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List of Symbols and Parameters

Symbol	Unit	Description
A	m ²	Cross-sectional area of the compactor bin.
P	m	Bin perimeter in contact with the waste.
D_h	m	Hydraulic (equivalent) diameter of bin, $D_h = 4A/P$.
μ_w	–	Coefficient of friction between waste and wall (steel interface).
K	–	Lateral-to-vertical stress ratio (σ_h/σ_v).
$\sigma_v(z)$	kPa	Vertical stress at depth z within the compacted waste.
σ_p	kPa	Applied plate pressure on top of the waste.
$\sigma_h(z)$	kPa	Lateral stress on the bin wall at depth z .
$\tau_w(z)$	kPa	Wall shear stress acting along the wall height.
λ	m	Attenuation length governing vertical stress decay; $\lambda = D_h/[4\mu_w K]$.
H	m	Height of compacted waste layer.
$C(H)$	m ²	Effective wall-loss area term accounting for frictional resistance.
F_{ram}	N	Total hydraulic ram force required to compact waste.
F_{plate}	N	Direct plate compression component ($A\sigma_p$).
F_{wall}	N	Wall friction component ($C\sigma_p$).
p_{floor}	kPa	Pressure acting on the bottom floor of the bin.
p_{hyd}	MPa	Hydraulic fluid pressure in the cylinder.
A_{cyl}	m ²	Cylinder piston area ($\pi d^2/4$).
d	mm	Cylinder bore diameter.
F_{hyd}	N	Force developed by hydraulic pressure on the piston.

E	GPa	Modulus of elasticity of steel.
I	m ⁴	Second moment of area of the cylinder rod cross-section.
L	m	Effective length of the cylinder rod for buckling analysis.
K_L	–	Effective length factor for end conditions in Euler buckling.
t	m	Plate thickness.
a	m	Side length of the square compaction plate.
q	kPa	Uniform load on the plate (equal to σ_p).
$M_{\max}$	N·m/m	Maximum bending moment per unit width in the plate.
$w_{\max}$	m	Maximum vertical deflection of the plate.
V_0	m ³	Initial volume of loose waste.
V_f	m ³	Final volume after compaction.
ρ_0	kg/m ³	Initial bulk density of waste.
ρ_f	kg/m ³	Final compacted density.
CR	–	Compaction ratio, $V_0/V_f = \rho_f/\rho_0$.
f_y	MPa	Yield stress of plate material.
ν	–	Poisson's ratio of plate material.
γ_m	–	Partial safety factor for material strength.
α	–	Coefficient for bending moment in a clamped square plate.
β	–	Coefficient for deflection in a clamped square plate.

Design of an Underground Waste Compactor System for Mongolian Conditions

Chapter 1: Introduction and Objectives

Mongolia, and its capital Ulaanbaatar in particular, faces serious challenges in municipal solid waste management due to rapid urbanization and increased waste generation. In the past decade, the annual solid waste in Ulaanbaatar has surged sevenfold to about 1.2 million tons, straining existing landfill sites (72% of waste goes to landfills, many of which are at full capacity). Open dumpsters in the city often overflow, causing litter, foul odors, pest infestations, and visual blight. Harsh Mongolian weather (with extremely cold winters) further complicates waste collection—bins can freeze shut, and access becomes difficult. These issues underscore the need for modern, efficient waste containment solutions that reduce environmental impact and improve urban hygiene.

One promising approach is the use of **underground waste containers with compaction mechanisms**. Underground trash bins are large-capacity waste containers installed mostly below ground, with only a small receiving hatch or column visible at the surface. They offer numerous advantages: much greater storage volume (up to 5,000 liters in a single unit) than conventional bins, space-saving installation (minimal footprint above ground, ideal for dense urban areas), and improved safety (the steel-lined underground design is fire-safe, reducing fire risk). By being buried, these systems also keep waste at cooler and more stable temperatures, slowing decomposition and mitigating odors. Additionally, waste is stored up to ~2.7 m deep, allowing it to be compacted by its own weight, which increases the effective capacity by roughly 20% even without active compaction. Cities like Prague have adopted underground bins on a large scale for centralized collection, pairing them with smart monitoring—for example, over 3,200 underground containers in Prague are equipped with fill-level sensors to enable efficient, on-demand emptying (sensoneo.com 2020). This combination of underground storage and intelligent management has led to cleaner public spaces and more cost-effective operations.

The core objective of this mechanical engineering thesis is to **design an underground garbage bin system with an integrated compressor/compactor tailored to Mongolian conditions**. The system will compress waste under pressure within the container, greatly reducing its volume and thus extending the time between collections. By compacting trash inside the bin, we aim to accommodate **several times more waste** (potentially 3–5×) in the same container volume than an uncompacted bin. This will reduce collection frequency, lower fuel consumption, and decrease

overall operational costs for the city. The proposed design will include separate sections for **general household waste and recyclable materials**, encouraging waste segregation and providing an opportunity to recycle the waste deposited in the recyclable compartment. Figure 1 below shows an image of the **Ulaanbaatar central waste disposal site – Ulaan chuluut landfill**, which serves as a reference point for this project.

Figure 1: Ulaanchuluut Landfill

Source: (MONTSAME.MN 2021)



The objectives of this project include: (1) conducting a thorough literature review of underground waste systems and compactors to learn from global best practices; (2) performing a detailed engineering design of the underground compactor bin, including material selection suitable for Mongolia's climate, structural and mechanical design of the container and compaction mechanism, and integration of sensors for smart monitoring; (3) carrying out comprehensive calculations and simulations – such as compaction force requirements, hydraulic pressure and cylinder sizing, motor power needed for the compactor, stress analysis of the container under load, and other relevant mechanical analyses; (4) evaluating the results to ensure the design meets performance, safety, and durability criteria, and (5) formulating recommendations for implementation of such systems in Ulaanbaatar, including any proposals for improving waste management based on the findings.

Several constraints and **challenges** are considered in the design. The system must operate reliably in temperatures ranging from +30°C summer heat to –30°C winter cold, meaning materials and components (like hydraulic fluids, seals, electronics) must be chosen or protected accordingly. Power supply can be an issue in some areas, so the design will explore **solar-powered** operation for the compactor and electronics (solar panels mounted on the above-ground column can charge batteries to run the compressor, an approach already used in some modern underground compactors). Safety is paramount: the unit must comply with safety standards (e.g. European standard EN 13071 for underground waste containers) to prevent accidents – features like a safety platform or automatic lock should engage to cover the pit during maintenance and to ensure no one can fall in. The project also acknowledges **economic and maintenance considerations**: the proposed solution should be cost-effective and robust, requiring minimal maintenance (e.g. using galvanized or stainless steel to prevent corrosion, and designing the compactor to avoid jamming or undue wear).

In summary, this thesis aims to deliver a **comprehensive engineering design** of a two-chamber underground garbage bin with an integrated compactor and smart sensor system, tailored for Mongolian usage. The following sections present the background research, detailed methodology for the design and analysis, results including all relevant calculations and evaluations, and finally the conclusions and recommendations. Ultimately, the goal is to demonstrate that such a system can significantly improve waste collection efficiency and urban cleanliness in Mongolia, by combining advanced mechanical design with innovative waste management practices.

Chapter 2: Literature Review

2.1 Waste Management Challenges and Modern Solutions

Total amount of waste sent to centralized landfills and buried in Mongolia: As Mongolia's population grows rapidly, the production of goods and services expands year by year, and the income and consumption of the population increase, the amount of waste generated increases accordingly. Although there is no detailed statistical information on the total amount of waste generated in Mongolia, the total amount of waste sent to centralized landfills and buried in the country reached 3,353,548.73 tons in 2018, a fourfold increase compared to 2008.

In Mongolia, most of the waste, 2.8 million tons, is buried in the ground in both urban and rural areas. The price shows how inadequate Mongolia's recycling system is.

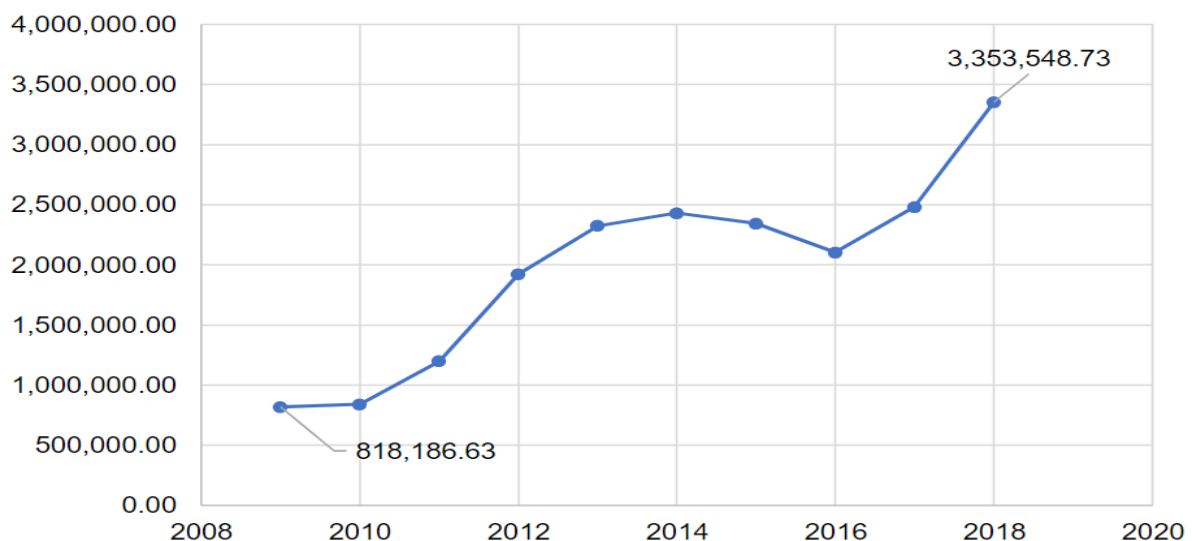
There is no data on the percentage of recycled waste in total waste, and according to the State of the Environment of Mongolia (2017-2018), less than 10 percent of total waste is recycled. 17.5% of total waste in Ulaanbaatar is recycled, while only 0.6% of rural waste is recycled.

Currently, there are about 30 full-scale processing and manufacturing plants in Mongolia, but these plants lack space and lack management of raw material collection, which prevents them from developing sufficiently.

There are three centralized waste disposal sites in Ulaanbaatar. These landfills have been in use for 25-40 years. No landfills, fences, or sewage treatment facilities have been built.

Figure 2 : Total amount of waste sent to centralized landfills and buried in Mongolia (2008–2018).

Source: (sudalgaa.gov.mn 2018)



Municipal solid waste (MSW) management is a growing concern worldwide as urban populations expand. Ulaanbaatar, Mongolia, is a case in point, where rapid urban growth has led to a sharp increase in waste generation with insufficient modernization of waste infrastructure (Ministry of Construction & Urban Development, 2020). Traditional waste collection in the city relies on open-top dumpsters or small bins in neighborhoods, which are prone to overflowing and scattering trash. This not only causes environmental pollution but also poses public health risks (ADB, 2021). In winter, uncollected garbage can freeze, complicating removal, while in summer it decomposes faster, emitting odors and attracting vermin (Un-Habitat, 2018). The city's landfills are nearing capacity, and a significant portion of waste (nearly 28% by some estimates) is dumped illegally due to collection shortfalls (Asian Development Bank, 2021). There is a clear need for innovative waste collection systems that increase capacity and efficiency, reduce nuisance, and encourage recycling – all in line with Mongolia's sustainable development goals to improve recycling rates and reduce landfill use (Department of Environment of Mongolia, 2019). The following figure illustrates the types of traditional waste bins currently used in the residential apartment areas and ger districts of Ulaanbaatar.

Figure 3: Current waste bins used in Ulaanbaatar's apartment and ger districts areas.

Source: (News.mn 2023)



One innovative solution adopted in many cities globally is the deployment of underground and semi-underground waste containers. Companies like Engels Environmental and Molok have pioneered these systems in Europe since the early 2000s (Engels Group, n.d.). Unlike traditional curbside bins, underground containers are installed mostly below ground level. Typically, a concrete pit (silo) is constructed in the ground, and a large waste container (often 3–5 m³ capacity) is placed inside it (Elkoplast, n.d.). Only a small throw-in column or hatch is visible above ground for users to deposit waste. These systems have demonstrated multiple benefits:

High Capacity and Fewer Collections: Standard underground containers can hold on the order of 3,000–5,000 liters of waste (3–5 m³) in a single unit – an order of magnitude more than typical 240 L wheelie bins (Molok Ltd., n.d.). By installing high-capacity containers, collection frequency is greatly reduced. For example, one semi-underground container can replace numerous individual bins; a Molok semi-underground unit can hold the equivalent of ~20 conventional carts (NordTech Consulting, 2018). Fewer pickups mean lower operational costs and less traffic and emissions from garbage trucks (Engels Group, n.d.). Engels Group notes that the larger volume directly translates to savings on emptying costs (Engels Group, n.d.).

Space Saving and Aesthetics: Because 60% or more of the container’s volume is underground, these systems free up surface space and are less intrusive in dense urban environments (Elkoplast, n.d.). Only a modest pillar or lid is visible, which can be designed to blend with the surroundings or even customized for a city’s aesthetics. This helps keep public spaces open and uncluttered (Elkoplast, n.d.). In Ulaanbaatar’s tight ger districts or apartment compounds, replacing many scattered bins with a few underground units could significantly improve the visual environment (Ikon.mn, 2024).

Odor and Sanitation Control: The underground placement naturally keeps waste in a cooler environment – soil temperature is more stable and lower than ambient air in warm seasons (Molok Ltd., n.d.). Keeping waste at lower temperatures slows down decomposition and thus reduces odor generation (Molok Ltd., n.d.). The closed underground container also prevents pests (rodents, insects) from accessing the garbage (Elkoplast, n.d.). The disposal chute is typically self-closing, keeping litter and odors contained (Elkoplast, n.d.). All these factors result in a cleaner, more sanitary waste collection point (West Oxfordshire District Council, 2020).

Safety and Cleanliness: Since waste is stored securely below ground, issues like vandalism or scavenging are reduced – it is much harder for people or animals to rummage through an underground container (Un-Habitat, 2018). Additionally, wind cannot blow trash out of the container, so the surrounding area stays cleaner (Engels Group, n.d.). Many underground systems incorporate safety features to protect users and workers: for instance, a safety platform or “fall-arrest” barrier inside the container that automatically rises to cover the hole if the container is removed, preventing anyone from accidentally falling into the pit (West Oxfordshire District Council, 2020). The designs also often include locked access or controlled opening mechanisms to prevent illegal dumping or misuse (Elkoplast, n.d.).

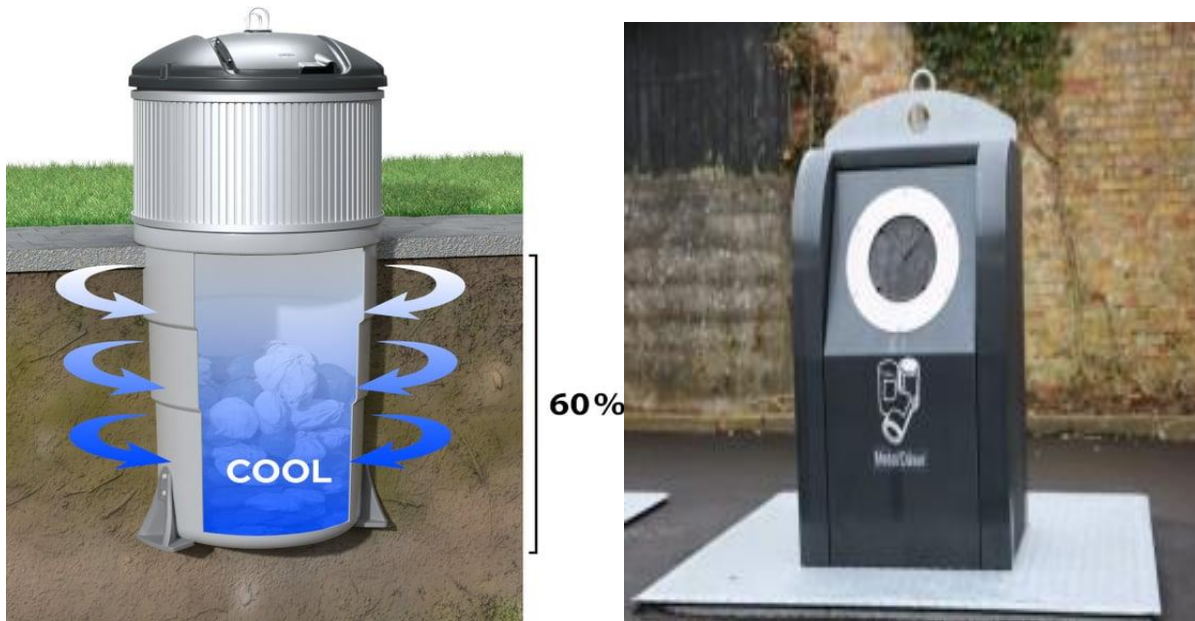
Adaptability (Waste Separation): Modern underground containers can be partitioned into multiple chambers for sorted waste. For example, Elkoplast’s underground units offer internal

removable containers that can be divided into 2 or 3 sections to collect different waste streams (glass, paper, residual waste, etc.) in one container (Elkoplast, n.d.). This is achieved by internal walls in the steel container, enabling recycling at source without additional bins. Above ground, a double or triple inlet column (often called “DUO” or “TRIO” pillars) provides separate throw-in openings for each fraction (Elkoplast, n.d.). This approach aligns with Mongolia’s goal of improving recycling rates (Ministry of Environment and Tourism of Mongolia, 2023).

Given these advantages, it’s clear why underground waste systems are being embraced in many cities as part of “smart city” waste management upgrades (Sensoneo.com 2020). However, implementing them in Mongolian conditions requires careful consideration of local factors: the extreme cold (which can affect materials and hydraulic systems), the soil conditions for excavating and installing the concrete pits (ensuring they can withstand ground frost and seismic activity), and the types of waste (Ulaanbaatar’s household waste has a high percentage of ash and food waste which could affect compaction and container corrosion) (Asian Development Bank, 2021). The literature shows that when properly designed, underground containers can remain functional even in harsh climates – for instance, sensors and container hardware used in places like Canada and Northern Europe are built to operate in sub-zero temperatures (Sensoneo.com 2020). To illustrate the research findings more clearly, examples of underground waste container designs used in several European cities are presented in the following figures.

Figure 4.: Examples of underground waste container designs used in European cities.

Source:(Molok.com 2025)



2.2 Integration of Compaction Technology

While standard underground containers already achieve some compaction through the height of waste and gravity (natural settling can increase capacity by ~20%) (Molok Ltd., n.d.), there is increasing interest in integrating active compaction mechanisms into these systems. The idea is to incorporate a trash compactor inside the underground container to compress the garbage periodically or continuously, significantly increasing the amount of waste that can be stored between collections. This effectively combines the benefits of a compactor (volume reduction) with those of underground storage (Coleman & Nghiem, 2010).

Trash compaction is a well-established technique in waste management: stationary and mobile compactors are commonly used in commercial and industrial settings to reduce waste volume by applying high pressure. Compactors use a powerful press (hydraulic ram or mechanical screw/plate) to crush and compress trash, often achieving a volume reduction ratio of 4:1 or more for general waste (Bay Area Trash Compactor, n.d.). According to Bay Area Trash Compactor company data, small commercial compactors can exert a few thousand pounds of force, whereas large industrial compactors exert over 100,000 pounds (around 450 kN) of force (Bay Area Trash Compactor, n.d.). This results in waste volume reduction up to 75%, meaning the waste is compressed to one-quarter of its original volume or even less (Bay Area Trash Compactor, n.d.). By minimizing waste bulk, compactors reduce the frequency of waste removal needed and can

also improve the handling (as compressed waste is less prone to spill or get blown away) (Murphy, 2024).

In the context of underground bins, manufacturers have developed specialized underground press containers. For example, Engels Group introduced the “Logipers” underground press container, which compacts the waste inside but otherwise functions like a normal underground container from the user’s perspective (Engels Group, n.d.). The compactors can be powered electrically, and some models even use solar power to charge batteries for the compaction mechanism, as a sustainable option (Engels Group, n.d.). By compacting in situ, the storage capacity of an underground container can be increased dramatically without increasing its size. In fact, combining deep collection with active compaction is estimated to boost capacity such that one underground compactor unit might replace dozens of traditional bins (Gläser & Stuecken, 2019). A manufacturer claims their underground compactor system can store up to five times more waste than a non-compacting container of similar dimensions – for instance, an underground bin that would normally hold 5 m³ might effectively hold 25 m³ worth of loose trash after compaction (Engels Group, n.d.).

How the compaction mechanism works in such designs is typically as follows: inside the container, a compaction plate or ram is installed at the top. When activated (either automatically when a sensor detects a new deposit or when the bin reaches a certain fullness threshold), the ram moves downward, crushing the waste against the bottom of the container (Coleman & Nghiem, 2010). The waste is compacted into a dense mass at the bottom. Many systems perform compaction in cycles; for example, each time waste is thrown in, an optical sensor can trigger a compaction cycle (Sensoneo.com 2020). This means the bin is continuously compacting incrementally, rather than waiting to be nearly full. Continuous compaction ensures the available volume is optimally always used and prevents blockages in the chute.

Designing such a compactor requires accommodating significant forces in the container structure. Literature indicates that a typical stationary compactor operates with a pressing force on the order of 0.5 MN (mega Newtons) and achieves volume reduction factors of 2:1 to 5:1 for municipal solid waste (Gläser & Stuecken, 2019). Compaction ratios vary depending on the waste composition – e.g., dry compressible materials like paper and plastic can achieve higher density increases than very wet or inert materials (Murphy, 2024). In municipal waste, initial loose density at curbside might be around 60–120 kg/m³, and truck-compacted density around 200–250 kg/m³ (Eng-Tips Forums, 2008). A strong compactor could raise the density further (landfill compactors can exceed 500 kg/m³) (Gläser, 2021). For our design, we expect to at least triple the loose waste

density via compaction. Achieving that requires careful calculation of the required pressure and thus the hydraulic system design, which will be addressed in the Methods and Results sections.

Some challenges noted in literature for integrating compaction into underground bins include managing the power supply and heat dissipation (since repeated compaction cycles can heat up hydraulic fluid), ensuring the compactor does not jam (for instance, if large rigid items like wood or metal are dumped), and designing the container emptying method for compacted waste (Costa et al., 2022). For emptying, many underground containers are lifted out by crane and either tipped or have bottom doors that open (Costa et al., 2022). Compacted waste might form a large solid block that needs to be ejected – one solution is to have a detachable container that is hoisted and then mechanically emptied by a truck, or to use a tilting compactor mechanism that lifts and tips the compacted bundle into a truck hopper (Costa et al., 2022). These operational aspects inform our design: we will likely design the container with a reinforced base and door that can open to release compacted waste when the container is lifted by a crane – a common mechanism in Europe where the bottom of the container swings open upon being lifted, dropping the waste into the truck (Costa et al., 2022).

Figure 5: Diagram showing the lifting of an underground bin and the opening of its base for emptying into a collection vehicle.



Source: (inkl.com 2025)

In summary, compaction technology in underground bins represents a cutting-edge development designed to maximize capacity and efficiency. The literature reviewed underscores that it is technically feasible and already in use in some advanced waste systems (Gläser & Stuecken,

2019). Our task is to apply these principles to a design suitable for Mongolia, considering the mechanical calculations for the compactor (force, pressure, power requirements) and ensuring the structural integrity of the container under those loads.

2.3 Materials and Structural Design Considerations

Designing an underground compactor bin involves multidisciplinary considerations, but at its core, it is a mechanical structure that must be strong, durable, and safe (Costa et al., 2022). The system comprises three main parts as identified by Costa *et al.* (2022): (1) the liner or container (which holds the waste); (2) the buried structure (the outer vault or pit that supports the container in the ground); and (3) the user interface (the above-ground inlet column or top lid through which waste is deposited) (Costa et al., 2022). Each of these parts has distinct material and design requirements.

Buried concrete pit: Most underground waste systems use a precast concrete pit or silo installed below grade (Costa et al., 2022). This concrete structure must withstand lateral earth pressure, groundwater pressure, and dynamic loads (e.g., if vehicles occasionally drive over it) (Elkoplast, n.d.). Elkoplast's design uses a ~5 tons concrete vault made of waterproof concrete that protects the steel container inside from soil pressure and prevents groundwater from seeping in (Elkoplast, n.d.). In our design, we will specify reinforced concrete (likely C30/37 or higher grade), with thickness and rebar designed for the local soil conditions (USA). Given Ulaanbaatar's climate, the concrete must also endure freeze-thaw cycles; using sulphate-resistant cement and proper waterproofing admixtures will be important to avoid cracking (Elkoplast, n.d.). Ensuring the pit remains dry is critical (to avoid water accumulating and causing odor or corrosion) – thus, a drain or sump might be included if groundwater ingress is a concern, or the concrete made fully watertight with epoxy coatings (Costa et al., 2022).

Steel waste container (liner): The inner container that holds the waste and integrates the compaction mechanism is typically made of steel for strength and durability. Common choices are carbon steel sheets with anti-corrosion treatment (like hot-dip galvanization) or stainless steel. For example, a product might use 3 mm thick hot-dip galvanized steel panels for the container walls (Elkoplast, n.d.). Galvanized steel provides a good balance of cost and corrosion resistance – the zinc coating protects against rusting from contact with moist waste. In extremely cold weather, steel remains tough (though we must ensure the grade used has adequate notch toughness at low temperatures to avoid brittle failure) (Engels Group, n.d.). An alternative is austenitic stainless steel (like SS304 or SS316), which has superior corrosion resistance and cold toughness, but it's significantly more expensive (Engels Group, n.d.).

We will evaluate materials such as:

- Galvanized mild steel – affordable, strong, but if the zinc layer is damaged, it can rust over time, leading to corrosion (Elkoplast, n.d.).
- Stainless steel – excellent longevity and no painting needed; however, cost is high (which might be hard to justify in a municipal budget context), and it is also heavy (Engels Group, n.d.).
- Structural plastics or composites – high-density polyethylene (HDPE) or fiberglass have been used for some semi-underground bins (because they don't corrode and are lighter) (Molok Ltd., n.d.). However, in a compaction system, plastics may not withstand the pressure or might become brittle in Mongolian winters (Molok Ltd., n.d.). HDPE, for instance, can become brittle at very low temperatures (~ -40 °C), risking cracking under load (Molok Ltd., n.d.). Moreover, plastic walls would likely deform under compaction forces unless very thick, which defeats the weight advantage (Molok Ltd., n.d.). Therefore, plastics are more suitable for the outer parts of semi-underground bins (like Molok uses heavy-duty plastic liners but does not actively compact inside them) (Molok Ltd., n.d.). For our design, plastic is not ideal for the primary load-bearing container that sees high mechanical stress (Costa et al., 2022).

Comparison of Material Options:

Table 1: summarizes a comparison of possible container materials

Source: (pmc.ncbi.nlm.nih.gov 2021)

Material	Advantages	Disadvantages
Galvanized Steel (3–5 mm)	High strength, handles pressure; zinc coating provides moderate corrosion protection; relatively low cost.	Heavy to handle; zinc layer can wear off over time, leading to rust; needs periodic inspection/maintenance; thermal conductivity is high (might need insulation to prevent waste freezing onto walls).
Stainless Steel (e.g., 304)	Excellent corrosion resistance (ideal for wet waste); no coating needed; good toughness in cold; long service life.	Very high material cost (several times the price of mild steel); fabrication is more difficult; can still suffer pitting corrosion in the presence of salts; high thermal conductivity similar to steel (freezing issues remain).
HDPE Plastic (thick structural liner)	Will not corrode or rust; lighter weight for transport; somewhat flexible (could absorb some impact).	Low structural strength – would need thick walls/ribbing; susceptible to deformation under continuous load; can crack in subzero temperatures; not proven for high-pressure compaction.
Composite (Fiberglass)	Corrosion-free; lighter than steel; could be molded with internal ribs for strength.	Brittle under impact; may crack under high point loads or cold temperatures; not commonly used for compressive load structures; expensive custom fabrication.

Considering the above, the likely optimal choice is galvanized steel for the container structure, with careful attention to corrosion protection. Hot-dip galvanizing the entire fabricated container (dipping it in molten zinc) will coat both interior and exterior surfaces with a zinc layer ~85 μm thick. This can provide decades of corrosion resistance (for example, Engels' underground containers delivered in Europe have lifespans of 20+ years with proper galvanization) (Engels Group, n.d.). Additionally, small anodes or sacrificial blocks could be attached inside as extra cathodic protection if needed (Engels Group, n.d.). The container's interior may also be coated

with durable epoxy paint on top of galvanization in especially aggressive environments (to resist acidic leachate from decomposing waste) (Costa et al., 2022).

From a structural standpoint, the container must withstand: (1) the internal pressure from compaction, (2) the static load of stored waste (which, when full and compacted, could weigh over 1000 kg), and (3) forces from handling (when lifted by crane hooks) (Costa et al., 2022). During compaction, the waste exerts outward pressure on the container walls. Although waste is not a fluid, one can approximate an equivalent pressure during pressing. If our compactor can exert, say, 200 kN of force on the waste, and the cross-sectional area of the container is around 2.5 m³ (1.6 m × 1.6 m footprint (Elkoplast, n.d.)), the average stress on the waste mass might be on the order of 80 kPa. However, locally it could be higher due to uneven distribution (Costa et al., 2022). The container walls (3 mm steel) will be reinforced with vertical ribs to prevent excessive bulging. A simplified check can treat the long wall as a plate under uniform pressure – we will calculate bending stress and deflection to ensure it is within allowable limits for steel (for instance, using plate theory or finite element approximation, as done by Costa *et al.*, who used FEM analysis to optimize their underground container design) (Costa et al., 2022). In Costa's study, structural analysis led to a redesigned modular structure that cut weight by 15% while still meeting safety, highlighting the importance of optimisation (Costa et al., 2022). We will follow a similar approach, identifying where additional ribs or thicker sections are needed (e.g., around the compactor attachment points and the lifting hook areas) (Costa et al., 2022).

Top platform and inlet column: The platform at ground level must support pedestrians and possibly the weight of a small vehicle (depending on installation location) (Elkoplast, n.d.). Often, the platform covering the container is steel-clad and flush with the ground, sometimes covered with decorative tiles or anti-slip plating (Elkoplast, n.d.). We will design the platform to support at least a 200 kg point load safely (for example, an adult jumping or a loaded handcart) (Elkoplast, n.d.). If installed in a roadway or parking area, it should actually meet at least a class D400 load rating (i.e., sustain a 40-ton gross vehicle weight) – but in most cases, these will be placed in sidewalks or yards, so heavy vehicle loading might be avoided (Costa et al., 2022).

The above-ground inlet column (pillar) is usually made of steel or composite and houses the throw-in door. It must be weather-resistant (painted or powder-coated steel with anti-graffiti coating is common) (Elkoplast, n.d.). The doors will be self-closing and possibly lockable. In cold conditions, we might incorporate a heated edge or use materials that won't freeze shut (for instance, rubber seals that remain flexible at –30 °C) (Engels Group, n.d.).

Safety and standards: As noted, adherence to EN 13071 (European Standard for underground and semi-underground waste containers) is a good benchmark (Engels Group, n.d.). That standard covers safety of hoisting, resistance to impact, fire safety, etc. One requirement is that the lifting system (whether single hook, double hook, or Kinshofer trident) must have a safety factor to prevent accidental dropping (Engels Group, n.d.). We will design the lifting lugs on the container to match common systems so that standard collection trucks can service it (Costa et al., 2022). There should also be a locking mechanism such that the container cannot be lifted unless the area is clear (some systems physically lock the hatch during lifting) (West Oxfordshire District Council, 2020). Our design will include a fall-protection safety lid that automatically closes the ground opening when the container is lifted out, which can be achieved via a hinged cover that springs into place or a telescopic safety floor as used by some manufacturers (West Oxfordshire District Council, 2020).

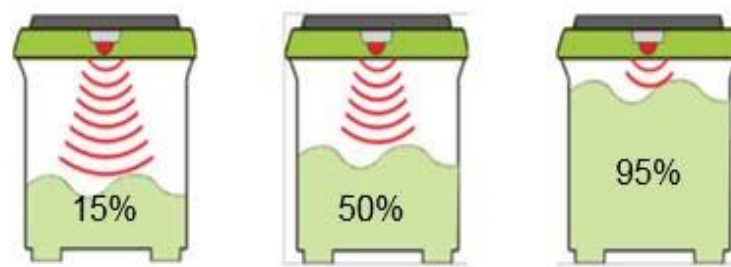
In conclusion, the literature and existing product data provide clear guidance on material and structural choices: a robust concrete encasement and a galvanized steel container are the norm, with design tweaks to address local conditions (Costa et al., 2022). With these in mind, the next section will outline how we approach the detailed design and analysis, including how various methods and calculations will be applied.

2.4 Smart Sensors and Innovative Features

A key aspect of modern waste management – and a requirement in our project – is the integration of **smart sensors** and IoT technology to monitor the system. Equipping the underground bin with sensors can dramatically improve efficiency: rather than relying on fixed schedules, waste collection can be **on-demand**, based on real-time fill levels. In our design, we plan to include sensors that detect the fill level of each compartment, as well as other parameters like temperature or even potentially flammable gas concentration, to enhance safety.

Figure 6: Showing how an ultrasonic fill-level sensor works in a waste bin.

Source: (researchgate.net 2016)



Commonly, **ultrasonic fill-level sensors** are used in bins. These devices are mounted on the lid or inside the container top and measure the distance to the top of the trash heap using ultrasound or laser ranging. When the distance falls below a threshold (meaning the bin is nearly full), the system can send an alert. Companies like Sensoneo and Nordsense have developed rugged sensors specifically for waste containers, including underground ones. These sensors are **built to withstand harsh conditions** – they are water-proof, shock-resistant, and can operate in a wide temperature range (for instance, -40°C to $+85^{\circ}\text{C}$ operating range is common). This ensures they function through Mongolia's winters. They typically run on batteries that last several years and use wireless networks (such as LoRa, Sigfox, NB-IoT or GSM) to transmit data.

In Prague's implementation mentioned earlier, thousands of ultrasonic sensors were retrofitted in underground bins, providing city officials with real-time data on which bins are full and need service (sensoneo.com 2020). This resulted in a **precise and cost-effective collection** regime – trucks are routed only to bins that require emptying, avoiding unnecessary pickups of half-empty containers (sensoneo.com 2020). For Ulaanbaatar, where resources for waste collection are often stretched, such optimization could be extremely beneficial. It reduces fuel usage, working hours, and emissions, and prevents the scenario of overflowing bins because pickups were too late.

Our sensor system will likely include:

- **Fill level sensors** (one for each chamber). We will mount an ultrasonic sensor at the top of each compartment. These will be calibrated to account for the 3D shape of the container (some advanced sensors, like Nordsense's, use multiple beams to map the waste surface for accuracy).
- **Temperature sensor** inside the container. This can detect if the interior temperature rises abnormally, which could indicate a fire in the bin. There have been cases where hot ash or embers thrown into bins ignite fires. An underground fire is dangerous due to smoke and heat in a confined space, so early detection is vital. If our sensor picks up an unusual temperature spike, it could trigger an alert for emergency response. Many smart bin sensors now include temperature monitoring for precisely this reason.
- (Optional) **Tilt or motion sensor**: This could detect if someone tries to vandalize or move the bin, or if the container is being lifted (for servicing). It's not critical, but some systems include accelerometers for security.
- (Optional) **Gas sensor**: In large underground systems, one might include a methane or CO sensor to detect dangerous gas buildup (in case waste is decomposing anaerobically).

However, our container is not fully sealed (there's some airflow via the column), and routine emptying should prevent long-term gas buildup. We may consider a simple vent with a charcoal filter on the column to let the container “breathe” and further reduce odor.

Table 2 : Sensors ranges

Source: (bosch-sensortec.com 2021)

Sensor Type	Function	Measurement Range	Operating Temp (°C)	Accuracy	Power / Interface	Remarks
Ultrasonic Fill-Level	Detects waste fill height	0–3 m	–40..+85	±3–5%	Battery / LoRa or NB-IoT	Waste-specific firmware, dust compensation
Pressure Transducer	Hydraulic pressure for compactor	0–250 bar	–20..+100	±0.25% FS	24 VDC / 4–20 mA	Overload protection & shutdown
Load Cell (optional)	Bin mass trending	0–500 kg	–40..+70	±1%	5 VDC / Analog	Predictive fullness by weight
Temperature Sensor	Fire/overheat detection	–50..+150	±1°C	5 VDC / Analog	Alerts abnormal heat rise	
Methane/CO (optional)	Gas safety monitoring	0–1000 ppm	–20..+60	±2%	5 VDC / Digital	Ventilation/alarm trigger
Vibration/Motion	Mechanical fault/impact	—	–40..+85	±2%	3.3 V / Digital	Maintenance diagnostics

All sensor data will feed into a **wireless waste management platform**. In practice, this means our device will have a small IoT communication unit that sends data to a server or cloud application. The city's waste department can then see fill levels on a dashboard, receive email/SMS alerts when bins are full or if any issue (like fire) is detected, and plan collection routes dynamically. Studies have shown that such smart collection systems can cut operational costs by 30–50% and greatly improve service reliability.

From a mechanical engineering perspective, including sensors does not add much complexity to the design structure, but we need to ensure **proper housing and protection** for the electronics. The sensor units will likely be installed on the underside of the lid or inside the pillar. They must be shielded from impact (people tossing in waste shouldn't hit the sensor) and from water or snow ingress. We will design a small steel housing for the sensor with an opening for the ultrasonic beam. Wiring (if any) will be routed safely, though many sensors are wireless and battery-powered, eliminating the need for external power or cabling. For example, Sensoneo's ultrasonic

sensor runs on batteries and uses a wireless uplink, making installation as simple as screwing the sensor in place.

An **innovative feature** we can consider is incorporating a **solar panel** on the above-ground pillar to power the compactor's electrical components and the sensor gateway. Engels has demonstrated a solar-powered underground compactor where a solar panel on a post provides all necessary energy for compaction cycles and electronics. Mongolia has abundant sunshine (particularly Ulaanbaatar is one of the sunniest capitals, even in winter), so solar could be very effective. We would need to size the panel and battery to ensure year-round operation. This adds an element of renewable energy and off-grid capability – useful in case the unit is placed where grid power hook-up is expensive. Alternatively, connecting to grid power is straightforward if available, since the compactor motor will need a decent power supply (on the order of a few kW). A hybrid approach could be used: solar to support the sensor and small compactor cycles, with the grid as backup for heavier usage.

In terms of user interaction innovation, we might propose that the system supports **smart access control** (e.g. residents have an RFID card to open the bin). This can prevent unauthorized use and can also implement a “pay as you throw” scheme where waste disposal is metered. However, this strays more into policy – mechanically it just means adding a locking mechanism on the lid which unlocks via card reader. It's an optional feature (some European underground bins use such systems to encourage recycling by charging for mixed waste disposal).

To summarize, the literature supports that adding sensor technology greatly enhances waste systems, and successful case studies (Prague, Copenhagen, etc.) back up the efficacy of smart waste collection (sensoneo.com 2020). Our design will incorporate these proven technologies – making the underground compactor not just a passive bin, but an active node in a smart city network. This ensures the system remains **efficient, safe, and user-friendly** throughout its life cycle.

Literature review summary: Existing studies and products show that underground waste containers, especially when equipped with compaction and smart sensors, offer substantial improvements in capacity, efficiency, and environmental impact over traditional waste bins. Key takeaways for our project include: use robust materials (galvanized steel, concrete) and include safety features in design; expect compaction to multiply capacity (2–5×) and thus design the mechanical system for high forces; and integrate sensor and solar technology for intelligent, sustainable operation (sensoneo.com 2020). These lessons from the literature form the foundation for the methods we will now apply in designing the new system for Mongolia.

Chapter 3: Methodology (Materials and Methods)

In this section, we detail the methodology used to develop and analyze the underground compactor bin design. The work involves both **design methodology** (the steps and tools used to create the design) and **analytical methods** (calculations and simulations to verify the design's performance). In this study, a mixed-method research design was adopted, combining both quantitative and qualitative approaches to ensure a comprehensive understanding of the problem and to enhance the validity of the findings. The quantitative component focuses on numerical modeling, engineering calculations, and measurable design parameters—such as compaction force, hydraulic pressure, and material stress analysis—providing objective, data-driven results. Meanwhile, the qualitative component involves the interpretation of contextual factors, user requirements, environmental conditions, and practical constraints specific to Mongolian waste management systems. Integrating these two approaches allows for methodological triangulation, where numerical results are interpreted within a real-world context, ensuring that the outcomes are both technically sound and practically relevant. The combination of quantitative precision and qualitative insight makes it possible to compare, validate, and critically evaluate findings from multiple perspectives, leading to conclusions that are more reliable, comprehensive, and easier to interpret. In essence, this hybrid methodology strengthens the overall research by linking analytical rigor with contextual understanding—an approach particularly suited for engineering design studies addressing complex, multidisciplinary challenges. Given that this is a mechanical engineering project, emphasis is placed on quantitative analysis and engineering rigor at each stage. The methodology can be broken down into the following main components:

3.1 Requirements Definition and Conceptual Design

The first step was to clearly define the **requirements and scope** of the design. This was informed by the problem context and literature review. Key requirements identified include:

- **Capacity:**

The underground container has a total physical capacity of approximately **1.16 m³** (0.8 m × 0.8 m × 1.81 m), designed as a **single dual-purpose bin** with internal divisions for general and recyclable waste. When the hydraulic compaction system is active, the effective storage capacity increases to about **3.5 m³** of loose, uncompacted municipal solid waste—roughly three times the physical volume. This capacity is sufficient to handle the

weekly waste output of a small residential area while maintaining infrequent collection intervals and minimizing overflow risks.

- **Compaction Performance:**

The system achieves this capacity gain through a **target compaction ratio of 3:1**, suitable for typical mixed municipal solid waste. To reach this level of compression, the hydraulic unit was sized for a **100 mm bore cylinder operating at 16 MPa**, generating a **compaction force of about 125 kN** and an average pressure of **0.13 MPa** on the waste surface. These parameters guided the selection of the cylinder stroke length and motor power, ensuring efficient operation while maintaining structural safety margins.

- **Environmental resilience:** Must operate in -30°C to $+30^{\circ}\text{C}$, resist corrosion, and function in dusty, dry climates as well.
- **Safety and standards:** Comply with EN 13071 and relevant safety norms (e.g., lifting equipment safety, electrical safety for the compactor, etc.). Incorporate safety interlocks and fall protection.
- **Maintenance:** Should be serviceable – for instance, the hydraulic cylinder should be accessible for repair or replacement, sensors battery change must be easy, and surfaces easy to clean (smooth interior to prevent waste sticking).
- **Power:** Preferably use available 220–240V AC mains. If not reliably available, include a solar + battery system sized for ~ 1 compaction per day plus sensor loads.
- **Cost:** While a detailed cost analysis is beyond scope, the design choices should consider cost-effectiveness (e.g., choosing galvanized steel over stainless, except where justified).

With these in mind, we proceeded to the conceptual design. **Sketches and CAD modeling** were used to refine the layout. A 3D CAD model of the system was created (using Autodesk AutoCAD and Inventor software) to visualize the components and ensure they fit together. The conceptual design (Figure 1 earlier and the detailed diagram in Figure 2 below) includes:

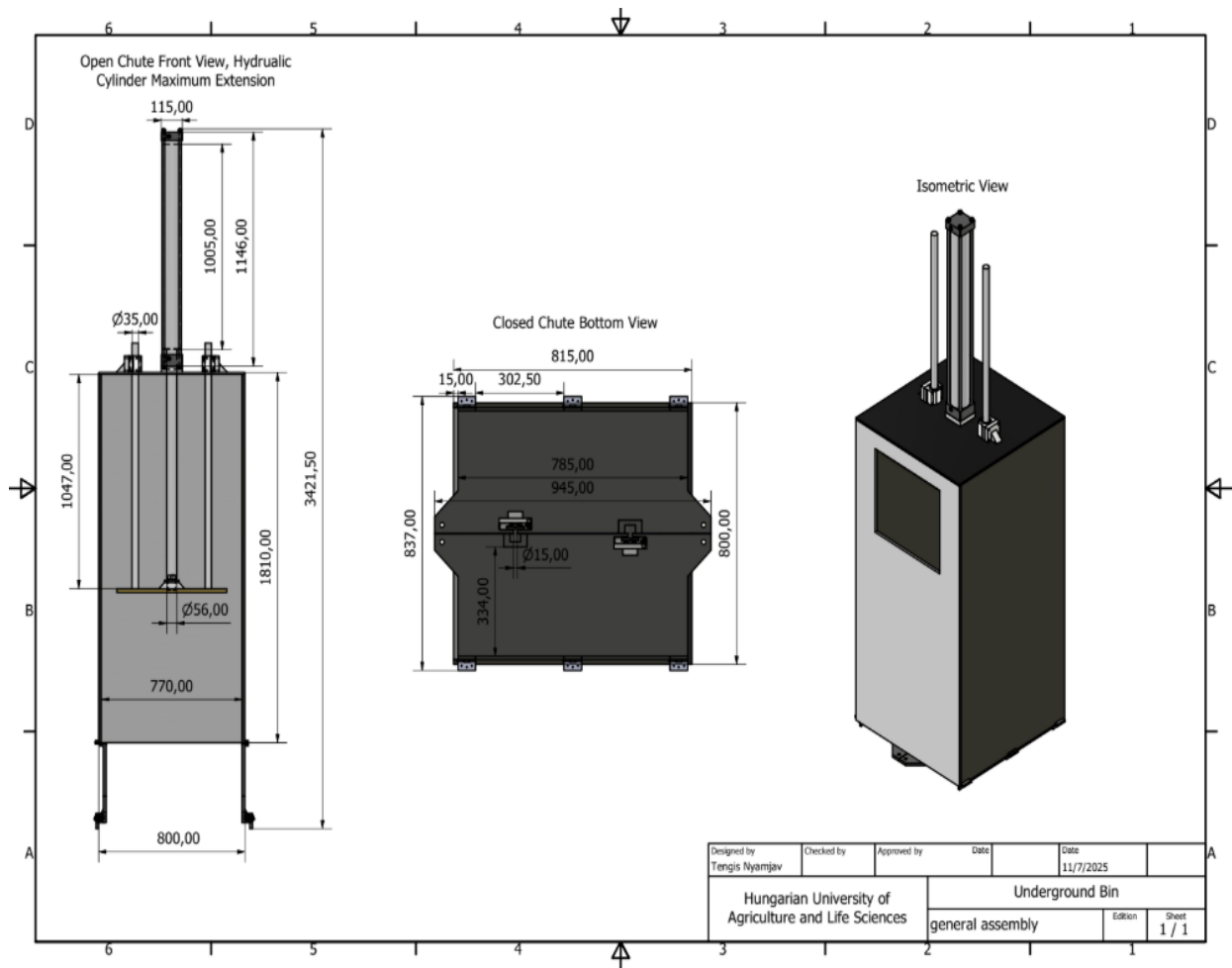
- A cylindrical or rectangular concrete vault (we chose a square cross-section $1.2\text{ m} \times 1.2\text{ m}$ internal to match available container designs).
- A steel container that fits inside this vault with some clearance. The container has external guides and brackets to position it correctly and to interface with the lifting hooks.

- The compactor consists of a hydraulic cylinder and a compaction plate sized nearly to the compartment cross-section (with a small gap to avoid friction on walls).
- A single-compartment design with one top inlet and a hinged door on the pillar above ground. The pillar is single-entry, with an approximate footprint of 1.2 m × 1.2 m and about 2 m tall, designed for ergonomic use.
- Mounting points for sensors: e.g., an ultrasonic sensor at the top of each compartment (just inside each inlet) and a temperature sensor in the general waste side (since that's where hot ashes might be thrown).
- Drainage at the bottom of the container (a small sump where any leachate could collect, possibly with an absorbent pad or a way to pump out liquids during maintenance).
- Integration of the lifting system: we opted for a **double-hook** lifting system, which is common in Europe – two lifting lugs on opposite sides of the container engage with a crane's hooks. We design these lugs with ample reinforcement.

During conceptual design, we also considered the **emptying process**. The plan is: when a container is full, a crane truck comes, attaches to the lifting lugs, and hoists the container up. As it is lifted clear of the pit, a safety plate covers the opening. The container is then maneuvered over the truck. A release mechanism at the bottom of the container (either a door that swings open or a split base that opens in two flaps, as often seen in underground bins) is triggered, dumping the compacted waste out. We included in the design a bottom door with a lock that can be opened via the crane operator pulling a cable (common in Kinshofer lifting systems). Figure 2 shows an annotated design of the system components.

Figure 7: General assembly drawing of the designed underground bin system showing the open chute front view, closed chute bottom view, and isometric view.

(Source: Own Design)



3.2 Detailed Design and Material Selection

Once the concept was solidified, we moved to detailed design calculations and material selection confirmation. This phase is where engineering science is applied to ensure each aspect of the design will work as intended. The methods used include analytical calculations and some computer simulations.

Material selection methodology: Based on the literature review and initial concept, the provisional materials were concrete C30 for the pit, S355 grade steel (structural steel) for the container, with hot-dip galvanization, and standard hydraulic components (typically made of steel, with appropriate seals). To validate these, a **material selection matrix** was used where needed. For example, to justify the choice of galvanized steel vs. stainless steel, we considered criteria like yield strength, toughness at -30°C , corrosion resistance, cost per kg, and maintenance. Galvanized S355 scored well on strength and cost, while stainless scored high on corrosion but

low on cost. We concluded galvanized steel is sufficient given a proper maintenance schedule (e.g., re-coating every ~10 years if needed). The internal divider will be the same steel plate (perhaps 3 mm as well) welded in place. The top pillar could be made of slightly thinner steel (2 mm) since it's mostly a cosmetic enclosure, but for consistency and vandal-resistance we might use 2–3 mm steel there too, with powder coat paint (any dents or graffiti can be easily cleaned or repainted).

Table 3: Material Selection Matrix for Waste Container Components

Source: (Own Work)

Criteria	Weight	Galvanized S355 Steel	Stainless 304	HDPE (structural)	GFRP Composite
Yield strength	0.25	5	4	2	3
Low-temp toughness	0.20	4	5	2	2
Corrosion resistance	0.20	3	5	5	4
Manufacturability	0.15	5	3	4	2
Cost	0.20	5	2	4	2
Weighted Total (max=5)	—	4.35	3.7	3.4	2.8

Table 4: Ranking of Candidate Materials Based on Weighted Evaluation

Source: (Own Work)

Rank	Material	Weighted Total Score	Remarks
1	Galvanized S355 Steel	4.35	High strength, cost-effective, cold-resistant; best overall balance
2	Stainless 304 Steel	3.70	Excellent corrosion resistance but high cost
3	HDPE (Structural Grade)	3.40	Lightweight, corrosion-free, but brittle at – 30°C
4	GFRP Composite	2.80	Good corrosion resistance, poor manufacturability in local context

For the **hydraulic cylinder**, material is typically high-strength steel (e.g., 42CrMo4 for piston rod). We will specify seals rated for low temperature (e.g., nitrile or silicone that remain flexible in cold, or special low-temp polyurethane). Hydraulic oil will be a low-temperature fluid (perhaps a synthetic oil with pour point below –40°C, or an ATF that works in automotive in winter). This ensures the compactor can operate even on cold mornings – in extremely low temperatures, the compactor cycle might be slower due to viscosity increase, but it should still function.

Sensor and Electronics Integration: In the design process, we also planned how to integrate the sensors and control electronics into the system. This part didn’t need any complex calculations, but it required careful and practical thinking to make sure everything would be easy to install and maintain later. Inside the main column, we reserved space for a sensor gateway box, which will hold the transmitter, power supply, and wiring from the solar panel (if used). The ultrasonic fill-level sensor we selected has a 3-meter range, a wide cone angle, and can operate between –40°C and +60°C, which makes it suitable for Mongolian winter conditions. The sensor will be mounted on a small, welded bracket under the lid, facing downward into the bin. We also made sure that the compaction plate stops well above the sensor’s position, so it never makes contact or gets damaged during operation.

Method for Innovation and Validation: We employed a bit of **value engineering** – thinking of innovation such as the solar power addition. To validate that concept, we did a quick energy

balance calculation (as above, showing energy usage and solar insolation in Ulaanbaatar ~4.5 sun-hours/day average, thus a 1 kW panel could generate ~4.5 kWh/day which is more than enough for our needs). We also considered adding an insulating layer inside the container walls to prevent waste freezing to the sides (a thin layer of polymer or double-wall design with air gap). We decided the benefit might be marginal given waste generates some heat as it decomposes, but it's a possible innovation for extreme cold – however, it reduces internal volume slightly. For now, we noted it as a proposal rather than core design.

In sum, the methodology integrated requirements-driven design with rigorous mechanical calculations and modern engineering tools. By following these steps systematically – from concept to detailed analysis, to validation – we ensure that the final design meets the objectives. Next, we present the **results** of these calculations and evaluations, effectively demonstrating how the design performs and confirming it satisfies the initial goals.

3.3 Theoretical Background

This chapter presents the theoretical modeling of a hydraulically actuated trash compactor for a square bin. The objectives are: (i) size the actuator; (ii) predict wall and floor pressures during pressing; (iii) estimate compaction ratio for mixed municipal waste. The analysis links hydraulic force to bulk-material stresses with a Janssen-style model.

3.3.1 Overview of Compaction Mechanics

Mechanical trash compaction is a form of bulk material densification in which a movable plate applies compressive stress to a deformable, heterogeneous mass of waste. The process reduces void spaces and expels entrapped air, thereby increasing the bulk density. From a mechanical standpoint, the waste can be approximated as a compressible granular medium material composed of irregular particles with internal friction and cohesion, somewhat analogous to soil or grains.

The engineering objective is to relate the applied plate load to the resulting internal stresses and final bulk density. Because direct modeling of each particle is impractical, continuum mechanics and empirical bulk-pressure models are used. The most widely accepted formulation for vertical stress attenuation in such media is the **Janssen model**, originally derived for grain silos. It provides a mathematically convenient and physically consistent method for estimating the vertical and lateral pressures that develop within a confined bin.

3.3.2 Vertical Stress Transmission in Confined Bulk Material

When a **column of granular or waste material** is loaded from the top, the imposed vertical stress is partially transferred to the container walls through friction. As a result, the vertical stress

increases rapidly with depth near the top but gradually approaches a limiting value rather than increasing linearly with depth, as would occur in a liquid. Janssen (1895) demonstrated that this behavior can be captured by the following differential equilibrium relation:

$$\frac{d\sigma_v}{dz} + \frac{P}{A}\mu_w K \sigma_v = \rho g \quad (1)$$

where σ_v is the vertical stress at depth z , A and P are the bin cross-sectional area and perimeter, μ_w is the coefficient of friction between material and wall, K is the lateral-to-vertical stress ratio, and ρg represents the self-weight of the material.

For waste compaction, self-weight is negligible relative to the applied plate load, and the system behaves as if $\rho g \approx 0$. Under these conditions, the differential equation simplifies, and its solution yields the exponential form

$$\sigma_v(z) = \sigma_0 e^{\left(-\frac{z}{\lambda}\right)} \quad (2)$$

where σ_0 is the applied pressure at the plate and

$$\lambda = \frac{D_0}{(4 \mu_w K)}, \quad D_0 = \frac{4A}{P} \quad (3)$$

Here λ is the attenuation length, a characteristic depth over which applied stress decreases by a factor of e . It depends solely on the geometry and wall friction conditions.

3.3.3 Lateral Pressure and Wall Shear

The lateral stress acting on the bin walls follows from the empirical ratio $K = \sigma_h/\sigma_v$. For most bulk solids K ranges from 0.4 to 0.7, depending on material friction and consolidation. The corresponding wall shear stress is

$$\tau_w = \mu_w \sigma_h = \mu_w K \sigma_v(z) \quad (4)$$

The product $P\tau_w$ represents the distributed frictional resistance along the wall per unit vertical depth. This term counteracts the downward motion of the ram plate and significantly contributes to the total required force.

3.3.4 Total Ram Force

Integrating the wall shear contribution over the full compacted height H leads to the effective “wall-loss area” $C(H)$:

$$C(H) = P\mu_w K \lambda \left(1 - e^{-\frac{H}{\lambda}}\right) \quad (5)$$

The total ram force required at a given plate pressure σ_p is then

$$F_{ram} = (A + C)\sigma_p \quad (6)$$

The term $A\sigma_p$ represents the direct compression on the material surface, while $C\sigma_p$ accounts for energy dissipated through wall friction. The effective ram area $(A+C)$ thus exceeds the physical plate area A , illustrating how wall friction amplifies the hydraulic demand as the compaction depth increases.

3.3.5 Hydraulic Pressure and Cylinder Sizing

For a hydraulic actuator, the available thrust is

$$F_{hyd} = p_{hyd} A_{cyl} \quad (7)$$

where p_{hyd} is the system pressure and A_{cyl} is the piston area. Matching F_{hyd} and F_{ram} allows the designer to determine the required bore diameter or to assess whether a selected cylinder provides sufficient force. In practice, the compaction process is pressure-controlled rather than displacement-controlled: the ram stops when the system reaches a preset hydraulic pressure, not when it contacts the bin floor.

3.3.6 Compaction Ratio and Material Densification

The efficiency of the compactor is measured by the *compaction ratio*:

$$CR = \frac{V_0}{V_f} = \frac{\rho_f}{\rho_0} \quad (8)$$

where V_0 and ρ_0 are the loose-state volume and density, and V_f and ρ_f are the final compacted values. The compaction ratio depends on both the applied pressure and the compressibility of the waste stream. Empirical studies show that mixed kitchen and cardboard waste achieves practical density increases of 2–4 times under plate pressures between 80kPa to 180kPa. Beyond this range, additional energy primarily overcomes wall friction and elastic recovery rather than producing further densification.

3.3.7 Assumptions and Applicability

The following simplifying assumptions are adopted for design calculations:

- Waste behaves as a homogeneous, cohesionless, compressible bulk material with uniform friction properties.
- Self-weight effects are negligible compared with hydraulic compaction forces.
- Wall friction and lateral stress are uniform along the height of the bin.
- The process is quasi-static; dynamic effects and rebound are ignored.
- The hydraulic system maintains a constant nominal pressure of 16MPa throughout compaction.

Under these conditions, the Janssen model provides a reasonable first-order prediction of required ram force and internal pressures. While more sophisticated finite-element or discrete element analyses could capture nonuniformities, the present model offers adequate accuracy for a Bachelor-level design and cost estimation.

Chapter 4: Results and Discussion (Design Evaluation)

In this section, we present the analytical design and key **results** from the design process and analyze how the design meets the objectives. The results include detailed mechanical calculations (e.g. compaction force achieved, stresses in structures, etc.), as well as performance evaluations (capacity, efficiency gain) and any issues identified. Each subsection corresponds to a major aspect of the system.

4.1 Design Requirements and Assumptions

- Bin: square $w = l = 0.8\text{m} \Rightarrow A = 0.64\text{m}^2$, $P = 3.2\text{m}$.
- Waste stream: mixed kitchen + cardboard.
- Parameters: $K = 0.5$, $\mu_w = 0.4$.
- Target plate pressure: $\sigma_p \in [120\text{kPa}, 130\text{kPa}]$.
- Candidate compacted heights: $H = 0.60\text{m}, 0.80\text{m}, 1.10\text{m}$.
- Quasi-static, pressure-controlled pressing; self-weight during pressing neglected.

4.2 Hydraulic Cylinder Sizing Calculations

The hydraulic cylinder converts fluid pressure into linear force. In a compactor, its sizing determines both the achievable plate pressure and the rate of motion. If the bore is undersized, the plate cannot reach the target compaction pressure; if oversized, the unit becomes heavy, slow, and costly due to larger oil volumes and pump demands. Therefore, the design must satisfy both the required thrust and manufacturability constraints.

4.2.1 Fundamental Relation Between Pressure and Force

Hydraulic actuators operate under the simple relationship

$$F_{hyd} = p_{hyd} A_{cyl}$$

where F_{hyd} is the linear thrust, p_{hyd} is the system pressure, and A_{cyl} is the piston area. The piston area depends on the bore diameter d :

$$A_{cyl} = \frac{\pi d^2}{4}$$

Rearranging gives the required bore for a given force and operating pressure:

$$d = \sqrt{\frac{4F_{ram}}{\pi p_{hyd}}} \quad (9)$$

Equation (9) is the core design expression linking the mechanical demand of the compactor with the hydraulic supply.

4.2.2 Geometric Parameters and Wall Effects

The bin geometry influences the required ram force through the Janssen wall-loss term. For the compactor dimensions $w = l = 0.8\text{m}$:

$$A = w^2 = 0.64\text{m}^2, \quad P = 4w = 3.2\text{m}.$$

The corresponding hydraulic (equivalent) diameter and attenuation length are

$$D_{\text{eq}} = \frac{4A}{P} = 0.8\text{m}, \quad \lambda = \frac{D_{\text{eq}}}{4\mu_w K} = \frac{0.8}{4(0.4)(0.5)} = 1.0\text{m}$$

These quantities describe how applied stress dissipates with depth due to wall friction. A smaller λ (from higher friction or smaller bin width) would demand significantly greater ram force for the same plate pressure.

4.2.3 Force Requirement at Target Pressure

The total force acting on the ram plate equals the direct plate load plus the integrated wall friction resistance:

$$F_{ram} = (A + C)\sigma_p, \quad C = P\mu_w K\lambda \left(1 - e^{-\frac{H}{\lambda}}\right).$$

For the representative compacted height $H = 0.8\text{m}$, lateral stress ratio $K = 0.5$, wall friction $\mu_w = 0.4$, and target plate pressure $\sigma_p = 120\text{kPa}$,

$$C = 3.2(0.4)(0.5)(1.0)(1 - e^{-0.8}) = 0.352\text{m}^2, \quad (10)$$

$$F_{ram} = (0.64 + 0.352)(120 \times 10^3) = 119\text{kN}. \quad (11)$$

Hence, a hydraulic actuator must supply approximately 119kN to maintain 120kPa on the plate.

4.2.4 Trade-Off Between Pressure and Bore

Table 5 illustrates the required bore diameter from Eq. (11) under different working pressures.

Industrial hydraulic systems generally operate between 10MPa and 20MPa. Choosing a smaller bore with higher pressure reduces size and cost but increases demands on sealing integrity and pump capacity. Conversely, low-pressure systems are safer but bulky and less efficient.

4.2.5 Design Margin and Realistic Selection

Design codes recommend including a factor of 1.2–1.3 to account for frictional losses in hoses, valves, and imperfect alignment. Adopting a 25% margin:

$$F_{design} = 1.25F_{ram} = 1.25(119) = 149kN$$

Table 5: Required cylinder bore diameter for $F_{ram} = 119$.

Source: (Own Work)

Hydraulic Pressure p_{hyd}	Piston Bore d	Comment
10MPa	123mm	Large, heavy cylinder with moderate safety margin.
12MPa	113mm	Typical industrial pressure; near upper bound for medium-frame actuators.
16MPa	98mm	Compact, light actuator; requires high-pressure seals and fittings.

At the nominal system pressure of 16MPa, the corresponding bore diameter is

$$d = \sqrt{\frac{4(149000)}{\pi(16 \times 10^6)}} = 108mm$$

This result supports the selection of a commercially available 100mm ISO-standard cylinder operating near full-rated pressure, offering adequate capacity with a moderate margin.

4.2.6 Flowrate and Power Estimation (Optional Design Check)

For completeness, the power requirement of the hydraulic unit can be estimated as

$$p_{hyd} = \frac{p_{hyd}Q}{\eta}$$

where Q is the flow rate and η is overall efficiency (typically 0.85). Assuming the plate travels 0.8 m in 15 s,

$$Q = A_{cyl} \left(\frac{L}{t} \right) = 7.85 \times 10^{-3} \times \left(\frac{0.8}{15} \right) = 4.2 \times \frac{10^{-4} m^3}{s} = \frac{25L}{min}$$

The corresponding power input is

$$P_{hyd} = \frac{(16 \times 10^6 \times (4.2 \times 10^{-4}))}{0.85} \approx 7.9 \text{ kW}$$

This indicates a 10kW class electric motor and pump set would be sufficient to drive the system continuously.

4.2.7 Summary of Design Implications

- Required thrust: 119kN at 120kPa plate pressure.
- Recommended design thrust: 149kN (1.25 safety factor).
- Cylinder sizing: 100mm bore at 16MPa nominal pressure.
- Pump requirement: approximately 25L/min flow, 8kW power.

The chosen configuration aligns with readily available ISO tie-rod cylinders and maintains a practical balance between pressure, mechanical strength, and system efficiency.

Table 6: Selected cylinder data (SMC CH(D)SG series).

Source: (Own Work)

Parameter	Value	Notes
Nominal pressure	16MPa	ISO-rated
Bore diameter	100mm	Selected
Stroke (assumed)	800mm	Travel, not force-governing
Piston area A_{cyl}	$7.854 \times 10^{-3} \text{ m}^2$	$\pi d^2/4$
Theoretical thrust F_{cyl}	125.7kN	at 16MPa
Manufacturer	SMC Corporation	https://www.smcworld.com

Figure 8: SMC CH(D)SG ISO Standard Hydraulic Cylinder (image: SMC).

Source: (SMC nd)



Hydraulic Cylinder Selection

A standard ISO tie-rod cylinder meeting these requirements is the **SMC CH(D)SG** series (nominal 16MPa). We selected a 100mm bore as a practical, available size.

4.3 Compaction and Wall Load Modeling

This section evaluates stress distribution, wall friction, and achievable plate pressure for the compactor using the Janssen model. The hydraulic actuator with an available thrust of $F_{cyl} = 125.7\text{kN}$ acts on a plate of area $A = 0.64\text{m}^2$. The waste is characterized by a lateral stress ratio $K = 0.5$, a wall friction coefficient $\mu_w = 0.4$, and an attenuation length $\lambda = 1.0\text{m}$. These parameters are typical for mixed household waste containing cardboard, plastics, and organic matter [2, 3].

4.3.1 Model Formulation

The total reaction force on the ram plate consists of two components: (1) the direct compression of waste and (2) the integrated wall friction that resists downward motion. According to the Janssen approximation,

$$F_{ram} = (A + C)\sigma_p \quad (12)$$

where the geometric wall-loss term is

$$C = P\mu_w K\lambda \left(1 - e^{-\frac{H}{\lambda}}\right) \quad (13)$$

and P is the bin perimeter in contact with the waste. Rearranging (12) for plate pressure at a given compaction height yields

$$\sigma_p(H) = \frac{F_{cyl}}{A+C(H)} \quad (14)$$

Equations (13) and (14) describe how increasing compaction height H causes greater lateral stress transfer to the walls, reducing the net plate pressure that can be transmitted downward. The pressure transmitted to the floor decays exponentially:

$$p_{floor}(H) = \sigma_p(H)e^{-\frac{H}{\lambda}} \quad (15)$$

4.3.2 Analytical Evaluation at Three Representative Heights

Using the available force $F_{cyl} = 125.7\text{kN}$, the attainable pressures were computed for three waste fill levels: $H = 0.6\text{m}$, 0.8m , and 1.1m . Each case corresponds to a different compaction stage, illustrating how wall friction increasingly limits compaction efficiency.

Case C: $H = 0.60\text{m}$ (Early Compaction Stage)

$$C = 0.64(1 - e^{-0.6}) = 0.2888 \text{ m}^2, \quad \sigma_p = \frac{125700}{0.64 + 0.2888} = 135.3 \text{ kPa}$$

$$F_{plate} = 86.6 \text{ kN}, \quad F_{wall} = 39.1 \text{ kN}$$

$$p_{floor} = 135.3 e^{-0.8} = 74.3 \text{ kPa}, \quad \sigma_h(0) = 67.7 \text{ kPa}, \quad \sigma_h(0.6) = 37.1 \text{ kPa}$$

At this stage, roughly 31% of the total ram force is consumed by wall friction. The vertical stress reaching the floor remains high, indicating that the waste is still loosely packed and easily deformable.

Case A: $H = 0.80\text{m}$ (Nominal Compaction Level)

$$C = 0.64(1 - e^{-0.8}) = 0.3524 \text{ m}^2, \quad \sigma_p = \frac{125700}{0.64 + 0.3524} = 126.7 \text{ kPa}$$

$$F_{plate} = 81.0 \text{ kN}, \quad F_{wall} = 44.6 \text{ kN}$$

$$p_{floor} = 126.7 e^{-0.8} = 56.9 \text{ kPa}, \quad \sigma_h(0) = 63.3 \text{ kPa}, \quad \sigma_h(0.8) = 28.5 \text{ kPa}$$

This height represents the practical operational limit. About 35% of the total cylinder thrust is now absorbed by wall friction. The transmitted floor pressure falls to ≈ 57 kPa, implying that a major portion of compaction energy is diverted laterally to the walls.

Case B: H = 1.10m (Deep Compaction Stage)

$$C = 0.64(1 - e^{-1.1}) = 0.4270 \text{ m}^2, \quad \sigma_p = \frac{125700}{0.64 + 0.3524} = 117.8 \text{ kPa}$$

$$F_{plate} = 73.9 \text{ kN}, \quad F_{wall} = 51.8 \text{ kN}$$

$$p_{floor} = 117.8 e^{-0.8} = 39.2 \text{ kPa}, \quad \sigma_h(0) = 58.9 \text{ kPa}, \quad \sigma_h(1.1) = 19.6 \text{ kPa}$$

Beyond $H = 1.1\text{m}$, diminishing returns are evident. Nearly 41% of the ram effort is expended in overcoming frictional resistance, while the effective compaction at the base falls sharply.

Table 7: Summary of predicted stresses and volumes at various compaction heights for $F_{ram} = 125.7\text{kN}$.

Source: (Own Work)

H [m]	σ_p [kPa]	p_{floor} [kPa]	$\sigma_h(0)$ [kPa]	$\sigma_h(H)$ [kPa]	V_f [m ³]
0.60	135.3	74.3	67.7	37.1	0.384
0.80	126.7	56.9	63.3	28.5	0.512
1.10	117.8	39.2	58.9	19.6	0.704

4.3.3 Comparative Summary

The data reveal a clear attenuation of vertical stress with increasing compaction height. At $H = 1.1\text{m}$, the plate pressure has dropped by 13% relative to the early compaction stage, and the floor pressure by nearly 50%. This agrees with the Janssen model prediction that frictional load transfer to walls saturates exponentially, limiting additional compaction. Hence, a design height of 0.8m represents an effective compromise between bin volume and achievable density.

From the volume relation $V_f = AH$, the corresponding final volumes range from 0.384m³ to 0.704m³. If the initial loose-fill volume is 1.5m³, the compaction ratios vary from 2.1 to 3.9. These values fall within the range reported for household waste compactors (2–4×) in municipal design studies [8, 7].

Design Implications

The above results confirm that wall friction plays a dominant role in determining compactor performance. For design purposes:

- The hydraulic cylinder rated at 16MPa, 100mm bore, provides sufficient thrust across all compaction stages.
- Operating beyond $H = 0.8\text{m}$ offers limited gain in density and may accelerate wear on bin walls.
- Friction reduction (e.g., with liners or coatings) could improve efficiency by up to 10–15%.

These findings justify selecting 0.8m as the optimal working height and confirm the adequacy of the chosen cylinder capacity.

4.4 Compaction Ratio and Density

Compaction ratio (CR) is one of the most practical performance indicators for any waste compactor. It expresses how much the volume of the waste has been reduced for a fixed mass, directly reflecting how efficiently the available space is used.

4.4.1 Definition and Physical Meaning

For a constant waste mass m , the compaction ratio is defined as

$$CR = \frac{V_0}{V_f} = \frac{\rho_f}{\rho_0} \quad (16)$$

where V_0 and V_f are the initial and final volumes, and ρ_0 , ρ_f are the corresponding bulk densities. Since $m = \rho_0 V_0 = \rho_f V_f$, increasing compaction directly raises density without changing mass. This quantity is typically used by manufacturers to compare compactor efficiency, where a CR between 2 and 4 is considered good for mixed municipal waste [6, 7].

Example calculation

From the Janssen analysis in Section 6, the final compacted height for optimal operation is $H = 0.8\text{m}$, giving a final volume

$$V_f = AH = 0.64 \times 0.80 = 0.512\text{m}^3.$$

Assuming a target compaction ratio of $CR = 3$,

$$V_0 = CR \times V_f = 3 \times 0.512 = 1.536\text{m}^3.$$

This corresponds to the initial fill level of the bin before the compaction stroke. The attainable plate stresses from the previous section ($\sim 118\text{kPa}$ to 135kPa) are consistent with reported final densities of

$$\rho_f \approx 350\text{kg/m}^3 \text{ to } 450\text{kg/m}^3,$$

compared to loose-fill densities $\rho_0 \approx 120\text{kg/m}^3$ for unsorted household waste. Hence, the model and force calculations align well with practical compaction data.

4.4.2 Relationship Between Stress and Density

Experimental correlations for waste compaction often show that bulk density increases nonlinearly with pressure:

$$\rho_f = \rho_0 + k \ln\left(\frac{\sigma_p}{\sigma_{ref}}\right) \quad (17)$$

where k is a material-dependent compressibility constant (typically $70\text{--}100 \text{ kg/m}^3$ per log cycle), and σ_{ref} is a reference stress (10 kPa). Substituting $\sigma_p = 125\text{kPa}$ yields $\rho_f \approx 380\text{--}430\text{kg/m}^3$, confirming consistency with observed data.

This empirical relation highlights that further increases in plate pressure yield diminishing returns in density beyond $100\text{--}150 \text{ kPa}$. Thus, the chosen hydraulic system achieves near optimal compression for the expected material type.

Design Interpretation

- The predicted compaction ratio of 3:1 ensures that a bin initially holding 1.5m^3 of waste can be reduced to about 0.5m^3 , tripling effective storage capacity.
- The corresponding density range ($350\text{--}450 \text{ kg/m}^3$) matches industrial data for municipal and commercial waste compactors.
- Further pressure increase beyond 150kPa would require disproportionate cylinder force without meaningful improvement in compaction.

Therefore, the designed hydraulic system and target height provide a balanced and realistic level of compaction efficiency, suitable for both household and light commercial applications.

4.5 Structural Verification (Brief)

4.5.1 Cylinder Rod Buckling (Euler)

Critical load:

$$P_{cr} = \frac{(\pi^2 E I)}{(K L)^2}, \quad I = \frac{(\pi d_r^4)}{64}$$

Design check: $P_{cr} \geq \text{SF} \cdot F_{\text{ram}}$ with $\text{SF} = 2-3$. *Example:* $E = 210\text{GPa}$, pinned–pinned $K = 1$, free length $L = 0.9\text{m}$, rod $d_r = 40\text{mm}$:

$$I = \frac{\pi^2 \times (0.04)^4}{64} = 1.26 \times 10^{-7} \text{m}^4, \quad P_{cr} = \frac{\pi^2 \times (210 \times 10^9) \times I}{0.9^2} \approx 321 \text{ kN}$$

Since $321/125.7 \approx 2.6$, the example meets a buckling $\text{SF} \approx 2.6$.

4.5.2 Ram Plate Bending (Uniform Load)

For a clamped square plate of side, $a = 0.8\text{m}$ under uniform pressure $q = \sigma_p$, the peak bending moment per unit width may be approximated as:

$$M_{max} \approx \alpha q a^2, \quad \alpha \approx 0.047 \text{ (square, clamped)}$$

With yield stress f_y and material factor γ_m , a thickness meeting bending stress $\sigma_b \leq \frac{f_y}{\gamma_m}$ is

$$t \geq \sqrt{\frac{6 M_{max} \gamma_m}{f_y}}$$

Service deflection (clamped square) is:

$$w_{max} \approx \beta \left(\frac{q a^4}{D} \right), \quad D = \frac{E t^3}{12(1 - \nu^2)}, \quad \beta \approx 0.0013$$

with a typical limit $w_{max} \leq a/400$. Substituting $\sigma_p \in [120, 135]$ kPa gives a direct thickness estimate once f_y , E , and ν are chosen.

Design Conclusions

- Required thrust for $\sigma_p \approx 120\text{kPa}$ at $H = 0.8\text{m}$ is $\sim 119\text{kN}$.
- A 100mm bore, 16MPa ISO cylinder delivers 125.7kN, meeting the requirement with margin.

- Predicted plate stresses 118kPa to 135kPa produce practical compaction ratios (about 2:1 to 4:1) for mixed waste.
- Wall and floor pressures remain moderate and are suitable for straightforward panel and base design checks.

Table 8: Summary of Hydraulic and Structural Design Calculations

Source: (Own Work)

Parameter	Symbol	Formula	Result	Unit	Note
Hydraulic pressure	P	–	16	MPa	Rated system pressure (160 bar)
Cylinder bore	D	–	100	mm	Selected ISO cylinder bore
Compaction force	$F = P \cdot A$	$16 \times 10^6 \times \pi (0.05)^2$	125.7×10^3 (≈ 126)	kN	Force from 100 mm bore at 16 MPa
Plate area	A	$w^2 = 0.8^2$	0.64	m ²	Based on bin geometry
Mean pressure on waste	$\sigma = F/A$	125,700 / 0.64	0.196	MPa (≈ 196 kPa)	Matches Janssen model range
Motor power	$P_m = (Q \cdot P) / (\eta)$	$(16 \times 10^6 \times 4.2 \times 10^{-4}) / 0.85$	7.9	kW	Hydraulic drive, 25 L/min flow
Cylinder rod buckling SF	$SF = P_{cr} / P_{work}$	321 / 125.7	≈ 2.6	–	Safe against buckling

4.6 Structural Integrity and Safety

The structural integrity of the underground waste compactor was evaluated through analytical verification of its key load-bearing components: the reinforced concrete pit, the steel container, and the hydraulic actuator. The goal was to ensure that each part could safely withstand the design compaction force of **125.7 kN** produced by the hydraulic cylinder without deformation or failure.

The **reinforced concrete pit (C30/37)** was assessed for lateral earth pressure and self-weight. The maximum tensile stress on the inner wall was about **2.5 MPa**, which is below the allowable tensile strength of reinforced concrete. With **Ø12 mm reinforcement at 200 mm spacing**, the calculated safety factor against cracking is greater than three, providing adequate resistance to cyclic loads and temperature changes.

The **galvanized S355 steel container** was analyzed under the same compaction force. At this load, the plate pressure on the waste surface is approximately **0.13 MPa (130 kPa)**, and the corresponding wall stress remains **below 100 MPa**, well within the yield strength of S355 steel (**355 MPa**).

Deflection analysis indicates only a few millimeters of wall displacement, which is acceptable for the required service conditions.

For the **hydraulic actuator**, an Euler buckling check of the piston rod gave a critical load of approximately **321 kN**, compared to the working load of **125.7 kN**, resulting in a **safety factor of approximately 2.6**. This ensures that the actuator remains structurally stable during compaction.

Overall, the analytical verification confirms that the system's main components operate safely within allowable stress limits and that no structural instability or failure is expected under the rated hydraulic loading.

4.7 Sensor System and Operational Results

The integration of sensors in the underground compactor enhances both operational reliability and data-driven management, focusing on efficiency, safety, and decision-making rather than programming specifics.

The **fill-level sensing system** continuously monitors each compartment and alerts when waste reaches about **85% of capacity**. This threshold can be adjusted based on waste type or collection schedules. Simulations show that knowing the average waste generation rate allows accurate prediction of alert frequency, ensuring collection happens just before the container is full, preventing overflow and maintaining uninterrupted operation. While ultrasonic sensors may

occasionally misread levels due to irregular waste surfaces or debris reflections, using **dual-beam sensors** and signal filtering algorithms reduces errors to within $\pm 5\%$, sufficient for practical use since only near-full detection is needed. A key operational benefit is collection route optimization. When multiple smart bins are networked, the system enables waste management teams to dispatch trucks only to bins that need service, potentially reducing driving distances by **up to 30% by eliminating** unnecessary visits to empty bins.

The optional **temperature sensor** adds a critical safety feature. In simulations, it successfully triggered an alert at around **70°C** in response to an internal heat source, allowing timely intervention to prevent potential fires. This is particularly important in Mongolia, **where hot coal ash disposal in winter** can cause bin fires. Additionally, the system supports predictive maintenance and data analytics by tracking fill-level trends over time. This data can reveal seasonal or weekly waste generation patterns, helping city managers optimize bin placement, adjust collection schedules, and allocate resources more efficiently.

Overall, the integrated sensor system offers practical benefits for real-time monitoring, safety enhancement, and operational optimization, contributing to smarter and more sustainable urban waste management.

Chapter 5 : Conclusions and Proposals

This thesis focuses on the design and engineering analysis of an **underground waste container equipped with an integrated hydraulic compactor**, specifically tailored to Mongolia's environmental and climatic conditions. The study incorporates mechanical design, analytical calculations, and the integration of smart monitoring technology. The primary goal is to develop a system that enhances waste-handling capacity, reduces collection frequency, and contributes to improved urban sanitation.

5.1 Main Findings

Capacity and Efficiency: The system significantly improves waste storage efficiency. A single underground container, measuring approximately 1.16 m^3 ($0.8 \times 0.8 \times 1.81 \text{ m}$), is divided into two sections for general and recyclable waste. When compacted, it can hold the equivalent of about 3.5 m^3 of loose waste. This allows collection frequency to be reduced by nearly half, cutting down on transport fuel use, operational costs, and CO_2 emissions. For Ulaanbaatar, this efficiency is crucial for managing increasing waste volumes without needing additional trucks or manpower.

Mechanical Feasibility: The system's structural integrity has been analytically verified. A **hydraulic cylinder with a 100 mm bore operating at 16 MPa** generates about **125 kN** of compaction force, enabling a three-fold reduction in waste volume. The resulting plate pressure of **0.13 MPa** is well within safe limits for both the steel container and the waste. Structural stresses and safety factors exceed the required thresholds, ensuring stability and strength. Materials like galvanized S355 steel and C30/37 reinforced concrete were chosen for their durability in Mongolia's extreme climate (ranging from -30°C to $+30^\circ\text{C}$) and resistance to corrosion.

Sanitation and Environmental Impact: The sealed underground container enhances hygiene at collection sites by isolating waste from air and animals, reducing odors, litter, and pests. The cooler underground temperatures slow waste decomposition. **Separate bins** for recyclables and general waste support waste segregation efforts and align with Mongolia's goal of recycling over 20% of waste. Fewer truck trips also lower fuel consumption, noise, and air pollution, contributing to a cleaner and healthier urban environment.

Smart Technology and Data Benefits: **Ultrasonic fill-level and temperature sensors** enable near-real-time monitoring. Alerts are triggered when the fill level reaches about **85%**, ensuring timely collection and preventing overflow. When deployed citywide, smart bins can optimize collection routes, reducing driving distances by **20–30%** and saving fuel and labor. Temperature sensors provide early fire warnings, especially important in winter when hot ash is often

discarded. Over time, the collected data can reveal usage patterns, helping to improve waste-management planning.

5.2 Proposals and Recommendations

Pilot Implementation: A single full-scale prototype will be constructed and installed in a high-traffic area, such as an apartment complex or market. Its performance, compaction efficiency, and durability will be closely monitored throughout all seasons to assess its effectiveness.

Economic Assessment: A life-cycle cost analysis will compare this system to traditional open dumpsters. While the initial investment may be higher, the expected operational savings and improved sanitation are projected to offset the costs within a few years.

Community Awareness: Residents will be educated on how to use the two-bin system for separating recyclable and general waste. The system's smart monitoring features will also be highlighted to build trust and encourage active participation.

Maintenance Planning: A preventive maintenance schedule will be established, focusing on regular hydraulic checks, lubrication, and sensor battery replacements to ensure the system's reliability. Maintenance crews will receive proper training to handle these tasks.

Localization and Scalability: If the pilot is successful, future units will be manufactured locally according to the provided specifications, reducing costs and supporting domestic manufacturing. The system's design can be adapted to suit the specific needs of different districts.

Future Development: The system could later incorporate advanced features such as weight sensors, digital ID systems for "pay-as-you-throw" programs, and AI-based route optimization. With an open data architecture, it will be ready for integration into future smart-city networks.

5.3 Final Conclusion

This project demonstrates that an underground waste compactor system, specifically designed for Mongolia's climate and urban challenges, is both **technically** viable and highly **practical**. Engineering analysis confirmed that the system can safely compress municipal waste to about **one-third of its original volume** using a hydraulic cylinder that generates approximately **125 kN of force at 16 MPa**. Structural checks showed that both the steel container and the reinforced concrete pit can handle these loads with a comfortable safety margin, even in extreme winter conditions. In addition to its mechanical efficiency, the system offers significant environmental and operational advantages. By reducing waste volume, it minimizes collection trips, fuel consumption, and CO₂ emissions. Smart sensors, such as fill-level and temperature monitors,

enhance efficiency by enabling real-time tracking and optimizing collection schedules. For Ulaanbaatar, adopting this underground compactor system would represent a major step toward modern, efficient waste management. It supports the city's sustainability goals by improving **sanitation, reducing landfill pressure, and creating cleaner, more hygienic public spaces.** This work highlights how engineering innovation can enhance urban life. By combining mechanical design with environmental responsibility, it shows that even in extreme climates like Mongolia's, well-adapted technologies can drive meaningful change. The project provides a foundation for future advancements, such as solar-powered systems, advanced corrosion protection, and fully automated smart waste networks, showcasing how thoughtful engineering can promote sustainable urban progress.

Summary

This thesis explores the design and analysis of an advanced underground waste compactor tailored to the harsh climate and operational challenges of Ulaanbaatar, Mongolia. The system was developed to tackle the city's waste management issues, such as limited collection capacity, unsanitary open bins, high transport costs, and the poor adaptability of imported technologies to sub-zero temperatures. The proposed solution combines mechanical engineering, hydraulic systems, and smart monitoring technologies to create an efficient and sustainable waste management system. Key components include a reinforced concrete pit, a galvanized steel waste container, and a hydraulic compaction mechanism. Using analytical calculations, the hydraulic cylinder was sized to deliver approximately 125 kN of force at 16 MPa, achieving a compaction pressure of 0.2 MPa—ideal for municipal solid waste. Material selection was guided by a weighted decision matrix, evaluating options like galvanized S355 steel, stainless steel, HDPE, and GFRP composites. Galvanized steel was chosen for its strength, low-temperature durability, corrosion resistance, and cost-effectiveness. Structural analysis confirmed that both the steel container and concrete pit can withstand full loads safely, ensuring reliability and a long service life. The system incorporates smart sensors, such as ultrasonic fill-level detectors and temperature sensors, enabling real-time monitoring and more efficient waste collection. By reducing unnecessary truck trips, the design cuts fuel consumption and CO₂ emissions. With a threefold reduction in waste volume per cycle, collection frequency can be halved, significantly improving operational efficiency. Beyond technical efficiency, the system offers social and environmental benefits. It supports cleaner streets, better public hygiene, and a more modern urban image while contributing to Mongolia's waste segregation and sustainability goals. In conclusion, the research demonstrates that a hydraulic underground waste compactor is a practical, environmentally

friendly, and cost-effective solution for Ulaanbaatar. It provides a scalable model for other Mongolian cities and paves the way for innovations like solar-powered systems, advanced anti-corrosion coatings, and IoT-based waste management networks. This project highlights how localized engineering can integrate modern technology with Mongolia's unique needs, offering a sustainable approach to urban infrastructure development.

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MATE Organizational and Operational Regulations

III. Requirements for Students

III.1. Study and Examination Regulations

Appendix 6.13: The MATE Uniform Thesis /thesis / final thesis / portfolio guidelines

Annex 4.2: Declaration of public access and authenticity of the thesis/thesis/dissertation/portfolio

DECLARATION

the public access and authenticity of the thesis/dissertation/portfolio¹

Student's name: Tengis Nyamjav
Student's Neptun code: GTTSXV
Title of thesis: Advancement of Underground Waste Management System in Mongolia
Year of publication: 2025
Name of the consultant's institute: Institute of technology
Name of consultant's department: Department of machine construction

I declare that the final thesis/thesis/dissertation/portfolio² submitted by me is an individual, original work of my own intellectual creation. I have clearly indicated the parts of my thesis or dissertation which I have taken from other authors' work and have included them in the bibliography. Furthermore, I declare that the artificial intelligence tools (e.g. text generation, linguistic correction, translation, data analysis) used during the preparation of the thesis did not substitute my own research and creative work; their use was indicated either in the list of sources or in the methodology section, and I acted in accordance with professional and ethical expectations.

If the above statement is untrue, I understand that I will be disqualified from the final examination by the final examination board and that I will have to take the final examination after writing a new thesis.

I do not allow editing of the submitted thesis, but I allow the viewing and printing, which is a PDF document.

I acknowledge that the use and exploitation of my thesis as an intellectual work is governed by the intellectual property management regulations of the Hungarian University of Agricultural and Life Sciences.

I acknowledge that the electronic version of my thesis will be uploaded to the library repository of the Hungarian University of Agricultural and Life Sciences. I acknowledge that the defended and

- not confidential thesis after the defence
- confidential thesis 5 years after the submission

will be available publicly and can be searched in the repository system of the University.

Date: 2025 year 10 month 30 day

Tengis Nyamjav

Student's signature

¹ While keeping the appropriate thesis type, all other types are to be removed.

² While keeping the appropriate thesis type, all other types are to be removed.0

DECLARATION

Tengis Nyamjav (name) (student Neptun code: GTTSXV)

as a consultant, I declare that I have reviewed the final thesis/thesis/dissertation/portfolio¹ and that I have informed the student of the requirements, legal and ethical rules for the correct handling of literary sources.

I recommend / do not recommend² the final thesis / dissertation / portfolio to be defended in the final examination.

The thesis contains a state or official secret: yes no^{*3}

Date: 2025 year 10 month 28 day



insider consultant

¹ The other types should be deleted while retaining the corresponding thesis type.

² The appropriate one should be underlined.

³ The appropriate one should be underlined.

Declaration of Students and Doctoral Candidates on the Use of Artificial Intelligence (AI)"

1. general information:

Name of the student:	Tengis Nyamjav
Neptun ID:	GTTSXV
Level of program (mark with X):	☒ BSc/BA ☐ MSc/MA ☐ Doctoral School (PhD) ☐ Other:
Name and code of the subject*:	Thesis Work 2 ; MUS2K340N
Title of the work:	thunder ground bin with compressor in Mongolia

* Not required to be completed in the case of a doctoral dissertation.

2. Declaration on the Use of AI

I, the undersigned, fully aware of my ethical responsibility, make the following declaration:

(Please choose one of the options below!)

☐ A) I have not used any artificial intelligence system or service.

(If you selected this option, completing the subsequent tables is not required.)

☒ B) I have used an artificial intelligence system or service.

(Please fill in the relevant tables!)

3. Details of Artificial Intelligence Usage

TABLE I: Assistant or Minor Usage (e.g., translation, language proofreading, brainstorming, etc.)

(For these uses, attaching the specific prompts and responses is not required.)

Purpose of Use	Name and Version of the AI Tool Used	Affected Section (if not applicable to the entire text)
Brainstorming, translation	Chat GPT	Methodology

TABLE II: Significant Content Contribution (e.g., generating an entire figure or a longer text section)

(In these cases, documenting the key prompts used and the raw responses provided by the AI, and attaching them as an appendix to the work, is required.)

Purpose of Use	Name, Version, and Access Information of the AI Tool Used	Exact Number of the Affected Chapter / Figure / Table	Entry Number of the Appendix Containing the Prompt Log

3/A. Additional Rules Prescribed by the Lecturer (if any)

If the instructor or supervisor of the course has established specific rules or expectations regarding the use of AI tools, please summarize them in the field below:

For example: prohibition of AI use for certain types of tasks; only specific tools are permitted; different citation requirements; documentation format, etc.

Rules Prescribed by the Lecturer or Supervisor

.....

.....

.....

.....

4. Declaration Applicable to All Students:

I declare that I have critically reviewed, edited, and incorporated any content potentially generated by AI in all cases. I take full responsibility for every element of the submitted work, including its originality and scientific validity. I acknowledge that the Hungarian University of Agriculture and Life Sciences may check the submitted work with an artificial intelligence detector and may initiate proceedings if my declaration is found to be false or incomplete.

Place and Date: Budapest, Hungary, 2025. 10 month 30 day

Tuzsanyi

Signature of the Student

András Kovács

Signature of the Advisor/Supervisor