PET bottles are collected from various sources like local restaurants, bars, canteens, and scrap merchants, serving as the primary material for constructing the toilet wall. These bottles, commonly used for beverage packaging, are highly recyclable, contributing to reduced plastic waste and emissions. Figure 7 depicts the assembly of a zero-waste toilet.

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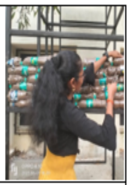
		
Plain cement concreting process	Filling PET bottles with foundry sand	Trial of arrangement of bottles as partition wall
		
Installation of toilet frame	Coding of program	

Figure 7. Assembling zero-waste toilet

In the second step, the PET bottles are fortified with industrial sand to enhance their strength and minimize the risk of air voids. This approach not only provides structural integrity to the bottles but also contributes to the reduction of industrial waste. Moving on to the third step, the installation of the toilet's frame provides the necessary structural support and cohesion for the entire zero-waste toilet. Typically constructed from sturdy materials like metal, the frame is designed to withstand the toilet's weight and usage.

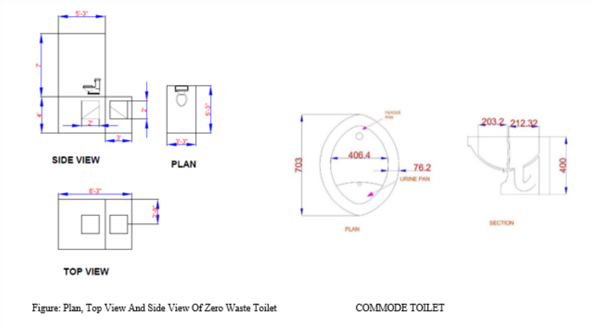
Following the frame installation, the toilet pan is put in place. The toilet pan, made of durable materials such as ceramic, serves as the receptacle for human waste before flushing. It's seamlessly integrated into the plumbing system to ensure proper waste flow and flush water control. Step five introduces the integration of sensors to enable touchless operation. These sensors detect human presence, control lighting, initiate flushing, and determine toilet seat occupancy. They also activate features like water jets for personal hygiene and odor-removing sprays. Furthermore, the zero-waste toilet's floor is self-cleaned using a water jet, and the entire system operates on solar power.

The next step involves a sophisticated collection system for feces. The flush water and human waste enter a separation tank beneath the toilet, with compartments designed for water removal and separated water storage. A filtration tank equipped with a 120-micron nylon mesh separates water from the flush material. Once the tank reaches its capacity, it tilts, transferring separated feces to a storage tank, where water-filtered feces undergo a 15-day drying process to remove odor and bacteria. To reuse separated flush water, step seven introduces an activated charcoal filter with multiple layers of filter bed, effectively removing fine particles. The filtered water can be repurposed for gardening, and a backflush water pipe allows for filter chamber cleaning when needed.

Lastly, step eight addresses the composting of fecal sludge, a controlled aerobic process that transforms organic materials into a nutrient-rich soil amendment. Dried human feces and bio additives like sawdust and flour mill waste are used, along with a composter (bacterial medium). This composting process follows specific temperature parameters to ensure proper decomposition while considering the nutrient values of the resulting compost, specifically Nitrogen, Phosphorus, and Potassium (NPK). The comprehensive zero-waste toilet system combines sustainability, resource efficiency, and functionality, representing a forward-thinking approach to waste management and sanitation.

4.2 Constructional features of toilet

The below **figure 8** shows the construction features of the Toilet.



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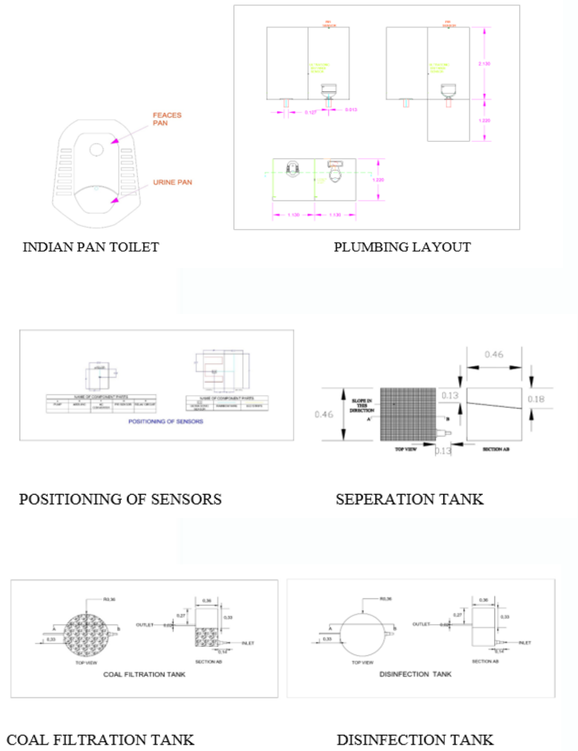

Figure 8. Construction features of Toilet

1.3 Flow diagram of operation

Below **Figure 9** shows the flow diagram of the operation.

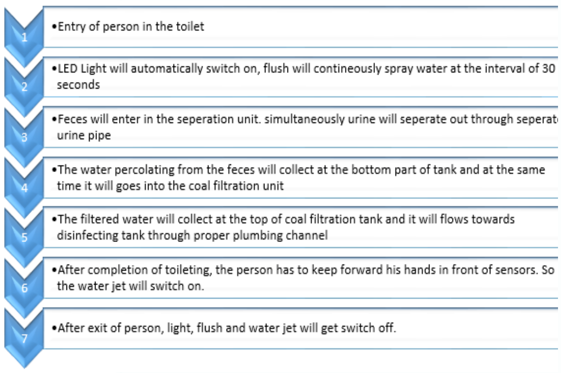

Fig 9. Flow diagram of operation

5. Results and discussion

5.1 Toilet pan (urine diverting pan)

The urine-diverting pan, a distinctive feature of this design, effectively separates urine from feces, offering several advantages. First and foremost, it allows for the easy collection of clear urine through the toilet outlet. This clear urine contains valuable nutrients and facilitates the extraction of urea, making the process more efficient. Additionally, the separated fecal sludge can be repurposed for fertilizer production, provided it maintains controlled moisture content. The urine separation plays a vital role in achieving this.

Furthermore, the pan has been engineered to withstand the weight of a person using the toilet, ensuring its durability and reliability. This urine-diverting feature is incorporated into both Indian and commode pans, extending its applicability to both rural and urban users. The flushing and water jet mechanisms are integrated into these pans, mirroring the convenience of traditional ceramic pans. Manufacturing the pan involves careful steps, including proper mixing of raw materials and applying heat to the prepared mixture to ensure optimal strength. Finally, the pan's dimensions are thoughtfully designed to ensure comfort and usability for individuals.

5.2 Sensor technology

Incorporating sensors into the toilet system streamlines its operation, rendering it completely touchless and promoting superior hygiene maintenance. This technology holds particular significance in mitigating the spread of diseases often associated with conventional toilet systems. By implementing touchless sensors in both the flush system and the water jet mechanism, water consumption is notably reduced. Without sensor technology, a single flush typically consumes 10 liters of water, whereas, with sensors, it efficiently manages to dispense just 6 liters per flush. This water-saving feature extends to the water jet system as well.

Water-repellent sensors are employed, ensuring optimal functionality even in the presence of water. This robust design prevents any system interruptions. A circuit box is positioned on the rear exterior of the toilet, housing essential components such as the relay module and Arduino system. This box is thoughtfully enclosed in a wooden casing to shield it from the effects of weathering. The meticulous organization of wiring within the system keeps all sensor functions running smoothly and efficiently.

5.3 Separation and collection unit

The separation unit efficiently divides urine from fecal sludge, with the inclined mesh facilitating the percolation of wastewater and its flow to the bottom.

This design ensures that feces remain in a dry state, simplifying the organic fertilizer manufacturing process. The system incorporates two meshes within the same tank: one constructed from mild steel and the other from nylon fabric. The mild steel mesh prevents solid residues from entering, while the nylon fabric prevents the passage of fine, powdered materials. This dual mesh approach significantly enhances the tank's ability to retain a maximum amount of residue at the upper section.

The bottom part of the tank is linked to an outflow mechanism, which directs wastewater to a disinfection tank. This tank features a handle on one side, enabling a 180-degree rotation. The handle is skillfully designed to maintain a tight seal during rotation, facilitating waste collection. The collection tank includes materials that aid in the early decomposition of the mixture and can effectively control odors through the incorporation of organic minerals. The outflow pipe is strategically attached to minimize the accumulation of wastewater at the bottom, and the plumbing system is thoughtfully engineered to ensure that the rotating motion does not disrupt the flow of wastewater.

5.4 Filtration unit

The filtration unit is a two-part system, consisting of a charcoal filtration tank and a disinfection tank. The first tank effectively separates solid residues, while the second tank is designed to remove smaller dissolved content. In the charcoal filtration tank, the presence of solid residue is prevented from passing through due to the action of charcoal. The quantity of charcoal used has been meticulously determined through laboratory testing, involving the flow of a small amount of wastewater through it. After several iterations, it was determined that 6 kg of charcoal is required for efficient filtration. It's important to note that this charcoal needs to be replaced after every 500 liters of water flow. Considering that each person uses approximately 10 liters of water per toilet use, this means that charcoal replacement is needed after about 50 usages. The charcoal primarily consists of carbon, which has an affinity for binding residual content. The system operates on a gravitational flow principle, allowing solid residues to settle at the bottom, while the lighter clear water flows upward.

The outlet of this tank is connected to the disinfection tank, which employs chlorine as a disinfectant. Post-disinfection, the water can be used for flushing or irrigation purposes, but it is not suitable for drinking or bathing. If rigorous disinfection processes are applied, the water can eventually be safe for drinking, although this depends on people's perceptions and attitudes towards water quality.

5.5 Quantitative analysis

The container's volume is precisely 0.095 cubic meters, a calculation based on the tank's dimensions, measuring 457mm x 457mm x 457mm. Within this container, there are two distinct sections: the upper part, designated for feces accumulation, occupies 0.0285 cubic meters, while the lower part, intended for wastewater, encompasses 0.0665 cubic meters. However, due to the drain outlet's location at the bottom, only 50.8mm in height is available for water storage in the lower section.

An individual typically excretes approximately 200 grams of feces. Feces density ranges from 1000 to 1300 kg per cubic meter. This translates to a feces volume of approximately 0.0002 cubic meters per person. By dividing the volume of the upper part of the tank by the volume of feces, we can estimate that the tank can accumulate waste from approximately 140 people, resulting in a total feces weight of 28 kilograms.

To prevent overflow, the tank cannot be filled to its full capacity, requiring a 5cm headspace to be maintained at the top. Consequently, 16 liters of water will remain in the lower part of the tank.

Considering the weight of the feces, the weight of the water, and the self-weight of the tank, the total weight of the tank is 58 kilograms. This calculation ensures that the system operates effectively and can manage waste from a considerable number of individuals while maintaining proper safety margins to prevent any potential issues like overflow.

5.6 Calculation of air requirement for fertilizer production

For preparation of organic fertilizer, aerobic process is adopted. For smooth conduction of the aerobic process, minimum 10% oxygen is required. Calculating the air requirement for fertilizer production from fecal sludge is a fundamental step in ensuring the efficient aerobic digestion of organic matter. This process involves estimating the amount of oxygen needed to facilitate the decomposition of organic materials within the sludge. The calculation is typically based on the organic content present in the sludge and the application of stoichiometric ratios. The stoichiometric ratio used depends on the specific composition of organic matter in the sludge.

For instance, carbohydrates typically require about 6 grams of oxygen per gram of organic matter, fats need approximately 5.3 grams of oxygen per gram of organic matter, and proteins demand around 4.57 grams of oxygen per gram of organic matter. By determining the organic content and applying the appropriate stoichiometric ratio, the air requirement can be quantified in terms of kilograms of oxygen needed for the aerobic decomposition process.

This calculation serves as a crucial foundation for designing and operating the system efficiently, ensuring that the right amount of air is supplied to facilitate the decomposition of organic matter, which ultimately leads to the production of high-quality fertilizer. Accurate calculations are imperative in optimizing the process and resource utilization while minimizing environmental impact.

5.7 Economic Analysis

Table 2. Economic analysis of materials

Sr. No.	Materials/ Mechanical part/ Object
1	Ceramic powder
2	Plastic bottles
3	Soil
4	Shed net
5	Toilet pan mould
6	Fiber Toilet pan (Indian)
7	Fiber Toilet pan (Commode)
8	Labor for manufacturing toilet pan and mold
9	Fabrication cost for wall frame
10	Plumbing cost
11	M.S. sheets used for septic tank
12	The overall mechanism of septic tank
13	Labor for construction of Septic tank
14	Sensors
15	Aggregates
16	Cement
17	Labor for construction of toilet block
18	Solar Panels

Table 2 shows Economical analysis of materials. For overall toilet preparation, approximately 90,000/- cost is required. This cost includes fabrication charges, sensor, pump, preparation of toilet pans, plumbing & electrification appliances etc. Firstly, 1 kilogram of ceramic powder, priced at 225 Rs/- per kilogram has been used. Additionally, 400 units of plastic bottles are needed, amounting to 300 RS/-. For the construction and landscaping aspects, 1 brass of soil is necessary, with a cost of 4000 RS/-. To provide shelter and protection, we'll be using a 35-meter by 13-meter shed net, which costs 450 RS/-.

The remaining items on the list include specific components and labor costs related to the construction of a toilet block and septic tank, as well as the installation of solar panels. These components encompass fiber toilet pans (Indian and Commode), labor for manufacturing toilet pan and mold, fabrication costs for the wall frame, plumbing expenses, M.C. sheets for the septic tank, the overall mechanism of the septic tank, labor for constructing the septic tank, sensors, aggregates, cement, and labor for the construction of the toilet block.

6. Conclusion

The research conducted on the zero-waste toilet, a sensor-operated solar-based urine diverting toilet, has revealed several positive outcomes regarding its design, functionality, and potential benefits. The findings of this study contribute to the understanding of sustainable sanitation systems and their implications for environmental, developmental, and sustainable practices.

The utilization of repurposed plastic PET bottles for constructing the walls of the zero-waste toilet presents a successful approach to reducing plastic waste. By repurposing these bottles, the zero-waste toilet not only contributes to environmental sustainability but also promotes local material availability and sustainable construction practices. The integration of sensors in the zero-waste toilet has proven to be effective in enhancing user convenience and efficiency. The touchless operation provided by the sensors eliminates the need for manual flushing and enhances the overall user experience. The sensors' ability to detect human presence, control lighting, initiate flushing, and determine toilet seat occupancy ensures a seamless and convenient operation. Moreover, the incorporation of water jets for personal hygiene and odor-removing sprays further enhances the cleanliness and comfort of the zero-waste toilet. The urine separation capability of the zero-waste toilet has significant implications for waste management and resource utilization. The specially designed pan effectively separates urine from feces, improving waste management practices and minimizing potential odors. With some models being able to separate up to 80% of urine within the pan, the zero-waste toilet presents an opportunity to utilize urine as a valuable resource for agricultural purposes, thereby contributing to sustainable agriculture and nutrient recycling.

Water conservation is a notable achievement of the zero-waste toilet. The automated flushing system, controlled by the sensors, ensures that water is used efficiently and only when required. By activating the flushing mechanism only when the user has finished using the toilet, the zero-waste toilet minimizes water wastage and promotes responsible water management practices, addressing water scarcity concerns and supporting sustainable water use. The hygienic qualities of the zero-waste toilet are commendable. The touchless operation, along with the water jets and flush mechanisms, reduces the risk of germ transmission and contamination. The design of the zero-waste toilet incorporates easy-to-clean surfaces and materials, further enhancing its hygienic attributes and ensuring a clean and safe user experience. The durability and long lifespan of the zero-waste toilet make it a sustainable solution for sanitation needs. The automated features reduce wear and tear, resulting in reduced maintenance requirements and prolonged usability compared to traditional toilets. This durability contributes to the zero-waste toilet's sustainability and cost-effectiveness in the long run, promoting its viability as a long-term sanitation solution.

The zero-waste toilet's ability to transform human feces into organic fertilizer showcases its potential to address waste management challenges and promoting sustainable agricultural practices. By diverting feces into a separate storage tank and employing a filtration system, the zero-waste toilet separates solid waste from liquid content effectively. The separated solid waste can be processed into organic fertilizer through composting, providing a valuable resource for soil enrichment and sustainable agricultural practices. This closed-loop system reduces reliance on synthetic fertilizers, promotes circular economy principles, and supports environmental sustainability. It is important to acknowledge the limitations of the zero-waste toilet as well. The implementation and maintenance of these advanced systems may require specialized expertise, potentially limiting accessibility and increasing reliance on trained professionals. The initial investment required for installing zero-waste toilets may be higher compared to traditional toilets, which can pose financial challenges for certain individuals or communities. Additionally, the maintenance of zero-waste toilets may demand additional efforts due to their complex automated systems. Overall, the research findings demonstrate that the zero-waste toilet has the potential to address various environmental, developmental, and sustainability challenges associated with traditional sanitation systems. Its advantages in terms of plastic waste reduction, convenience, water conservation, hygiene, and resource utilization make it a promising solution for sustainable sanitation. Further research and implementation efforts are necessary to

Merits

Zero-waste toilets offer numerous merits that contribute to improved sanitation and environmental sustainability. Firstly, they are equipped with a fully automated sensor for the flushing system, eliminating the need for manual flushing and promoting convenience and efficiency. Additionally, these toilets are designed to save water, addressing water scarcity concerns by utilizing water-saving mechanisms. Zero-waste toilets also play a significant role in enhancing hygiene and sanitary conditions. They provide a fully contactless experience, minimizing the risk of germ transmission and promoting cleanliness. Moreover, these toilets experience less wear and tear due to their automated features, resulting in reduced maintenance and longer lifespan.

One of the notable benefits of automatic toilets is their ease of use. The automated functions streamline the user experience, making them accessible to a wide range of individuals. Furthermore, zero-waste toilets promote environmental sustainability by transforming feces into compost, providing a valuable resource for soil enrichment. They also incorporate water reuse systems for gardening, maximizing the utilization of available resources and reducing water waste.

The construction of Zero-waste toilet walls using plastic bottles is a notable advantage, as it contributes to the reduction of plastic pollution. By repurposing these bottles, the toilets actively address environmental concerns associated with plastic waste. Additionally, zero-waste toilets feature urine separation capabilities, with some models capable of separating up to 80% of urine in the pan itself. This helps in the efficient management of waste and reduces potential odors in the toilet area. Users of Zero-waste toilets also experience enhanced comfort, as these toilets are designed to provide a high level of comport during use. In terms of sanitation, zero-waste toilets ensure proper cleanliness by incorporating effective flushing mechanisms and providing a hygienic environment for users. Furthermore, these toilets offer a long lifespan, providing a durable and sustainable solution for sanitation needs. Notably, in the case of Indian pan toilets, zero-waste toilets address the challenge of bacterial infection transmission, as their design minimizes the spread of bacteria.

Demerits

Zero-waste toilets, while offering several merits, also have certain demerits that should be taken into consideration. Firstly, the operation of these toilets may require expertise, making them potentially challenging for individuals who are not familiar with their automated features. Additionally, the setup of Zero-waste toilets also requires specialized knowledge, which can limit their accessibility and increase reliance on trained professionals. One notable drawback is the higher initial investment required for Zero-waste toilets compared to traditional toilets. The advanced technologies and eco-friendly materials used in their construction contribute to the increased cost. Furthermore, zero-waste toilets typically require more maintenance due to their complex automated systems, which may involve periodic checks and repairs.

Sensors in zero-waste toilets may not always flush immediately when desired, as they operate on preset timings. This can cause inconvenience to users who expect immediate flushing. Moreover, there is a risk of dirty water splashing onto the user's bottom if the toilet flushes while they are still sitting, which can be unpleasant and unhygienic. Using this particular toilet requires a certain level of expertise due to various factors. Firstly, setting up the toilet itself demands specialized knowledge. Additionally, the initial investment for this toilet is relatively high compared to traditional options. Maintenance is also a concern, as it requires more attention.

The sensors in this toilet may not always respond as desired, sometimes delaying the flush and causing inconvenience. Moreover, there is a risk of dirty water splashing onto the user if the flush occurs while they are seated, which can be unpleasant. This can also be a source of fear for some children, making them hesitant to use it. Accidental drops can result in objects being flushed away permanently, which is a potential drawback. A broader issue is people's limited perspective on innovation, which can hinder the adoption of such advanced toilet systems. Separation of urine from feces is not complete, as approximately 20% remains mixed. Stopping the process when the feces tank is full can be challenging, particularly if someone is currently using the toilet.

Water-repellent sensors are essential for this system, but they come at an additional cost. Furthermore, efficient fertilizer production technology needs to be developed by the user to make the most of the waste. In terms of cost, this toilet is more expensive than traditional ones. Additionally, the production of ceramic toilets relies on molds that are not feasible for small-scale production due to the distance of major factories. Cleaning these toilets can be a more difficult and time-consuming task, and the plastic walls lack sufficient strength. Furthermore, filtering flush water in this system takes more time than standard toilets.

The concept of zero-waste toilet, a sensor-operated solar-based urine diverting toilet, presents a promising solution to overcome the limitations observed in traditional sanitation systems. This research paper has explored the design and functionality of the zero-waste toilet, highlighting its potential benefits in terms of convenience, water conservation, hygiene, and environmental sustainability.

One of the key advantages of the zero-waste toilet is its utilization of repurposed plastic PET bottles for constructing the walls. By repurposing these bottles, the zero-waste toilet actively contributes to reducing plastic waste and addresses environmental concerns associated with plastic pollution. This innovative approach showcases the potential for using locally available materials in sustainable construction practices. The integration of sensors in the zero-waste toilet enables touchless operation, eliminating the need for manual flushing and enhancing user convenience and efficiency. These sensors are designed to detect human presence, control lighting, initiate flushing, and determine toilet seat occupancy. Additionally, the sensors activate water jets for personal hygiene and trigger odor-removing sprays, promoting a clean and hygienic environment. The entire system operates on solar power, further enhancing its sustainability and reducing its reliance on conventional energy sources.

An important feature of the zero-waste toilet is its urine separation capability. By incorporating a specially designed pan, the toilet efficiently separates urine from feces, improving waste management and minimizing potential odors. Some models of the zero-waste toilet can separate up to 80% of urine directly within the pan, reducing the amount of waste that needs to be processed further. This urine diversion system not only contributes to better waste management but also presents an opportunity for utilizing urine as a valuable resource for agricultural purposes. Water conservation is another significant advantage offered by the zero-waste toilet. The automated flushing system, controlled by the sensors, ensures that water is used efficiently and only when necessary. The zero-waste toilet minimizes water wastage by providing a touchless experience and activating the flushing mechanism only when the user has finished using the toilet. This feature addresses water scarcity concerns and promotes responsible water management practices.

In terms of hygiene, the zero-waste toilet provides a high level of cleanliness and minimizes the risk of germ transmission. The touchless operation, along with the water jets and flush mechanisms, ensures that users have a fully contactless experience, reducing the potential for contamination. Additionally, the design of the zero-waste toilet incorporates easy-to-clean surfaces and materials, further enhancing its hygienic qualities. The zero-waste toilet offers a durable and long-lasting solution for sanitation needs. Its automated features reduce wear and tear, resulting in reduced maintenance requirements and a longer lifespan compared to traditional toilets. This durability contributes to the zero-waste toilet's sustainability and cost-effectiveness in the long run.

One of the most significant advantages of the zero-waste toilet is its ability to transform human feces into organic fertilizer. By diverting feces into a separate storage tank and employing a filtration system, the zero-waste toilet effectively separates solid waste from liquid content. The solid waste undergoes a drying process to remove odor and bacteria, while the liquid content can be reused for flushing or other purposes. The separated solid waste can be further processed into organic fertilizer through composting, providing a valuable resource for soil enrichment and sustainable agricultural practices. This closed-loop system not only addresses waste management but also contributes to environmental sustainability by minimizing the reliance on synthetic fertilizers. While the zero-waste toilet offers numerous merits, it is essential to acknowledge its demerits as well. The implementation and maintenance of these advanced systems may require specialized expertise, potentially limiting accessibility and increasing reliance on trained professionals. The initial investment required for installing zero-waste toilets may also be higher compared to traditional toilets, which can pose financial challenges for some individuals or communities. Maintenance of zero-waste toilets may demand additional efforts due to their complex automated systems.

Future Scope

The research conducted on the zero-waste toilet has shed light on its potential as a sustainable sanitation solution. However, there are several avenues for further exploration and development in this field. The future scope of this research paper lies in the following areas:

1. Technological advancements: The zero-waste toilet can benefit from ongoing technological advancements. Further research can focus on enhancing the efficiency and effectiveness of the sensor-operated system. Innovations in sensor technology, such as improved occupancy detection, water flow regulation, and waste separation mechanisms, can contribute to better performance and user experience.

2. Accessibility and afordability: To ensure widespread adoption and accessibility of zero-waste toilets, future studies should explore cost-effective approaches for manufacturing and installation. Investigating alternative construction materials and production methods can help reduce the initial investment required for zero-waste toilets, making them more affordable for individuals and communities with limited financial resources.

3. Community engagement and user acceptance: Community engagement plays a vital role in the success of any sanitation intervention. Future research can focus on understanding the social and cultural aspects related to the acceptance and adoption of zero-waste toilets. Involving local communities, understanding their needs and preferences, and incorporating their feedback into the design and implementation process can contribute to increased acceptance and long-term sustainability.

4. Performance monitoring and evaluation: Long-term monitoring and evaluation of zero-waste toilet systems are essential to assess their performance, durability, and impact on the environment and public health. Future studies should focus on developing monitoring frameworks and evaluating the effectiveness of zero-waste toilets in terms of water savings, waste management, and resource recovery. This data can provide valuable insights for policymakers, practitioners, and researchers to optimize system performance and address any potential challenges.

5. Integration with circular economy practices: The zero-waste toilet's potential for waste-to-resource conversion opens up opportunities for integration with circular economy principles. Future research can explore ways to maximize resource recovery from human waste and integrate the by-products, such as organic fertilizers, into local agricultural practices. Understanding the socio-economic implications and assessing the environmental benefits of such integration will contribute to the overall sustainability of the zero-waste toilet system.

6. Scaling Up and Replication: While the research paper focuses on the zero-waste toilet concept, future studies can explore strategies for scaling up and replicating these systems in different contexts. Understanding the barriers and enablers for scaling up zero-waste toilet installations can help inform policy decisions and promote wider adoption of sustainable sanitation practices. Case studies and best practices from successful implementations can serve as valuable guidance for future projects.

7. Environmental impact assessment: Assessing the environmental impact of zero-waste toilets throughout their life cycle is crucial for understanding their overall sustainability. Future research should consider conducting life cycle assessments (LCAs) to evaluate the environmental footprint of zero-waste toilets, including their construction, operation, and waste management processes. This assessment will provide insights into potential areas for improvement and guide decision-making towards more environmentally friendly practices.

In conclusion, the future scope of the research paper lies in further technological advancements, cost-effectiveness, community engagement, performance monitoring, integration with circular economy practices, scaling up, and environmental impact assessment. By exploring these areas, researchers can contribute to the development and sustainability of zero-waste toilets as a viable solution for improved sanitation, environmental conservation, and community well-being.

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