SEVENTH FRAMEWORK PROGRAMME

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SPEEDKITS

Rapid deployable kits as seeds for self-recovery

Deliverable D3.3 – Public version
Prototypes

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Content

0. Executive Summary

Within S(P)EEDKITS, workpackage WP3- "watsan" (water and sanitation) focuses on the development of flexible sanitation solutions suited for emergency cases and on low cost water kits that help to generate, transport and store (potable) water. Focus in both domains is on the easy deployment of the kits.

Within this document D3.3, we report on the prototypes for the various watsan kits and the outcome of the (first) testing.

Sanitation kits. Within this part, a *raised latrine* (consisting of a frame structure, textile cover and a storage device) was presented and tested. A solution for *mobile desludging unit* is presented capable of handling most sludge in lined and unlined pit latrines and in septic tanks and able to access a high percentage of toilets. Key components are the fluidizer and the vacuum pump. For *sludge treatment*, solutions based on lime, urea and lactic acid are described. The necessary starting materials can be offered as kits. A *pasteuriser unit* was prototyped that is able to kill pathogens via a heat and time regime that complies with the EU-regulations.

Water drilling kits. Two semi-manual water drilling kits have been prototyped: the *jetting* and *capstan kit*. Both kits have been extensively tested and underwent iterative improvements. Prototypes are ready for field deployment, all technical information is available. The solutions can be offered in a compact kit.

Water storage kits. Two kits for improved storage of water are presented: the *water tank* and the *flexible water container*. The first is large scale (10 m^3 or more), the latter is an alternative for the currently used flexible jerry cans (10-20 litre).

Container based watsan kits. In order to be able to provide watsan solutions for the containerised (medical) infrastructure, following components have been developed: a *flexible supply water tank* to be placed on top of the container, a *water filtration kit*, a *flexible waste water tank* and a *multistep waste water treatment*. For all solutions an (early) prototype exists, the water filtration has already been field tested.

Water tower kit. This kit provides a water tower, it is primarily developed for use in combination with an emergency hospital setting. A prototype was made and its set-up was tested: the 3.5 m high tower structure was assembled within 4 hours with only two persons.

It is important to realise that the development path of the kits did not all follow the same path (see also deliverables D3.1 and D3.2). Further, also the cost of making an advanced prototype differs largely. As a result, the actual implementation status of the available prototypes does vary. This is not considered negative but rather reflects the pragmatic approach to prototype as far as required to give the best chances for demonstration, field deployment and take-up towards a commercial solution, thereby taking into account the available resources.

Outlook. The goal is to present these watsan prototypes to find demonstration field deployment opportunities so that the value of these kits can be demonstrated. Outcome of this will be further reported in WP6 – demonstration. Further, also public information, including guideline/manuals will be provided (D3.4).

1. Introduction

WP3- "watsan" (water and sanitation) is an important part within S(P)EEDKITS. The general objectives of the dedicated work package (WP3) are:

- Development of flexible sanitation system suited for emergency cases.
- Development of low tech, low cost water kits that help to generate, transport and store (potable) water.
- Focus in both cases is on the easy deployment of the kits, thereby taking into account the best packaging/ design practices (from WP1) and relying on the use of lightweight and durable (textile) materials.

Sanitation. As an introduction to this report, we refer back to the original descriptions in the DoW. On the part of sanitation, it reads: "a flexible sanitation platform, … which has different add-ons that can be activated on-the-spot depending on local and temporary needs." In this report, the part on sanitation shows how this translated into the development of a raised latrine for emergency situations with different add-ons for sludge removal and treatment.

Water. Within the DoW it was written for the water aspect: "Such solutions will be investigated for different size scales of users: household level (ca. 5 people), small community level (ca. 200 people), large community level (ca. 2000 people), village level (ca. 10.000 people). Potential interesting solutions for these four different levels will be investigated…". Initially, several options for water kits have been proposed to the humanitarian organisations. The outcome of this was the definition of a selection of water kits to be worked on (see also D3.1). The solutions that were favoured by the humanitarian organsiations still cover different scales of use, eg the water bag and the foldable water tank can be used for family level, the drilling and siting kit are relevant from small community to village level. In D3.2, these solutions were continued on and the most promising/ asked for solutions were further developed. Here in D3.3 we present the prototypes.

This document is structured as follows:

- *Section 2 – sanitation kits*: focus on solutions for the whole process of sanitation: raised latrine, desludging, off-site treatment.
- *Section 3 – water drilling kits*: presentation of the prototypes for the capstan and jetting kit.
- *Sections 4 - water reservoirs*: here we present two types of storage kits: a large scale water tank and a small scale foldable water bag.
- *Sections 5 & 6 - water kits / add-ons*: here we present two types of storage kits (container kit , water tower kit) that are intended to be used together with medical infrastructure.
- *Section 7 – summary*

For the sections 2 to 6, which describe the kit development, a uniform approach of presenting the activities is followed as much as possible.

2. Prototypes Sanitation kits

Sanitation chains consist of storage, desludging and treatment/disposal of faecal sludge. We discuss here the following sanitation kits that have been developed:

(1) A raised latrine including on-site faecal sludge storage, see § 2.1;

(2) Desludging in 'difficult' areas, see § 2.2;

(3) Sludge treatment and disposal, see § 2.3;

(4) Sludge pasteurizer unit, see § 2.4;

2.1 Prototypes 'Raised Latrines'

2.1.1 What did we do last time?

After the development, building and reviewing (by several humanitarian organizations, sanitation experts, knowledge institutes, the private sector) of a first prototype and detailed discussions with potential buyers, new insights surfaced. In order to bring the concept of the raised latrine to a mass producible product, an updated third version (V2) for the requirements was made.

With this new Requirement Specification a mass producible product was designed and produced. This latrine fulfils all requirements and includes an Installation Manual.

This new latrine was on display for review during the Global WASH Cluster meeting in Oslo (together with several other latrines for the emergency response sector) and during the S(P)EEDKITS Progress Meeting in Brugge. The feedback from the experts was positive. We also performed a cost analysis, in order to gain insight in the target cost prices.

A detailed description of the raised latrine can be found in Appendix 1.

BOX 1

Feedback from Global WASH Cluster meeting in Oslo

Positives

- *Easy access to bottom, removable*
- *Stable*
- *Standard parts*
- *Steps easy to clean*
- *Structure good*
- *Grill structure on steps is god and light*
- *Standard parts only so quick to assemble/produce, easy to repair/copy locally*
- *Can be converted to permanent solutions*
- *Modular so can setup in a 4 and can be used one house only or container only*

Negative

- *The string holding up the pit is a very useful piece of string/rope and it could get nicked*
- *How flat can it pack?*
- *Pipes not ideal*
- *Privacy*
- *Too big (stairs etc)*
- *Over designed*
- *Could puncture*
- *Would be taken part locally*
- *Lots of tools needed*
- *Gap in between slab and structure*
- *No lock*

Feedback from S(P)EEDKITS Progress Meeting in Brugge:

- *Need for extra reinforcement for legs when used separate*
- *Material choice alu bars good*
- *Lock required*
- *Extra ventilation required*
- *When put in blocks of 4, to much canvas and bars – find solution with zippers in canvas*
- *Double bars at the bottom, necessary?*
- *Look for optimization to connection pieces, can be less*
- *Stairs overdesigned*

2.1.2 Process: What did we do now and how?

The feedback from the S(P)EEDKITS Progress Meeting and the Global WASH Cluster meeting (**see Box 1**) was analysed and translated into solutions/design changed for the optimization process. These changes were put on paper (a redesign of the raised latrine only on paper, not in the computer), this process is described in chapter: **Redesign on paper**.

The next step was to order all materials to assemble the actual product, according to the new design, and verify all solutions. Also a new canvas was made. This process is described in chapter: **Building op the design and refitting the canvas.**

Afterwards all changes where processed into the 3D-cad computer package, which enabled us to make the Instruction manuals. This process is described in chapter: **Drawings and manuals.**

The final product and all the manuals were shipped to the United Kingdom for a practical test during a training at the British Red Cross. This process is described in chapter: **Testing.**

Finally we identified several suppliers who are able and willing to make the new frame for the raised latrine according to the made technical drawing. This process is described in chapter: **Suppliers.**

2.1.2.1 Re design on paper

We re-designed the frame, connections and canvas according the feedback. Below a table with points that needed attention and the solutions we designed:

Feedback	**Solution**
Rope for canvas not feasible on location could get nicked	Rope replaced by cable-binders
Gap in between slab and structure	Optimized dimensions of the frame make a good fit without a gap (see figure 1).
Privacy	Optimized dimensions of the frame make a good fit without a gap (see figure 1).
Too big (stairs) / Overdesigned	The stairs can be made locally from wood or other local materials, a small stairs will be sent with it for assembly purpose only.
Flat packed?	The stairs can be made locally from wood or other local materials, a small stairs will be sent with it for assembly purpose only.
Can be punctured	The canvas can be replaced locally by wooden planks. A tool to make holes in the frame and smart connection plugs will be sent with the kit.
Need for extra reinforcement for legs	The structure of the frame is designed with a 'block-structure', in order to make the whole structure more stable with less tubes (see figure 1).
Lock required	Several locks have been tried, this is an unsolved

	issue that is still been worked on at the moment.
Extra ventilation required	A bigger ventilation hole at the bag and a bigger gap at the front and an extra piece of canvas for (optional) a PVC ventilation pipe has been designed.
Canvas and frame not suitable for modular set up	The canvas, connections and the frame have been optimized. The frame and canvas are now designed in such a way that there are no double bars or pieces of canvas when more latrines are set up next to each other. Also the connections at all ends of the frame make it now possible to put up an extra latrine on the spot, without having to change the connections of the latrine that is already there (see figure 2).

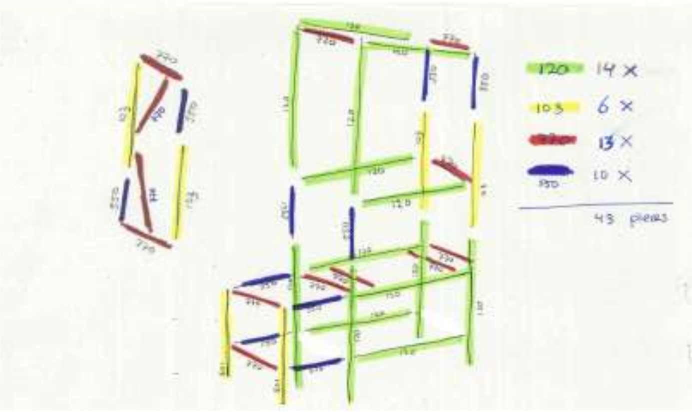


Figure 1: First drawing of tubes for optimisation

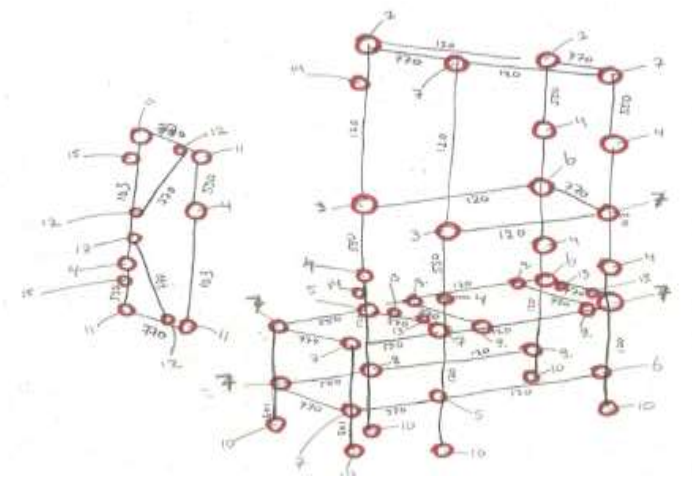


Figure 2: First drawing of connectors for optimisation

2.1.2.2 Building up the design and refitting the canvas

To be able to reuse most material from the first prototype, most of the tubes were cut into the right size and some connectors were ordered extra. All material was shipped to partner SIOEN and assembled there.

Also the design for the canvas was made. Because all tubes and connection were changed, the whole canvas needed to be made again to be suitable for the new structure. Also SIOEN optimised the canvas according to the feedback (see table below).

Extra ventilation required	A bigger ventilation hole at the bag and a bigger gap at the front and an extra piece of canvas for (optional) a PVC ventilation pipe has been designed.
Canvas and frame not suitable for modular set up	The canvas, connections and the frame have been optimized. The frame and canvas are now designed in such a way that there are no double bars or pieces of canvas when more latrines are set up next to each other. Also the connections at all ends of the frame make it now possible to put up an extra latrine on the spot, without having to change the connections of the latrine that is already there (see figure 2).

Figure 3: Example of canvas refitting by SIOEN

2.1.2.3 Drawings and manuals

The adapted drawings were processed in a 3D-CAD program to make a 3D model and to be able to make the Assembly manuals for the frame and canvas (for full manual, see Appendix 2 and 3). Also a technical drawing was made for a supplier to be able to make the frame.

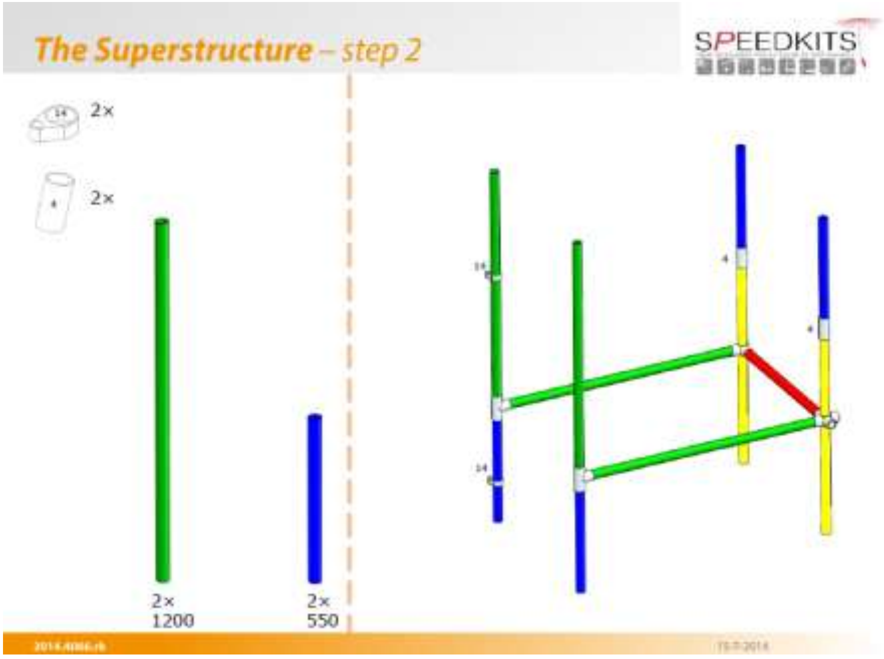


Figure 4: Example of page from the Assembly Instruction manual

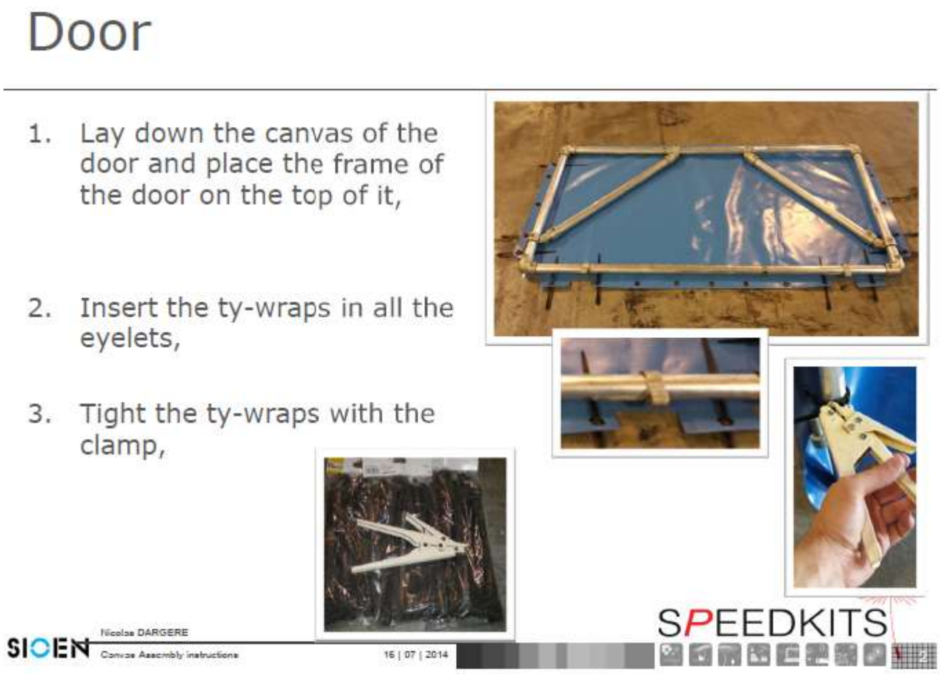


Figure 5: Example taken from the Canvas Instruction manual

2.1.2.4 Testing

The kit was sent to the United Kingdom for testing during a British Red Cross field workers training. This training is held each two years to refresh and give updates on the sanitation sector. Participants are sanitation engineers and hygiene promoters with long experience in different emergencies. The idea of this exercise is to assembly the WASTE latrine in the training compound but it will not be tested in use.

They analysed the raised latrine and provided the following feedback:
- package and easiness to transport/carry

- assembly methodology and its simplicity (how long, how many people needed, difficulty, understand instructions, etc.)
- resistance / stability to be used by high number of people
- appropriateness to be deployed in emergency situations, looking as well at cultural appropriateness (deign, material, etc.)
- desludging method

The design was adapted according to this feedback, the result is reported in section 2.2.2.6 Result: What is the prototype?

Figure 6: Test at British Red Cross

For the full feedback report, please see Appendix 4.

2.1.2.5 Suppliers

To be able to communicate with potential suppliers for the tubes and connectors of the product, a technical drawing was made.

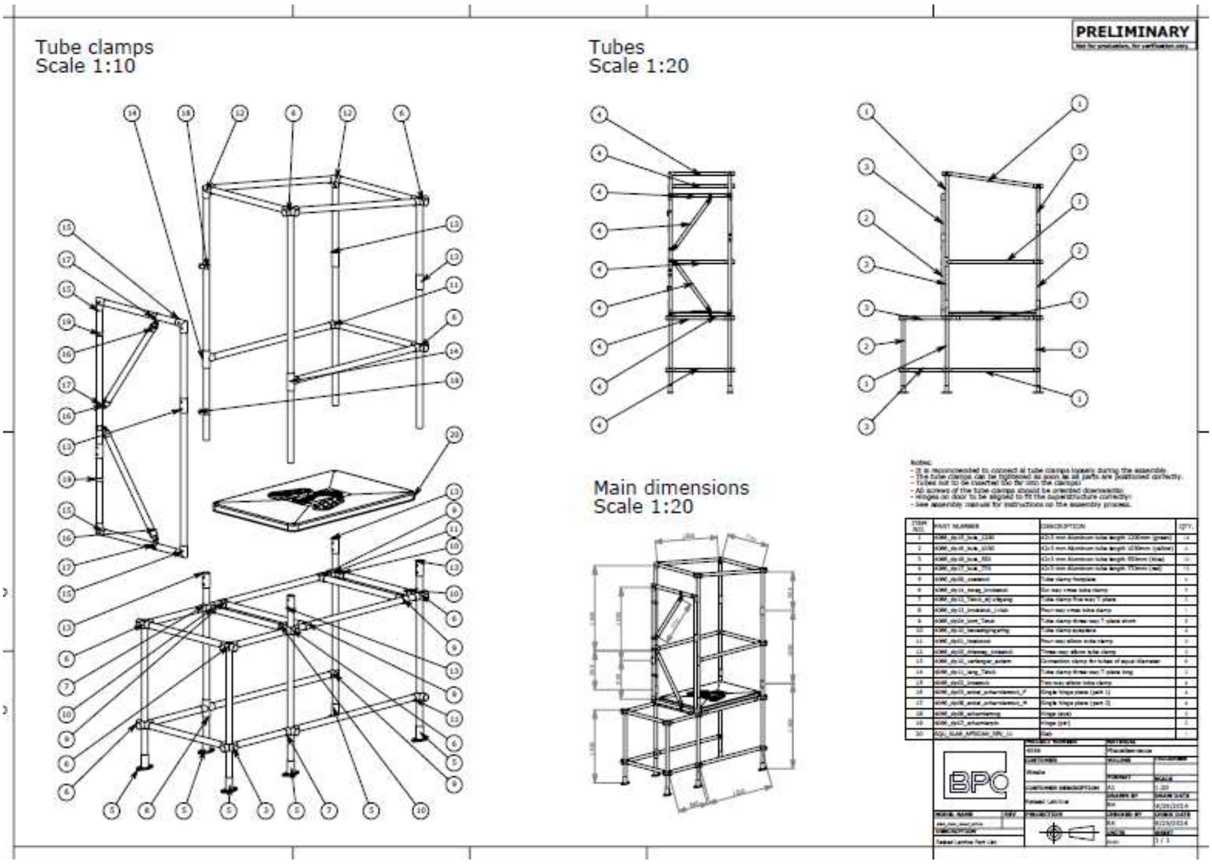


Figure 7: Technical drawing for supplier, see also Appendix 5.

Also 4 suppliers were identified and contacted, who are able and willing to supply the raised latrine, some with request for design changes:

Metaalwinkel.nl (Rotterdam)
www.metaalwinkel.nl
+31 (0) 10-414 83 81
Contact person: Simone Droog
s.droog@metaalwinkel.nl

Handelsonderneming Tuin-Bouw ('s Gravenzande)
www.tuin-bouw.nl
+31 (0) 174-725 230
Contact person: -
info@tuin-bouw.nl

Buiskoppelingshop.nl (Rotterdam)
www.buiskoppelingshop.nl
+31 (0) 297-75 36 27
Contact person: Ramon Kweekel
info@buiskoppelingshop.nl

Flexxolutions
www.flexxolutions.nl
+31 (0)541 760404
Contact person: Martin Martin Nieuwmeijer
Faradayweg 4
NL-7591 HD Denekamp

2.1.2.6 Result: What is the prototype?

Light weight and longer term

The materials of the raised latrine all have a long lifetime or are easy to be replaced by local material. For example, the canvas around the aluminum frame is attached with cable binders (ty wraps) and can be replaced by local material such as bamboo or drift wood. For this a hand drill and blind rivets are included in the kit.

Easy to transport and install

The kit contains two latrines and fits on a euro-pallet. Due to smart dimension of the package, the kit can be easily transported via boat, air and road. Once arrived on location, an intuitive manual with pictograms explains step by step how to build the latrine. This can be done by two people within one and a half hour.

Modular

The kit starts with two latrines, each containing a squat plate and a containment bag. Depending on the users, each cabin can simply be converted to a sitting toilet, a urine diversion sitting toilet, woman urinal or man urinal by attaching an interface part and the required object on to the squat plate. The bag can hold the waste (urine, washing water and feaces) from fifty people during two weeks. After those two weeks, the bag can be emptied by a desludging pump via an outlet at the back. In case it is required to collect the urine separately or treat the waste on site, the bag can be replaced or accompanied by one of more hundred twenty liters wheel bins.

This Raised latrine is 1 kit and contains several items. This kit can be combined with other kits. Below an overview of the items in the Raised latrine kit in black. The items in other kits are blue.

Frame (see Manual in Appendix 2)	**Canvas** (see Manual in Appendix 3) or **plugs** (see Upgrade package in chapter below). The canvas is for short term use and can be re ordered. The plugs are for the 'upgrade package', to use local building materials the frame to build a long term superstructure	A **wheelie bin** (see Bin solution in chapter below) (x 10), each containing 120 L, for treatment on site or a **waste-collection-bag** containing 1500 L for storage for 50 people for 2 weeks.	One of three options for instruction manuals (treatment on site) or a desludging pump (for treatment or disposal of site)	A big bladder

Definition of kit: A diversified modular rapid deployable raised latrine kit that can easily be adjusted according to the local circumstances.

Keywords:

- easy to transport,
- quick and easy to install (modular),
- adaptable for long term use,
- affordable,
- applicable in areas with a flood risk,
- comfortable for all possible social cultures,
- avoid soil contamination,

2.1.3 Next steps

During the Aidex 2014 in Brussels and the UN Buyer days in Den Hague, several potential buyers have been identified such as MSF and Unicef.

For the next step we have partnered with Flexxolutions for production. Together we are now integrating the design of the Flexxotoilet and the WASTE Raised latrine. At the moment we are developing a Flexxolutions-WASTE-Raised-latrine-combination, combining the best parts of both toilets which will result in one design with:

- aluminium frame modular base with canvas housing,
- an optimal number of basis toilets (tested at the moment at Flexxolutions) on 1 Europallets,
- optional upgrade package (from the WASTE Raised latrine),
- lock and stairs (developed by Flexxolutions),
- optional add ons (being the urinals, sitting user interface and children toilets developed by WASTE, produced by NagMagic).
- optional one or two big bags, depending on the choice for the buyer for a man or woman urinal cabin (2nd bag option initiated by WASTE, produced by Flexxolutions with SIOEN canvas).

Now five latrines according to the latest Flexxolutions-WASTE-Raised-latrine-combination will be tested in an internal WASH training of MSF in Bordeaux (planned for January 2015). As next step, we are aiming at a field test.

2.2 Prototypes 'Desludging in difficult areas'

The mainstream technology of vacuum tankers is inefficient when it comes to emptying pit latrines, due to issues such as:

- Access to toilets in crowded areas;
- The semi-solid nature of the sludge;
- The amount of rubbish in the sludge causing frequent blockages to 75mm suction pipes of vacuum machinery.

When it comes to the semi-solid nature of the sludge, the usual solution is to add water to the pit, mix and leave for some days and pump out the sludge. The result is not efficient as a lot of water must be transported to and from the site, and the sludge, which is pumped out, is very diluted. This has unwanted consequences on efficiency and costs.

2.2.1 Process: What did we do and how?

With the objective to recommend a reliable mobile desludging equipment to empty pit latrines in emergency situations, three types of desludging equipment were tested in Blantyre City (Malawi): i) vacuum-operated machine with an integrated high-pressure pump for fluidizing sludge and a 800L holding tank (called ROM 2); ii) vacuum-operated machine with a 500L holding tank (called Vacutug Mk2) and (iii) diaphragm sludge pump (Lombardini diesel engine) (*See Figure 1*). These equipments were tested during 9 months, starting in September 2013, in peri-urban areas, high-density housing and institutional toilets, removing 430 m^3 of thick sludge in over 200 lined and unlined pit latrines and a number septic tanks. The total number of trips was more than 500. The parameters evaluated during testing period are: design, effectiveness & efficiency, ease of use, reliability and durability.

a) b) c)

Figure 8. Mobile desludging equipment a) ROM 2; b) Vacutug Mk2 and c) Diaphragm sludge pump

The main technical characteristics of this equipment are shown on Table 1.

During the first trial, none of the equipment as supplied by the manufacturers proved suitability for removing the thick, semi-solid, rubbish loaded sludge typically found in local pit latrines. However, after extensive modifications and the inclusion of 2 essential processes: fluidizing and fishing out rubbish, the testing found that it is possible to effectively and efficiently empty pit latrines with thick sludge under a wide range of conditions.

Table 1. Technical specifications of desludging equipment

Specification	ROM 2	Vacutug Mk 2	Diaphragm sludge pump
Description	Petrol driven vacuum pump with pressure pump for fluidising. Steel holding tank.	Diesel driven vacuum pump. Steel holding tank.	Diesel driven diaphragm pump.
Shipment gross weight and volume	500 kg; (4.48m^3)	869 kg; 5.69 m^3	808 kg; 4.69 m^3
Propulsion	Truck mounted or trailer	Self-propelled, 3 – 4 km/h	Truck mounted
Engine type and power	Honda 6.6 kW. Electric or manual start	Unbranded Chinese diesel, 9,1 KW, electric / manual start	Lombardini diesel engine. Manual start
Vacuum pump capacity	Model RV2500. 2.500L/min, Kevlar vanes (+ spares). Additional oil reservoir	Make: Pagani 2,750 L/min Relative pressure: 1.5 bar Vacuum -0.91 bar Max power 7kW	n/a
Pressure pump capacity	Speck Brand 140 bars –maximum pressure - unloaded set on 60 bars. No need for pressurised water inlet. Power requirement 4.1 kW. Capacity 15 litres / minute. Water filter: ½”	n/ a	n/a
Holding tank capacity	800 L	500 L	No holding tank
Water tank holding capacity	200 L	0	0
Suction hose diameter	2” and 3”	3”	3”
Suction hose length as supplied	15 m	2 x 15 m	30 m

Hose connectors	Plastic cam locks	Quick release, Metal	Bauer Quick release, Metal
Ball valves	Plastic	Metal	Metal Bauer
Instruction and maintenance manual	yes	No	no
Spares	Engine spares kit Vacuum pump spare blades Hose repair kits	engine spares kit No vacuum pump spares Hose repair kits	Engine spares kit Spare Diaphragm

Fluidisation**:** In general, the nature of the sludge found in most of the tested pits was 'difficult', with very high total solids content (>15%). In order to handle this semi-solid sludge, a fluidization process was developed using pressurized water and specially designed nozzles (*See Figure 9)*. This process was based on the thixotropic property of sludge (the shearing action of the pressurised water fluidises the sludge). Without this prior fluidization of the pit, none of the equipment was capable of removing significant amounts of sludge from the pit latrines. In most cases, the amount of water used during the fluidization process was between 15 – 20 % of the total sludge removed and after fluidization, the solids content of the sludge was tested at around 15%. . The quantity of water used in the fluidisation of the pit sludge has a bearing on the efficiency and cost of the operation. A bigger percentage of water used means that less sludge is pumped out of the pit resulting in less operational efficiency and higher transport costs. There are also consequences for dewatering the sludge.
The same high pressure equipment used in fluidising is used to clean the toilet and equipment after the desludging operation.

Figure 9. Spray pattern fluidizer using a 4 jet nozzle at 100 bar

Fishing out rubbish: The thick sludge was invariably found to contain various forms of rubbish. Examination of fished out rubbish revealed items such as old clothes, shoes, bottles, plastic carrier bags, maize cobs, menstrual cloths, medicine bottles and debris from the pit structure itself such as gravel, stones and large rocks from unlined pit walls. The testing regime found that the larger items should be manually removed from the pit with an adapted grappling or fishing hook before pumping out the sludge (*See Figure 10*). Fishing takes place after fluidization but before sludge pumping, and the process is repeated if necessary. Failure to fish out the rubbish resulted in suction hoses becoming blocked. It was found that 1000 litres of sludge could contain at least 50-100 litres of larger rubbish items. The testing regime found it was not possible to fish-out the smaller items, such as small pieces of plastic, medicine bottles and stones. Over time, these can accumulate in the holding tank and eventually block the discharge ports of the holding tank. The vacuum-driven machines, namely the ROM and the Vacutug, were found to be capable of emptying sludge with rubbish. While the diaphragm pump functioned extremely well in septic tanks with no solid waste it proved to be the most sensitive to rubbish and cannot be recommended for this purpose.

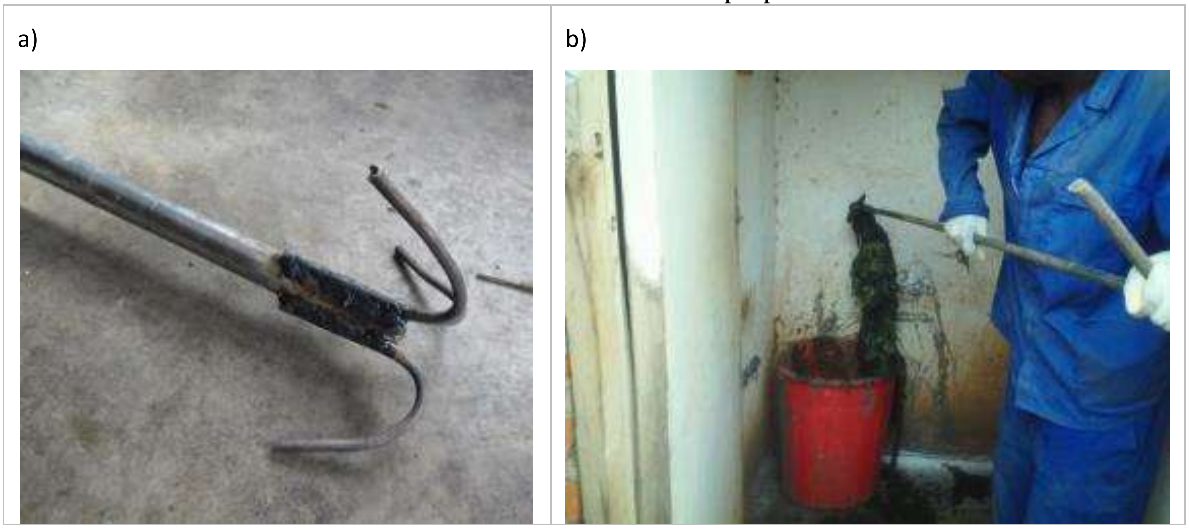


Figure 10. a) Fishing tool; b) Fishing out rubbish

After testing period the following results and recommendations were identified for each type of equipment:

a) **ROM 2.**

The ROM 2 is a vacuum-operated machine with an integrated high-pressure pump for fluidizing sludge and an 800L holding tank manufactured in The Netherlands. Its main specifications are mentioned in Table 1.

This equipment was tested in the following conditions:

- 16 Septic tanks ;
- 19 Lined pit latrines in households and schools;
- 60 Unlined pit latrines in households and schools;
- 6 Abandoned pit latrines with very solid sludge.

Problems identified during field testing

The main problems (experienced during testing period) and modifications applied in field are summarized in the following:

- 2” suction pipe supplied easily blocked with rubbish → Use only 3” suction pipe;
- Rigid suction probe makes entry into small toilets difficult → Removed rigid suction probe;
- The attachment of the high-pressure hose to the suction pipe made fluidising difficult → Separated hoses and attached fluidising hose to a separate lance;
- Removed ball valve from suction end → and use only suction pipe;
- Replace plastic ball valves with metal valves;
- Replace plastic pipe connectors with metal cam locks;
- Filter from water tank to pressure washer gets blocked → increase size of filter;
- Fuel tank difficult to fill → better funnel
- Battery difficult to install → relocate terminals
- After prolonged use or pumping toilets with lots of small rubbish (not fished) outlet to holding tank gets blocked → installed man hole
- Fitting ROM 2 on a 3 ton flatbed truck made access to some toilets difficult →fitted to a trailer and increased length of suction pipe and high pressure hose to 30 meters.

Conclusions & Recommendations

As it was mentioned before, the initial testing demonstrated that ROM 2 was not suitable to remove difficult sludge, however after including the process of fluidizing, fishing out rubbish and some modifications in the equipment the following results were obtained:

- After fishing (approximately 30 minutes) and fluidising (approximately 15 minutes) ROM 2 could empty 800 L from a pit in 4 minutes;
- ROM 2 could empty from a maximum tested distance of 30 m and an elevation of 2 m;
- ROM 2 can discharge the sludge in less than 1 minute;
- It has excellent fuel economy of an average of less than 0.2 L fuel per pit. It is very reliable – only faults were the drive belts and the pressure hose and water filter;
- One major adaptation was the ***extension of pressure hose:*** The pressure hose had already been detached from the suction pipe, but in order to match the length of the 30 m suction hose with the fluidising, the length of the fluidising pressure hose was increased to 30 m;
- To improve access to difficult to reach toilets, in addition to the 30 m suction hose and pressure hose, the ROM2 was mounted on a trailer to be towed by any vehicle with a towing capacity of 1200 kg. The towed unit was tested on the public roads as well as off road and proved stable, but has yet to be tested in crowded areas such as townships;
- The ***inspection cover*** was fitted for ease of cleaning the holding tank from blockages affecting the gauge and discharge (emptying).

b) VACUTUG

The Vacutug has a diesel-powered vacuum pump with a 500 L steel holding tank. The diesel engine also provides motivation for the self-propulsion. It does not have a separate fluidiser, and it was later tested in conjunction with an independent fluidiser.

The Vacutug could only be tested on pit latrines after the procurement of the high-pressure pump (Karcher). While it worked fine on septic tanks, vacuum pumps without fluidising capacity are ineffective on hard sludge.

The manufacturer recommended that ‘fluidizing’ of the sludge be done by first setting the pump to vacuum, then after sucking some sludge to set the pump to pressure and then blow back into the pit. However this was considered not suitable for pit sludge in Malawi, as the liquid content was too low. And the concern that this action may cause unlined pits to collapse.

Due to the frequent breakdowns and the lack of mobility of the Vacutug, it was tested on 10 toilet facilities all unlined pits, removing a total of 7100 litres of sludge.

- Pumping of fluidised sludge: tested effectively to 30 m and an elevation of 2 m. Speed of pumping sludge less than 5 minutes for 500 lts (comparable to the ROM);
- Fuel consumption: recorded as 5 litres diesel per 500 lts of sludge

Problems identified during field testing

The following problems were identified during the Vacutug testing:

- Under its own power (self-motivation) the Vacutug is both very slow at 4kph, it cannot handle even mildly rough terrain or mild slopes, and is unstable. It cannot be licenced to operate on the public roads and cannot keep up with traffic. Due to the slow travel speed, the work progresses very slowly. This means that while the team managed to pump sludge, the sludge could not be transported efficiently. To solve this the team emptied the sludge into an IBC (Intermediate Bulk Container) and then used the ROM to transfer the sludge from the IBC to the disposal site;

- Towing the Vacutug proved slow and dangerous – towing over 15 km took over 4 hours and at one point it tipped over damaging the pressure chamber bracket and breaking the vacuum pump pulley. After this the Vacutug could no longer operate under self-propulsion;
- The starter system of the diesel engine failed – the manual pull starter spring broke so that the engine could only start using the battery. Then the battery failed completely resulting in further loss of operating time;
- During the short time it operated under self-propulsion the suction pipe from the tank to the vacuum pump fell on the hot exhaust pipe and melted.

In order to get the Vacutug back to work, the following modification and reparations were applied:

- The transporting problem was solved by dismantling the 2 parts: the tank and the driving side. The tank was towed using a one ton pick up at normal speed and it proved stable. The driving side (two narrow wheels, engine, pumps etc.) were placed on a pick up;
- As the manual starter broke, and the original battery failed, a different one was used;
- After attempting repairs on the pulley (poor quality workmanship), a new pulley from aluminium was fabricated. After fitting, the engine and pump ran very well;
- The vacuum pump was very effective (-0.6 bar compared to -0.5 bar with the ROM) – so, at least initially, it is performing well.

Conclusions & Recommendations

Based on the findings in Malawi the following recommendations can be made:

- Include a fluidiser that can spray high-pressure water of around 60 bar in the latrine sludge. The fluidiser can be mounted on the same chassis as the vacuum pump and driven by the same engine;
- Improve engine quality, preferably it should be reliable, economical and has a good dealer network;
- Improve the safety of the drive system – i.e. operators should be protected from the belts with belt guards and an emergency stop button that is easily accessible is essential;
- Implement a holding tank of around 800 – 1000 litres to store and transport sludge. Our experience is that this size tank is sufficient to make an impact in emptying an average household pit latrine yet remain manoeuvrable in congested areas;
- A gauge (not merely an eyeglass) should indicate the filling progress;
- The unit should be mounted on a small trailer. The company already manufactures and markets a 2000 litre unit mounted on a trailer.

c) MECHANIZED MEMBRANE PUMP

The third type of equipment was the diaphragm (membrane) pump supplied by Butyl, its specifications are mentioned in Table 1.

The sludge pump was trialled mainly on septic tanks as it failed to operate effectively even on fluidised pit sludge. In total 18 septic tanks and 1 pit latrine were emptied using this pump.

Problems identified during field-testing

- Over 2 days less than 200 litres of sludge were pumped and the main problem was that the pump could only operate for a maximum of 2 minutes before it stopped pumping, and the following problems were identified;
- On dismantling the pump ports we found small pieces of trash stuck in the ports thus causing the suction side and the delivery side not to seal – therefore the pump was unable build up

any pressure – so the sludge just move back and forward with the diaphragm action but did not move forward;

- The dismantling and reassembly of the port took ten minutes – a simple operation. The repair of both ports and cleaning took 30 minutes. But the pump kept blocking in 2 minutes.

Note: it is not possible to fish this small trash out, and neither is it possible to put a smaller size sieve as the suction would block all the time.

Conclusions & Recommendations

- The diaphragm pump is perfectly useable with septic tanks in which there is no rubbish and does not require fluidising. In fact for such an application it may be the best of the 3 machines because it can pump directly to an independent sludge tank or bladder.
- For use in pit latrines, the sludge pump can cope with thick, fluidised sludge for short periods of time, but the ports easily lose their seal with small pieces of trash that can neither be fished out nor sieved.
- It can be assumed that the sludge pump can be effective in removing fluidised pit sludge that has no trash.
- Based on the findings in Malawi the supplier of the pump has now proposed a macerator pump that is suitable for use with hard sludge and a certain amount of rubbish as the pump has a shredder. The macerator pump has yet to be tested in field conditions.

2.2.2 Result: What is the prototype?

As result of modifications on the most reliable pump tested in Malawi, below is the description of a mobile desludging unit fit for service in difficult conditions:

Specifications for a functioning mobile desludging unit: In order to meet the above challenges in managing the difficult sludge found in pit latrines, major modifications were made to the most promising of the equipment tested, which was the ROM2. These modifications were also subjected to long-term testing for pumping efficiency and effectiveness. It is now possible to recommend a design for a mobile pit emptying machine capable of handling most sludge in lined and unlined pit latrines and in septic tanks and able to access a high percentage of toilets. The key components of such a vacuum-operated ‘mobile desludging unit’ should include:

- A fluidizer that can spray high-pressure water at around 60-100 bar into the latrine sludge using a lance and a special nozzle. For safety reasons, it is not advisable to use pressure exceeding 100 bar. The unit should have a tank that can hold at least 200 litres of clean water for fluidizing and clean-up operations;
- A vacuum pump capable of creating a vacuum of 0.5 bar and with a capacity of at least 2000 litres per minute;
- Three inch flexible suction and outlet hoses in order to avoid frequent blockages by rubbish;
- A holding tank of 1000 litres to store and transport sludge. The inside of the tank should be easily accessible in case the discharge port becomes blocked;
- The unit should be mounted on a small truck or trailer and the lengths of the suction pipe and fluidizing hose increased to 30 metres to increase accessibility;
- Improvements in the logistics of operating the unit, including access to localized disposal (or a transfer station), make it possible to desludge up to eight pits in one working day.

2.2.3 Next steps

Other challenges remain. Due to the relatively small capacity of the holding tank, transportation to a disposal site is expensive and results in a loss of operational efficiency. Therefore, the setting up of decentralized disposal sites would make the operation more efficient. The equipment is expensive and should be designed with at least some local assembly in mind to reduce capital costs and make the equipment more accessible. The presence of so much rubbish in the sludge, requiring the dirty and dangerous job of fishing, will remain a challenge. Market analysis indicates that few pit latrine owners are aware of modern emptying services and most clients are surprised to find the equipment so effective in emptying pits.

'ROM3' is now on the market. The work in Malawi has encouraged the manufacturer, ROM, to come up with a device suitable for the 'difficult' sludge in 'difficult' areas. See leaflet on the following pages. WASTE and other partners as the NL Red Cross have disseminated the device (e.g. at the World Water Week in Stockholm, September 2014) and will continue to do so. WASTE forwards interested parties such as Oxfam UK to ROM so that orders can be placed. Upon request WASTE will organize visits of interested parties to Blantyre to demonstrate the desludging process. The SPA partners from Ethiopia already came to Blantyre. The ultimate goal is that the device enters the catalogues of the IFRC and Oxfam GB. Before that time the device has to be demonstrated in relief situations, e.g. South Sudan.

Ordinary vacuum trucks are unable to effectively and efficiently empty the hard sludge usually found in pit latrines, so the emptying is often done using manual means that are dangerous for both the operators and the environment. WASTE, The Netherlands Red Cross and ROM bv got together to meet this challenge. The ROM Mobile Desludging Unit is a service unit which is specially developed for emptying and cleaning pit latrines, even those with hard sludge. It is designed and engineered for development aid and emergency aid. The unit includes all proven ROM technology in order to ensure reliability and durability. The low weight of the unit makes it well suited for placement on light vehicles or trailers. You can even transport the unit in the trunk of a common pick-up vehicle.

For emptying and cleaning pit latrines

The ROM Mobile Desludging Unit is ideal for safely emptying and cleaning pit latrines in a very simple and economical manner. The unit has been designed to be easy to operate without danger to the environment or operators. This unit contributes to a higher standard and more durable sanitation systems in developing countries. The unit has proven to be reliable and easy to use in development settings. All common international safety requirements are fully met and features included an emergency stop, over pressure and under pressure safety valves.

For emergency sanitation

Hygiene and sanitation is very important in case of emergency situations. Especially after natural disasters such as earthquakes, tsunami's and hurricanes. In those situations there is an increased risk of epidemics. An adequate level of sanitation can help to prevent an outbreak of communicable diseases. The ROM Mobile Desludging Unit makes it possible to maintain hygienic sanitation and prolong the lifespan of sanitation structures such as pit latrines, elevated or mobile latrines and septic tanks, even in the most demanding situations. The unit can optionally be equipped with a high pressure pump, a lance and specially developed nozzles. This allows the unit to fluidise and pump old sludge with minimum amounts of water. With high quality and functionality, the ROM Mobile Desludging Unit is very reliable, and easy to operate... exactly what you need in an emergency situation.

Several configurations

The desludging unit is available in two configurations:

- 800 liter vacuum tank - 200 liter clean water tank
- 1000 liter vacuum tank - 400 liter clean water tank

WASTE

The Netherlands Red Cross

SPEEDKITS

ROM bv • Harselaarseweg 63 • 3771 MA Barneveld • The Netherlands • Tel. +31 (0)342 49 04 17 • Fax +31 (0)342 49 28 00 • www.rombv.com

2.3 Prototypes 'Sludge treatment and disposal'

2.3.1 Process: What did we do and how?

With the objective to provide the relief organizations with a number of safe options to treat faecal sludge, three faecal sludge sanitisation methods (Urea Treatment; Lactic Acid Fermentation and Hydrated Lime Treatment) were investigated by undertaking small scale field trials with pit latrine sludge in Blantyre, Malawi. Following is a description of the activities done and the results for each treatment method.

2.3.1.1 Faecal Sludge Treatment by Urea Addition

Urea treatment is based on the sanitizing effect of uncharged ammonia (NH_3) which has been demonstrated to be a harmless chemical substance capable to efficiently inactivate bacteria. Ammonia is known to be highly soluble in water as well as lipids; this characteristic enhances the transportation of ammonia over the cell membranes and other cellular walls by diffusion. Once in the cell, ammonia causes an increase in the internal pH, destruction of the membrane potential as well as denaturalization of the bacterial membrane and cell proteins. This eventually leads to cell decay overall pathogen destruction. Additionally ammonia gas causes cell damage by quick alkalinisation of the cytoplasm.

Based on the described theory , two experiments were undertaken in the field. The first experiment evaluated different urea dosages and the second experiment focused on the impact of mixing intensity at a set dosage.

The first experiment consisted of one control and two treatment reactors. All three reactors were filled with approximately 25-30L of faecal sludge and their weight recorded (*See Figure 11*). Urea prills sourced from a local agricultural dealer were added to the two treatment reactors at dosage rates of 1% and 3%w/w urea to sludge respectively taking into account the 40% purity of the urea prills. The three reactors including the control were manually mixed for 3 minutes and hermetically sealed with an aluminium ring to avoid ammonia loss throughout the experiment. Samples were taken and analysed after 0, 4, 6 and 7days.

Figure 11: filling the drums (left); one of the two custom made mixers (middle); overall set-up (right)

The second experiment consisted of four 50L plastic drum reactors which were filled approximately two-thirds full with faecal sludge. Two drums served as controls and two drums were treatment reactors using a dosage rate of 2%w/w urea. One control and one treatment reactor was intensely mixed continually for three days using a motorized agitator. The remaining treatment reactor was only initially mixed manually for a few minutes after the urea dosage to evenly distribute the urea. Samples were taken in duplicates at 0, 4, 6, 10, 24, 30, 48 and 72 hours.

The peak pH was recorded on day 2 after the addition of urea and remained stable around pH 9 for both 1% and 3% w/w urea additions. The ammonia concentration continued to increase over the period of 8 days. The concentration of E-coli measured below the WHO guideline limit of $<10^3$

CFU/100ml by day 4. Urea Treatment is more suited to treating thick sludge due to the importance of the urease enzyme for urea decomposition and impact upon treatment time.
In the second urea treatment experiment, the E-coli concentration was measured at $1.2x10^6$ MPN/100ml for both unmixed and mixed treatment reactors after 72 hours. Therefore to meet the WHO guidelines on safe sludge handling (E-coli $<10^3$ MPN/ 100ml), urea treatment with 2%w/w has to be applied for a period exceeding three days. Overall, there was no significant difference between the properties of samples taken from reactors that were continuously mixed compared to from those which were only mixed briefly upon the addition of urea. An estimated minimum treatment time of 5 days was predicted for 2%w/w urea treatment using linear regression and based on the upper 95% confidence interval.

For more detailed information of faecal sludge treatment based on Urea addition, please refer to the following documents: MSc Thesis conducted by Lobke de Pooter and M. Eliette Gonzalez P. at TU Delft University and UNESCO-IHE respectively. This can be downloaded from the WASTE website http://www.waste.nl

2.3.1.2 Faecal Sludge Treatment by Lactic Acid

Lactic Acid Fermentation has been already used for sanitation within the food industry. Weak organic acids such as lactic acid have inhibiting capabilities on a wide range of microorganisms. The inhibitory effect of the un-dissociated organic acid is 10 to 600 times stronger than of the dissociate form. The antimicrobial action of lactic acid is partially attributed to its ability to penetrate the cytoplasmic membrane of microorganisms, resulting in the reduced intracellular pH and disruption of the trans-membrane proton motive force of the lipopolysaccharides molecules of the outer membrane of the pathogenic organism.

Based on the described principle, a research project conducted by Dennis Malambo in collaboration with UNESCO-IHE was done in Blantyre – Malawi (the field trial) and at UNESCO-IHE laboratory in Delft – The Netherlands. In the field trial, lactic acid was formed through fermentation of sugars using Lactic Acid Bacteria (LAB). The strain of lactic acid bacteria used in the research was *Lactobacillus casei Shirota* which is present in the probiotic fermented milk drink: *Yakult*. This bacteria is a gram-positive specie which is a preferential non-aerobe but is also aero-tolerant, acid-tolerant and strictly fermentative. Each 65 mL bottle of Yakult contains approximately 6.5 billion live *Lactobacillus casei shirota* bacteria. The inoculum media was created by adding 15L pasteurized whole milk and 30ml Yakult into a sterile 20L glass container in the ratio of 99.8% w/w and 0.02% w/w respectively. The mixture was allowed to stand for 48h at room temperature in order for the lactic acid bacteria to exponential grow to levels of approximately $3x10^{11}$ CFU/100ml.

The Lactic Acid Fermentation experiment consisted of one control and the three treatment reactors (*See Figure 12*). Each of the four reactors was filled half-way with faecal sludge and the mass recorded. 10% w/w molasses and 10% w/w starter culture were added to each of the three treatment reactors. All four reactors were mixed using a power mixer for 3 minutes, samples were collected and analysed after 0, 2, 4, 7 and 9 days.

As result it have been found that at day 7, *E. Coli* was suppressed to below detectable numbers in all three reactors. An average log reduction of more than 5 log units was recorded from $1.5x10^8$ to less than 10^3 CFU/100ml. This pathogen reduction in the field was notably faster than the laboratory tests (which required 15 days before the E-coli count was below the detectable limit). Additionally, it can be deduced that pH conditions (approximately pH = 4) induced pathogen inactivation. This correlated with the sanitization mechanism in the field being triggered when the lactic acid concentration reached the range of 30 g/L.

a) b)

Figure 12: a) 50L Reactors b) Mixing procedure

For more detailed information of faecal sludge treatment based on Lactic Acid Bacteria, please refer to the following document: MSc Thesis MWI SE 2014-21 UNESCO-IHE. This can be downloaded from the WASTE website http://www.waste.nl

2.3.1.3 Faecal Sludge Treatment with Hydrated Lime

Alkaline or Lime stabilization is a simple process which reduces odour, vector attraction and pathogen concentration in wastewater and wastewater treatment sludge. Numerous studies described the effectiveness of lime in reducing microbiological hazards in water and wastewater. Calcium hydroxide ($Ca(OH)_2$) is an alkaline compound that can create pH levels as high as 12.4. At pH levels greater than 12, the cell membranes of harmful pathogens are destroyed. The high pH also provides a vector attraction barrier, preventing flies and other insects from infesting the treated biological waste. Because lime has low solubility in water, lime molecules persist in biosolids, this helps to maintain the pH above 12 and prevents re-growth of pathogens.

In order to produce scientific evidence for the use of lime to treat faecal sludge and to establish standard operating procedures to apply this treatment method, field trials have been performed in Blantyre, Malawi. The lime stabilisation experiments consisted of five 50L plastic drum reactors filled with approximately 25-30kg of faecal sludge. One reactor acted as a control and hydrated lime sourced from a local hardware store was added to the four remaining reactors to achieve certain target pH for example pH 9, pH 10, pH 11 and pH 12 in each drum respectively. In the four treatment reactors the lime was mixed into the faecal sludge for 10 minutes using an electric power mixer. Samples were taken from each of the five drums before lime dosage, after mixing, after 1, 2, 5 and 24 hours.

a) b)

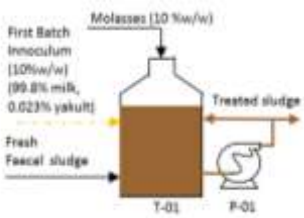
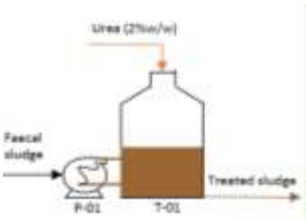
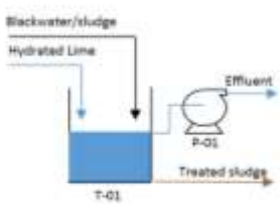
Figure 13: a) Mixing Faecal Sludge with Hydrated Lime. b) 50L reactors

The results of this treatment method showed that conditions above pH 10.5 induced E. Coli reduction, however for the E. Coli concentration to be consistently below the WHO guideline limit of less than 1000 CFU/100ml for a period of 24 hours, the pH was required to be maintained above pH 11.5. The amount of lime required to stabilize faecal sludge is determined by the type of biosolids, its chemical composition and the solids concentration (Williford, Chen, Shammas, & Wang, 2007). The lime dosage required to achieve a certain pH varied significantly between faecal sludge batches due to differences in solids content and chemical composition. For the lime stabilization experiments conducted in the field, the lime dosage to achieve pH 11.5-12 ranged between 17g-30g Hydrated Lime per kg wet sludge. Stabilisation with solid sludge was limited however with liquid sludge a COD reduction of 75% was observed for the produced effluent. During the hydrated lime treatment, the Total Solids (TS) increased marginally by 2-3% through the addition of chemicals and the impact on volatile solids (VS) over the 24 hour experiment was minimal even for high lime doses.

2.3.2 Result: what is the prototype of the sludge treatment and disposal?

Field results indicated that all three treatments have the potential to produce sanitised sludge which complies with the WHO guideline limit 10^3 *E. Coli* CFU/100ml. Lactic Acid Treatment required a treatment time of approximately 2 weeks (7-15 days) and involved the addition of a sugar source (Molasses 10% w/w) and a starter culture (10% w/w) to the faecal sludge. Urea treatment requires a one week treatment time (4-8 days) and the addition of the common fertilizer urea (2%w/w) to the faecal sludge. Faecal sludge treated using Hydrated Lime required a treatment time of 2 hours and pH 11.5-12 conditions. For Urea and Hydrated Lime Treatments, initial homogeneous mixing of the chemical with the faecal sludge was observed to be critical to the process. Temperature was observed to be the most important process parameter for the biologically based Lactic Acid Treatment. Overall Lactic Acid, Urea and Hydrated lime were identified as potential faecal sludge treatment methods that could be effective as simple, safe and robust sanitation methods in an emergency situation.

Table 2: Emergency Faecal Sludge Treatment Comparison

CRITERIA	LACTIC ACID	AMMONIA	LIME
Technology	Biological Treatment	Chemical Treatment	Chemical Treatment
Process Scheme			
Sanitisation time	7 - 15 days	4 - 8 days	2 hours
End pH of Faecal Sludge	3.8 - 4.2	9 - 9.5	11 - 12
Chemical Use	**Sugar Additive**	**Urea**	**Hydrated Lime**
	2g simple sugar/kg sludge 10% w/w pre culture (Pre-culture: 0.2% Yakult, 99.8% Milk) → 30g/L Lactic Acid	2% w/w Urea (20g Urea/kg Sludge – 9g TAN/kg Sludge)	17 - 30g Hydrated Lime/kg Sludge
Chemical cost per m^3 faecal sludge*	**€2.20/m^3** (100L Molasses) **€31.20/m^3** (Pre culture: 100L Milk, 0.2L Yakult)	**€16/m^3** (20kg Urea)	**€12/m^3** (25kg Lime)
Limitations	Temperature dependence for Lactic Acid Bacteria fermentation	Homogeneous mixing required Air-tight container	Homogeneous mixing required
Additional Treatment/ Re-use	Drying bed/ inoculum for subsequent batches	Drying bed/ fertilizer	Drying bed/ soil conditioner for acidic soils

* Note chemical costs are based on product costs sourced from Malawi originally in Malawian Kwacha

2.3.2.1 Prototype Faecal Sludge Treatment by Urea Addition

UREA TREATMENT

DESCRIPTION:

Chemical Treatment of Faecal Sludge using Urea is a suitable technology to be implemented in an emergency situation. Urea when added to Faecal Sludge is catalyzed by the enzyme Urease (present in faeces), to decompose into ammonia and carbonate. The urea decomposition results in alkaline pH that affects the equilibrium between Ammonia and Ammonium – favoring the formation of ammonia. The obtained unionized ammonia (NH3) is the main sanitizing agent for pathogen inactivation. The equilibrium with Ammonia gas is also important for the process. The solubility of ammonia gas in liquid depends on the temperature and partial pressures of Ammonia gas above the liquid. Therefore Ventilation and head space also influence the dissolved ammonia gas concentration and are important for process conditions. It is recommended that the treatment is undertaken in a sealed vessel to minimize the amount of ammonia gas that escapes and force the equilibrium towards the soluble ammonia. It is recommended that the treatment occurs as a batch process to ensure sanitization levels in the sludge are reached.
The process for Urea Treatment involves the addition of urea to Faecal Sludge in a ratio of 2% w/w using the wet weight of the sludge. The urea is initially placed in the bladder or sealed tank and then the fecal sludge is pumped into the vessel. The pump is subsequently used to recirculate the sludge within the bladder/sealed tank.
Contact between ammonia and the sludge: An initial homogeneous mixing is required to ensure an adequate contact between the urea and sludge. The Urea decomposition requires at least 4 days and therefore to allow sufficient residence time for the ammonia treatment: the sealed vessel for a period of approximately 1 week.

ADVANTAGES:

- Treatment time ≈ 1 week (4-8 days)
- Sanitises the Faecal Sludge (6 Log removal of E-coli)
- Simple Process which uses readily available material : UREA
- Final product with high nitrogen content beneficial for an agricultural re-use.

DISADVANTAGES:

- High chemical Input
- Initial mixing is essential for the process
- Vessel is required to be sealed
- Additional post-treatment is required for stabilisation

CONSTRUCTION REQUIREMENTS

Urea Treatment is required to take place in a sealed vessel. If using a portable bladder as the sealed vessel, it can be placed either above or below ground.

HEALTH ASPECTS / ACCEPTANCE

Urea : Hazardous in case of skin contact or eye contact (irritant), or ingestion or inhalation. May be combustible at high temperatures.

MAINTENANCE

Regular maintenance of pumps will be required

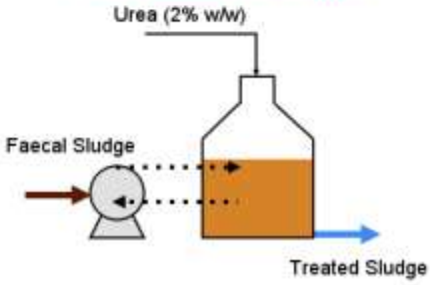
ADEQUACY

Urea Treatment is particularly suitable for the relief phase of the emergency due to its short treatment time (1 week), simple process and use of readily available materials

COST

Chemical: 16 euro/m3 Faecal Sludge (20kg Urea)

PROCESS SCHEME



2.3.2.2 Faecal Sludge Treatment by Lactic Acid

LACTIC ACID TREATMENT

DESCRIPTION:

Biological Treatment using Lactic Acid Bacteria has the potential to be adopted during emergency situations. Lactic Acid Bacteria (LAB) are bacteria which pose the ability to form relatively significant quantities of lactic acid from carbohydrates and are readily use for sanitation and fermentation processes in the food and fermentation industries. Lactic Acid, in its dissociated form is able to penetrate membranes and inhibit and destroy pathogens. The sanitization mechanism is triggered when the lactic acid concentration reaches approximately 20-30 g/L. This also corresponds to pH, where pH conditions of less than pH 4 induce pathogen inactivation. It is recommended that this process is carried out under batch conditions in a sealed vessel where possible. The critical lactic acid bacteria is cultured in an inoculum before being added to the fresh faecal sludge during the treatment process. The inoculum for the first batch will be a mixture of milk (99.8%) and yakult (0.02%) that has been mixed and stored at room temperature for 48 hours. For subsequent batches the treated sludge can be used as the inoculum.

For this biological process, Molasses and the inoculum are initially added to the tank in the ration of 10% w/w wet weight of the sludge. The Fresh faecal sludge is pumped into the vessel and recirculated to encourage mixing between the fresh sludge, inoculum and molasses. The sludge is then stored over a period of 2 weeks monitoring the pH daily to ensure a sanitised sludge is produced.

Optimally the process would be carried out in a sealed vessel as LAB are more dominant under anaerobic conditions. However LAB are aero-tolerant and therefore open tanks are a possibility if no sealed vessel could be sourced.

CONSTRUCTION REQUIREMENTS

Lactic Acid Treatment can take place in a sealed vessel or an open pit. If using a portable bladder as the sealed vessel, it can be placed either above or below ground.

HEALTH ASPECTS / ACCEPTANCE

Molasses is neither a health hazard or a physical hazard.
NEPA : Health:0, Reactivity:0, Flammability :1, Environment:0
(0= insignificant, 1= slight, 2= Moderate, 3=High, 4= Extreme)

MAINTENANCE

Regular maintenance of pumps will be required especially due to the acidic nature of the treated sludge

ADEQUACY

Lactic Acid Treatment is suitable for the relief phase of the emergency due to its simple process and use of readily available materials. It can also be applied as an on-site treatment opitions with pit latrines

COST

Chemical: €2.20/m³ Faecal Sludge (100kg Molasses)
Initial Chemical cost : €31.20/m³ Faecal Sludge (100L Milk, 200ml Yakult)

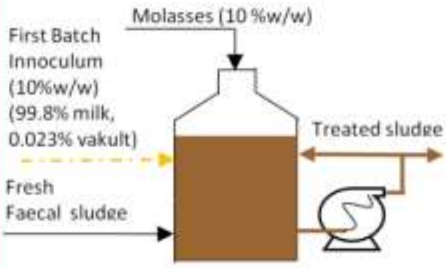
ADVANTAGES:

- Sanitises the faecal sludge (6 Log removal of E-coli)
- Simple Process which uses readily available material : molasses
- Produced sludge has a high lactic acid content (30g/L) can be used as inoculum for next batches
- Medium Treatment time ≈2 week (15d)
- Mixing is advantageous but not required for small batch sizes

DISADVANTAGES:

- Biological Process therefore susceptible to environmental conditions
- High Temperatures are required (30 C optimum)
- The initial batch requires milk and yakult (LAB culture)
- Produced sludge is acidic pH 4
- No stabilisation occurs and additional post sludge treatment is required

PROCESS SCHEME



2.3.2.3 Faecal Sludge Treatment with Hydrated Lime

LIME TREATMENT

DESCRIPTION:

Chemical Treatment of Wastewater or Faecal Sludge using Hydrated/slacked Lime (Calcium hydroxide : Ca(OH)2) is a suitable technology to be implemented in an emergency situation. This treatment uses hydrated lime to increase the pH of the wastewater/sludge and create a highly alkaline environment to destroy pathogens and sanitise the sludge/wastewater. It is recommended that the pH should be maintained above pH 12 for a minimum of 2 hours to ensure adequate reduction of pathogens. The Hydrated Lime treatment process is recommended to be undertaken as a batch process and is a robust technology that can be used to treat both solid and liquid sludges. Above pH 10.4 Hydrated lime also acts as a coagulant with the precipitation of Mg(OH)2 and allows for separation of sludge and effluent for liquid sludges with <3% dry solids. Hydrated Lime Treatment has been employed subsequent to the floods in the Philippines and it was also employed during the Haiti Cholera Epidemic.

CONSTRUCTION REQUIREMENTS

Hydrated lime Treatment can either take place above ground within a tanks or below ground by digging a pit and using a tarpolian as a sealing material.

HEALTH ASPECTS / ACCEPTANCE

Hydrated Lime is in powder form, therefore adequate PPE (masks and longsleave clothing) must be worn when handling hydrated lime to prevent irrigation to eyes, skin, respiratory system, and gastrointestinal tract.

MAINTENANCE

Lime is corrosive in nature due to its alkalinity, therefore regular maintenance of pumps used for mixing will be required.

ADEQUACY

Slacked or Hydrated Lime Treatment is particularly suitable for the relief phase of the emergency due to its short treatment time, simple process and use of readily available

COST

Chemical: €10/m³ Faecal Sludge

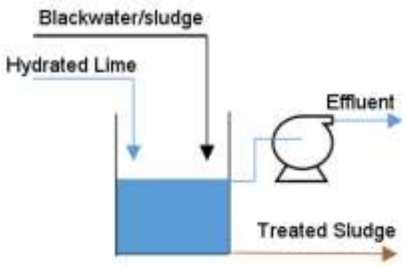
ADVANTAGES:

- Short Treatment time < 1d Sanitises the wastewater/faecal sludge (6 Log removal of E-coli).
- Simple Process which uses readily avaialable material
- For liquid sludges – a sanitised and stabilised effluent is created suitable for soil infiltration

DISADVANTAGES:

- High chemical input
- Mixing is essential for the process
- Highly-alkaline sludge &effluent created – requires subsequent neutralisation
- Additional treatment required
- Lime quality can impact dosage rates

PROCESS SCHEME



2.3.3 What is next?

Based on the results of the field testing, the three methods are capable to sanitise faecal sludge from public toilet of Blantyre, however; in order to prove the robustness of each method and their applicability in real emergency situations (under different types of faecal sludge and climate conditions) it is required to test each method at large scale.

Three different emergency scenarios will be proposed and according to the location (agreement with local partners) and budget availability, the methods will be tested. Once the testing process is finished, final recommendations will be included and the products will be ready to apply in emergencies.

2.4 Prototypes 'Sludge pasteurizer'

Within this project we have designed and built a pasteuriser unit that is able to kill pathogens through a defined heat and time regime that complies with the EU-regulations (EC) No. 1069/2009 and (EC) No. 142/2011[3]. The pasteuriser has been tested in a laboratory in the first quarter of 2014. Details on pasteuriser design and test have been described in the M27 progress report.

Figure 14: Pasteuriser unit, set-up for laboratory test

2.5 Laboratory tests – material and methods, result

We have tested the digester at the University of Hohenheim, which is recognised for the work in animal health as well as in anaerobic digestion. Instead of raw human faecal matter, which is not readily available in the required quantities, we have used cattle slurry from the neighbouring university farm "Meiereihof" to test the effectivity of pathogen removal in our pasteuriser. Compared to human faeces the cattle manure contains more fibres. Also, cattle slurry has a higher viscosity than human faecal matter (including urine). This is important with respect to heat transmission within the slurry and its mixability. Viscosity and fibre content have a negative effect on both heat transmission and mixability. Therefore it is assumed that the results achieved using the more "difficult" substrate can be transferred to human faeces.

In the following sections we will describe how we have tested the pasteuriser and the corresponding findings.

[3] Both EC-regulations actually deal with animal by products. The test organisms they refer to are, however, the same for human faecal matter and therefore we use them as reference. The parameters for pasteurization specified in Regulation (EC) 142/2011 are: temperature = 70 °C, hold time = 1 hour, max. particle size = 12 mm.

2.5.1 How did we test the pasteuriser

First the principle functions of the unit itself, the pasteurising process and the useablity of the control unit was tested with water. Those tests serve as a basis for comparison for later tests with cattle slurry. In both cases relevant test organisms have been introduced into the main pasteurizing vessel and into the pipelines using special germ carriers from the from the Institute of Animal Hygiene and Veterinary Medicine at the University of Hohenheim. The germ carriers were inserted into the vessel using tea balls and tea eggs.

Figure 15: Germ carriers before and after heat treatment in pasteurizer plus control samples

Figure 16: Test points in pasteuriser (left: tea ball on chain in main vessel, right: tea egg at valve in pipeline)

The following test organisms have been used:

- Escherichia coli (used strain: E. coli ATCC AA229)
- Salmonella typhimurium (used strain: Salm. typhim DSM 26529)
- Enterococcus faecalis (used strain: E. feacalis DSM 2570)

Additionally two non-pathogenic strains of Vibrio cholera (Vibrio cholerea 0395-NA nqr and Vibrio cholerea WT: 0395-NA) were used as indicator organisms.

After insertion of the test organisms the liquid inside the pasteuriser has been heated up to 70 °C using two electric heat coils with a connected load of 9 kW_{el} each.. At the beginning both coils have been used, but one coil has been switched off once the slurry has reached a temperature of 40 °C. Once the liquid had reached the target temperature, the heat coils have been switched off and the actual pasteurisation has started.

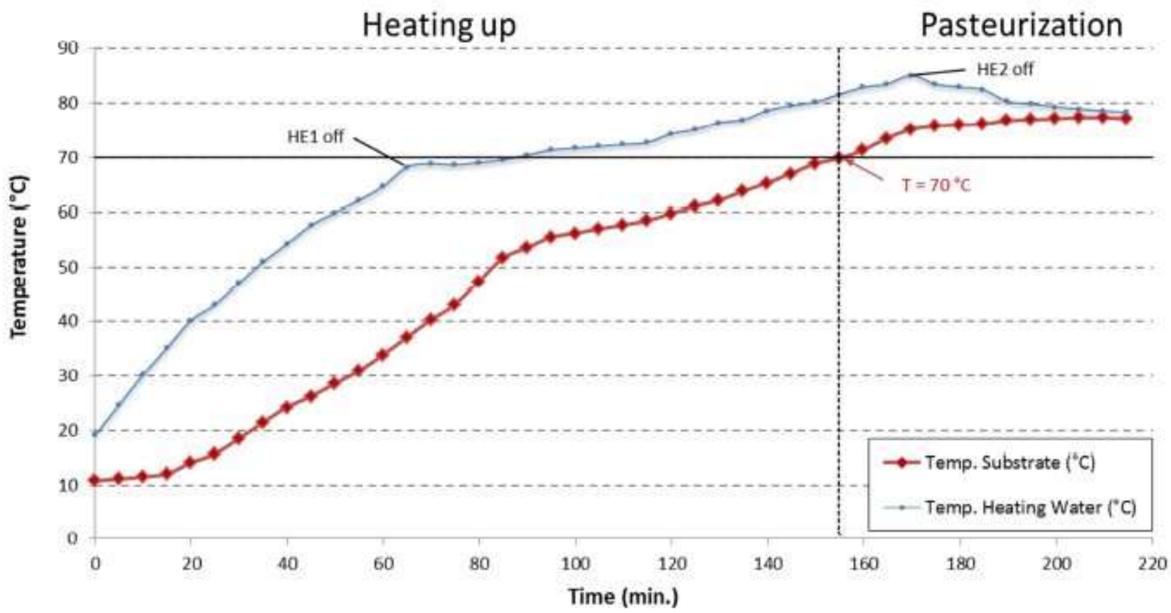


Figure 17: Heating curve of cattle slurry in pasteuriser

2.5.2 Test results

After completed treatment the pathogens have been re-isolated and re-cultivated at 37 °C. When assessing the re-growth of the pathogens a clear distinction between sample and control sample was visible. While control samples showed a growth rate between 10^7 and 10^{10} CFU/ml the treated samples only showed low growth rates. Pathogens from the larger germ carriers formed up to 36 CFU/ml, while those from the small vessels stayed at maximum 3 CFU/ml. The table below shows the corresponding reduction rates, that are in any case higher than 5 log units.

Table 3: Reduction rate of the tests at a glance

Indicator organisms	**Germ Carrier (GC)**	**Reduction rate (lg R) water**	**Reduction rate (lg R) 1st row manure**	**Reduction rate (lg R) 2nd row manure**
E. coli	GC 1	>7,70	>7,10	>8,56
E. coli	GC 2	>8,49	>8,90	>9,56
Salmonella typhimurium	GC 1	>7,56	>7,85	>6,90
Enterococcus faecalis	GC 1	>7,70	>7,49	>7,19
Vibrio cholera	GC 2	n.t.	>6,42	>6,66
Total germs	-	n.t.	n.t.	2,00

In this respect the pasteurizer unit is a suitable way to sanitize human faecal matter.

3. Prototypes Water drilling kits

For this deliverable PRACTICA has focused on:

- The further improvement of the Jetting kit;
- The testing and design of a 'Capstan kit' aimed at mechanizing manual drilling.

3.1 Prototype Jetting kit

3.1.1 Process

For the jetting kit, the focus since the last deliverable has been the improvement of the starting concept (see deliverable 3.2) with the aim to improve on:

- **Technical robustness**: all parts should be technical sound and proven in the laboratory as well as in the field. The following pictures show, as an example, the development of the drill bit in which the best practices of professional drill bit design are combined with experiences from the field.

Figure 18: Evolution of drill bit design

- **Simplicity:** reducing the complexity and number of parts resulting in a more robust and cheaper design. The following pictures show the process of reducing complexity in the design of an inlet for the kit as an example how the complexity of this part was reduced. The first photo shows the current practice in the field (no inlet), the photos after that the evolution in design.

Figure 19: Evolution of inlet design

- **Weight**: the decrease of weight results not only in lower transport cost but also in easy of drilling as 90% of all parts used are lifted and rotated during the drilling process. The following pictures show the weight reduction (and safety improvements) for the pitbox. The pictures above show the current situation in the field (left) and the improved version (right). The lower pictures show the evolution of the design;

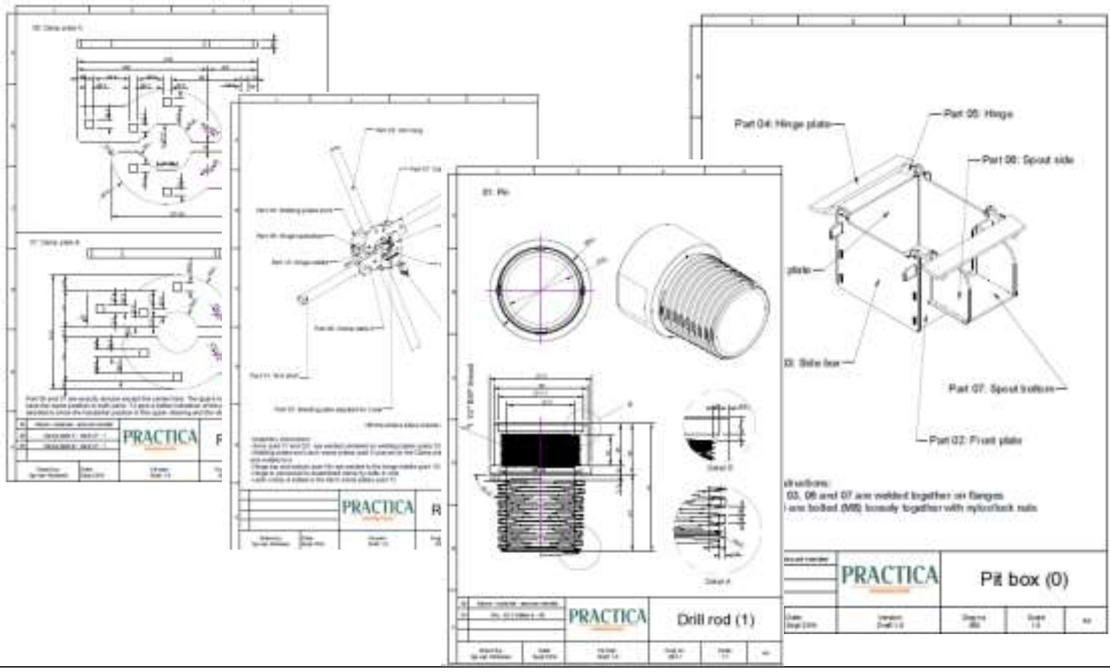
Figure 20: Evolution of pit box design

- **Production (cost)**: by using simple techniques - such as making parts a 'puzzle' that allows easy assembling before welding - reduces the labour cost. An impression of such 'cost reducing puzzle' can be found on the following pictures:

Figure 21: Example of a 'puzzle' for cutting cost in production

3.1.2 Result

Each and every part of the concept kit has been examined and improved based on the parameters described above. Frequent feedback of experts was asked. Improvements have been tested in the lab as well as in the field for multiple times during different stages in the design process. The full description of these improvements can be found in the Appendix 6. Technical drawings have been made of each part.



3.1.3 What's next

The next step will be extensive field testing which will provide input for further improvements. Currently possibilities for testing the kit in the field are explored, e.g. with the Red Cross.

3.2 Prototype Capstan kit

3.2.1 Process

In the first phases (deliverable 3.2) of the S(P)EEDKITS project, multiple technical concepts were examined for professionalizing and/or mechanizing a drilling kit. A professionalized rotary jetting kit was ranked as most promising within the 'Speed' context. Ranked second, the mechanization of sludging or percussion by means of a rotating capstan came out as a promising option. This solution might have its application in emergencies, but more clearly will have high potential in the 'Seed' context as it can be used as an add-on with existing manual drilling kits.

The main problem determined in the feasibility study is the degradation of the tested ropes on the capstan system. To overcome this problem a literature study was performed. Based on the findings in the literature research it was concluded that:

- Three (design) parameters affecting the degradation of the rope are: (1) the contact length (of the rope on Capstan), (2) friction force and (3) the speed of the capstan relative to the rope as the line slides on the drum.
- Drilling (in general) with a capstan is possible. It is performed on a regular basis for 'standard penetration tests'; an off-the-shelf product is available.
- The technique generates a relative efficient free fall (which in needed for the manual drilling techniques) given a limited number of turns on the capstan.

Yet, the boundary conditions for the 'standard penetration tests' are different. The test uses a limited weight (about 64 kg). The effect of wearing of the rope with heavier weights (up to 200 kg) being used with the Rota sludge technique could not be determined and would need to be tested.

The following testing process was determined to come to an optimal design based on the determined design parameters.

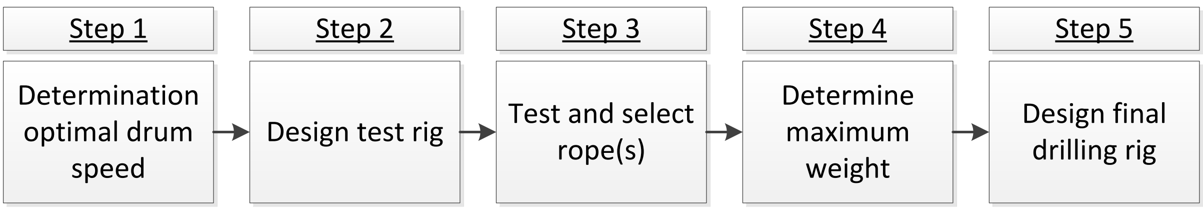


Figure 22: Testing process for the rope.

The optimal drum speed was determined empirically. With multiple gear ratios tested on an in-house prototype it was concluded that the optimal speed is about 30 m/min. A test rig was engineered. The rig was used to test multiple ropes with different weights and multiple drum speeds. This was done by visual inspection of ropes and indicative temperature readings.

After extensive testing it was concluded that:

- Natural fibered ropes are favored above technical/synthetic ropes. The temperature readings combined with visual observation show that the degradation of the different ropes is distinct different. The high-tech rope appeared to give less grip which appeared to give a higher temperature increase, potentially due to higher friction. In addition these ropes seemed to suffer more from the temperature, resulting in discoloring and unraveling, while natural fibered ropes tended to suffer less as a result of high temperatures;

- In a comparison made between two different natural fiber ropes, manilla can be favoured above hemp. The temperature increase and degradation of the manilla rope appears to be less;
- The heavier the weight, the faster the degradation of the rope. Although heavy weights (100-200 kg) are possible, it was concluded the rope degrades in such a rate that it is advisable to limit the weight. A weight up to 100 kg appears to result in an acceptable degradation rate of the rope. This limits the applicability of the machine to low weight sludging methods (Baptist, EMAS, SHIPO) and percussion gear.

Figure 23: Manilla rope: left picture 2 wraps, 76 kg, 80 rpm, middle: 2 wraps, 118 kg, right: 80 rpm/2 wraps, 160 kg, 80 rpm

- The capstan design does influence the degradation of the rope. This factor was not mentioned in the literature found. Particular a steel design (see picture below) which centeres the rope in the middle of the drum proved to be a design that limits the damage to the rope;

Figure 24*: Capstan design.*

- Safety is an issue as the rope can knot itself on the drum making it impossible to stop. Safety stops on the engine are highly recommended.

3.2.2 Result

Based on these findings a final design was made and successfully tested. Important design parameters were the ability of local production, maintenance and repair and the ability to fit it to standard tripods used in the field so the kit can be used as an add-on by exiting manual drilling companies. The pictures below show the result.

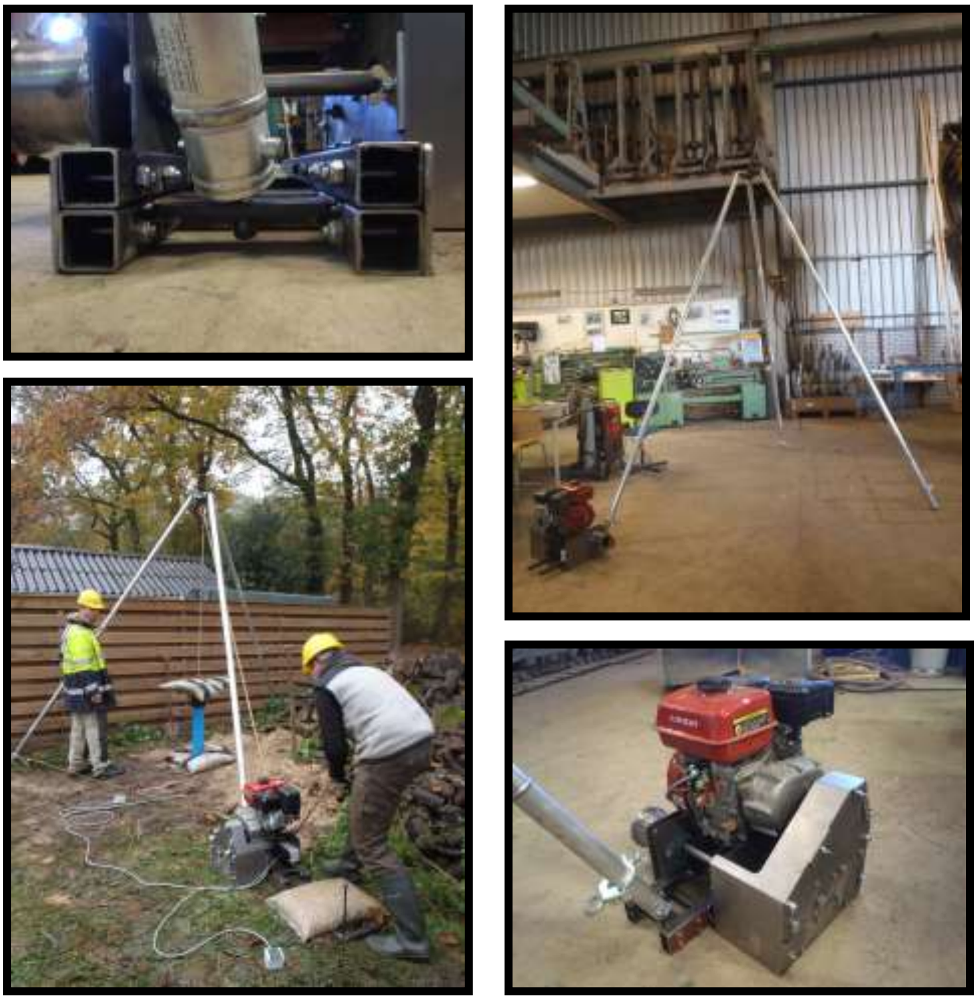


Figure 25*: Final design*

A complete set of drawings including an assembly manual of the machine was produced.

3.2.3 What's next?

The next step will need to be extensive testing in the field on a suitable location for longer periods of time. These tests also need to prove the local fabrication and maintenance of the system, the availability of parts and the social and financial acceptance of the method by manual drilling teams.

4. Improved water storage

In this part, two kits for improved storage of water are presented: the water reservoir and the water bag. The first is large scale (10m3 or more), the latter is an alternative for the currently used flexible jerry cans (10-20 litre).

4.1 Water reservoir

4.1.1 Process: What did we do and how?

The initial intention was to develop a foldable water reservoir exclusively made of flexible materials like water liner and textile based reinforcement scrim (cf. D3.2 Concept and Design of WatSan Kits). The goal was to obtain a light weight foldable tank.

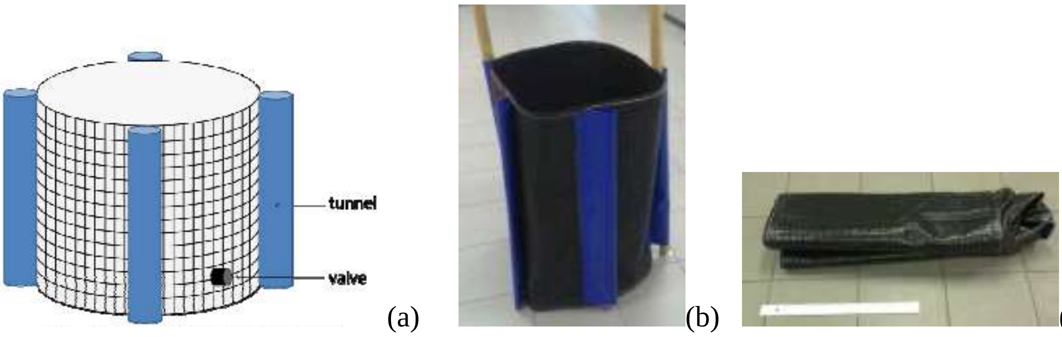


Figure 26: foldable water reservoir in coated textiles

Such reservoirs must be designed for the storage of water quantities up to 90 m^3.

Calculations were performed for forecasting the maximum affordable dimensions for the container regarding to the materials used for making it. Results shown that by using only textile as reinforcement material for a water reservoir, dimensions are limited to volumes up to 10 m^3.

Regarding to these results, it has been decided to evaluate the use of a state of art reinforcing frame in steel. Up to day such frame consists in 1.4m high steel posts reinforced with 0.85m horizontal bars (cf. *Figure 27*).

Figure 27: 10m^3 steel frame reservoir.

The intention was to up-scale such reservoir to 2.4m height in order to challenge Oxfam tank made with corrugated steel plate surroundings.

Indeed such reservoir would have interesting features compared to an Oxfam tank. Its weight would be lower and it could be repacked. However it cost would be slightly higher (cf. *Table 4*). By analyzing the contribution of the steel frame in the weight and the cost of the reservoir, we evidenced that the steel element represent 45% of the cost of the reservoir and 55% of its weight.

Table 4: Comparison between steel frame reservoir and Oxfam tank.

70m3 container	Steel frame reservoir	Oxfam tank
Weight	570 kg	650-700 kg
liner	PVC coated textile	EPDM
valve	To be determined	3"

Calculations based on the mechanical resistance of 45*45*2 (S235) tubes showed that a height of 2.4m is not realistic regarding to the frame resistance which is exceeded about 7 times. Thus at that stage, efforts need to be made on the design of the frame itself and the material choice

4.1.2 Result: What is the prototype?

Up to now the prototype of the water reservoir consists with a 1.45m high steel frame.

4.1.3 What's next?

Lately there has been renewed interest from an NGO in this development. They are going to share information about opportunities for 1.4m high steel frame container. Depending on that, an improved prototype might be built for more extensive testing.

4.2 Foldable water container

4.2.1 Process: What did we do and how?

Several concepts emerged from the designing phase driven by PRACTICA (cf. D3.2 Concept and Design of WatSan Kits). Four of them have been selected for evaluating their feasibility and production costs by a prototyping phase leaded by SIOEN (cf. *Figure 28*).

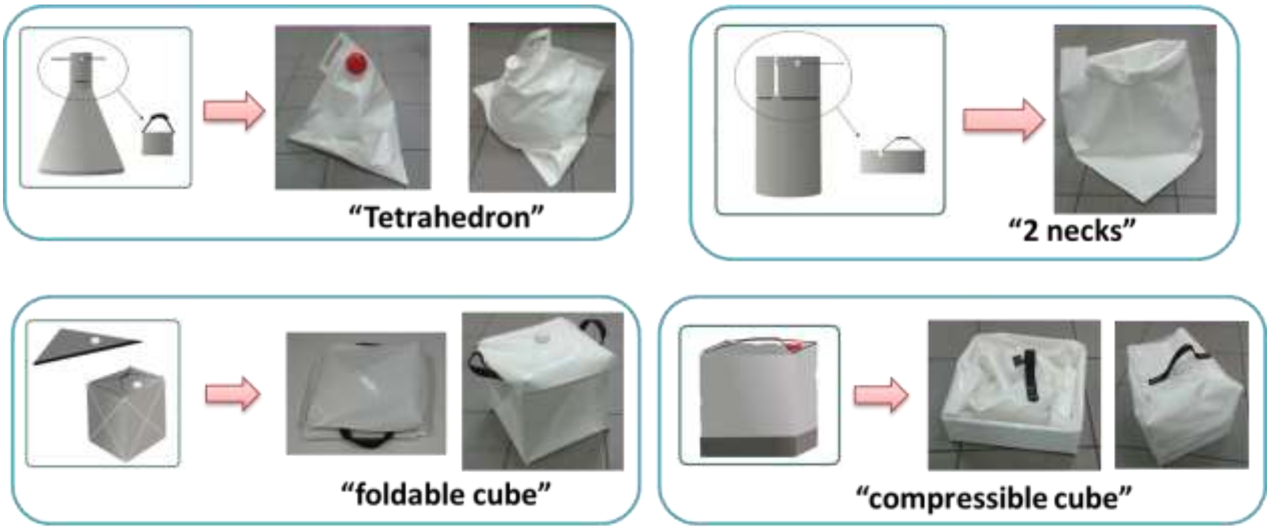


Figure 28: Four selected concepts by PRACTICA and prototyping results from SIOEN.

Three concepts out of the four were successfully prototyped by using coated textile as the main raw material. For refining the selection, the need in materials (textile, accessories) and the relative time to produce each concept was evaluated and compared (cf. *Table 5*).

Table 5: Comparison of the four concepts regarding to the manufacturing point of view.

Concept	Need in textile (in m2)	Time needed for one piece (in hours)	Bill of Material	Need/possibility for an inner liner?
Tetrahedron	0,87	0,22	Flange and cap, rope, eyelets	Yes/no
Foldable cube	1,44	0,44	yarns, "kador", strap	Yes
2 necks	?	?	?	No
Compressible cube	1,26	0,36	Yarns, plate, strap	Yes/no

Base on the data reported in *Table 5*, it was evidenced that the tetrahedron concept represents the most promising design to further develop. Indeed this concept has the smallest need in textile and confectioning time. Moreover it presents the advantage to be used with or without a liner. If such a liner is needed, its production will have to be outsourced.

In November 2013, partner IFRC-SRU offered the opportunity to send some foldable water containers to Burkina Faso. At that stage the water container "Tetrahedron" consisted in a 20 liters PVC coated bag with a tetrahedral shape and a 50mm opening with a screw cap (cf. *Figure 29*). Pieces in two colours were sent; white and sandy yellow. Coated textile material used, SIOEN B6303, is compliant with EU directive EC 1935/2004 for food contact materials.

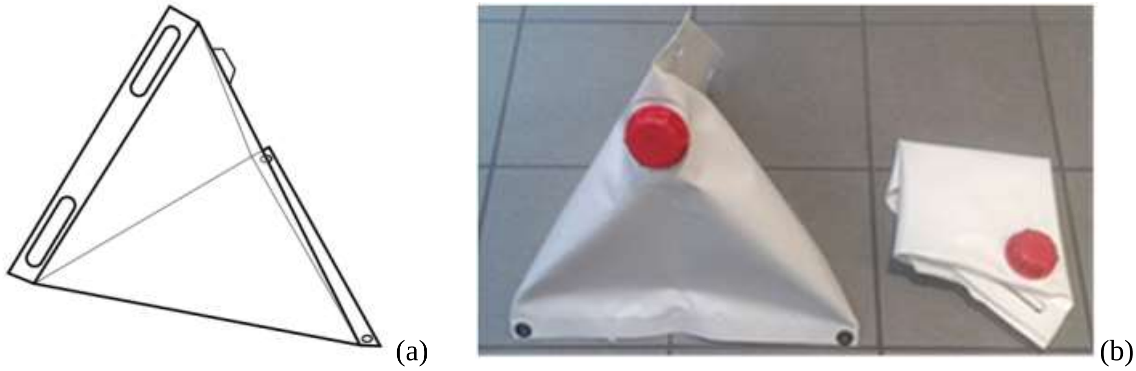


Figure 29: representation (a) and picture (b) of the "Tetrahedron" as shipped to Burkina Faso in November 2013.

12 pieces of the "Tetrahedron" have been shipped to a Touareg refugee camp and distributed by Red Cross local staff and to Touareg refugees. *Figure 30* shows pictures from the field test.

Figure 30: pictures made by IFRC-SRU during the field test in Burkina Faso in November 2013.

After the distribution, feedback was obtained from the users and allow us to focus on the following topics to improve the tetrahedron:

1. Choice of the material in contact to the water (preservation of water quality),
2. Opening system (for improving the easiness to fill and to empty in a controlled way),
3. Handle's design (for a better carriage's ergonomics and weight balance).

The first issue can be tackled in two ways; or using an inner liner with a tetrahedral shape, or switching to PVC coated material to TPU or TPO based coated textile. As PVC offers the best price/performance balance for this application, we decided to outsource tetrahedral inner pouches for insuring the contact with water. Such shape, at such dimensions has never been produced in the packaging industry. Several companies were consulted for supplying the inner liner, two accepted the challenge and made prototypes of 20 litres tetrahedral liner after several months of development.

The second issue consists in optimizing the opening system. Changes should permit to avoid losing the cap when unscrewed from the flange. And helping the filling and emptying of the bag with appropriated cap design (e.g. cap with tap). This issue can be tackle meanwhile to the choice of the liner. Indeed various cap designs are available on the market (cf. *Figure 31*). A design with a tap and a link between the cap and the flange has been requested to the pouch suppliers.


(a)

(b)

Figure 31: screw cap equipped with a tap (a) and cap with a link (ring) for attachment to the flange.

The third issue regarding the handle design must only induce minor changes in the outer bag design in order to stick with the tetrahedral shape. Thus, it was proposed to simply add a third handle.

In parallel to the development and the optimization of the Tetrahedron concept, another concept has been developed.

This parallel approach is based on the integration of a commercially available inner pouch in a flexible container made in technical textile. This new concept is called "Column" (cf. *Figure 32*).

Figure 32: "Column" concept

A 12 litres "Column" water bag has been prototyped and tested regarding to the drop test. The prototype successfully passed the drop test with 3 drops at 2.5m high.

4.2.2 Result: What are the prototypes

Two prototypes of water container have been developed in parallel; the "Tetrahedron" and the "Column"

The "Tetrahedron" consists in a 20 litres bag with a pyramidal design. When filled with water, the external shell in coated textile passes the drop test at 2.5m. The pyramidal shape offered stability while standing on the ground (cf. *Figure 33*). An inner liner with 63 mm has been developed on demand.

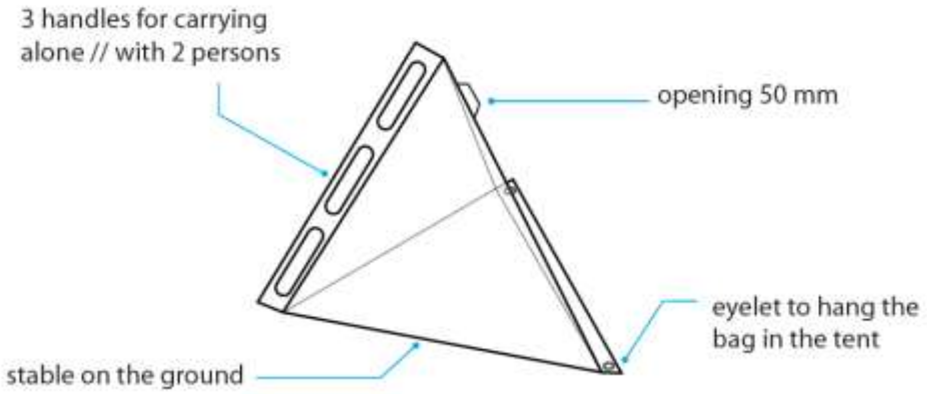


Figure 33: Representation of the outer bag of the tetrahedron.

The second concept, the "Column" consists in a vertically oriented elliptical extruded shape (cf. *Figure 34*).

It is made with a plastic inner liner and has been validated regarding to the drop test with 12 liters capacity.

Figure 34: prototype of a 12litres "Column" bag

Table 6 here below is comparing the features of the two concepts.

Table 6: Comparison of the two small water container concepts

	Tetrahedron	**Column**
Volume	20 l	12 l
Price estimation	5-7€	7-9€
Opening	Ø 63mm	Ø 63mm
Drop test	To be tested with the liner	3 times @ 2,5m

4.2.3 What's next?

The next step regarding the optimization of the "Tetrahedron" concept will consist in prototyping new pieces by using the last inner pouch received.

Following this, 20 pieces of "Tetrahedron" and "Column" will be produced.

10 pieces of each will be tested by partner CTB in comparison with 10 Oxfam bucket and 10 collapsible Jerry cans.

10 pieces of each will be used for a comparative field test with Oxfam bucket and collapsible Jerry can.

The objective of the comparative testing and field test is to evidence the benefits of the new concept by comparing their durability, easiness to shipment, price with state of the art solutions.

5. Prototype container based kit

The container- based kit consists of the following components:

i Supply water tank
ii Water Filtration Kit
iii Waste water tank
iiii Waste water treatment

The progress for each item is summarised in the following chapters.

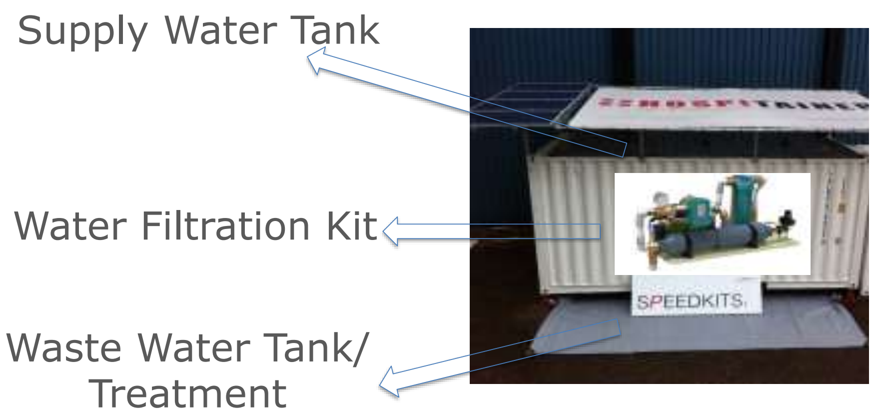


Figure 35: The various parts of the container- based kit.

5.1 Supply water tank

5.1.1 Process: What did we do and how?

For different containerized solutions developed within S(P)EEDKITS, like the rapid deployable field hospital (see WP4), large amounts of water will be needed. Flexible water tanks are currently used in disaster areas to have big storage capacity, but limited volume and weight during transport.
By placing these tanks on the roof of the containerized solutions, some additional advantages can be achieved: no additional floor space is needed (useful in urban areas), there is always water pressure (even without power), and the tanks are protected against damage or abuse.
The drawing below shows the dimensions of the first design. Three height-reducing systems are installed in the middle.

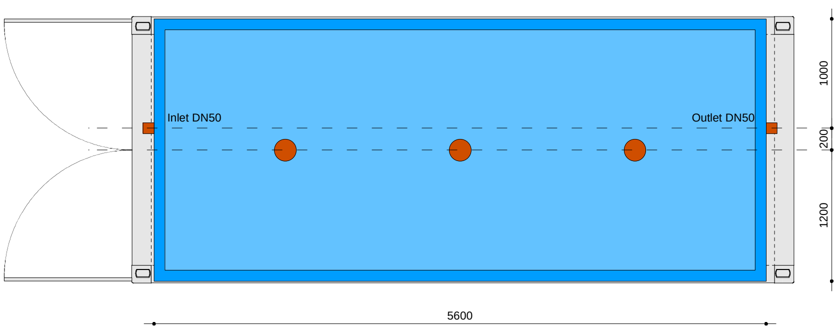


Figure 36: water tank on the roof of the containerized solutions - sketch.

The tank has been tested on a real container roof to verify the deformation of the containers roof:

Figure 37: water tank on the roof of the containerized solutions – picture of protoype.

Results:

- A 20ft sea container can safely carry a flexible storage tank with 2000 litres of water.
- The height reducing provisions need to be improved to prevent contact between water and air (with contamination of potable water as possible result).
- Overfill of the flexible container will not directly result in unsafe situations (tested up to 6000 litres)

Assuming electricity is not available, it has also been tested if the water pressure is sufficient to let the water flow through the current particle filters. The system can still give 7 litres of water per minute, which is acceptable for a shower or one tap.

5.1.2 Result: What is the prototype?

A prototype of the supply water tank has been made and is tested. Minor improvements will be added during the next months, so the system can be tested during the Demonstration Phase.

5.1.3 What's next?

After finishing the tests, the results show that the containers roof was a little bit lowered and deformated compared to the starting position. This could be the result of the overload test as it was applied on an old container, which is weaker as the standard containers used. Additional tests will be executed to verify what the results are if the test is executed with the tank filled up to the maximum of 2000 litres of water instead of 6000 litres.

Additionally improvements to the height reducing system will be tested. One-way valves are added, so no small animals can enter the tank and still the water can overflow when necessary.

The type of connection to the water filtration system can also be improved. The system should be easily (re) connected and interchangeable with the water tower or basic IBC tank.

5.2 Water filtration kit

5.2.1 Process: What did we do and how?

In containerized solutions like medical operation theatres, the supplied water should be clean enough for washing hands, disinfection etcetera. Because in a disaster area the quality of the supply water can differ, an additional water treatment system will be needed to have a guaranteed water quality.

Together with Leo Groendijk, lecturer in Watertechnology at Van Hall Larenstein and the University of Wageningen in the Netherlands, different options for a water treatment system are studied and compared to each other regarding robustness, simplicity, maintenance, price, volume and weight. After this study, the most promising components were combined into a system.

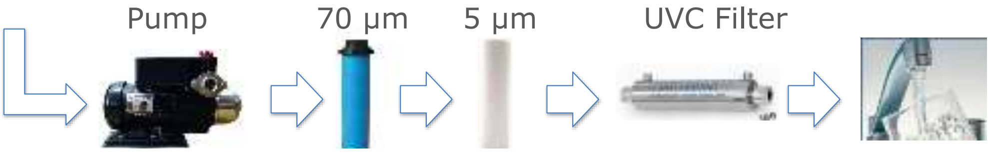


Figure 38: Water flow for the water filtration kit.

Prototypes have been tested at the following three locations:

1) Mobile operating theatre in Homs-Syria
2) Mobile maternity clinic in Daraa-Syria
3) Emergency Maternity Clinic in Palo Leyte – the Philippines

Initially the following dis-advantages have been noted:

- Maintenance needs to be executed frequently. The 5 micron filter needs to be replaced each month and the UVC filter each year. If maintenance is not executed the water will become dirty without any warning.
- The system cannot treat water with particles smaller than 5 micron (bacteria and viruses are eliminated through the UVC filter)

Based upon the field results the following conclusions are taken:

1) The filtration system is only working properly, based upon good maintenance (management).
2) A filtration system which is fail-safe would be an improvement

Research is being executed to improve the system with four objectives:

- Keep the robustness of the current design
- Reduce the maintenance frequency
- Design a fail-safe system
- Extend the particles work field

The following graph indicates different filter techniques in relation to the removed particles and their size in micrometres.

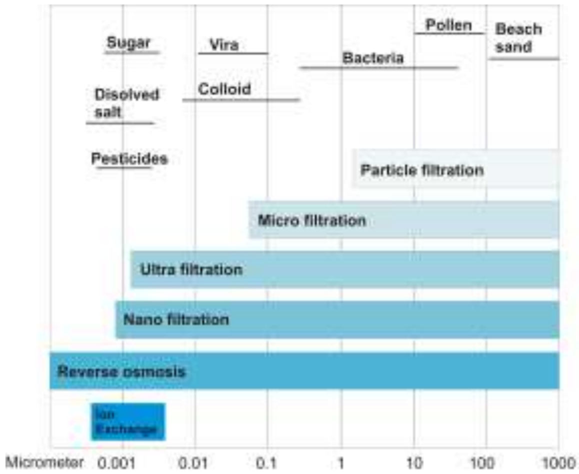


Figure 39: different filter techniques in relation to the removed particles and their size.

The initial prototype is filtering up to 5 micrometre and the UV-filter makes sure the bacteria and viruses are de-activated.

The goal of the research was to finally have a maximum of three designs that are supplementary. Based upon the project objective, available water quality and budget, it can be quickly decided to use one of these three systems. All systems should be scalable for small (household water demand) and large (village) water demands.

Generally a larger filter working range is introducing smaller filter membranes resulting in a higher water flow resistance. To compensate the resistance a more powerful pump is needed. Another characteristic of tighter filters is the risk of clogging. Therefore forward and backward flushes are needed to clear the filter, resulting in inefficient water use.

Reverse Osmosis is covering the widest range of water filtration. It is a proven concept, but has also the highest power consumption and most inefficient water use. Next to these dis-advantages also minerals and salts are removed from the water. The output water is only pure water that can be aggressive for the distributing pipes and cannot be used as drinking water. To get the water at an acceptable acidity level, minerals must be added to the output water.

It has been concluded that reverse osmosis could be used to convert brackish, salt water or water containing chemicals into drinking water. For other sources different techniques are sufficient.

Nano and Ultra filtration are introducing still a big range of particles, which are filtered. The advantage is that the salts and minerals remain in the water. An acceptable acidity level is maintained in the output water.

It has been decided to initially design a water filtration system based upon ultra filtration, based upon an open foam structure with 7 capillaries in each filter straw. This technique eliminates as much as possible clogging of the filter.
Next to these characteristics the filter can easily be extended with a forward and/or backward flush. If the system is clogging it can be flushed easily.

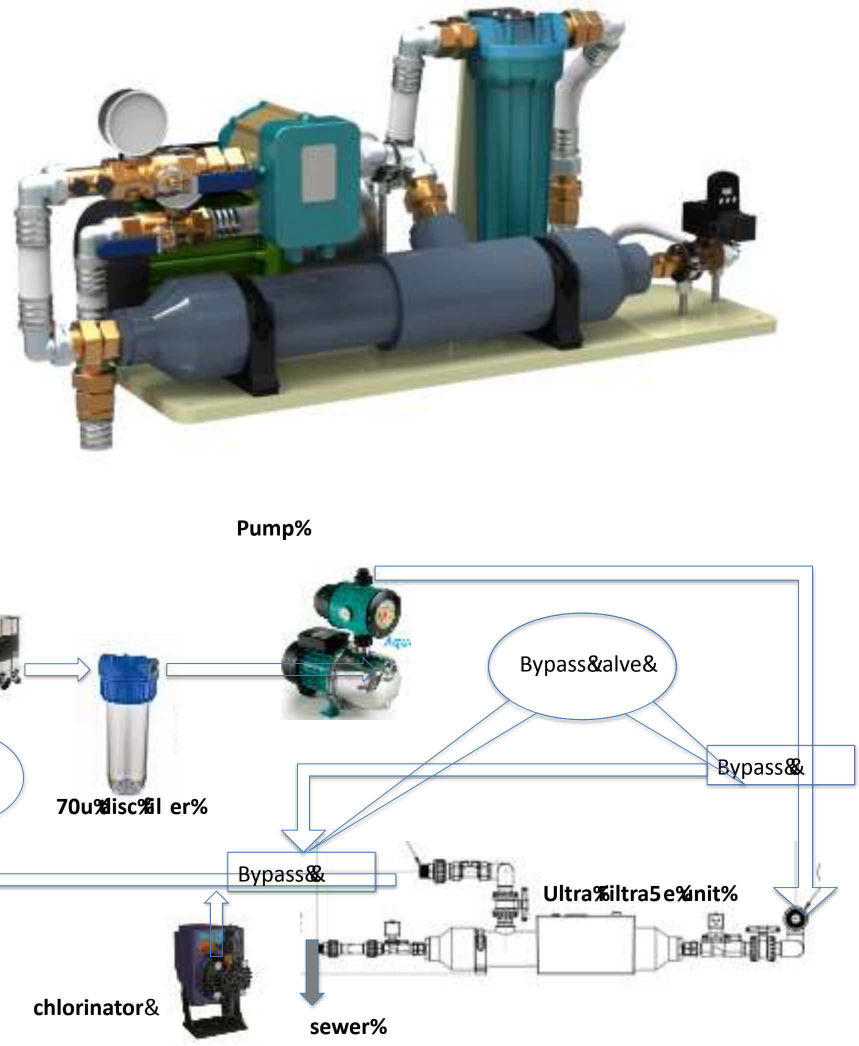


Figure 40: Sketch of ultra filtration system.

Advantages of the system:

- Only a disc filter as pre-filter. The filter can be easily cleaned and does not need to be replaced (no spare parts needed).
- The filter module only needs to be replaced each 5 years or approximately 40 cubic metres of water
- Automatic forward flush timer to prevent the filter against clogging.
- Automatic backward flush timer can also be added (minimum of two filter modules).
- Fail-safe. If the filters (disc and ultrafiltration) are not replaced or flushed it will clog and no water will flow out of the taps.

Disadvantages

- Initial costs are higher comparing to the first prototype (although less spare filters are needed, thus being competitive).
- The filter module is quite long

- A pump is necessary to push the water through the filter
- Higher power consumption due to back-flush.

Parallel a literature research is executed on alternative techniques. The following table shows the current techniques under research. This research will be continued in the next months.

Technique	**Findings**
Voltea http://www.voltea.com	- Specifically for brackish water - Scalable - Low energy consumption
Drinking with the wind http://www.drinkingwiththewind.com	- Specifically for brackish or sea water - One wind mill for 7000 litres of water per day - Reverse Osmosis technique - Much space needed for high volumes of water - Big installation for rather small amount of water production.
Solar DW http://www.solardew.com	- Any water can be used - Scalable - Rather big surface needed for rather small water production - Not yet in production
Eole Water http://www.eolewater.com	- No water source needed (water is retrieved out of the air) - Windmill - Rather big surface needed for rather small amount of water

5.2.2 Result: What are the prototypes?

In total seven prototypes have been built and are currently under test:

5 micron filtration unit including UVC disinfection:

	Mobile operating theatre in Homs-Syria
	Mobile maternity clinic in Daraa-Syria
	Emergency Maternity Clinic in Palo Leyte – The Philippines

Ultra filtration

	Mobile laboratory – Sierra Leone Single ultrafiltration unit Water production of 1m3 per hour
	Containerised laboratory (2x) – Liberia & Sierra Leone Single ultrafiltration unit Water production of 1 m^3 per hour

	Automatic forward flush
	Ebola treatment centre – Sierra Leone Double ultrafiltration unit Water production of 2 m^3 per hour Automatic forward and backward flush

5.2.3 What's next?

Three prototype ultra filtration systems are currently tested in the field. Based upon the feedback the system will be reviewed.

Scalability is achieved by adding more filters, but also a buffer tank. The option for buffer tanks should be reviewed and tested.

It would be interesting to test one of the state-of-the-art water filter techniques, which are currently researched.

The current applied pump is introducing high peak electric currents. A desk research will be executed to find a more leveled pump.

5.3 Waste water tank

5.3.1 Process: What did we do and how?

In addition to the supply water tank on the containers' roof a wastewater tank under the container has been designed and prototyped.

To prevent clogging of the tank, a grease trap has been selected. This grease trap can be placed next to a container to ensure a correct flow of the wastewater.

The complete system, including improved supply water tank and new wastewater tank, is ready for testing.

5.3.2 Result: What are the prototypes?

A prototype of the wastewater tank has been made and is currently under test. Based upon the test results it will be improved for the demonstration phase.

Figure 41: Prototype of waste water tank under container.

5.3.3 What's next?

The prototype is ready and must be tested in combination with the selected grease trap. Based upon the test results the tank will be improved.

Also fitting materials will be reviewed, so pipes and valves can be easily (re)connected.

5.4 Waste water treatment

5.4.1 Process: What did we do and how?

In a hospital, much water is used for cleaning and disinfection. This wastewater has other characteristics as 'normal' wastewater, for example due to disinfectants and pathogens. For safe discharge of wastewater regarding the WHO-guidelines, treatment will be needed.

Together with students of the faculty of Water technology and Environmental Sciences from the Van Hall Larenstein University of Applied Sciences, a new research is done based upon an aerobic biological treatment system.

The main objective of this research was to investigate whether it is technical feasible to use an aerobic activated sludge system to treat hospital wastewater.

The following research questions were defined in order to achieve this main objective.

1. Is hospital wastewater negatively affecting the purifying capacity of activated sludge?
2. Is it possible to achieve a faster start-up time by using freeze-dried activated sludge?

A literature study identified eight cleaning agents that might negatively affect the treatment capacity of the activated sludge. Synthetic hospital wastewater was created and buffer tank tests with this water revealed that hospital wastewater that is buffered for a period of 24 and 48 hour does not negatively affect the respiration rate of the sludge. Tests in which peak discharges of cleaning agents were simulated revealed that the disinfectant Surfanios and HTH negatively influence the respiration rate of activated sludge.

Sludge from the wastewater treatment plant in Leeuwarden was freeze-dried and tested in a pilot. Analyses on respiration rates and COD removal efficiency showed that reasonable activity can be regained within a start-up time of about two weeks. COD removal efficiencies of almost 90% within 10 days were achieved with hospital waste water. Normally the start-up period for a wastewater treatment system takes at least several weeks.

Based on these results it can be stated that a biological treatment system is possible in disaster areas when a buffer tank of one day is applied. A quick start-up period can be achieved by adding freeze-dried activated sludge. Two points have to be noted. The first concern is that foaming might become a practical issue during the operation of the treatment plants. Therefore anti foaming products have to be added. The second issue is the bad sludge water separation that was noted in the lab scale reactors, special additions have to be made to create a sufficient separation in order to maintain the sludge within the system.

5.4.2 Result: What are the prototypes?

During the research a prototype setup has been determined:

Figure 42: Prototype of waste water treatment system.

The research demonstrates that the system works. During the demonstration phase a complete setup will be build and tested.

5.4.3 What's next?

A complete setup will be build and put under test during the demonstration phase. Parameters like outside temperature, cleaning agents and maintenances will be reviewed.

5.5 Additional developments

During the research and development additional questions rose regarding water management in general. The following techniques are quick solutions to these questions:

Chlorination of the water can be applicable in different kind of situations:

- If the water will stay for a longer period in a water tank
- In some cultures drinking water is only acceptable if you smell the chlorine
- For specific medical applications (e.g. water borne infectious diseases)

One of the ebola treatment centers, installed in Sierra Leone, is equipped with an ultrafiltration system and chlorinator. The system will be tested in the field.

Waste water pumps are often used to get the grey water to a different location. Two types of pumps are under test in combination with the units where the ultrafiltration systems are installed.

Figure 43: Waste water pump.

Combined squat and sitting toilet. Worldwide different types of toilets are used. Commonly you have the squat or sitting toilets. Since it is not known in which country the toilet will be used, a flexible system is under research. Two options are under investigation: Introducing either a toilet, which could be used in both positions, or just one to be selected and easily installed when the final destination is known.

6. Prototype Water Tower kit

In D3.2 only the first stage of the development process of the Water Tower kit was reported, since the development only just had started. Currently there is no solution available for quick and safe assembly of a water tower. The quality and safety of locally built solutions is often unsure, while the structure has to bear a substantial load, and often remains in place for many years. Therefore partner MSF was asking for the development of a kit, that enables MSF to easily build a secure Water Tower fit to their specific requirements, and include it in their total package solution for hospital compounds. In essence, this Water Tower Kit is developed specifically for MSF for use in a hospital compound, it can however be used in many other situations. Adoption of the S(P)EEDKITS design principles ensures that the development aims at low weight, low volume, smartly packaging, multi-functionality and cost-effectiveness, as described in D3.2.

As described in D3.2, these development criteria were identified, State of the art solutions were identified and indicative structural calculations were made to gain insight in the feasibility and applicability of a Water Tower Kit approach.

Currently the first prototype is in production and a first test setup was executed in December 2014.

In this report we will explain how the final development requirements were identified, then the development process will be explained, and lastly the final design will be presented and further elaborated upon.

6.1.1 Development criteria and boundary conditions

The SOTA analysis and indicative calculations gave good insight in the determent development criteria and normative forces and the tower structure. In the remainder of this paragraph, design conditions and solution principles for the water tower kit are further investigated in order to compose a solid and verifiable set of boundary conditions to start the product development with.

Since the earlier request of MSF gave too little information on usability aspects, an extra meeting was planned to clarify and more specifically define the criteria for development. A meeting was held in Amsterdam at MSF with Frank Rammeloo (MSF shelter advisor) and Biserka Pop-Stefanija (MSF WatSan advisor) with the following main conclusions:

- 2m height difference between tank and tap practically always is sufficient, in case of unfavorable terrain conditions height should be more than 3m
- Column distances (and component sizes) are dependent on available tank sizes (often not more than Ø1.9m) – these lengths are critical for the packaging size
- Water availability should be guaranteed also during critical functions (e.g. operation theatre, sterilization, maternity). Minimize water use! Therefore, for other purposes, water use should be minimized.

Based on the conditions above, the water distribution network in a typical compound lay-out was analyzed and the flow rate was calculated, in order to verify if the tower height is sufficient.

6.1.1.1 Water distribution

Flow rate / head loss analysis of hospital compound use

In order to verify the minimal tower height, a head loss analysis is made for the water distribution network in a typical hospital compound. Ultimately, the flow rate acceptable for MSF is 3 l/min for each tap. This is lower than the flow rate of 7.5 l/min, which is according to the SPHERE standards[4].

[4] http://www.spherehandbook.org/ (The Sphere project)

The demand rate of 3 l/min per tap is the critical value for head loss/flow rate. It is advised to calculate a 50x50m loop distribution system, connected to one water tower, in which 6 taps may be opened simultaneously.

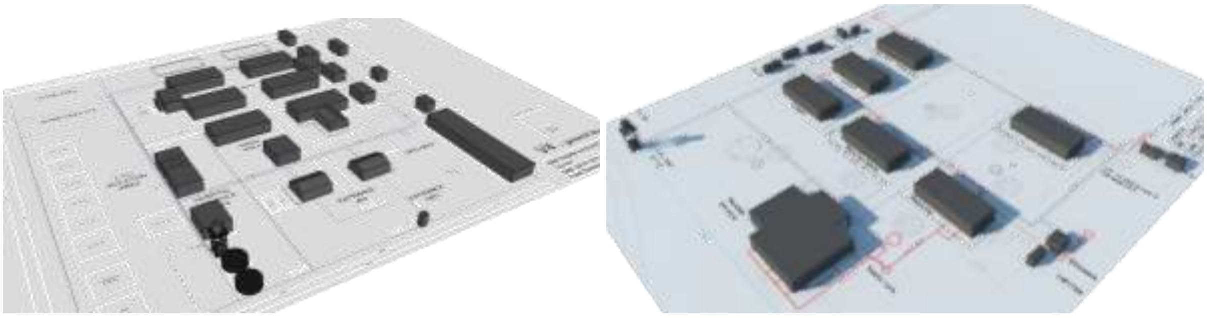


Figure 44: Illustrations of typical MSF hospital compound lay-out in Sudan (left) and Congo (right).

MSF provided some requirements of the distribution network components, such as the Ø50mm HDPE pipes (Ø44mm nominal) for the main loop, elbow and T-connections, narrowings and Ø25mm HDPE pipes (Ø19mm nominal) for the branches. Further, a typical compound contains 25 self-closing taps. The preferred type is the Talbot Talflo tap[5].

For the head loss analysis the pressure losses in pipes and narrowings, T's and elbows are calculated with the use of the ISSO manual for installation services[6]. It is expected beforehand that the main pressure losses are in the taps (0.1m head loss per tap) and in the main pipe due to the length and turbulent flow. Below the head loss is given for the typical water network when all six taps are opened in the far end of the network (in regard to the tower position). In practice, this is a worst case scenario, which increases the flow speed in the main pipes and maximizes pressure loss due to a turbulent flow.

Taps	6*0.1 =	0.6 m
Pipe with nominal diameter 19mm:	6*0.1 =	0.6 m
Elbows	6*0.0007 =	0.0042 m
Narrowings 44-19mm:	6*0.0133 =	0.08 m
T's:	7*0.002 =	0.014 m
Pipe with nominal diameter 44mm:	17m ,18 l/m =	0.13 m
	100m,9 l/m =	0.20 m
	94m,9 l/m =	0.19 m
	7.4m.6 l/m =	0.004 m
	15m,6 l/m =	0.007 m
	12m,3 l/m =	0.0007 m
	5m,3 l/m =	0.0003 m
Total headloss		**1.83 m**

Figure 45: Head loss calculation of water distribution network in a typical 100x100m MSF hospital compound.

[5] http://f2557522.td-fn.net/wp-content/uploads/2013/10/Talbot-Talflo-Datasheet.08.12.pdf

[6] ISSO (2002) Handboek installatietetechniek, ISSO, Rotterdam

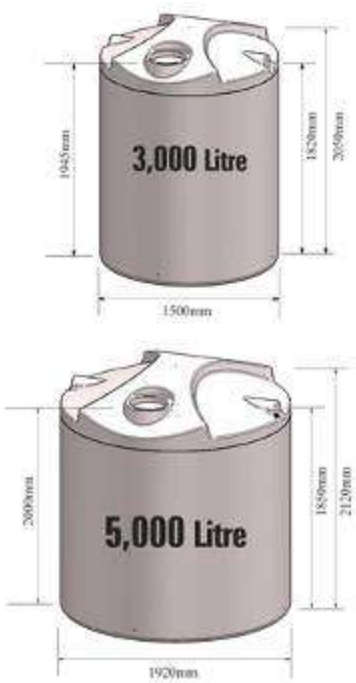
Generally spoken, the pressure loss will increase at higher flow rates and longer distances. In the table above it is seen that the total head loss will be 1.83m. Given the tap height of approximately 1 m, the tower should be at least 1.83+1= 2.83 m high. A height of 3m therefore would be sufficient. In the case of unfavorable terrain conditions, such as sloped terrain, extra height should be added. The calculation above confirms that water tower heights between 3m and 5m will be sufficient in practically every situation.

Water storage – tank sizes

In the field, a variety of water tanks are used, such as bladder tanks, onion tanks, frame tanks with plastic liner and tanks built from corrugated iron sheeting (such as the Oxfam tank). MSF have requested the use of a plastic tank, because of cost-effectiveness and since their experience is that these are locally available all over the world. Since these tanks are also rather voluminous and not demountable, it will not be included in the kit, but purchased on location. For the Water Tower kit design an inventory of available tank sizes is necessary to identify possible limitations for the design. MSF has indicated that they prefer to include a spare tank, which will be placed between the tower columns. Therefore column distance needs to be tuned to a commonly existing tank size, since the tank needs to be placed and possibly exchanged after assembly of the tower.

The list below includes 20 tank dimensions of 5000 l tanks available on the market. It seems that all tank diameters are less than 2000mm. the minimal distance between the columns should therefore be at least around 2000mm.

Ø x Height (5000 l)	Supplier
1770 x 2350	Tankgigant.nl
1850 x 1950	Shawsonplastics.co.za
1900 x 1960	Tanks-direct.co.uk
1860 x 2200	Tanks-direct.co.uk
1990 x 1990	Envirowatertanks.com
1800 x 2250	Tanks.co.nz
1850 x 2100	Qtank.com.au
1850 x 2200	Precisionpoly.com.au
1790 x 2210	Postma-kunststof-tanks.nl
1790 x 2210	Dbcom.nl
1780 x 2235	Wildkamp.nl
1820 x 2100	Rainharvest.co.za
1840 x 2100	Neltanks.co.za
1760 x 2100	Classifieos.co.zw
1850 x 1980	Atlasplastics.co.za
1810 x 2100	Aorisupplies.co.za
1840 x 2170	Rainwatertanksdirect.com.au
1830 x 2080	Rainwatertanksdirect.com.au
1800 x 2200	Rainwatertanksdirect.com.au
1730 x 2300	Rainwatertanksdirect.com.au



[picture: taylex.com.au]

Figure 46: Commonly available tank sizes.

6.1.1.2 Material use for tower

Water tower structures exist in a large variety of geometry, material use, heights and water volume. For water volumes in the range of 3000-5000 liters, often frame structures built with metal or wood members are applied, as seen in the SOTA analysis in D3.2. In this volume range there are currently no structures available that are easy to transport and assemble.

Figure 47: Examples of material use in water tower structures (from left to right: steel, aluminum, wood, concrete, brickwork).

The material choice for the Water Tower Kit depends on the effectiveness and efficiency with respect to load bearing capacity, member dimensions, design and fixation of joints, prefabrication possibilities, ease of assembly, local maintenance and costs.

The table below gives an overview of material properties and the estimated impact on critical design criteria in respect to the use of five different materials in the construction of Water Tower structure of 5 meters high and a 5000 liters water volume.

Table 7: Comparison of material use.

Criteria	Steel	Aluminum	Wood	Concrete	Brickwork
Weight	7850 kg/m^3	2700 kg/m^3	330 kg/m^3	2400 kg/m^3	2400 kg/m^3
Comp. Strength	235 N/mm^3	310 N/mm^3	19 N/mm^3	20 N/mm^3	20 N/mm^3
Tens. Strength	310-510 N/mm^3	105-540 N/mm^3	12 N/mm^3	2.3 N/mm^3	2.3 N/mm^3
Lifespan	100 years	50 years	50 years	100-300 years	100 years
Availability	worldwide	limited	worldwide	worldwide	limited
Prefabrication	possible	possible	possible	difficult	difficult
Assembly	easy	easy	easy	difficult	difficult
Equipment	few	few	Few	heavy	Heavy
Joint complexity	low	high	moderate	low	low
Transport	easy-moderate	easy	easy-moderate	difficult	difficult
Cost	€130-200 (100kg)	> €200 (100kg)	< €150 (100kg)	€230 (1m^3)	€120 (1m^3)

From the table above it is seen that the use of steel seems to be the most efficient choice as construction material due to the mechanical properties, possibility of prefabrication, the low joint complexity and cost-effectiveness. Further, it is known that steel is a widely accepted material which people are accustomed to work with all over the world. If however during the first structural calculations appears that the weight of the members is too large to compile a transportable kit, than aluminum could be a better choice.

6.1.1.3 Exploration of optimal geometry

Most water tower structures used in emergency relief have a height between three and ten meter with a platform on top that carries a water tank containing between 1000 and 10000 liters of water. Even within frame type structures, that in most cases have a square-shaped base of four columns, much variety is seen in geometrical appearance. The water tower is generally divided in four parts, namely foundation, tower structure, platform and tank. The tower structure consists of columns, horizontal members and bracing. The placement of horizontal members reduce buckling of the columns, while together with bracing they transfer horizontal loads to the foundation and ensure stability. A variety of bracing composition is possible, such as X-bracing, K-bracing and V-bracing. Stiff bracing members are capable to resist both tensile and compressive forces, while flexible members, like cables, only are activated when tensioned.

For the ease of assembly and dimensional control, the number of connections and variations in components should be minimized. Modularity and uniformity of elements therefore are key features to limit the risk of construction failures. However, uniformity in member dimensions might also lead over dimensioning of members and an unnecessary weight increase. Therefore a balance has to be found between weight optimization on one side, and modularity on the other side, through uniformity of elements and minimization of assembly mistakes.

Some of these issues are shortly discussed below.

Basic geometry

For the tower, two basic geometrical options are possible, a rectangular and tapered geometry (see picture below). Both geometrical shapes have their advantages. The tapered structure is less prone to tipping over due to horizontal forces and therefore also requires a lighter foundation. The downside is that the members are longer and that vertical loads are not transferred down as optimally as in a rectangular geometry. The amount of unique members in the rectangular tower is less than in the tapered one, which increases the modularity and interchangeability of components. Finally, the tapered structure requires more surface area.

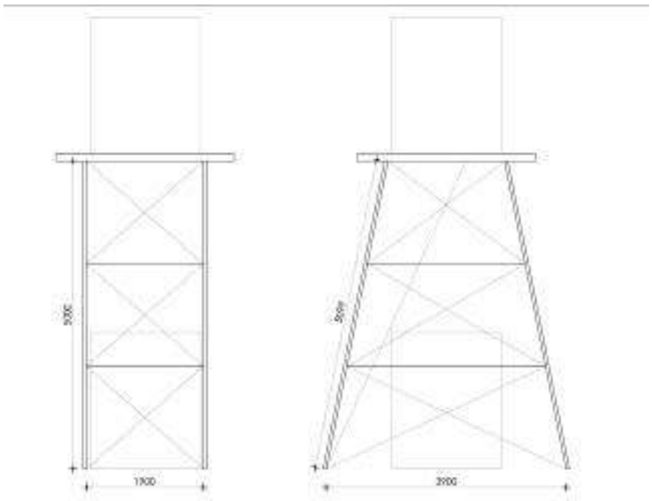


Figure 48: The basic geometry of a water tower can be rectangular (left) or tapered (right).

Since two tower heights are demanded, it needs to be investigated whether modularity of components is possible, in order to assemble both the 3m and 5m with the same elements. Knowing this, the tapered structure shown above might not be optimal. In the picture below, an example is given of a rectangular 3m and 5m tower, with module sizes of 1,5m and 1m.

Figure 49: Impression of rectangular tower structures of 3m and 5m height built with modules of 1,5m (left) and 1m (right).

Bracing will be applied for stability reasons. In the picture below it is seen that a number of variations in composition are possible. A straight structure with X-bracing or V-bracing is optimal in regard to material use and uniformity of profiles and dimensions. However, material use needs to be limited. The advantage of the use of cables, which can only be activated under tension, is that these are very efficient in terms of load bearing. The result is that the amount of weight is limited and the packaging volume is minimal. Application of only cables is most optimal, which implies that X-bracing will be applied on all sides, however only with tensile members (therefore resembling the bracing variation that is second from the left).

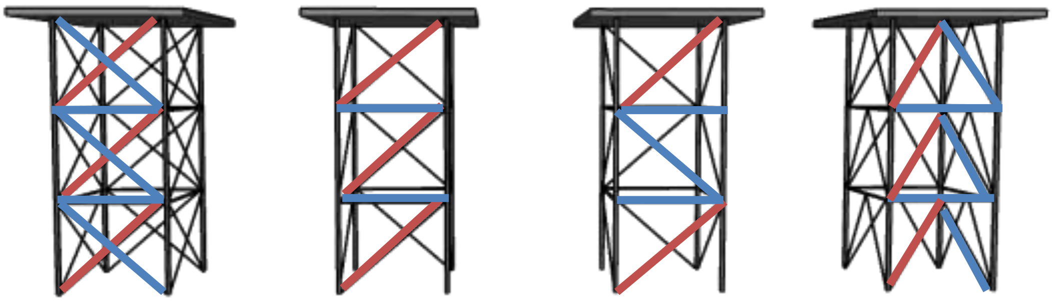


Figure 50: Variations in bracing composition. When a horizontal load is pushing from left to right, the red members are under tension, while the blue members are compressed.

In practice, it might not be possible to construct a permanent foundation directly. It is therefore explored whether it is possible to apply a temporary stabilization solution, in order to benefit immediately form the towers functionality when it arrives. The picture below shows some ideas that would ensure the stability form the start and that provides the opportunity to build a foundation with reinforced concrete in a later stage.

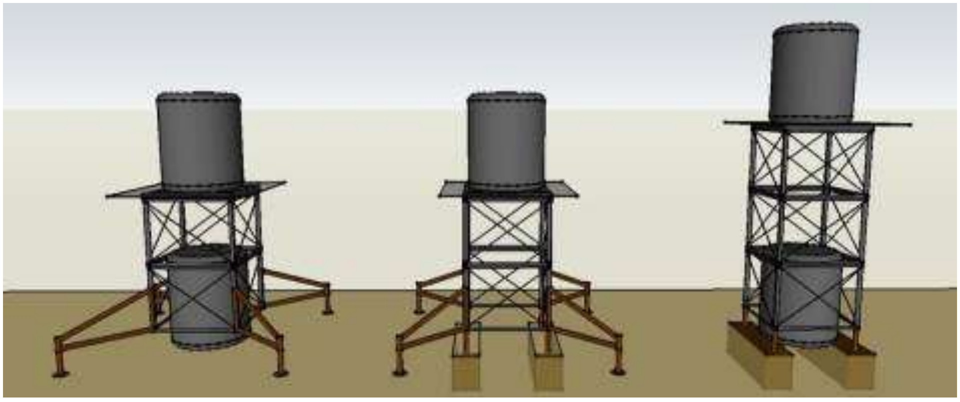


Figure 51: Sketches of a phased approach in the construction of the tower and its foundation.

6.1.1.4 Packaging

The package and its content should be efficient and assistive in the logistic and assembly process. Optimally, the packaging materials should not be redundant and have multifunctional use. However, the package must sufficiently protect the content. Packaging guidelines defined in WP1 are leading in the development.

The water tower, when disassembled and divided into parts, should fit on a pallet. Pallet level is chosen due to the expected weight of the total package. The maximum load on a pallet is 1500 kg. It is aimed to dimension the individual members to not exceed pallet size and to be within 25 kg of weight, so one person is able to lift it manually.

6.1.1.5 Boundary conditions

Below is a list containing the critical design conditions for the water tower. This list is used as guidance in the development process and serves as a validation tool afterwards.

Table 8: list containing the critical design conditions for the water tower.

Item	Sub item	Demand
Water provision	Tank Volume	3000l / 5000 l
	Maximum dimensions tank (DxH)	1.9 x 2.2 m
	Tank weight	120 kg
Foundation	Temporary foundation	Additional anchoring/weight
	Permanent foundation	Reinforced Concrete
	Levelling possible	
Tower Structure	tower height	3.0 / 5.0 m
	Minimum distance between columns	1.9 m
	Material	Steel
	Spare tank	Removal possible
	Horizontal stability	X-bracing, cables
	Modularity	Limit # of unique components
Platform	Space around tank	0.5 m
	Accessibility	Ladder
	Fall prevention	Railing, height 1m
Kit dimensions	Packaging level	Pallet
	Maximum dimensions (lxwxh)	1.20 x 0.80 x 2.00m
	Maximum weight	1500 kg
Assembly	Assembly time	4 hours
	Number of people needed	2/4 pers.
	Maximum weight / element	25 kg
	Ease and safety of assembly	Manual tools / symmetrical and interchangeable elements / manual included / only safe climbing
Durability	Lifespan	30 years

	Likely to remain in place after emergency phase	
Wind loads	Terrain category	II
	Reference period	30 years
	Basic wind speed	31 m/s (10m height, 10 min average time, 50 year ref. period)

6.1.2 Concept development

Now the boundary conditions are determined, next step is to develop the concept further. In this paragraph, insight is given into the development and processes of:

- Assembly principle (levelling, safe assembly methods, lifting the tank)
- Packaging
- Optimization of components
- Structural verification

6.1.2.1 Assembly principle

Exploration of assembly principles

The assembly method will have a large impact on the design. Firstly, a promising assembly principle needs to be chosen, which allows safe and rapid assembly, preferably with minimal (unsafe) climbing actions involved. Further, the chosen solution must be low tech, in order to ensure applicability in practice, especially in case of an untrained assembly crew, and to minimize the chance on failure or technical problems. A number of concepts have been developed and analyzed, often developed by making an analogy with solutions form other branches. In the picture below a selection is presented, showing, from left to right, a concept similar to stacking of crates, a truss and winching principle, a scaffolding approach and finally a concept using pulleys.

Figure 52: Selection of assembly concepts.

Selected assembly principle

From the explored assembly concepts, the crate-stacking and scaffolding system seem the most feasible, in terms of simplicity and low risk of failure and cost effectiveness. Therefore a combination is made of both principles. The tower will not be assembled fully from ground level, but the use of temporary work platforms will ensure safe climbing. Since the members should not exceed 25kg each, lifting them to these platforms will not bring difficulties. In the picture below, the assembly principle is illustrated. It should be investigated whether the members used in the final platform may be used also for the temporary assembly platforms.

Figure 53: Illustration of three steps in the proposed assembly method using a temporary platform.

Lifting the water tank

Putting a tank on a 5m high platform is a challenge in itself. The idea is to use the railing of the platform to create a guidance rail when lifting the water tank (see sketch below).

Figure 54: Sketch of suggested method on how to lift the water tank.

Another possible solution is to lift the water tank vertically form the center of the tower through an opening in the platform. A disadvantage is that the platform must be quickly assembled when the tank is still lifted above the platform and that it will probably requires the help of many people on the platform. The concept as shown in the picture above therefore seems the most promising, whilst it also allows multifunctional use of components.

Levelling

In the field, soil conditions are largely unknown and often not levelled. Therefore the tower should include an internal levelling system to ensure vertical levelness, in order to prevent skewness and unsafe situations. In scaffolding, a rotating levelling footing is often used, which would be perfectly applicable in the steel tower structure. This solution makes it possible to precisely level each footing independently (see pic below). For application in the water tower design, some relatively simple alterations may be needed to the system.

Figure 55: Example of scaffolding footing with levelling functionality. (Source: www.rolight.nl).

6.1.2.2 Packaging

Packaging constraints are strict in the development of S(P)EEDKITS. Therefore the packaging options have a high priority in the concept development of the Water Tower kit. Large preassembled elements have the advantage that assembly errors are less likely to be made and connections are minimized. It will however also mean that packages tend to become rather voluminous, which is a clear disadvantage for transport. Due to the expected size and the weight of the kit, it will be transported on a pallet. Small items will normally be put in boxes. It would however be interesting to see whether it is possible to use parts of the water tower kit to eliminate the need of the pallet or the additional boxes.

Below, two ideas are shown for packaging. On the left, a pallet full of preassembled stiff 2D elements, for the assembly of a 3m high tower is shown. The picture on the right shows the full packaging volume of a 5 m tower but fully disassembled into 1D elements. It can be clearly seen that the transport volume is decreased substantially when no parts are preassembled into 2D elements. Therefore it is suggested to limit package size and focus on intuitive joints and assembly techniques, using the disconnected 1D elements.

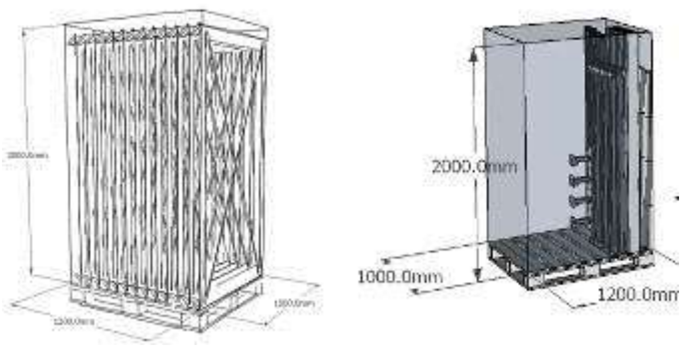


Figure 56: Sketches of the expected package sizes of preassembled 2D elements (left) and individual 1D parts (right).

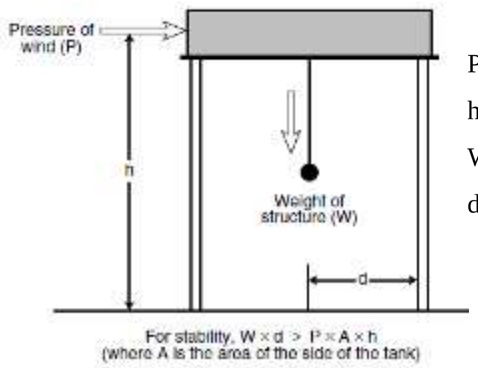
6.1.2.3 Optimization of system/components

For the optimization of the structure, it will be divided in three parts that will be individually optimized, knowing the platform, the tower structure and the foundations solution. The latter is directly linked with the tower stability and risk of overturning. Size and weight of components are leading in the optimization, however also the number of components and connections are highly important. It may well be that both requirements cannot be fulfilled simultaneously and a compromise must be made.

In the process of weight optimization, structural performance is often defining member dimensions. Since the water tower will be constructed in a hospital compound, in the vicinity of people, a high level of safety will be applied. The structure, which aims at a lifespan of 30 years, will be calculated with the safety factors applicable for Consequence Class 2 according to EN-1990/EN1991[7].

Stability

The most favorable situation is to build the water tower kit on top of a concrete foundation. A foundation will prevent the tower from sagging and overturning. If the construction of a reinforced concrete foundation is not feasible in the specific (emergency) situation, a temporary solution must ensure a safe situation. Below a relatively simple calculation is shown to see if measures need to be taken to prevent overturning.



	5 meter tower	**3 meter tower**
P * A =	3.92 kN	3.6 kN
h =	5.2 + 0.78 = 5.98 m	(5.2-1.67) + 0.78 = 4.31 m
W =	5.79 kN	5.41 kN
d =	= 1.04 m	1.04 m
	6.02 > 23.44	5.63 > 15.52
	NOT STABLE	NOT STABLE

Figure 57: Indicative calculation of proneness to overturning due to wind load[8].

The above calculation shows that when the tank is empty and exposed to extreme wind loads, that the the tower will overturn when no foundation or other precautions are applied. Several solutions for this problem will be elaborated upon for the 5 meter variant. Possible solutions are adding weight, enlarging the column distance at the base or reducing the size of the tank.

Below on the left picture is shown of the water tower, when the base of the tower will be enlarged in order to prevent overturning. The tower base would be around 5x5 m then. Another option, which is shown before, is to attach extended footings, as seen in the picture below on the right**.**

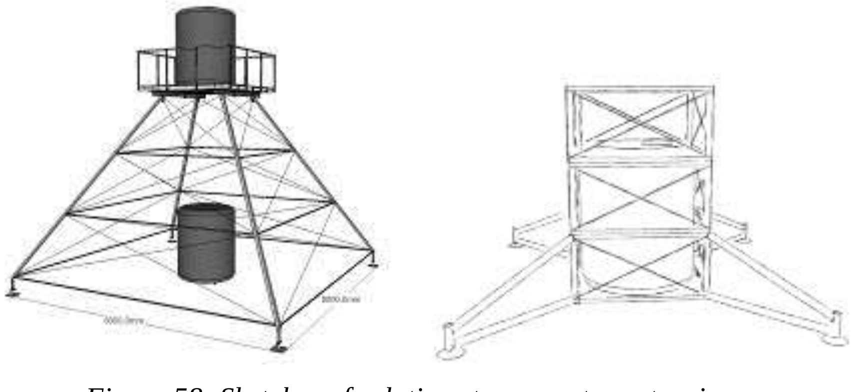


Figure 58: Sketches of solutions to prevent overturning.

Bringing down the tank size is not a good option, since than only a volume of approximately 1 m^3 would be feasible.

[7] EN 1990: Basis of structural design (Eurocode 0)

EN 1991: Actions on structures (Eurocode 1)

[8] Davies, Lambert (2002) Engineering in emergencies – a practical guide for relief workers

A rather straightforward solution would be to simply add weight. In that case around 2300 kg should be added. The specific weight of concrete is 2400 kg/m^3 so a concrete foundation should consist out no less than 0.96 m^3 concrete. Other solutions in adding weight could be to put sand bags on top of the footers or anchoring the tower to the spare water tank between the columns (this tank should then contain at least 2200 liters of water, when the top water tower is less than half full). If sand bags are applied, 92 bags of 25 kg a piece should be stacked on top of the footers. These sand bags could be shipped empty and filled at the location with the available sand or gravel. Another option is to apply additional straps or cables and anchor the tower with them to the soil. In that case, anchor capacity is critical, as well as soil conditions. Below a picture is shown with the most promising solutions if no concrete foundation can be applied.

Figure 59: Potential solutions for application of temporary anchoring/foundation in order to prevent overturning.

Platform

The platform is composed of primary beams, secondary beams and grating on top. The research was started with seven different variants of the platform in order to search for the best load distribution and most efficient member dimensions. The total platform size is 2.9x2.9 meters. For the grating elements, both steel and plastic grating is considered. Properties of these grating elements are obtained from the Dejo product guide (www.dejo.nl).

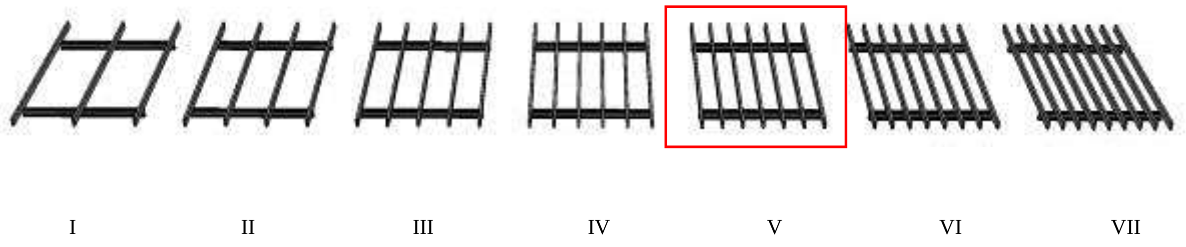


Figure 60: Platform composition variants varying in amount of secondary beams.

On the platform, also a railing must be applied to prevent people from falling. The railing has to be able to resist downward force of 1.25 kN and 0.3 kN upwards and sideways[9]. The height of the railing should be at least one meter. The railing span will be determined by the distances between the secondary beams.

[9] Dakenraad (2012) valbeveiliging in de praktijk (Fall protection in practice).

The table below shows the comparison of the platform compositions shown above. When comparing the variants it is important to review the number of parts, weight per part and the total weight. These criteria lead to the most efficient composition of the platform. However variant 6 is ultimately 6 kg lighter that variant 5, still variant 5 is chosen, because of a more optimal placement of the railing columns and the elimination of one secondary beam.

Table 9: Overview of platform composition optimization.

Variant		I	II	III	IV	V	VI	VII
Span in between secondary beams	[m]	1.45	0.97	0.73	0.58	0.48	0.41	0.36
Steel grating	[kg]	376	224	177	154	131	131	131
Plastic grating	[kg]	-	-	160	160	106	106	106
Safety railing	[kg]	41	43	51	45	43	47	48
Primary beams	[kg]	75	60	75	60	60	60	60
Secondary beams	#	3	4	5	6	7	8	9
	[kg]	112	121	151	139	137	126	142
Total weight bemas	[kg]	187	181	226	200	197	187	203
Total weight platform	[kg]	604	448	437	399	346	340	356

Columns, horizontal members and bracing

For the tower structure, the module size is a key indicator, since it is preferred that the two tower sizes of 3m and 5m can be assembled with the same elements. Below, four variants are shown with varying module sizes. The smaller the module, the more bracing elements and horizontal members need to be applied. It however also lowers the demanded resistance to buckling of the columns. Further, lengths are limited to 2m length with respect to transportability. Lastly, if the tower will be assembled with the platform method, all connections need to be in reach form the platform. Therefore module sizes of more than 2 m are not feasible.

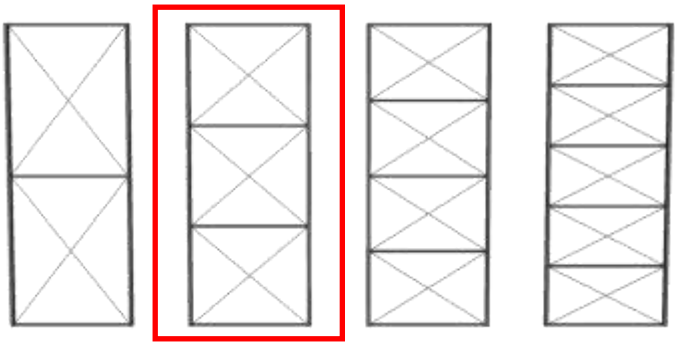


Figure 61: Variants of module sizes of the tower structure.

The loads from the platform are transferred to the tower structure and wind on the tower is added. In the picture below, the loads applied are shown for all four variants. These forces will lead to the dimensioning of columns, horizontal members and bracing.

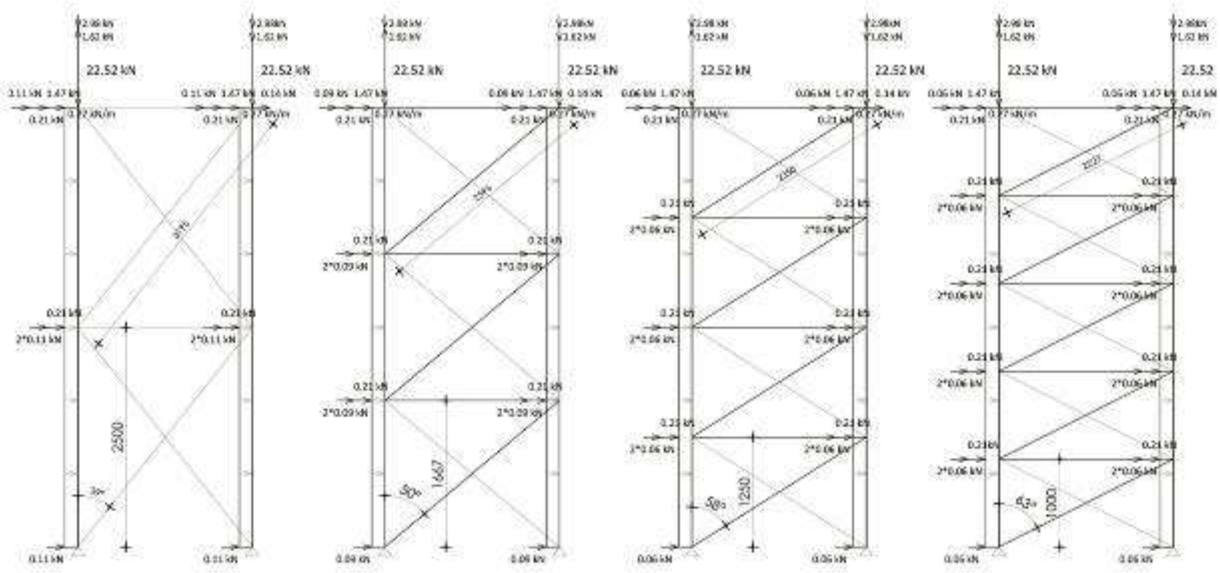


Figure 62: Loads on the tower structure variants.

The table below summarizes the results of the calculations of the member dimensions. The weight difference in weight for the first two variants is really small. In terms of weight optimization the best variant will be variant I. Not only the optimal weight is of importance but also the fact that elements have to fit on a pallet and have to be easy to handle. This can be achieved by using a little more weight, variant II would be the best solution overall.

Table 10: Overview of tower composition optimization.

Variant		I	II	III	IV
Column length	[m]	2.50	1.67	1.25	1.00
Total weight of columns	[kg]	58.6	46.2	39.8	33.6
# of horizontal members	#	8	12	16	20
Total weight hor. members	[kg]	26.8	40.1	53.5	66.9
# of bracing elements	#	16	24	32	40
Total weight bracing	[kg]	19.3	20.6	23.6	29.4
Total tower weight	[kg]	104.6	106.9	116.9	129.9

6.1.2.4 Structural verification

The individual members have been optimized. The next step is to validate the design and dimensions through a structural verification calculation. For this, literally a top down approach is applied. First the loads as a result of placement of the water tank of the platform are determined. This includes wind load on the (empty) tank, and the horizontal load due to the weight of the water. Below some snapshots are shown from normative load combinations on the platform.

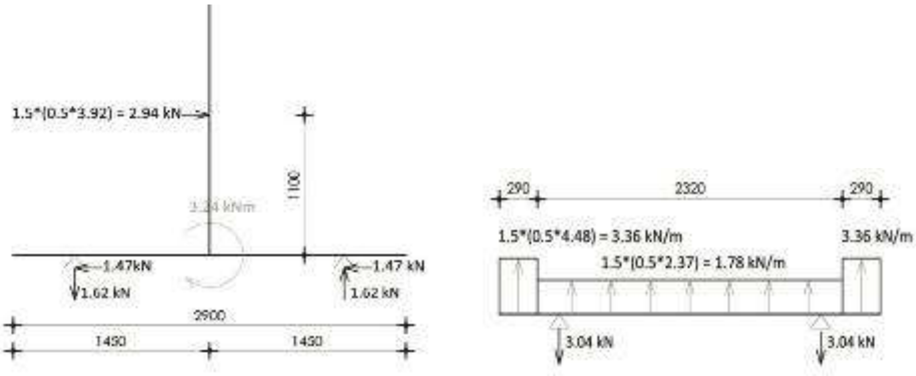


Figure 63: Loads on the platform due to self-weight of components, the water volume, wind and maintenance (people).

The load on the platform results in a vertical and horizontal load transferred into the top of the tower columns. Vertical load (water + platform weight) will be transferred vertically to the foundation. The columns therefore need to be checked on buckling. The horizontal load, added by the wind load on the tower itself is transferred down by the horizontal members and the bracing elements. In the paragraph of component optimization, the loads in the final tower lay-out are shown. Finally, the loads are included in a structural calculation model in SCIA Engineer. Below, two snapshots are shown of the results, which show the internal tension and compression in the tower members (normal forces) for two load combinations.

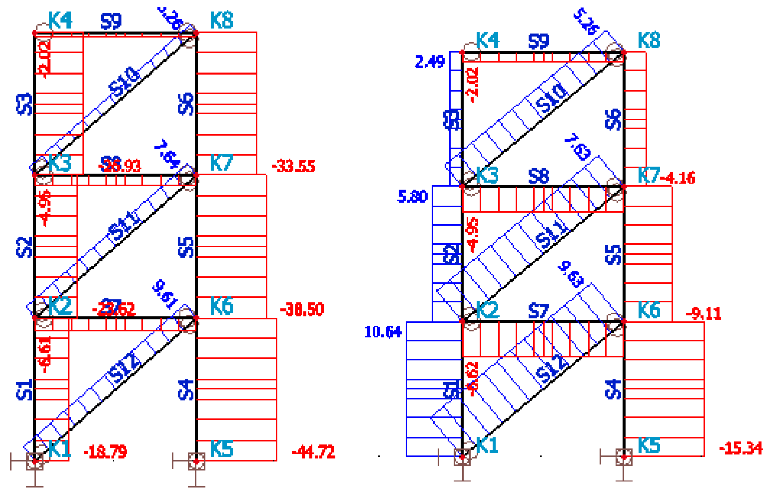


Figure 64: Snapshots of the structural validation model.

6.1.3 Final design

In this paragraph, the final design of the tower is shown. All in all, it can be said that the end result appears to be fulfilling all demands set in the boundary conditions. The tower is composed of modular, interchangeable elements, which eases the assembly of it and provides the possibility to construct different tower sizes. In addition, multifunctional use of components is achieved and the packaging volume and weight is minimized. Lastly, a manual has been developed that clearly shows which steps need to be taken in the process. Below, an impression is given of the final product.

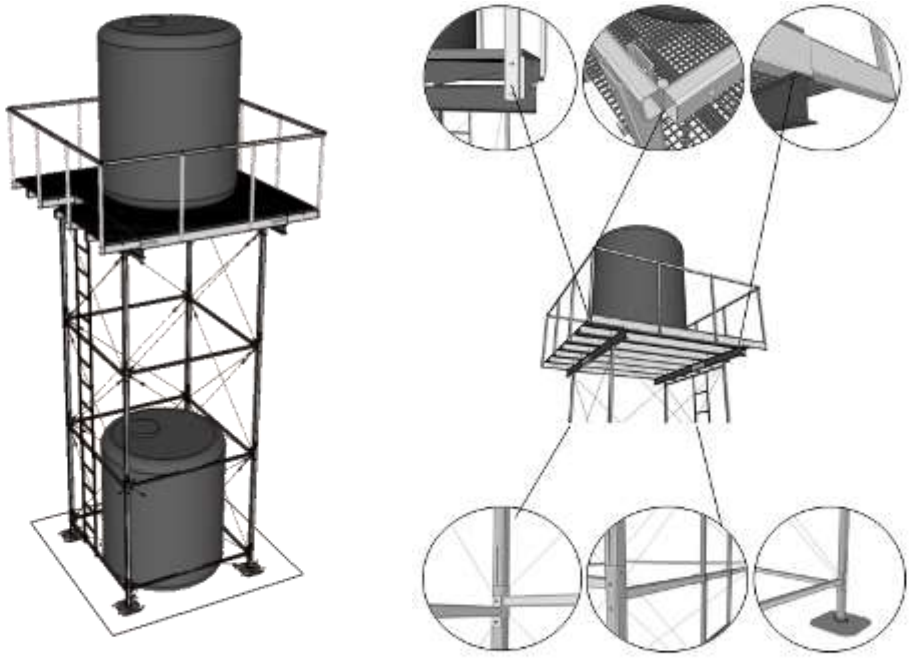


Figure 65: The final Water Tower Kit design.

6.1.3.1 Member design

In the picture below, all the components in the water tower kit are shown (with exclusion of fixation materials). In the table below an overview is given of member sizes and quantities. The final design consists of 10 different elements in total, with exclusion of fixation materials.

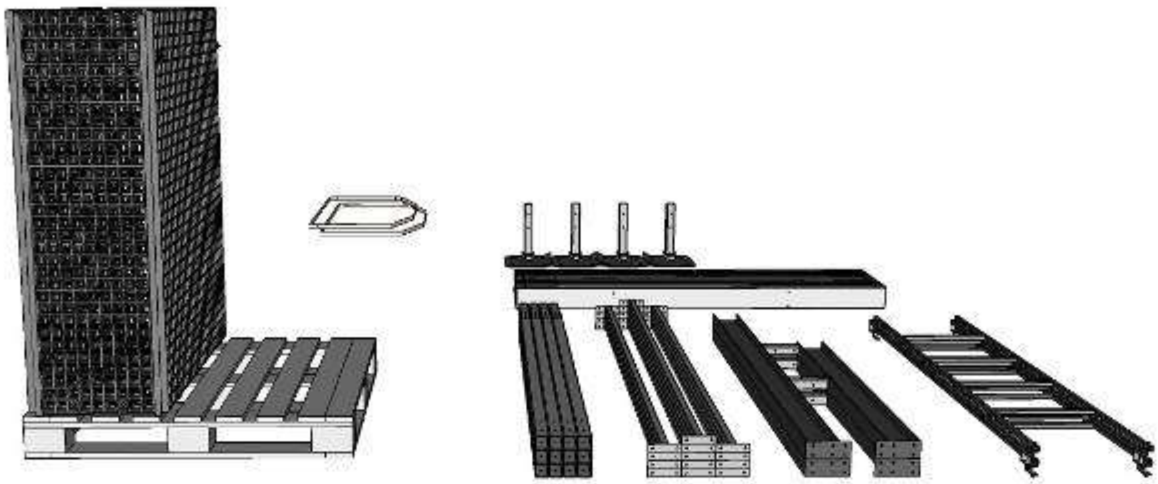


Figure 66: Individual members of the final Water Tower Kit design.

Table 11: Parts list, including sizes and weights.

Part	Size [mm]	Quantity	Mass per part [kg]
Grating	990*1437 409*1437 409*945	4 3 1	18 9 5
Secondary beams	2900 (telescopic)	7	22
Primary beams	2900 (divided in 2 parts)	2	32
Railing beams	5830 (foldable)	2	10
Railing columns	1103	12	2.2
Columns	1670	12	6
Horizontal members	1896	13	3.3
Bracing	2400 (rollable cables)	24	0.4
Foundation parts	150 (incl. spindles and footings)	4	7
Ladder	1670	3	5.2
Total mass			**536.5**

6.1.3.2 Multifunctionality

An important demand in the development is multifunctionality. In the smart assembly and packaging principle of the Water tower Kit, several members are used multifunctional.

The grating elements that close the platform are used in the packaging of the smaller elements and form a protective box to keep all elements together during transport (see picture). The clips that are used to connect the grating to the platform beams are also used to assemble the box for transport. No additional connection elements are therefore needed.

During construction of a concrete foundation, the pallet may be disassembled to be used as formwork for anchor placement (see picture below)

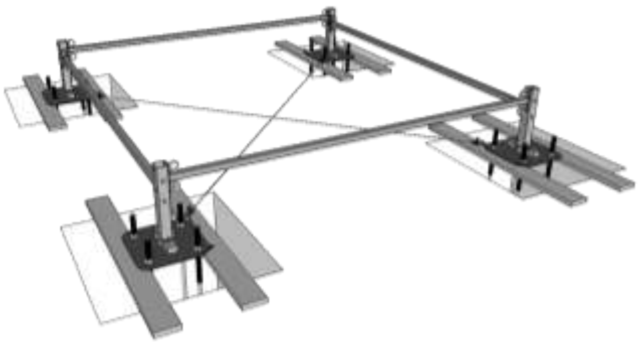


Figure 67: Multifunctional use of pallet wood for anchor placement.

The secondary beams and grating of the platform will also have additional during the assembly process as temporary work platforms.

Finally, the protective rail that prevents from falling off the platform is foldable and can be used to serve as a guiding rail to lift the tank to the platform.

6.1.3.3 Packaging

Since packaging sizes were strictly limited, a number of elements have been downsized for optimal transport. As indicated in the former paragraph, the grating elements function as a box that contains and keeps together the majority of components.

Some members, such as the primary and secondary platform beams and the railing elements are larger than 2m length. Therefore the primary beams have been divided in two elements that can be connected on site. The secondary beams contain telescopic ends, in order to be extended from 1.9 to 2.9 meters length. Finally the railing is divided in parts and connected with hinges, so it can fold to an acceptable size.

In the end, the full package has a fairly limited weight of 536 kg. The full package nearly fills half a pallet, meaning that two Water tower Kits could be placed on one pallet.

Total weight of package (5m)

Tower	168 kg
Platform steel parts	264 kg
Platform grating	104 kg
Total	**536 kg**

Figure 68: Overview of package volume and weight.

6.1.3.4 Assembly process & manual

To assist in the assembly process, a manual has been developed that clearly shows which steps need to be taken in the process. Below, an overview is given of the steps to take when assembling the Water tower kit.

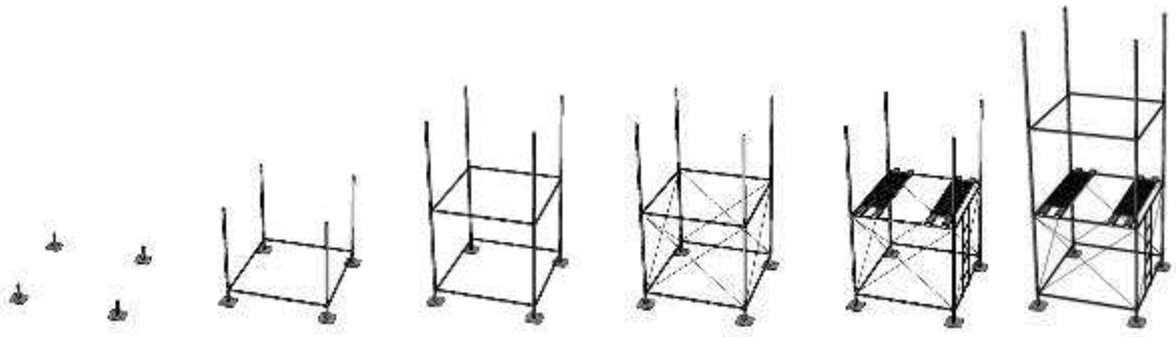


Figure 69: Overview of assembly steps for the water tower.

6.1.4 Result: What is the Prototype

The prototype parts for a 5 m water tower have been ordered. The first test setup has been performed at partner TUE. The picture below shows the assembled finished prototype. It was possible to assemble the 3.5 m high tower structure within 4 hours of building time with only two persons equipped with a ratchet and wrench. The test proved that the basic idea is really intuitive and easy, but also that some small necessary adjustments to the elements and the planned assembly sequence are needed.

Figure 70: Picture of the assembled prototype of the water tower.

6.1.5 What's next

Since the Water Tower Development was commenced later that the other kits within WP3, still some final steps have to be taken, mainly the finalization of the packaging concept. Further, it will be investigated if the involvement of a company is needed to make the final development steps onto market introduction.

7. Summary

Here, we reported on the prototypes for the various watsan kits and the outcome of the (first) testing.

Sanitation kits. Within this part, a *raised latrine* (consisting of a frame structure, textile cover and a storage device) was presented and tested. A solution for *mobile desludging unit* is presented capable of handling most sludge in lined and unlined pit latrines and in septic tanks and able to access a high percentage of toilets. Key components are the fluidizer and the vacuum pump. For *sludge treatment*, solutions based on lime, urea and lactic acid are described. The necessary starting materials can be offered as kits. A *pasteuriser unit* was prototyped that is able to kill pathogens via a heat and time regime that complies with the EU-regulations.

Water drilling kits. Two semi-manual water drilling kits have been prototyped: the *jetting* and *capstan kit*. Both kits have been extensively tested and underwent iterative improvements. Prototypes are ready for field deployment, all technical information is available. The solutions can be offered in a compact kit.

Water storage kits. Two kits for improved storage of water are presented: the *water tank* and the *flexible water container*. The first is large scale (10 m^3 or more), the latter is an alternative for the currently used flexible jerry cans (10-20 litre).

Container based watsan kits. In order to be able to provide watsan solutions for the containerised (medical) infrastructure, following components have been developed: a *flexible supply water tank* to be placed on top of the container, a *water filtration kit*, a *flexible waste water tank* and a *multistep waste water treatment*. For all solutions an (early) prototype exists, the water filtration has already been field tested.

Water tower kit. This kit provides a water tower, it is primarily developed for use in combination with an emergency hospital setting. A prototype was made and its set-up was tested: the 3.5 m high tower structure was assembled within 4 hours with only two persons.

It is important to realise that the development path of the kits did not all follow the same path (see also deliverables D3.1 and D3.2). Further, also the cost of making an advanced prototype differs largely. As a result, the actual implementation status of the available prototypes does vary. This is not considered negative but rather reflects the pragmatic approach to prototype as far as required to give the best chances for demonstration, field deployment and take-up towards a commercial solution, thereby taking into account the available resources.

The goal is to present these watsan prototypes to find demonstration field deployment opportunities so that the value of these kits can be demonstrated. Outcome of this will be further reported in WP6 – demonstration. Further, also public information, including guideline/manuals will be provided (D3.4).