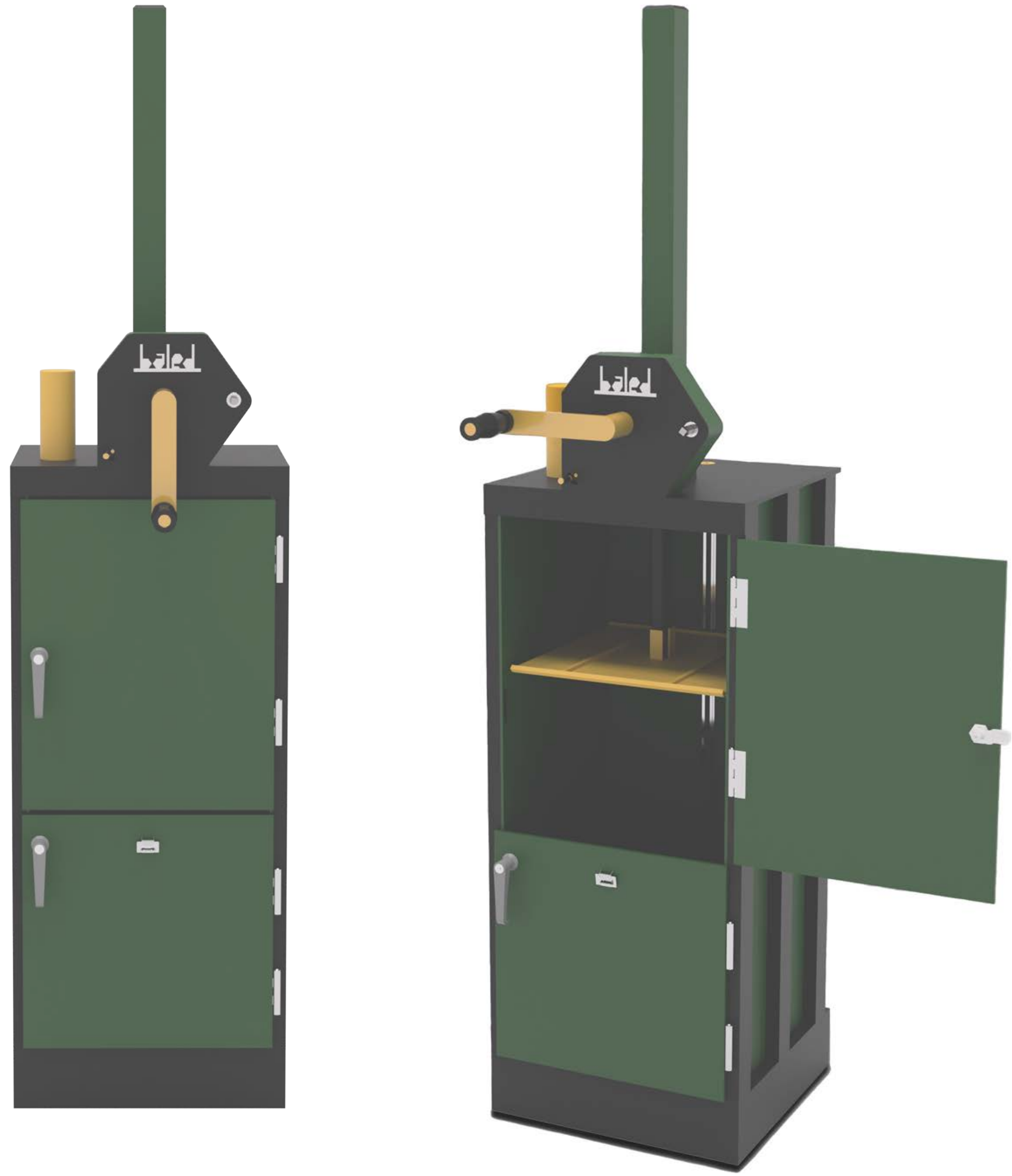
baled

SORT, COLLECT, COMPACT



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MEng Product Design Engineering

PROJECT SUMMARY

University of Glasgow

THE GLASGOW SCHOOL OF ART

SEPTEMBER 2022 – APRIL 2023

ACKNOWLEDGEMENTS

Jonathon Barnes for GSA tutorials and advice, ensuring that my project was smoothly steered towards success. Often, it is easy to get absorbed in one's project and the ability to step back and talk things through with a tutor was helpful. Ideas generation and concept development would not have been the same without Jon's support. Also, thanks to Nick Bell alongside other GSA tutors including Hugh Pizey, Ben Craven and visiting professor David Richards for occasional meetings which offered additional support and advice over and above the fortnightly tutorial sessions.

Dr Donald Ballance for regular meetings, advice and invaluable support throughout the project. Fortnightly meetings were a significant time commitment and it is greatly appreciated that he took the time to support me from concept development, to engineering calculations and final refinements of the design. One of the strongest assets of the PDE degree is the combination of support between engineering staff at UofG and design staff at GSA. Having a committed, helpful advisor at GU drove the project forwards during both semesters.

With thanks to both the James Watt School of Engineering and the GU68 Engineers Trust for supporting me with funding for prototyping, ensuring that there was financial support to enable concepts to be tested in depth. It would not have been possible to fabricate a prototype without vital support and advice from the GSA workshop technicians, particularly Giulia Lazzaro who helped hugely with the final steel prototype.

There are also many people to thank for taking the time to meet during the project and proffer key insights which drove forward the design. Adam Herriott – films & flexibles sector specialist at WRAP for meeting and giving key insights to drive the project forward. Also thanks to Jon Molyneux – Scottish Greens Councillor, Nicole Morarescu – Sustainability Officer at Primark, and Molly Finlay – BBC Young Reporter for online meetings to discuss my concept during the first semester. The 2050 Climate Group's "Pint & A Plan" event was a great opportunity to chat about the topic including an in-depth discussion with Gemma Elliott, recycling officer for East Renfrewshire Council. In second semester, thanks are owed to Frazer Morton from Mil-tek balers Glasgow for an explanation of their products and tour of their baler during "ScotHot 2023" at the SEC. Further thanks go to Henning von Spreckelsen and Darren Northcott for offering and arranging a tour of their "Plastecowood" factory in North Wales. Seeing a potential end destination and recycling process for films and flexibles once baled was useful in validating the need for my concept.

Finally, thanks to the many friends, family and coursemates who have supported me throughout the year. Offering insights, advice and ideas to help me on my way to success has been instrumental. The demanding nature of the MEng final year project would not be possible without an extensive support network during tough times.

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GU68 ENGINEERS TRUST

Mil-tek Minimize your waste

2050

wrap

SCOTTISH GREENS

PLASTECO WOOD Smartawood Endurance Plastic Products

PRIMARK

PROBLEM OVERVIEW - KEY INSIGHTS & LEARNING

What is the big deal with recycling?

In SEPA's 2021 data, Scotland's total recycling rate was **42%**, and in Glasgow the total recycling rate was **27.3%**. Resource efficiency is a major objective for moving to a circular economy. Plastics are contentious. In Glasgow's municipal recycling, pots, tubs, trays & flexible plastics go straight to landfill. The only plastics recycled from Glasgow's blue bins are bottles.

Why are soft plastics the project focus?

Soft plastics, or as industry calls them, *"films & flexibles"*, are an interesting material. They are thin and flexible in nature, therefore they are some of the most resource efficient packaging materials we have, which is why they are widely used. Efficient means low energy, which means cheap - which is great for businesses.

Energy efficiency and low emissions are good, so what is the big problem with flexibles?

They are a complex mixture of polymer types, making them tough to recycle. The UK consumes 300,000 tonnes of consumer films & flexible plastics every year. In 2019, just **7%** was collected for recycling. This is partly due to lack of investment in infrastructure, but also because they are a complex, low value material.

Why are recycling rates of films & flexibles so poor in the UK specifically?

The issue is largely due to policy. The UK is the only major European consumer of flexible plastics without local authority collection infrastructure. The current objective is potentially to introduce this in 2027. Until councils and governments start making moves we have to rely on consumers and industry to drive investment.

If they are tricky to deal with, why not stop using flexible plastics? Why not switch to cardboard, metal, rigid plastic or bioplastics for packaging?

Soft plastics have a much lower carbon footprint than other packaging materials. A paper carrier bag has triple the carbon emissions of a plastic one. Plastics are a waste circularity issue. Demonising them will only create new problems in other sectors. A circular economy requires resource efficiency, and plastics are efficient. Reducing plastic consumption can be helpful, however in many applications they are still vital and practical solutions are needed to drive genuine recycling and deal with the waste volume.

Why not reduce packaging in general?

The concept of zero waste shops is a good one. Locally sourced food has no need for packaging. However, a globalised food chain needs a hygienic way of keeping things fresh. Avocados do not get from South America to Sauchiehall Street alone. Sending just 1kg of food waste to landfill produces the same carbon emissions as 25,000 plastic bottles. In Scotland, we waste nearly 1000,000 tonnes of food annually which has a much bigger carbon footprint than the plastic it is packed in. Soft plastic is a vital ally in the fight against food waste.

Municipal collection of flexibles will not happen until at least 2027. So how do we recycle it?

Currently, the supermarket industry has rallied against flexible plastic waste through the roll-out of over 6000 collection points in UK supermarkets. Behavioural shift is needed to encourage consumers to collect their plastics and bring them into shops. Increased commercial collection is driving investment in recycling infrastructure through the private sector.

Supermarket collection points are helping, but ultimately are a PR stunt. Why is there no financial incentive in recycling soft plastics?

The key issue is that the material has limited value. A tonne of soft plastics could be worth £500 at best. That makes a kilo worth 50p, which makes a crisp packet worthless. To make a profit a large quantity is needed, and they are not volume efficient.

Why is volume efficiency of waste important?

An articulated lorry of paper might hold 30 tonnes. That same lorry of plastic would be around 16 tonnes. More volume means more space, more fuel and more cost. This contributes to the lack of cost effectiveness in soft plastics recycling. Large scale materials recycling facilities use hydraulic and pneumatic balers to compact materials. Compacting waste is a common solution in industrial settings.

How does compacting at scale translate to small businesses?

Businesses pay for their waste per bin load, not per kg so a heavier bin does not cost more but multiple bin loads will. Compacting waste saves money. The smallest existing commercial balers are pneumatic. They are bulky and require an air compressor. They also cost several thousand pounds, and the compression ratio is so high that the compacted bale might way up to 100kg. Consequently, lifting equipment is needed. These drawbacks can restrict their usefulness in small business environments.

Introducing ***"BALED"***, a cheap manual baling solution.

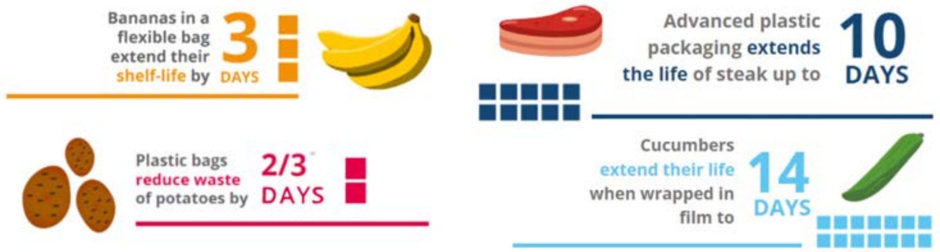
KEY INSIGHTS

Adam Herriott:
- sector specialist on films & flexibles at WRAP

"100% being able to bale them up onsite would be brilliant. Films and flexibles are very, very light which means they are expensive to transport because they take up a lot of space."

User Engagement Survey:
Over 50% of respondents did not know exactly what a soft plastic is, and over 50% did not know that they could be taken to a local supermarket to be recycled.

Market Need for Plastics:
Issues surrounding food waste warrant more attention:



Source: British Plastics Federation (BPF) food waste statistics

Financial incentive
Commercial waste is charged per bin i.e. volume, not by weight. Hence, compacting will always save money.

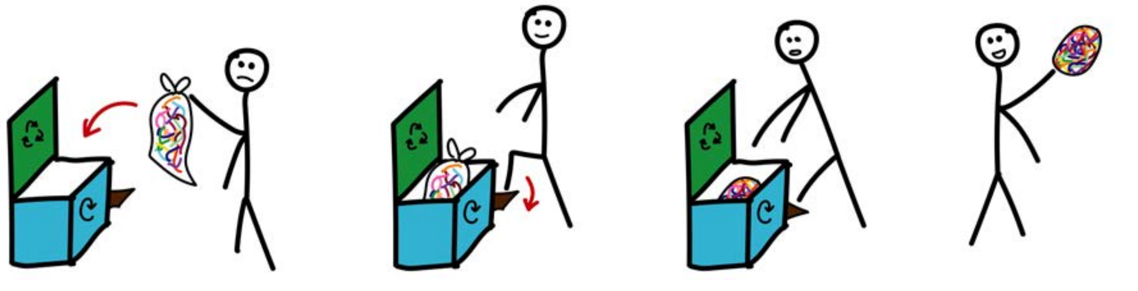
Potential End Markets:
Visit to "Plastecowood" in North Wales established a clear end market for post-consumer flexible plastic waste. They are growing fast, and can easily recycle any soft plastic into a carbon negative wood alternative:

INITIAL RESEARCH & CONCEPTS

Existing Market Research - Mil-tek balers
Meeting Frazer Morton from Mil-tek balers gave useful market insights. Hydraulic & pneumatic balers are useful for many businesses. A major issue is that they are bulky, expensive and have a very high compacting ratio such that bales can weigh up to 100kg. This product is less suited to small businesses and stores.

Shop Visits
Research conducted in central Glasgow found many supermarket soft plastic collection points. Clearly, management of these recycling points is difficult. Scenes like this full trolley spilling over are common. Big stores have hydraulic balers but there is no product for small shops.

Initial proposed user cycle:



Sketch of proposal in context of user environment:

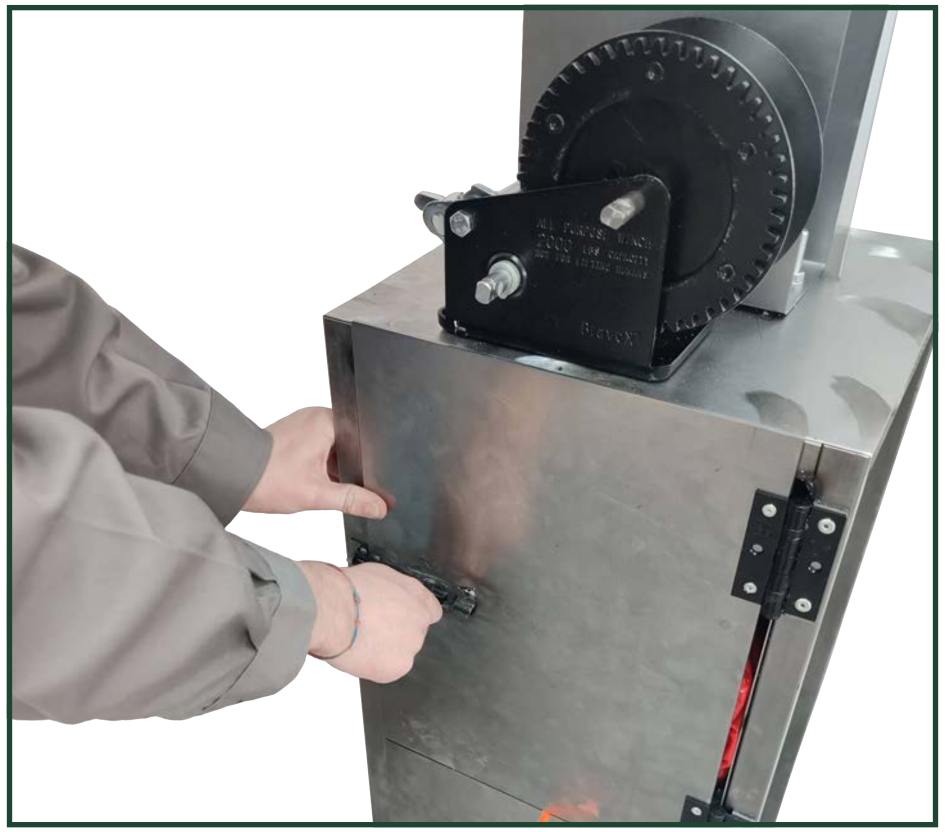
Specified User Group:
- Floor staff at small businesses
- Age 18-64
- Any gender
- Good strength / dexterity
- Basic training in manual handling
- Any height (smallest user is 5th percentile British female & largest is 95th percentile British male)

Key User Cycle Requirements:
- Quick to compact waste
- Safe level of force needed from user (standard pushing / pulling force)
- Quick to raise compression plate back up after baling completed
- Easy to open / close / lock doors
- Easy to constrain bale quickly
- Safe body position during use
- No risk of toppling / injury

USER CYCLE

1. Insert bagged soft plastics into baler

2. Close door & attach crank handle



3. Crank down to compact plastic (45secs)

4. Tie banding with plate down

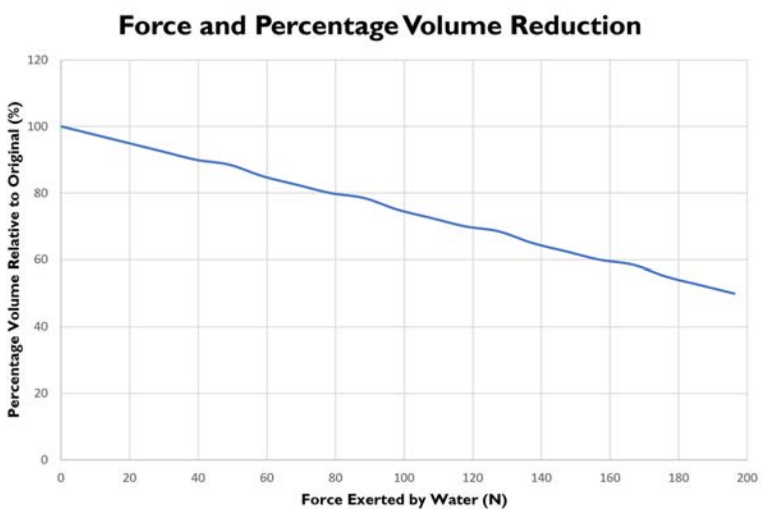
5. Crank up to raise plate (10secs)

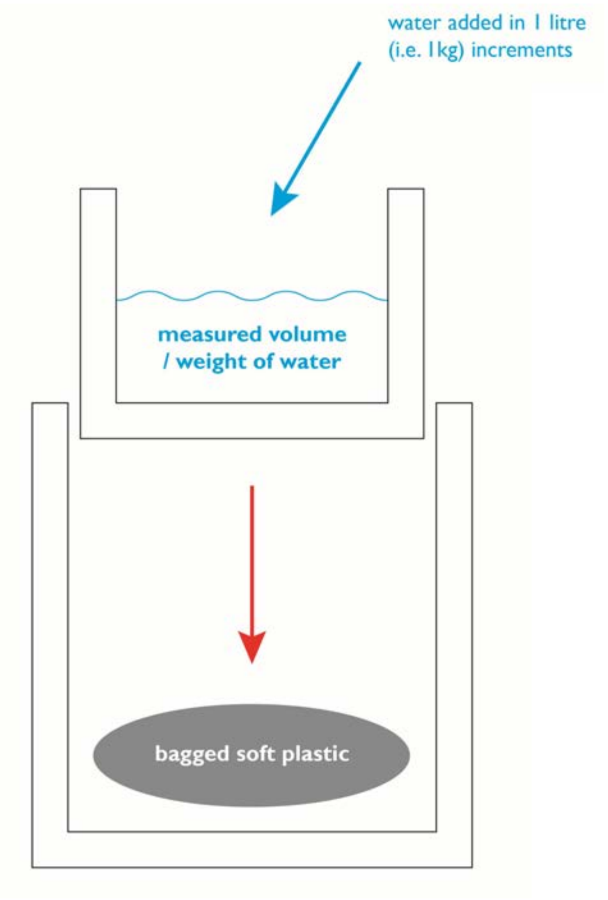
6. Lift plate and remove bale for recycling

COMPACTING MECHANISM

Initial Force Testing

An initial compression test, using 1 litre increments of water, established that 1kg of plastic needed 200N of force to be compacted by 50%. The force increases linearly, and hence a minimum of 3kN of force is needed to compact 15kg of plastic.





Compaction Mechanisms Explored

The key insight from the initial experiments was the need for mechanical advantage. The next task was to select the most appropriate mechanism. Key exploration:

1. Lever arm compression
2. Hydraulics & pneumatics
3. Corkscrew
4. Linear ratchet
5. Gearing

The mechanisms were explored through investigation, existing product research, sketching, CAD modelling and prototyping including 3D printing & workshop sessions.

Final Decision - Gearing

Gears were selected through both technical and user considerations. The ability to magnify torque to significant forces, via gear ratios, is useful for gaining mechanical advantage. For the user, a circular motion is more comfortable than a downward press. The ability to connect to different gears also enables multiple speed and torque options on a single configuration. This is achieved by connecting the crank handle to different gear shafts.

CONSTRAINT MECHANISM

Constraining Mechanisms Explored

Another insight from initial experimentation was that although the material compacts fairly easily, it quickly returns to its original size and shape once the compression force is removed. It is thus necessary to constrain the plastic after baling. Key exploration:

1. Rigid valve vacuum bags
2. Soft valve vacuum bags
3. Heat sealing
4. Shrink wrapping
5. Baler banding

The options were investigated initially by research of the potential mechanisms. In addition, experiments were performed on vacuum bagging and heat sealing using purchased equipment.

Key Issues: Vacuum Bag

Expensive - the technology is in a disposable component, and vacuum bags are much more expensive than regular bin bags.

Key Issues: Heat Sealing

User Issues - although the melted seals are reasonably strong, if the baled bag gets any holes during transportation then it will be rendered unconstrained again.

Key Issues: Shrink Wrapping

Bulky - system needs full external access to the bale which is a problem. Shrink wrap machines are typically very large and expensive.

Final Decision - Banding

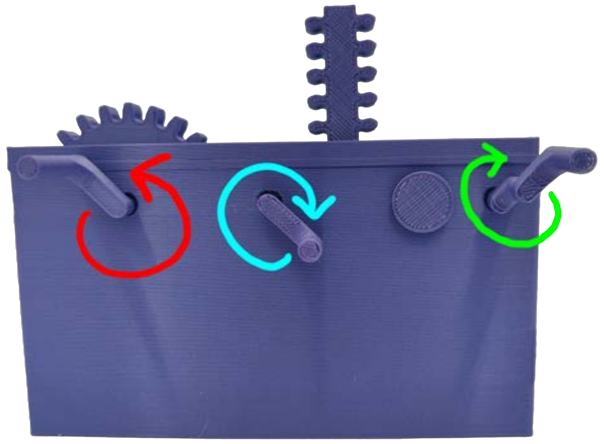
Baler banding is cheap, effective and is used as the industry standard for good reason. Other containment mechanisms explored posed cost, expense and user interaction issues. Banding is strong, durable, and costs around 4 pence per metre. The disposable aspect of the product is cheap and hence does not introduce a significant operating expense. Banding is unlikely to break during transportation and can be wrapped several times to ensure a tight seal.

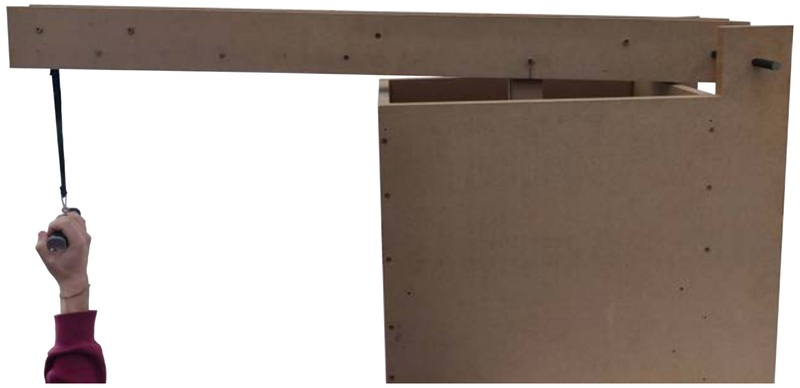
Source: Mil-tek & QCR baler banding images

INITIAL PROTOTYPING

Lever Compression Testing
To establish how compacting forces decrease with distance away from a pivot point, an MDF box was made and tested with a 1kg sample of flexible plastics. However, the lever was incapable of the desired forces without being impractically long.

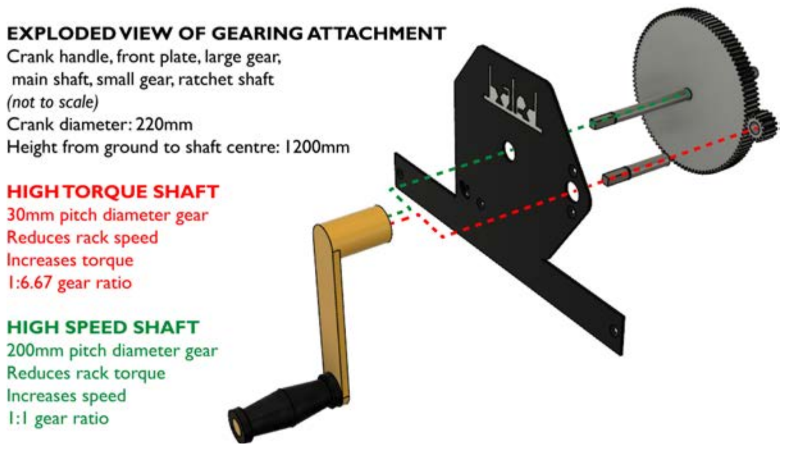
Hydraulic Bottle Jack Testing
The MDF prototype was also used to test compaction using hydraulics. This was an effective technology but the expense and awkward user cycle made it unsuitable for this project.





Gear Testing
Several miniature prototypes were generated to test the mechanism of gearing, including 3D prints and a workshop prototype using purchased gears. Fundamentally, having a small gear on the crank handle connected to a larger gear on the rack will reduce speed yet increase the torque and forces on a compacting plate.

USER TESTING

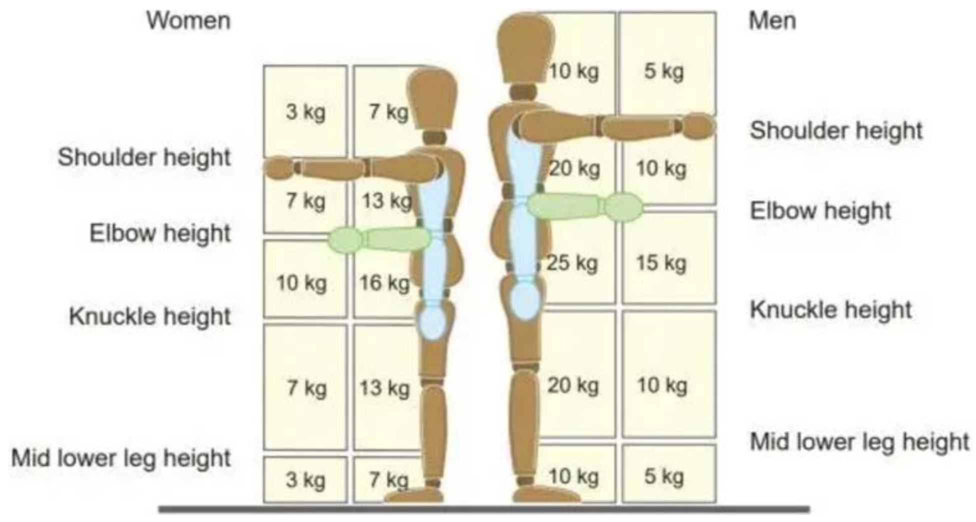


EASE AND SPEED OF USE

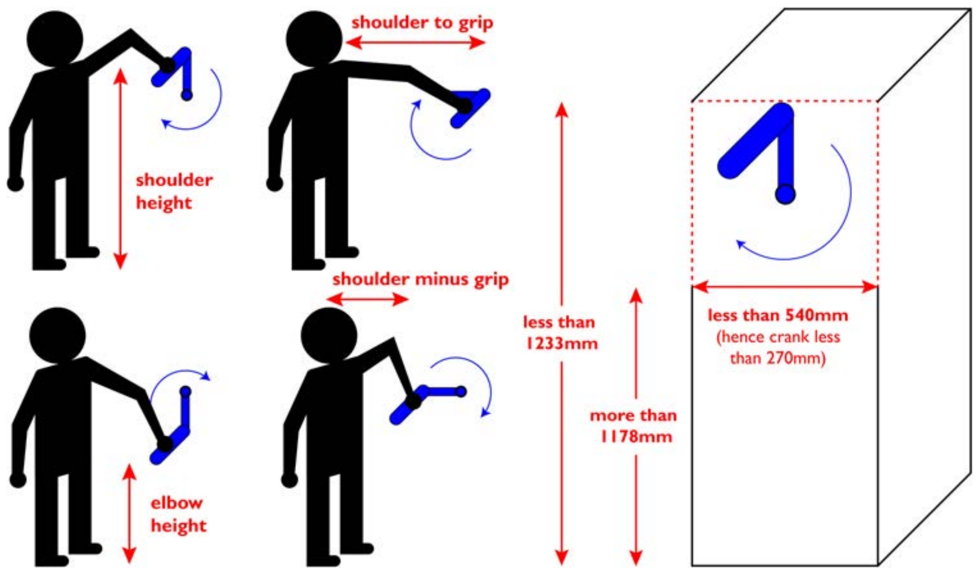
A key reason for the choice of the gear mechanism is the opportunity for two speeds. The crank can be attached to the high torque shaft for lowering in 42 rotations or the high speed shaft for raising in 6 rotations. Assuming one second per crank rotation, this gives a user cycle of less than 45 seconds for compacting and less than 10 seconds for raising the plate back to the top position. The full user journey compacting down and raising the plate back up takes less than a minute.

BALE WEIGHT

Small businesses may not have access to lifting equipment such as forklifts or pallets. Therefore, the bale weight must be low enough that it can be safely carried by hand (25kg for a male and 16kg for a female). A 300mm cube was selected because a 100% compacted bale would be 24kg *(density of pure LDPE is ~900kg/m³)*, and it is likely that compaction rates will be no higher than 65%, thus it will be safe to carry. This design also fits exactly 48 bales onto a Euro pallet for shipping.



Source: Health & Safety Executive (HSE) safe lifting guidelines



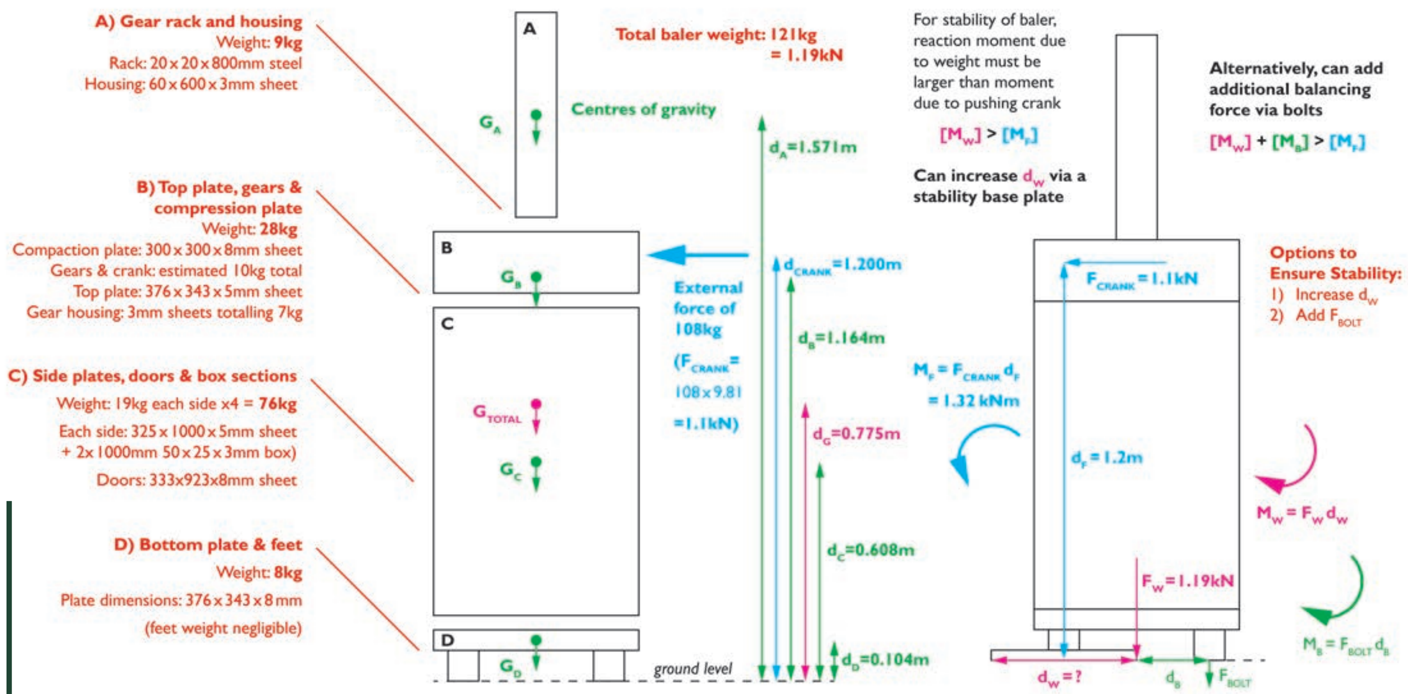
ANTHROPOMETRICS

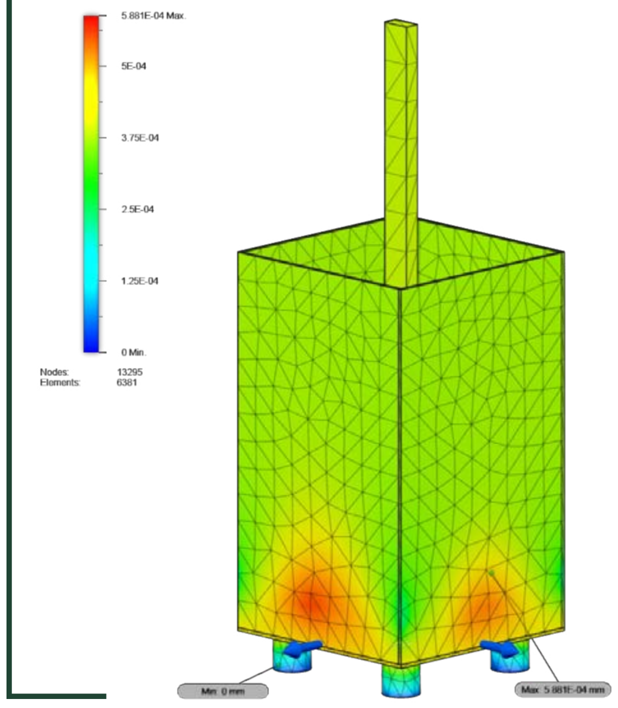
The crank handle diameter, grip width and height of rotation point have been designed to ensure they are safe and comfortable from the smallest use *(5th percentile British female age 18-64)* to the largest user *(95th percentile British male age 18-64)*. The results of this determined that the rotation point for the crank should be 1.2m from the ground, and the crank diameter was selected to be 220mm. These results were verified through user testing with a cardboard prototype

TECHNICAL CONTENT

STABILITY OF BALER

The moment generated by the heaviest user (95th percentile male) was assumed as the potential topple risk. The centre of gravity was calculated, and the moment due to the baler weight must be larger than the moment due to tipping to ensure stability. Hence, two options are proposed to ensure the baler will not tip. One is a stability base plate to reduce the impact of the moment, and the other is bolting the device to the floor to introduce a resistive force.



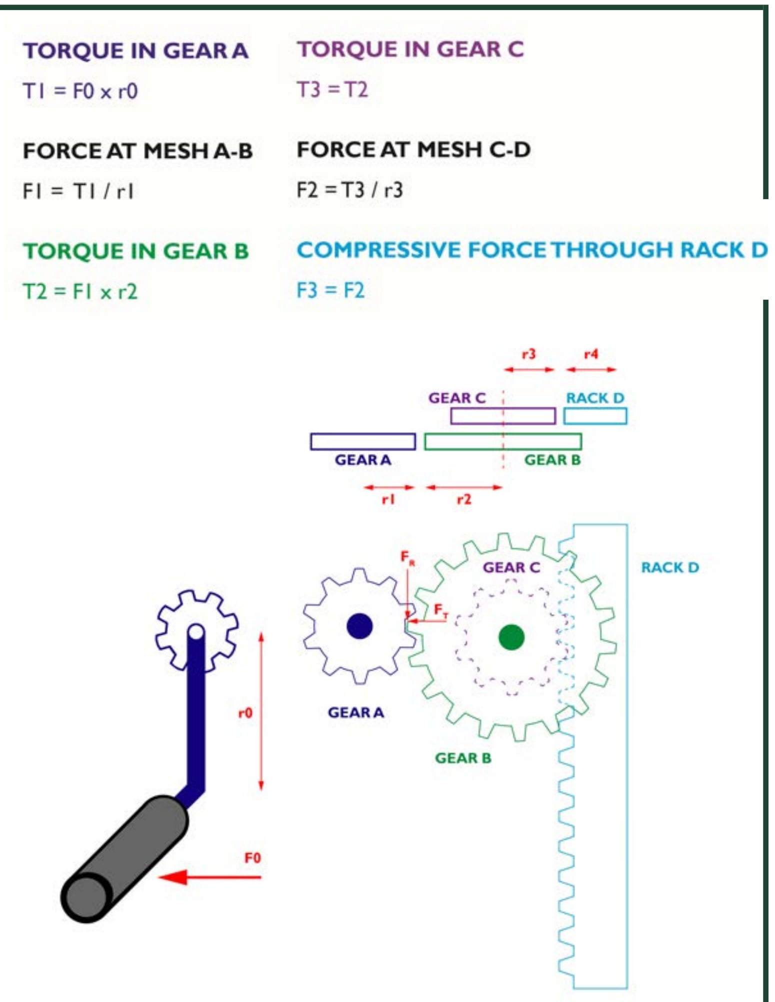


WALL THICKNESS OF BALER

A finite element analysis of stresses and deformations in the baler under a loading force of 10kN was undertaken. Based on this, a wall thickness for the main body of 5mm was chosen with an additional nine 25x50x3mm box sections to support against deformation. The doors are not supported by box section, so a thicker 8mm steel was selected. The non load bearing structures such as the gear housing is constructed from a thinner 3mm sheet in order to save on weight and material costs. Most of the main frame is welded together.

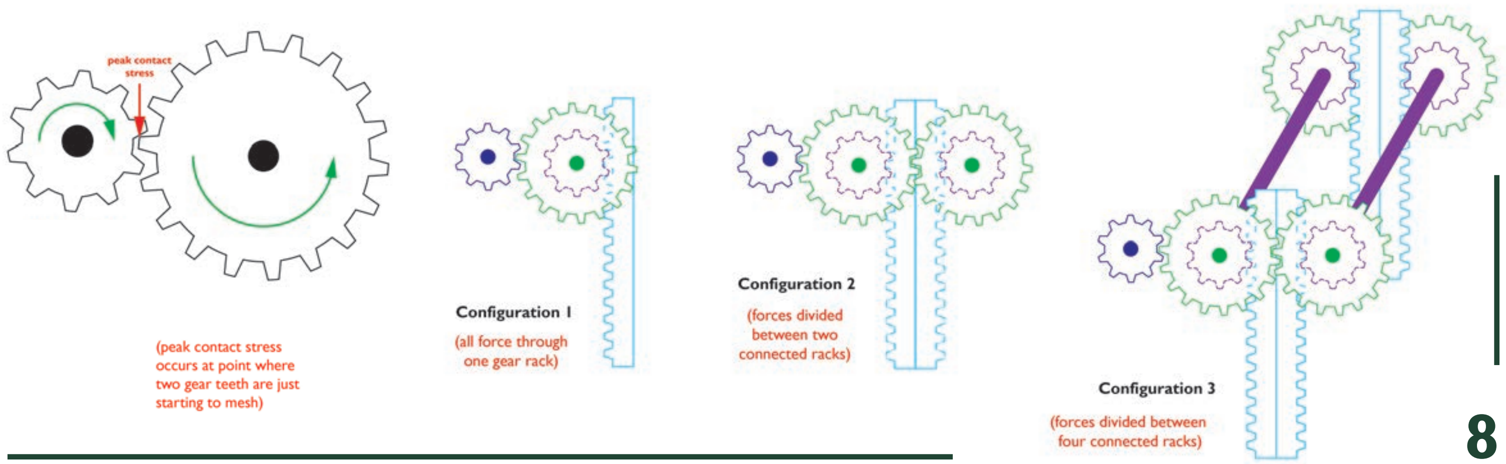
TORQUE INCREASE & GEAR RATIO

Experimentation was undertaken to measure the required force to compact 1kg of mixed soft plastics, and hence estimate the forces required to compact 15kg of material. It was estimated that a human can apply around 50N of force to the crank. Then, to scale that force up to the desired 5kN, a gear shaft configuration was designed that increases the torque using gearing ratios. The final selected gears were 30mm pitch diameter for the small gears and 200mm pitch diameter for the large gear. This achieves the desired compaction forces on the compression plate without requiring any unsafe forces from the human operator onto the crank handle.



CONTACT STRESSES ON GEAR TEETH

To ensure longevity of the product, it is vital to ensure that the gears are operating well below their tensile strengths and fatigue limits. The peak contact stress occurs where the gears just start to mesh at a single contact point. Calculations were undertaken to determine the maximum contact stresses in each gear in the shaft. Then, three potential gearing configurations were proposed to distribute the forces. However, minimising the number of gears and racks is beneficial to reducing cost and complexity of the device. The final decision was that configuration 2 was the most appropriate. This uses two driven gear racks to ensure that the gears are operating safely within their specifications.



FINAL STEEL PROTOTYPE

The final prototype was fabricated from steel sheets, box sections, gears and a ratchet winch. This was tested with a sample of 5kg of mixed post-consumer soft plastics. Initial results were very promising and the plastics were compacted to 25% of their original volume with very little human cranking effort. The images below show the material prior to, and after compression

4kg of soft plastic compressed into 0.3x0.3x0.4m

FINAL CONCEPT

ASSEMBLY - PARTS TO BE FABRICATED

MAIN BODY - constructing by welding components: frame containing folded sheet of 5mm steel welded to 9x 50x25x3mm box section, 5mm internal floor, 4x box section, 5mm external floor, 5mm top plate

GEAR HOUSING: sub-assembly described in detail on next page, mixture of welded and bolted mini assemblies, including laser cut logo plate to be friction fitted to front

BOTTOM SKIRT: 4x adjustable feet (to be purchased) connected either to skirt or stability plate

COMPACTION PLATE: 2x gear racks bolted to 8mm steel plate reinforced by steel bars

GEAR SHAFTS: fabricated with connector section at ends, gears grub screwed into shafts

ASSEMBLY - PARTS TO BE PURCHASED

BANDING MOUNTS & GRIPS, CRANK HANDLE, M5 BOLTS, BANDING HOLDER, RATCHET PAWL, GEARS, CAM HANDLES, STEEL HINGES, ADJUSTABLE FEET

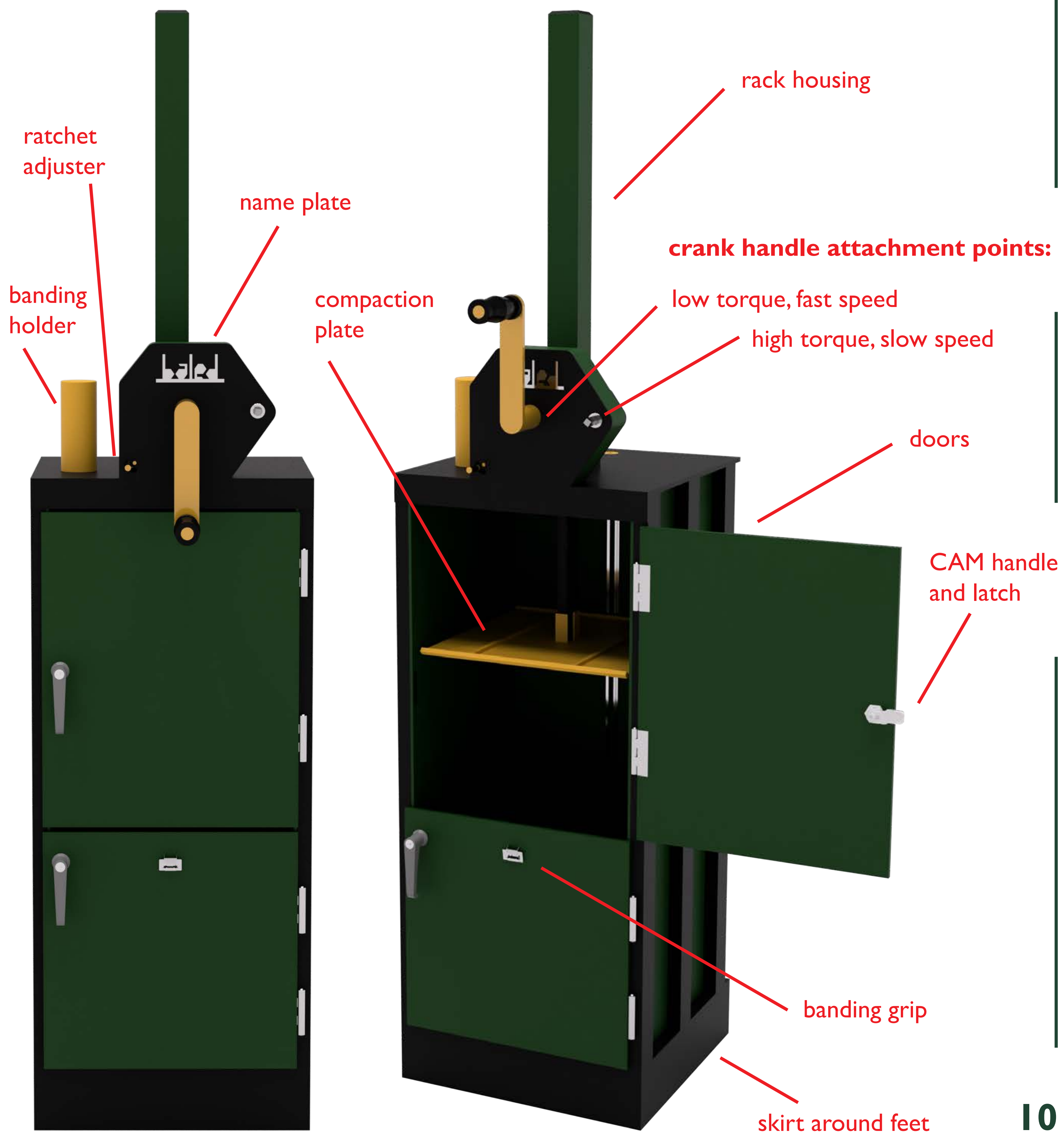
MATERIALS & SURFACE FINISH

The steel sheets will all be powder coated, ensuring better resistance to environmental degradation and fatigue of the steel, and also enabling the device to be branded with the distinctive dark green colours

TOLERANCING

+/- 1mm unless specified

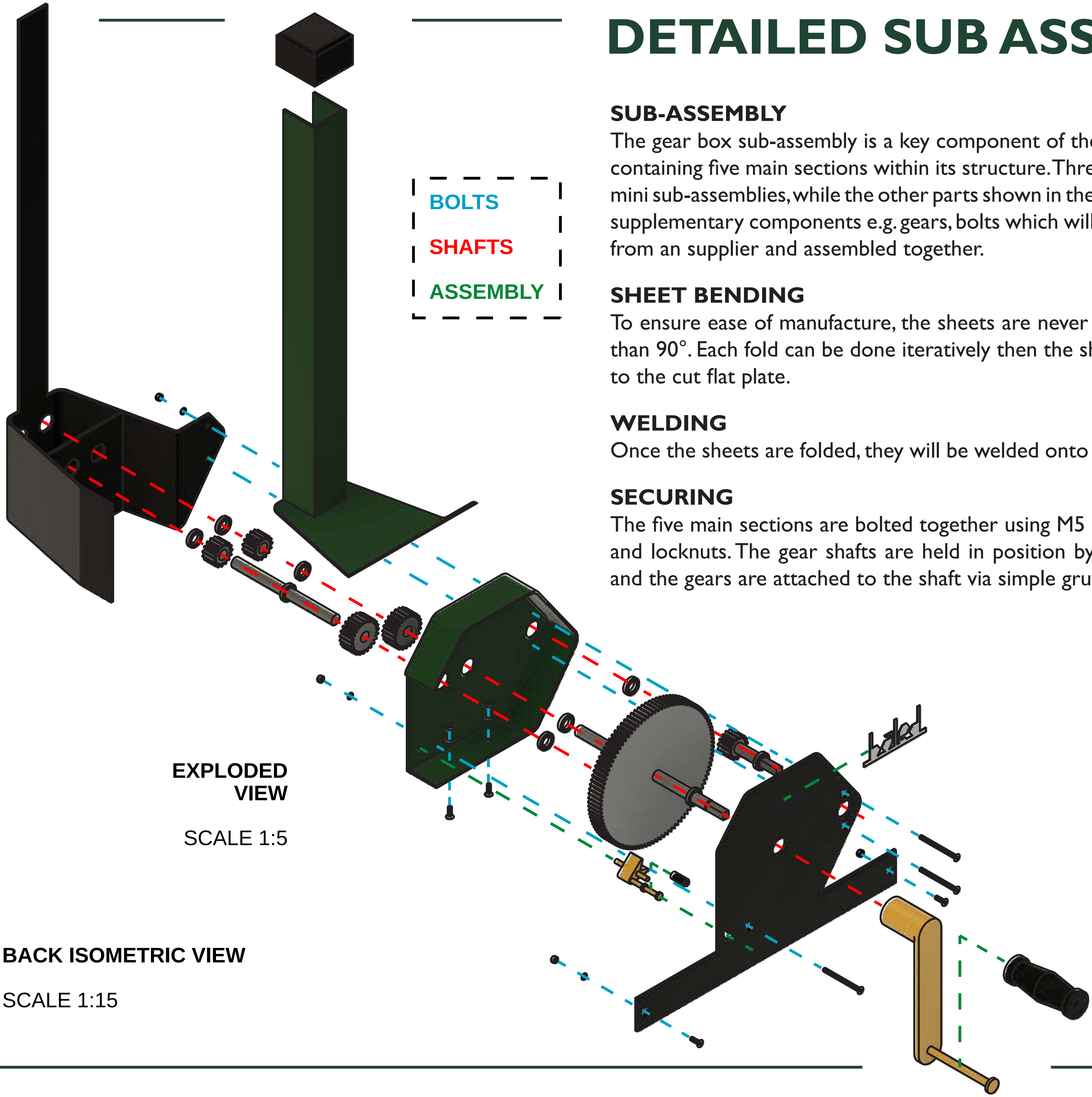
(full technical drawings in project design journal)



DETAILED SUB ASSEMBLY

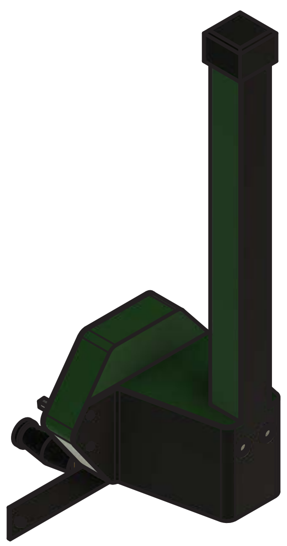
FRONT ISOMETRIC VIEW

SCALE 1:15



EXPLODED VIEW

SCALE 1:5



BACK ISOMETRIC VIEW

SCALE 1:15

SUB-ASSEMBLY

The gear box sub-assembly is a key component of the overall baler, containing five main sections within its structure. Three of these are mini sub-assemblies, while the other parts shown in the explosion are supplementary components e.g. gears, bolts which will be purchased from an supplier and assembled together.

SHEET BENDING

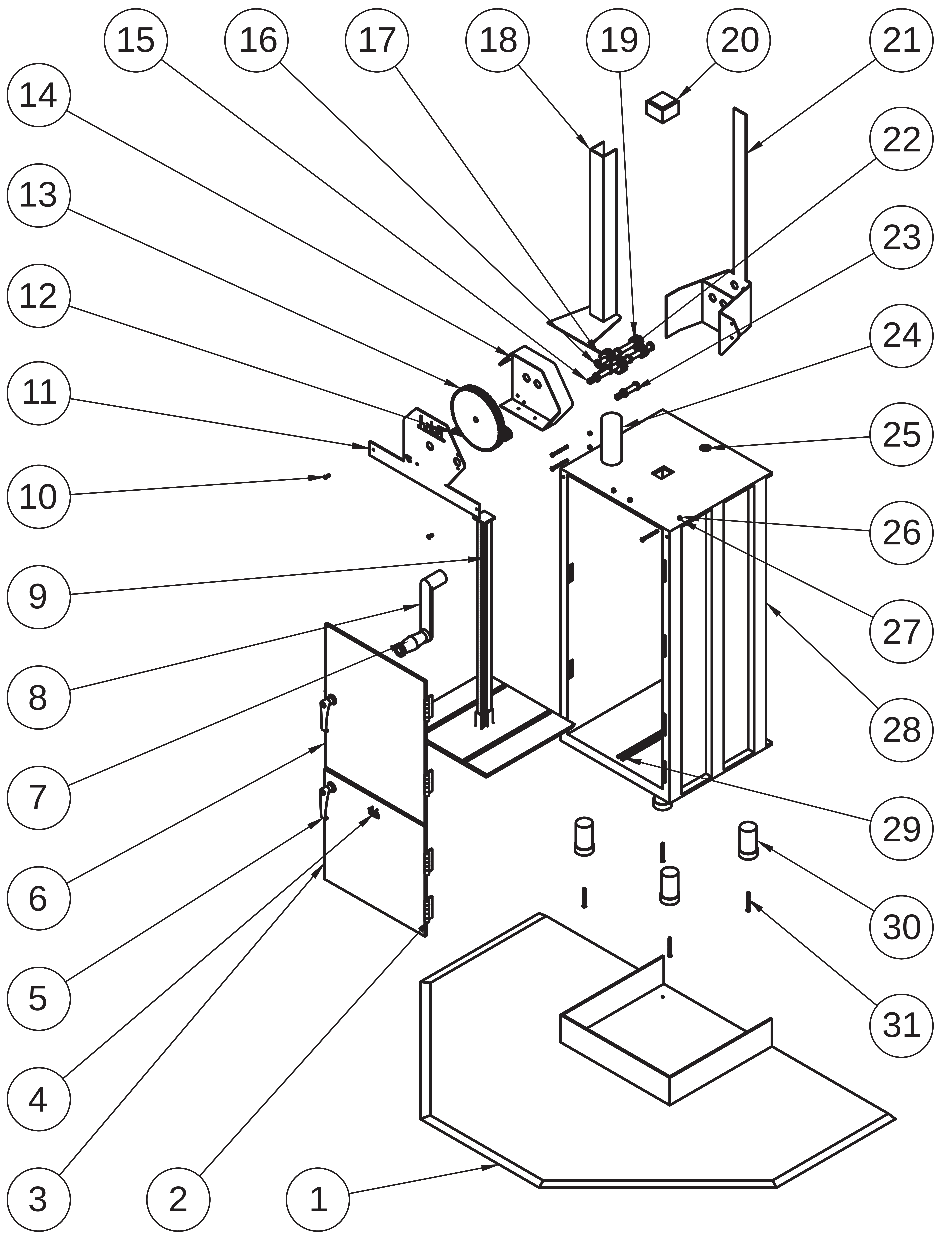
To ensure ease of manufacture, the sheets are never bent by more than 90°. Each fold can be done iteratively then the sheet is welded to the cut flat plate.

WELDING

Once the sheets are folded, they will be welded onto the flat plates.

SECURING

The five main sections are bolted together using M5 bolts, washers and locknuts. The gear shafts are held in position by ball bearings, and the gears are attached to the shaft via simple grub screws.



EXPLODED ISOMETRIC VIEW

Item	Qty	Name	Description	Material
1	1	stability plate	5mm steel, welded to skirt & bolted to feet	steel
2	4	hinges	stainless steel door hinges, welded to body	steel
3	1	bottom door	8mm steel, welded to hinges	steel
4	1	banding grip	secures baler banding during compaction	plastic
5	2	CAM handle	lockable with key, secures doors closed	plastic / steel
6	1	top door	8mm steel, welded to hinges	steel
7	1	crank grip	rubberised grip for comfort during use	plastic
8	1	crank handle	steel handle for spinning to control gears	steel
9	1	press plate	sub-assembly containing racks & plate	steel
10	4	short M5 bolt	18mm thread, connects housing to body	steel
11	1	front housing	sub-assembly including name plate	steel
12	1	ratchet pawl	to ensure gears cannot spin unintentionally	steel
13	1	large gear	200mm pitch diameter gear for torque increase	steel
14	1	gear housing	welded sub-assembly for housing gear & pawl	steel
15	1	main shaft	connecting large gear to rack & mesh gears	steel
16	1	driven shaft	connects mesh gears to drive other small gear	steel
17	2	mesh gear	46mm pitch diameter gear for shaft meshing	steel
18	1	top housing	welded sub-assembly to cover top of housing	steel
19	3	small gear	30mm pitch diameter gear for rack & crank	steel
20	1	top attacher	friction fit box to connect rack housing	steel
21	1	side housing	welded sub-assembly to secure gear shafts	steel
22	9	ball bearing	to ensure smooth rotion of gear shafts	steel
23	1	ratchet shaft	meshes small ratchet gear with large gear	steel
24	1	mount	for storing rolls of baler banding during use	plastic
25	1	back grip	to guide banding into body of baler smoothly	plastic
26	7	locknut	to secure bolts onto housing	steel
27	7	washer	to ensure a tight fit between nut & bolt	steel
28	1	main body	welded sub-assembly for frame of baler	steel
29	6	guides	to guide banding through body of baler	steel
30	4	feet	to attach baler to floor or stability plate	steel
31	7	long M5 bolt	to secure feet & housing together	steel

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Project name: BALED - technical drawings	Created for: PDE MEng 5 Final Project
Sheet title: General Assembly Sheet 1 Exploded View & Parts List	Scale: 1:15 *(unless specified)* · Units: mm *(unless specified)*
	Sheet number: 1/1 · *(for academic use only)*