Conceptual Design of AM Container for “3D-Printer Cloud” Close to Customer Site

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2016-08-18
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PLANT-IN-THE-BOX

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Abstract

This is a master thesis about the Plant-in-the-box concept. The master thesis is to develop initial requirements and an initial layout to further investigate the concept.

Plant-in-the-box in combination with the Vertical Workshop concept are a part of the “Digitalization @ PS”-Initiative, at Siemens, that started in October 2015 and forms a way of portable and flexible workshops.

Plant-in-the-box is based on the idea to have a Additive Manufacturing, AM, machine with all its surrounding systems and equipment in a container which can easily be shipped to a new destination if desired. This AM container can then be combined with other containers containing anything from machinery for cutting processing to desktop stations and equipment for climate control. The set of containers are organized in a Vertical Workshop, where the containers can be slipped into a rack which supports the multi-storage workshop with accessibility and the necessary media.

The Vertical Workshop can easily be deployed close to customer and as a part of a 3D-Printer Cloud provide a network of production units placed on strategic locations.
Preface

This Master Thesis is written by Vincent Sidenvall, student at Linköping University, at Siemens Industrial Turbomachinery AB in Finspång, Sweden.

I would like to show my gratitude to my examiner Kerstin Johansen and supervisor Varun Gopinath at Linköping University, as well as my supervisors Andreas Graichen and Pajazit Avdovic at Siemens Industrial Turbomachinery AB for their guidance and constructive criticism, which have let me achieve the results that I am proud of.

I would also like to send special thanks to my opponent Carl Rabenius for his proofreading, support and the rewarding discussions.

Finspång, June 2016

Vincent Sidenvall
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Abbreviations

Abbreviations used in the report

**AM** Additive Manufacturing
**CAD** Computer Aided Design
**CNC** Computer Numerical Control
**DM** Distributed Manufacturing
**EHS** Environment, Health and Safety
**ELT** Electrical Lifting Truck
**GMRP** Generic Modular Reconfigurable Platform
**ISO** International Organization for Standardization
**IUPAC** International Union of Pure and Applied Chemistry
**LiU** Linköping University
**OSHA** United States Occupational Safety and Health Administration
**PDP** Product Development Process
**RaBuTiR** Rapid Burner Tip Repair
**SLM** Selective Laser Melting
Nomenclature

Descriptions of words used in the report

**Additive Manufacturing, AM** Production methods where material is added to get the finished part, compared with subtracting methods like milling and turning.

**Boxes stapled on boxes level** Level of detail on a 3D-model. Machinery and objects are modeled in a simplified manner, as boxes representing the volumetric need.

**Container / ISO Container** A container with the same outer dimensions as an ISO shipping container, except for doors and openings.

**Distributed Manufacturing** Idea of geographically distributed manufacturing facilities, see 2.3.

**Media** Collection of gas, powder, pressurized air, data etc.

**Multi-Topic Subject Weighing** Method setup during master thesis to evaluate subjects with respect to topics, see 3.4.

**PLANT-IN-THE-BOX** The concept studied in this thesis. The idea is to place machines in containers to form portable and flexible workshops.

**RaBuTiR** Process of repairing burners with additive manufacturing, see 1.1.1.

**Selevtive Laser Melting, SLM** Additive manufacturing process where a powder is laid layer by layer and a laser melts the desired surface of each layer to form a 3D-part.

**Vertical Workshop** Way of arranging PLANT-IN-THE-BOX containers in a multi-storage way to form a vertical workshop.

**3D-Printer Cloud** Geographically distributed 3D-printer resources connected to a digital marketplace. These resources may, or may not be controlled by a central function.

Short description of ISO standards considered in the thesis and appendix

**ISO 668** Series 1 freight containers – Classification, dimensioning and ratings

**ISO 830:1981** Freight containers – terminology

**ISO 838** Freight Containers – Vocabulary

**ISO 1161** Corner Fittings

**ISO 1496-1** Series 1 freight containers – Specification and testing – part 1: general cargo containers for general purposes

**ISO 1496-2** Series 1 freight containers – Specification and testing – part 2: Thermal containers

**ISO 3874** Series 1 freight containers – Handling and securing
ISO 6346  Freight Containers – Coding, identification and marking
ISO 8573  Compressed air - part 1: contaminants and purity classes
Chapter I

Introducing the Subject and Methods

In this first chapter the master thesis is introduced and the problem formulation and background is setup. Then relevant theories and methods are described, including the product development strategy.
1 Introduction

Introduction to the master thesis project, including its background and purpose.

1.1 Background

Siemens Industrial Turbomachinery AB, in this thesis denoted as Siemens, is an international company developing and manufacturing small and medium sized industrial gas turbines for power generation and mechanical drive.

One of the important parts in the gas turbines are the burners. The burners are used to burn the fuel and heat the air flowing through the turbine. The burners are during operation damaged by the intense heat at their tip, causing cracks to form. To repair the burners their tips are cut of and replaced by new tips. Recently Siemens has discovered the opportunity to perform this repair with the help of Additive Manufacturing, AM. With the AM technology it is possible to print a new tip directly on the burner, this process is called Rapid Burner Tip Repair, RaBuTiR. The RaBuTiR process saves time, and makes it possible to update the geometry of the burner tip.

Siemens has a strong desire to further improve the burner tip repair and are therefor looking for a new way of setting up their repair process.

1.1.1 Rapid Burner Tip Repair

The Rapid Burner Tip Repair process has been invented to increase the performance of burner tip repair for certain Siemens gas turbines. The reason for this possibility is the fact that only the top millimeters are damaged due to the intense heat in the gas turbine. The traditional way of repairing is to cut away the top 120 mm of the burner and replace it with a new part. This re-manufactured part is complex and includes several machined parts and precision welds. The new way is to cut away only the tip, 22 mm, and then with the help of a Selective Laser Melting, SLM, machine rebuild the tip directly on top of the burner. Within the tip of 22 mm the critical section from a cracking and damage perspective is located, including a safety margin. The reason for not only cutting away the cracked section instead of all the way around the burner tip is the limitations of the SLM process, 2.1.1. Selective Laser Melting. The SLM process needs a flat 2D-surface to start the build job upon. See figure 1 for a principal overview of the RaBuTiR process.
The simplified processes of repairing a burner with the help of RaBuTiR is

- straighten the burner and cut of the tip with a lathe,
- debur and clean surface where the new tip will be built,
- print a new tip using a SLM-machine,
- remove powder that has seeped into the burner,
- process surfaces of the new tip using a CNC lathe or mill,
- coat the tip with ceramics to protect it against heat.

A detailed overview of the SLM part of RaBuTiR can be seen in figure 2.
When the burner tip has been replaced with additive manufacturing the surface needs to be machined and coated with a ceramic coating.

1.1.2 Surface Finishing

The conventional way of surface finishing the burner tips, to protect them from the intense heat in the gas turbines, are to machine a smooth surface on the tip, give it a fine texture and coat it with a ceramic coating. This is a relatively expensive process with high precision which needs machinery that is rather big. The capacity of a coating machine is high in comparison with the SLM process, which means it would take many SLM machines to repair enough burners to serve the coating machine.

This makes it non ideal to include such a machine in the vertical workshop. Another opportunity is to send them to a local manufacturer to perform this coating. That takes a big network of suppliers and much work to make sure they produce good quality, which would be necessary since the burner is a critical part of the gas turbines.

Figure 2: Detailed principle of RaBuTiR SLM process (Courtesy Siemens Industrial Turbomachinery AB)
Fortunately there is promising research going on with SLM production of burner tips. The research shows that the surface temperature can be reduced by using a smart design with internal cooling. This is believed to make it possible to use burner tips without a ceramic coating in the future.

To constrain this master thesis it is assumed that by the time the PLANT-IN-THE-BOX concept is ready for market, the coating is not needed.
1.2 Industrial Challenge

Siemens Service Division’s Centre of Competence for Additive Manufacturing (PS DG TI AMF) based in Finspång, Sweden, intends to develop a technical solution for the regionalization of spare parts repair and new component manufacturing with 3D-printing at any site close to the company’s customers around the globe. This regionalization project is part of - and financed by - the “Digitalization @ PS”-Initiative that started in October 2015.

Core of this project is an idea of a container based PLANT-IN-THE-BOX factory with additive manufacturing, AM, or rapid repair, most likely in the form of Selective Laser Melting, SLM.

PLANT-IN-THE-BOX is based on the idea to have the manufacturing equipment in a container which can easily be shipped to a new destination if desired. The AM container will be equipped with a SLM machine and all its surrounding systems and equipment necessary for the process. This AM container can then be combined with other containers containing anything from machinery for cutting processing to desktop stations and equipment for climate control. The set of containers are organized in a Vertical Workshop, where the containers can be slipped into a rack which supports the multi-storage workshop with accessibility and the necessary media.

The combination of Vertical Workshop and PLANT-IN-THE-BOX results in an interesting concept, see figure 3. The concept gives the freedom to rapidly set up a production plant which then quickly can be modified if the production demands changes. If the need has decreased for one of these plants some of the containers can easily be moved to a different location, and later on shipped back if there is a new demand. This enables a smart usage of production capacity on a world wide scale.
Figure 3: Conceptual drawing of the Vertical Workshop and PLANT-IN-THE-BOX concept. (Courtesy Siemens Industrial Turbomachinery AB)

The PLANT-IN-THE-BOX are to

- Enable flexible repair and manufacturing close to customer
- Provide a modular workshop that can be changed on demand
- Ensure a well defined and safe working environment

By analyzing the project idea, with the help of a SWOT-analysis, the main Strengths, Weaknesses, Opportunities and Threats of the concept has been identified.

Strengths

- Additive manufacturing as manufacturing technology gives new opportunities
  *Earlier impossible geometries can be manufactured*

- Modularization of production capacity
  *The set up can quickly be changed and adjusted to new demands*

- Flexible manufacturing capacity
  *The AM technology allows quick changes of part geometry produced*

- Repair close to customer
  *Shorter lead time and regionalization is important to customers*
Weaknesses

- Small scale production units
  Does not benefit of being a big and centralized unit

- Spread competence
  More complex to share competences, as competences are divided by geographically distributed units

- Long distance between manufacturing units
  Harder to organize a widely spread organization

Opportunities

- Decrease the lead time of burner tip repair
  Repairing closer to customer reduces the shipping time

- Increase quality of burner tip repair
  With manufacturing units streamlined for a specific purpose

- Increase the performance of burners in existing and new gas turbines
  AM allows for easy application of design changes

- Increased flexibility and capacity
  With more and flexible capacity one can meet the increased demand

Threats

- Increased competition
  Competitors are working hard to improve their products

- Rapidly changing market needs
  The markets needs changes rapidly and can easily change the conditions
1.3 Purpose

The purpose of this master thesis project is to perform a conceptual study to investigate the plausibility of the PLANT-IN-THE-BOX concept. The study is to explore the opportunities of fitting equipment and systems in a container to form a mobile and modular workshop unit. It is of interest to identify limitations and opportunities for the continued work with the concept. The results will be used as a decision basis to plan the future of the PLANT-IN-THE-BOX concept, if it is plausible it shall provide a knowledge basis for further development.
1.4 Objective

The objective with this master thesis is to develop a conceptual design of the additive manufacturing PLANT-IN-THE-BOX container for a RaBuTiR Vertical Workshop.

The first part of the project aims to analyze the RaBuTiR process and establishing the needs of the process, as well as analyzing the needs of the container itself. These analyses results in an initial requirement specification for the AM container, which is used to generate an initial 2D and 3D layout.

The purpose of the initial requirement specification is to give a good overview of the container concept and a base for further development. A systems engineer shall be able to use the analysis and the initial requirement specification to further define the concept and establish a requirement specification that is suitable to hand to a team of designers.

The 2D and 3D layouts aims to investigate the physical opportunities and boundaries of the PLANT-IN-THE-BOX concept for the AM container.

Special focus shall be put on

- health, safety and ergonomic aspects
- protection of intellectual property when outside Siemens premises and
- ease of maintenance and serviceability

of the PLANT-IN-THE-BOX.

The major phases of such a PLANT-IN-THE-BOX’s life are

- The test and development phase of a new process at the original erection point in Finspång,
- The Acceptance Test of an AM process by an (internal Siemens) customer,
- The transport close to the (internal Siemens) customer site
- The functional life of the PLANT-IN-THE-BOX at one or multiple use sites
- The taking out of service at the end of the useful life of the unit.
1.5 Scope

The intention with this master thesis is to define the initial requirements and design of such a Plant-in-the-box. Considering the current additive manufacturing in Finspång as a fixed workshop based process the idea of the master thesis is to transform this into a mobile container based concept.

The scope is to focus on one container, for Selective Laser Melting, SLM, repair of burners as a part of a multi-container plant, a “Vertical Workshop”. The master thesis is a conceptual study of this SLM container and its interactions with the surroundings. It is of interest to identify what parts of the Vertical Workshop will be included in the SLM container and what should be placed in separate containers.
1.5.1 Delimitation

Set of limitations set up during the project to maintain focus.

A. Standard Freight Container - Size

Restrict the work to the use of a container with the same outer dimensions as an ISO standard sized freight container. Do not research the design criterion of a freight container, other than specifications connected to use of the container. The result of the master thesis may point in the direction of using a specially built container. The size of this container must however follow the ISO standards regarding freight containers, since this affects the shipping opportunities.

B. Installation Standards - Media

Do not look into the rules and standards for installation of: pressurized air, gas, electricity, ventilation, but identify the needs of the equipment.

C. SLM Container

Focus the work on a container including equipment that are to perform the SLM part of the RaBuTiR process. This means, processes before and after the SLM repair will only be mentioned as needed for the big picture, but will not be further researched or developed.

D. Rack

Do not look into the requirements or layout of the rack, except for basic requirements connected to the containers.
2 Theory

This section introduces the theory base for the master thesis

2.1 Additive Manufacturing

Additive Manufacturing, AM, is a manufacturing method where material is added during the manufacturing process instead of being removed. This means that the part is built up during the process, using a raw material such as powder, wire, resin etc., until it corresponds to the designed part. In comparison, the methods of subtractive manufacturing builds upon the idea of removing material. The material is removed from a piece of raw material that is bigger than the designed part, until it corresponds to the design.

Rapid prototyping was the first AM method developed to use computer-aided design, CAD, to create three-dimensional objects. The most prominent benefit of AM is the capability of manufacturing shapes that is not possible with other manufacturing methods. Until now AM has been most used for prototyping, modeling and rapid tooling. This is about to change as small scale production with mass customization becomes more and more interesting. For this kind of manufacturing AM presents chances of time and cost reduction - due to reduced or no need of special tooling - as well as the reduced human interaction and the shortened product development cycles. (Gardan, 2016), (Brant and Sundaram, 2015)

Additive manufacturing is thought to be a “revolutionary technology likely to restructure supply chains, relocated productions facilities and profoundly alter the geographical, economical, social, demographic, environmental and security landscape”. Thus far AM has the capability of producing fully functional parts of a variety of materials including metals, plastics and composites. (Pinkerton, 2015)

Depending on the material of interest there are different AM processes that are suitable. One of the most prominent methods are Selective Laser Melting, SLM, with which both metal and plastic parts are manufactured by melting / welding powder particles together to form the product.

2.1.1 Selective Laser Melting

Selective Laser Melting, SLM, is an AM process where a part is built by melting layer by layer of powder with the help of a laser. Siemens are currently using machines from EOS, which are built for SLM of metals. See figure 4 for a general overview of the process.
Figure 4: Schematic process description of Selective Laser Melting (Rehme, 2010)

The simplified SLM-process of a regular, non RaBuTiR, build is

- a CAD model is prepared and sliced into 2D computer-generated drawings for each layer,
- these drawings are sent to the SLM machine, together with build parameters for the specific job and material,
- a thick steel building plate is loaded and secured to the building platform in the machine,
- powder is loaded into the machine,
- the machine is set up and it is made sure that there is a smooth and thin layer of powder covering the building plate,
- the machine flows the process chamber with an inert gas to reduce the amount of oxygen in the build chamber before starting the job,

Repeat

- the powder layer is scanned with the laser to form a metal part corresponding to the current 2D drawing,
- the building platform is lowered by one layers thickness and is cover by new powder,

- when the part is finished the excess powder is removed and recycled and the part can be cut loose from the building plate.
2.1.2 Metal Powder

The metal powder considered is *EOS NickelAlloy HX*, used for additive manufacturing. “*EOS NickelAlloy HX is a nickel-chromium-iron-molybden alloy in fine metal powder*”, which composition follows the standard of UNS N06002. Parts built with additive manufacturing have good elongation and high strength even without after-treatment. With solution annealing the micro structure will be homogenized and internal stresses relieved - giving an increased elongation and a lower strength. (EOS GmbH, 2014)

HX is often used in aerospace and gas turbine technology since it can be used up to 1200°C, while maintaining full oxidation resistance and high strength. (EOS GmbH, 2014)

The HX alloy is mainly composed of nickel, chromium, iron, molybdenum and cobalt, with small amounts of other alloys. (EOS GmbH, 2014)

2.2 Health and Safety

Health and safety aspects of the metal powder and solitary work in a confined space.

2.2.1 Metal Powder Health Effects

During metal 3D printing metal particles of other sizes than the original metal powder are generated. In samples at Siemens Industrial Turbomachinery, small round particles of size $\sim 1-2\mu m$ have been found in recycled powders. The size of these particles are within the range to raise caution about health and safety issues. Meanwhile, it is believed that even smaller particles may be produced, depending on material and machine combination. Particles of $\sim 1-2\mu m$ are not small enough to fully be absorbed by the skin, while airborne powder easily can be inhaled. (Mellin et al., 2016)

Particles with a shape or features on the scale of 1-100nm are defined as nano-scale particles by the International Union of Pure and Applied Chemistry, IUPAC (Lövestam et al., 2010). Within this size range a significant part of the particles atoms are located at its surface, thus giving them unique nano properties. (Mellin et al., 2016)

Considering the generated particles they may not qualify as nano particles by the IUPAC, while some concerns about harmfulness may include particles up to 1000nm from a health and safety perspective. These particles can be partially absorbed by the skin and release ions which is a potential way of entry into the body. A more obvious risk is inhalation of the particles, which is clearly dangerous, where particles smaller than 3-5 $\mu m$ can be inhaled (Jönsson, 2016). When the particles have entered the body, become attached to a cell or released ions they can, for instance, damage DNA or cause cells to turn into cancer cells. (Mellin et al., 2016)

Materials considered to cause health issues, in previous research, include nickel and cobalt. In these cases inhalation of particles are considered the main risk, and when they have en-
tered the body they may cause long-terms effects. Inhalation of cobalt have shown effects like: reduced lung capacity, asthma, and respiratory distress (Karlsson, 2015). “Protective measures must be taken and the powder should preferably be handled in a confined space. Good ventilation equipped with filter and personal breathing masks is a must, when handling the powders outside a confined space.” (Mellin et al., 2016)

Siemens in collaboration with Sandvik proposes a few safety precautions, (Sandvik and Siemens Industrial Turbomachinery AB, 2016):

1. Access must be limited to authorized personnel
2. Protective equipment including breathing masks must be used when necessary
3. In the case of re-circulating ventilation, high-performance filters, such as HEPA-filters, must be used

2.2.2 Solitary Work

Solitary work, or working alone, means work without close or direct supervision. It could be performed in mobile or fixed establishments. (Gurney, 2012) Solitary work is not by itself against the law, while health and safety risks must be carefully considered by the employer, as the employer are responsible for welfare, health and safety at work. (Health and Safety Executive, 2013)

Some factors that needs to be considered, (Health and Safety Executive, 2013):

1. involve the workers in the periodically performed risk assessment
2. removing risks or implementing control measures
3. training and supervision of workers

In some cases there is a need for atleast one other person to be present, eg. when working in confined spaces. In this case there may be a need for a supervisor and a dedicated rescue person to be present. If another person is not needed to be present at all times, there is a need for procedures to monitor the person working alone. This may include the “supervisor periodically visiting and observing people working alone". (Health and Safety Executive, 2013)

2.2.3 Confined Space

Confined spaces can be defined in many ways. United States Occupational Safety and Health Administration, OSHA, defines confined spaces as “a space that: (1) is large enough and so configured that an employee can bodily enter and perform work; (2) has limited means of entry or egress; and (3) is not designed for continuous employee occupancy”(Burlet-Vienney et al., 2015a), Tony Fishwick, in his examinations, defines confined spaces as “any space of an enclosed nature where there is a risk of death or serious injury from hazardous substances or other dangerous conditions (eg a lack of oxygen)."(Fishwick, 2012).
Defining and identifying confined spaces are areas of disagreement. “However, a confined space that is not enclosed within the meaning of the regulations does not relieve an organization of its obligation to properly manage the risks associated with this space.” (Burlet-Vienney et al., 2015b)

Following Fishwick the main hazards of confined spaces are, (Fishwick, 2012)
1. lack of oxygen
2. presence of poisonous gases
3. use of machinery
4. falling items
5. restricted escape routes.

These hazards, which may cause “death, temporary impairment, functional disorder, or an inability to exit the space” (Burlet-Vienney et al., 2015a), must be considered as serious. Risk factors that needs to be assessed includes, (Burlet-Vienney et al., 2015b):
1. “the training of the workers involved and the information made available to them"
2. “the gathering of information, in writing, about hazards and preventive measures to be taken prior to work in a confined space"
3. “the use of ventilation to maintain acceptable atmospheric conditions (i.e. oxygen, contaminants, lower explosive limit)"
4. “the management of combustible dusts presenting a fire or explosion hazard, and hot work"
5. “gas monitoring and measurement"
6. “mandatory supervision"
7. “tested rescue procedures that make rapid rescue possible"

2.3 Distributed Manufacturing, DM

Distributed Manufacturing, DM, is basically the idea of geographically distributed manufacturing facilities.

The original ideas of globalization was applied about 20 years ago and focused on breaking up manufacturing in sub-parts and processes and locate them at different locations. More recently enterprises has seen the opportunity to compliment each other and share work force and technology. Nowadays there has been a shift from mass production to mass customization. This has lead to the need of small, flexible and scalable manufacturing units to be able to serve customers just-in-time with freedom of customization in a sustainable way. (Rauch et al., 2015a)
There are currently 8 categories, (Matt et al., 2015), for classification of existing forms of DM, which of three are of interest in this study. The first case, *figure 5*, “Standardized and replicable model factory”, is based on a well defined and standardized product that is manufactured at production sites close to customer. The sixth case, *figure 6*, “factory on-site”, is based on the use of fully functional small scale mobile facilities temporarily placed on a customer site. While the eight case, *figure 7*, “Cloud production” and “Production labs of additive manufacturing”, where one sells the product data for manufacturing instead of a physical part that has to be shipped.

**Figure 5:** Standardized and replicable model factory

**Figure 6:** Factory on-site

**Figure 7:** Cloud Production, Production Labs of Additive Manufacturing

### 2.3.1 Opportunities of Distributed Manufacturing

**Economy** Due to the rising cost of logistics and transportation it is beneficial to produce locally and reduce transportation. (Rauch et al., 2015a)
Environment The need of transportation is reduced when only raw material and data are transported long distances, and therefore the CO2 emissions decrease, (Rauch et al., 2015a).

Regionalism Consumers are more selective and fond of locally produced goods which increases regional growth, and they are often willing to pay more for that, (Rauch et al., 2015a). This is extra important since Siemens customers often are states who are fond of benefiting locally from big investments.

Regulations Due to the regulations of some countries, eg. Russia, it is hard to bring materials out of the country, which makes it beneficial to perform repair work within the country instead of shipping parts out of the country and back in.

Flexibility Flexible plants are able to rapidly reconfigure to follow the trend of mass customization in a cost-effective way, (Rauch et al., 2015a), (Stillström and Johansson, 2006). A modular configuration is then needed to easily change the setup of the manufacturing facilities.

Mobility Mobile manufacturing units makes it possible to move them to new locations and reconfigure the setup of a facility, (Winroth and Jackson, 2007).

On Demand Being located close to customer makes it possible to reduce lead times and to deliver on demand with reduced stock holding, (Jackson and Zaman, 2006).

Agile Production Be able to quickly respond to changes and taking advantages of newly arisen opportunities. (Stillström and Johansson, 2006)

Holonic Manufacturing Different building blocks of the manufacturing system can cooperate with other blocks as well as working autonomously, (Jackson and Zaman, 2006). Which connects with the flexibility of PLANT-IN-THE-BOX and Vertical Workshop in the manner of being able to use a single container or multiple containers to form a more complex facility.

In a study concerning the current and future mobility of manufacturing systems twenty-three Swedish companies were asked about the mobility grade of their manufacturing systems. On a scale from 1 to 6, where 1 represents “Mobility unimportant” and 6 “Mobility very important”, the average for systems today were 2.28 while the values for the future plans were 2.83. This highlights the future need for mobile manufacturing units. (Stillström and Johansson, 2006)

2.3.2 Risks of Distributed Manufacturing

Geographical Distance A bigger geographical distance between locations of manufacturing may cause problems. One problem is trying to keep control over the satellite plants, without putting a to big burden on the organization.
Small Scale  It may be a risk that one looses the benefit of being a large scale manufacturer when one has to divide its sites into smaller and distributed plants.

2.4 Mobility

Mobile manufacturing and standardized freight containers.

2.4.1 Mobile Manufacturing

Youssef et al. describes mobile manufacturing as: “Mobile manufacturing is an enabler to increase the possibility to change and to adapt to altering needs, where the geographical position is not fixed. The main idea with the mobile manufacturing concept is to easily and quickly reuse manufacturing capacities between different orders or projects.”, with the purpose “to move manufacturing equipment from a stationary location (the site where the actor that controls and manages the capacity is) to a temporary location (the site where the capacity is used in operation)”. (Benama et al., 2014)

Mobile manufacturing allows the manufacturing to be characterized by flexibility, mobility and rapidity instead of cost. This is achieved by enabling geographical relocation of production capacity to wherever it is needed. From the perspective of business models, this allows functional sales and renting/leasing of modular production capacity. (Stillström and Johansson, 2006) This could be especially important to companies without in-house production capacity, who needs resources for pilot or temporary production, (Hedelind et al., 2007).

One benefit with modular production capacity is that it allows for modules to quickly be combined into production systems, while they enable the possibility of reconfiguration for new products and changed volumes. Thus, “Production capacity may be provided as a mobile and flexible resource that rapidly can be tailored to fit the needs of a company, at a specific point of time.”. (Hedelind et al., 2007)

The operating cycle of such a mobile manufacturing unit is described by Upton as: “the life cycle starts with configuration of the manufacturing modules to a specific order. Thereafter, the modules are transported to the location where they will be used in production. When the order is finished, the manufacturing modules are transported to home site, or to another location, where they are reconfigured and reused”.(Upton, 1995)

The design of a mobile manufacturing system is affected by the distance between the stationary parts of the company and temporary location for production capacity. In this matter, not only the geographical distance has an affect, but also the organizational, technological and social, etc., distances. The geographical distance is the physical distance, eg. kilometers, while the organizational distance depends on the company structures. The organizational distance may be between companies, departments, functions or levels and greatly affects, for example, information handling. (Stillström and Jackson, 2007)
Other benefits of mobile manufacturing are; (1) Just-in-time supply with production capacity close to customer; and (2) Manufacturing networks with multiple partners - collaboration with core competences and resources. (Rauch et al., 2015b)

2.4.2 ISO Freight Containers

The standardization of freight containers size and capacity has been done to make it easier for international transport systems. This includes, not only, sizes of trains, trucks and ships, but also support systems as cranes and equipment for securing loads and containers.

Freight containers are standardized by ISO for intercontinental transport. One of the standards is ISO 668 - “Series 1 freight containers - Classification, dimensions and ratings”, which establishes external dimensions and ratings for series 1 freight containers. (ISO, 2013)

2.5 Modularity

Modularity can be defined as “building a complex product or process from smaller subsystems that can be designed independently.” (Manuf Shaik et al., 2014). The modules can be seen as building blocks which can be used in different combinations to form various products (Anderson, 1997). The overall product function can be divided into subfunctions, which then may be represented by different modules, and these modules can be described as sets of structurally or functionally independent components. The use of such modules may reduce lead times and decrease manufacturing costs, as well as creating strong product families. (Manuf Shaik et al., 2014) Furthermore, the use of modular and mobile manufacturing modules reduces the need of investments in manufacturing equipment as they may be used at multiple sites, (Benama et al., 2014). The modules may be combined differently to meet the needs of a specific customer. (Sun and Cheng, 2008)

Implementing modular production and assembly techniques are important from a mass customization perspective. Modularity gives the opportunity to adjust the level of customization, with respect to individual functions and features of a product. (Manuf Shaik et al., 2014)

2.5.1 Reconfigurable Manufacturing Systems

“Reconfigurability is an essential feature of agile manufacturing system, and such system can use basic building blocks, both hardware and software, which can be reconfigured quickly and reliably providing an project oriented and modular method of modeling manufacturing activities.” (Manuf Shaik et al., 2014) A Generic Modular Reconfigurable Platform, GMRP, can be used as a “product-oriented reconfigurable, highly responsive manufacturing system”, which can easily be reconfigured to meet new customer needs. (Sun and Cheng, 2008)
The operating cycle of such a reconfigurable manufacturing unit is described by Upton as: “the life cycle starts with configuration of the manufacturing modules to a specific order. Thereafter, the modules are transported to the location where they will be used in production. When the order is finished, the manufacturing modules are transported to home site, or to another location, where they are reconfigured and reused”. (Upton, 1995)

2.6 Maintainability

“Maintainability is a design characteristic of a product that determines the performance of various maintenance activities such as inspection, diagnosis, repair and replacement”. (Luo et al., 2014) When looking into design for maintainability some factors that are relevant to consider is; (1) accessibility; (2) ease of removal of component; (3) maintenance frequency; and (4) maintenance space, (Luo et al., 2014). These factors are connected to the need of available space around a machine, and how often the maintenance is needed.
3 Method

Description of methods used in the master thesis. As well as derivation of methods that were set up.

3.1 Overall Work Process

An overall work process to give the work a structural plan as guideline where set up, see figure 8. The process is suitable for projects where the limited time frame requires that focus is put on establishing a general overview of the project and a detailed view of the most important parts of the project. This process is suitable for the initial stage of a larger product development project - as a pilot study to confirm the plausibility of the product. The process structure is similar to the product development process described by Ulrich and Eppinger, (Ulrich and Eppinger, 2008).

The process structure begins with identifying the systems and subsystems of the container. Then, with the identified systems, the available time and knowledge are used as a decision base, to reduce the number of systems to the ones of greatest importance, Focus areas. The focus areas can then be further defined to get a better overview of what they contain. From the further defined focus areas requirement specifications can be set up to identify design restrictions. When the systems are known they can be modeled, in 2D and 3D, and used to make a layout, in 2D and 3D.
3.2 Analysis of RaBuTiR Process

Methods used for analyses of the RaBuTiR process to identify the requirements put on the container solution.

3.3 Process Analysis

Methods to analyze of the RaBuTiR process and container concept to identify equipment and systems that are of interest.

3.3.1 Function-Method Breakdown Structure

Investigation of what machines and equipment are needed in the RaBuTiR container a method was needed to systematically go through all process steps. It was also necessary to identify equipment that needs be researched and what equipment are to be implemented in the RaBuTiR container.

A version of a Function / Method Tree (Ulrich and Eppinger, 2008) was found to be a suitable way. This takes advantage of the systematic approach to break down a process.
into functions, and adds conclusions about further work, such as if the equipment is to be implemented in the container and if there is a need for further research of the technology.

Research focuses on the knowledge of the equipment needed to implement it in the container and includes things such as standards for constructions, connections to media and other requirements of the equipment.

Implementation suggests that the equipment is included in the RaBuTiR container, should be put in another container or if it is part of other equipment. An explanation of designations can be found in *table 1*.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Research required</td>
</tr>
<tr>
<td>(R)</td>
<td>Information about size and connections needed</td>
</tr>
<tr>
<td>-</td>
<td>No information needed</td>
</tr>
<tr>
<td>I</td>
<td>Include in RaBuTiR container? (yes/no)</td>
</tr>
<tr>
<td>(I)</td>
<td>Part of other equipment</td>
</tr>
</tbody>
</table>

### 3.3.2 Fish Bone Analysis

The Ishikawa/Fish Bone analysis, *(Kerzner, 2003)* starts with a main subject which is broken down into sub-subjects, forming the fish bone structure when done graphically. These sub-subjects can then be divided into the next step of smaller bones giving a better description of the sub-subjects. This breakdown is done until the analysis has reached a level of detail that is sufficient for the specific case.

The analysis gives a good overview of the main subject and it keeps a good structure even for complex systems.

### 3.4 Multi-Topic Subject Weighing

Multi-Topic Subject Weighing is a method, set up during this master thesis, to evaluate the importance of a set of subjects with regards to a series of topics. The evaluation is done in a time efficient way and allows a limited amount of detailed knowledge about the subjects.

The number of topics is what effects the time of the analysis the most since each subject must be evaluated with respect to the topic.

The purpose of the analysis, in this master thesis, is to find the subjects that are the most important to the scope, thus enabling time allocation focused on importance.
3.4.1 Derivation of Method

The start of the method were the question

Initial question: What makes a subject important?
My answer: The subject has a big impact on the result.
The result is: a layout based on a requirement specification.
A layout is: a placement of equipment, and when deciding on a layout the three main topics to consider are

- Work Environment,
- Function and
- Cost.

This gives

\[ \text{Result} = \text{Layout} = f(\text{WorkEnvironment}, \text{Function}, \text{Cost}) \]

These three topics are in turn effected by all the subjects. Inverting this gives each subjects effect on the three topics. To estimate what effect each subject has on the topics two parameters were chosen:

Effect on Topic How much does the subject effect the topic

Degree of Freedom How much freedom is there to change the effect of the subject on the topic

In the project it is more important to focus on the subjects that have a big impact on the result. To have a big impact on the result the subject has to have a big effect on the three topics and that the subject allows freedom of design.

A piece of equipment that is fixed in its design does not require much research or work for redesign, and a piece of equipment that has a non-important function is not important to study in such an early stage of the project.

With the help of the three individually rated topics a combined comparative value for each subject is received. For further explanation of analysis see table 2.
3.5 Work Process and System Function Analysis

The Work Process and System Function Analysis focuses on analyzing how the operator works with the equipment and how subsystems work together. The analysis is similar to the Function Analysis described by Cross, (Cross, 2008), except that it here is performed on a wider system level including the operator in the mapping. The focus is on identifying what items are manually moved - such as substrates - and automatically moving - such as media - between the different pieces of equipment. The purpose is to make it easy for the operator to move from one piece of equipment to the next in the work process, as well as having support equipment near at hand.

The analysis results in a chart describing the work process and systems function from a transfer of material and connections perspective. The chart has three types of symbols; ovals, diamonds and arrows. The ovals represents machines or equipment which will have a stationary placement when in use. The diamonds represents the objects being moved or moving between the machines. This may be a piece of material, media, heat or even the operator depending on what is studied. The arrows describes how the transfers are made; in one direction or both.

Lets take an example: a gas turbine. The turbine is connected to a fuel tank and an air intake on one end and an exhaust system on the other. It does also have electrical controlled fuel injection and sensors sending data back to the control system. In this system the turbine, fuel tank, air intake and the control system will be regarded as equipment and the fuel, air, exhaust gas and data as the moving objects. See figure 9 for the resulting chart.
Figure 9: Work process and system function analysis example of gas turbine.
4 Product Development Strategy

Presentation and comparison of product development strategies, based on a process from Siemens and a theoretical process described in (Ulrich and Eppinger, 2008).

4.1 Siemens Strategy

Introduction and explanation of the product development process used at Siemens to develop gas turbines. The information is gathered from (Siemens AG, 2014).

4.1.1 Overview

“The Product Development Process (PDP) provides a systematic approach to the development of Power and Gas Division related products and solutions. It implements a quality-assuring, measurable, organized, step-by-step model designed to develop products/solutions in the shortest possible time, with minimum amount of cost at minimized risk.” (Siemens AG, 2014). The PDP is to be used during development projects based on known technologies with proven applications and known manufacturing methods.

The PDP is built on five blocks, see figure 10, of activities:

- **Strategic Product Planning** Planning phase, including analysis of market and customers.
  - **Product Strategy** Evaluation of ideas, market data, technology and customer process as well as performing “Product Strategy Review (R0)”.
  - **Product & Development Planning** Analysis of product specific market, definition of Product Requirements Specification, PRS, and conduct “PRS Review (R1)”.

- **Design** Establishment of solutions to requirements and design of those.
  - **Conceptual Design** Performing a Quality Function Deployment to translate requirements into solutions. Create and propose concepts, generate Product Design

![Figure 10: Siemens Product Development Process (Based on (Siemens AG, 2014))]
Specification, PDS, and conduct “PDS Review (R2)” and “Product Design Gate (QG2)”.

Basic Design Using proactive quality tools, define detailed design tasks, carry out basic design and perform “Design Review (R3)”.

Sales Preparation Preparation for product launch.

Commercialization Planning Initialization of market entry, set up of market entry concept, perform “Commercialization Review (R4)” and conduct “Product Release Gate 3 (QG3)”.

Design Implementation Final design, production planning and commissioning.

Final Design & Procurement Conduct FMEA for Final Design, carry out final design and procurement preparation, perform “Final Design Review (R5)”, determine need of Readiness for Production / Procurement, RPP review, perform “RPP review (R6)”.

Manufacturing & Assembly Schedule productions activities, supply material for production, perform production and testing, perform “Product Review (R7)”, pack finished goods, stage finished goods, release product to deliver.

Erection, Installation, Commissioning & Trial Operation Ship product with documentation, install at customer site, perform “Commissioning Review (R8)” and “Conditional Series Release Gate (QG4)”.

Validation Making sure the product performs as planned.

Product Monitoring & Validation Monitor performance, perform “Product Monitoring Review (R9)”, “Performance, Reliability, Availability, Serviceability, PRAS, Review (R10)” and conduct “Final Series Release Gate (QG5)”.

4.1.2 Product Development Process

Reviews, R A thorough examination of documents and products, performed in a systematic and documented way, to ensure that all customer and functional requirements are met. Reviews are performed to better overview the status of projects during the whole process from project proposal to project commercialization and there are ten reviews:

R0 - Product Strategy Review
R1 - Product Requirement Specification, PRS, Review
R2 - Product Design Specification, PDS, Review
R3 - Design Review
R4 - Commercialization Plan Review
R5 - Final Design Review
R6 - Readiness for Production/Procurement Review
R7 - Product Review
R8 - Commissioning Review
R9 - Product Monitoring Review
R10 - Performance, Reliability, Availability and Serviceability Review

Depending on the nature of the project all of them or a set of them are performed.

Gates, (Q-)G Evaluation of strategic, technical and commercial risks to determine the progression of the project. Extra attention are put on Quality Gates, where general and project risks are evaluated. There are five gates:

G1 Project Initiation Gate
QG2 Product Design Gate
QG3 Product Release Gate
QG4 Conditional Series Release Gate
QG5 Final Series Release

Key Performance Indicators, KPIs Indicator values to evaluate the economical aspects of the project. Important part of the project, both for development costs and market value.

4.2 Theoretical Strategy

Introduction and explanation of one of the product development processes described in (Ulrich and Eppinger, 2008).

4.2.1 Overview

The general product development process described by (Ulrich and Eppinger, 2008) consists of six blocks and three main divisions, see figure 11.

Figure 11: Ulrich and Eppinger’s Product Development Process (Based on (Ulrich and Eppinger, 2008))

Planning Preparation of mission statement
Marketing Identify the market
Design Consider new technologies and product platform
Production Identify constraints of production

Concept Development Generation and evaluation of product concepts
Marketing State of the art analysis and identification of the needs of the target market
Design Development and testing of concepts and prototypes, and investigation of product feasibility
Production Initial production cost and verification of production feasibility

System-Level Design Geometric layout and functional specification
Marketing Planning of product versions and product family
Design Develop an overall product architecture and design with sub-systems and interfaces
Manufacturing Decide about make-buy strategy and identify key suppliers

Detail Design Generate control documentation of product
Marketing Set up of marketing plan
Design Detailed design of systems and components, material choice and tolerance assignment
Manufacturing Set piece-vise production methods and design tooling

Testing and Refinement Test and build prototypes
Marketing Prepare marketing material and initiate field testing
Design Testing of preproduction prototypes with respect to performance, durability and reliability
Manufacturing Refine manufacturing processes, and ramp-up of production

Production Ramp-Up Sort out the production process
Marketing Testing of early built products with key customers
Design Evaluation of early product tests and production
Manufacturing Start of full scale production
4.2.2 Product Development Process

The generic PD Process described by (Ulrich and Eppinger, 2008) consists of six blocks with reviews and / or gates in between as a way to make sure the last phase is complete and that the project may proceed. The five reviews are

- **R0** - Mission Approval
- **R1** - Concept Review
- **R2** - Preliminary Design Review
- **R3** - Critical Design Review
- **R4** - Production Approval

This PDP is designed in a general way and describes the basic structure of the process. The process can be modified to the needs of a company and implemented in a way that is suitable.

4.3 Comparison of Strategies

The general ideas of the processes are the same: provide a structured way to go from product idea to production and full sales. The main differences are due to that the methods are developed for different types of products. The method presented by (Ulrich and Eppinger, 2008) are more aimed towards development of consumer products that are to be mass produced, from tens of thousands to millions of copies. While the Siemens PDP aims towards developing gas turbines, complex products, which may sell in a hundred copies over a few decades. Development of gas turbines takes many years and the sales numbers are commonly low for a new gas turbine, while a mass produced product may sell thousands of copies on the day of launch. The market is thus smaller and there are fewer opportunities for full scale prototype testing.

A conclusion could be that it is of great importance, for Siemens, to have a PDP that provides a more detailed review process during the development of gas turbines. This to make sure there are fewer errors that may cost many hours in redesigning, or many hours of repair at a customer site. On the other hand since there are commonly few turbines sold in the time after a new product launch it is more likely that there is time to fix problems before you sell many.

**Similarities**

- Chronologically the same structure
- Reviews to ensure a qualitative process

**Differences**
• The PDP described by (Ulrich and Eppinger, 2008) is a “Generic Product Development Process”. While the Siemens PDP process is more of a “Complex Systems Development Process” with parallel stages of development, where figure 10 only shows the overall picture (Ulrich and Eppinger, 2008)
• Grouping of activities are different
• Siemens uses more reviews to ensure a qualitative process

Comparison of the correlation of activities from the two PD Processes, see table 3 and figure 12.

Table 3: Correlation between the Siemens PDP and the generic PDP described by (Ulrich and Eppinger, 2008). Numbers refer to figure 12

<table>
<thead>
<tr>
<th>Nr</th>
<th>Siemens PDP</th>
<th>Ulrich and Eppinger generic PDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strategic Product Planning</td>
<td>Planning + Concept Development (Marketing)</td>
</tr>
<tr>
<td>2</td>
<td>Conceptual Design</td>
<td>Concept Development + (Design, Production)</td>
</tr>
<tr>
<td>3</td>
<td>Basic Design</td>
<td>System-Level Design (Design, Manufacturing)</td>
</tr>
<tr>
<td>4</td>
<td>Sales Preparation</td>
<td>System-Level Design (Marketing), Detail Design (Marketing), Testing and Refinement (Marketing)</td>
</tr>
<tr>
<td>5</td>
<td>Final Design &amp; Procurement, Manufacturing &amp; Assembly</td>
<td>Testing and Refinement (Design, Manufacturing)</td>
</tr>
<tr>
<td>6</td>
<td>Erection, Installation, Commissioning &amp; Trial Operation, Validation</td>
<td>Production Ramp-Up</td>
</tr>
</tbody>
</table>
4.4 Set Up of Strategy

Applying the Siemens PDP to the project results in including part 1 Strategic Product Planning and part 2 Design, see figure 13. This in term makes some Reviews necessary. To reduce the amount of project management work the gates are considered as a part of the reviews and the extent of the reviews are decreased in comparison with the Siemens PDP process.

The first part results in

- planning of the project,
- state of the art analysis,
- analysis of product function and process,
- further definition of concept,
- requirement specification
and the second part results in

- layout planning 2D,
- 3D-modelling,
  - initial concept
  - final concept
- verification of concept.

The review process will be as

**R0** Review of planning, state of the art, analysis of product and further definition of concept with LiU and Siemens representatives

**R1** Review of requirement specification with Siemens representatives

**R2** Review of initial concept with Siemens and LiU representatives and stakeholders

**R3** Final review/presentation of project with Siemens and LiU representatives
This chapter begins with a state of the art analysis. Next an analysis of the working conditions of the container - internal as well as external - is done. The end of the chapter includes an analysis of the subjects that are important when designing the container, and planning of the 2D-layout.
5 State of the Art Analysis

Before starting the development process it is useful to see if there are or have been any activities on the market which is of interest.

5.1 Similar Activities

The main competitor activities that have been found and are of interest when developing the PLANT-IN-THE-BOX concept. They are presented below as a list of products and projects, including a short description of them and their benefits.

**Cassa Mobile** “Flexible mini-factory for local and customized production in a container”, (CassaMobile Project, 2013), - Configurable system of process modules, in 20’ ISO-container, including Additive Manufacturing, CNC-milling and automated assembly. Advantages:
- “Plug & produce” - easy to install
- Easy to adapt to new requirements
- Minimal investment and infrastructure costs

**Siemens** “Modular Container Solutions”, (Siemens Industrial Turbomachinery AB, 2015) - is a container solution for on-site service and repair, where the specialized equipment is shipped in a container. Advantages:
- Fast world-wide shipping
- Effective use of time, due to reduced set-up cost
- Minimal downtime of plants

**Gichner** NAVAIR, “rapidly deployable 20’ ISO Mobile Facilities”, (Gichner Shelter Systems, 2011), - containers with the benefit of allowing connection of multiple containers to form an environmentally controlled work space. Advantages:
- Removable side panels and connectable
- Insulated
- Integrated support systems, such as electrical provisions

**Factory-in-a-box** A Swedish three year research project by a combination of industries and universities, (Forskningsprojekt, 2007). The goal of the project was to develop five demonstrators, with different purpose depending on the company. Advantages:
- Five subjects: assembly, welding, casting, function sales and movable production
- Industry oriented subjects
• Practical demonstrators

The activities of CassaMobile, Siemens, Gichner and Factory-in-a-box have been identified as the most interesting to the PLANT-IN-THE-BOX project. Furthermore, there are other activities that present mobile and modular solutions which is available on the market, see below.

**BillerudKorsnäs** Development of a two container production facility of nanocellulose for demonstration purposes, (Inventia and BillerudKorsnäs, 2014).

**Mobile Healthcare Facilities LLC** Mobile healthcare facilities for a series of different purposes from dental care to surgery, (Mobile Healthcare Facilities, 2014).

**ARM** Mobile climate research facilities to reach destinations far away from the fixed research sites, (Department of Energy - United States Government, 2016).

**K & K Mobile Storage Incorporation** Mobile storage and office containers, (K and K Mobile Storage, 2014).

**GEMCO** “Site On Wheels” - trailer based telecom support facilities, (Gemco Mobile Safety, 2016).

**Scandic Container** “Display and showcase container” - Containers with a one side of full-size glass windows, (Scandic Container, 2016).

**Savel** Gas station solutions based on 20’ and 40’ ISO containers, (Savel Global, 2016).

**ABB** Container built mobile switchgear solutions for extreme conditions, (ABB, 2016).

**Modular** Apartment complex built of containers, (Modular, 2016).

### 5.2 Solutions of interest

Evaluation of solutions from the four competitor concepts; CassaMobile, Siemens, Gichner and Factory-in-a-box, that are the most similar to the PLANT-IN-THE-BOX concept and of the most interest.

**Mobility** The three concepts use standardized sizes for their containers. Gichner uses their own design with flat walls made of light weight materials.

**Wall construction** Gichner’s flat wall construction of light weight material reduces the wall thickness, resulting in more space inside the container while keeping the same level of insulation.

**Equipment** Cassa Mobile’s purpose is a container for flexible manufacturing with additive manufacturing and CNC-milling which is very similar to the purpose of PLANT-IN-THE-BOX. Siemens on the other hand uses their container for tools and equipment and it is furnished as a work station.
Rails Cassa Mobile uses a rail system on which machines and equipment can be slid into place.
6 Conditions

Analysis of what machines and equipment to put in the SLM container, what climate conditions the container will be subjected to and what ways of transportation is of interest.

6.1 Reason for Vertical Workshop

One can identify three main cases of SLM workshops

**Conventional workshop** a workshop in a fixed building.

**PLANT-IN-THE-BOX** a workshop that within a few months can be set up on a new location.

**Truck based workshop** all equipment are fitted on a truck which can easily be moved and temporarily be secured to ground.

When comparing these three by mobility and robustness it shows that there is a trade-off between mobility and robustness, see figure 14, where the conventional workshop is very immobile but robust and the truck is very mobile but not robust. PLANT-IN-THE-BOX fits in the middle which is very suitable for additive manufacturing, where a customer may need the production line from a couple of months to several years. It does also offer flexibility with the possibility to add, remove or change the set up of containers in the vertical workshop as the production changes.

![Figure 14: Comparison of fixed workshop, PLANT-IN-THE-BOX and truck based workshop by mobility and robustness.](image)

This concludes that the PLANT-IN-THE-BOX concept is well suited for additive manufacturing close to customer site.
6.2 Black-box for the SLM Container

To identify the inputs and outputs of the SLM container a black box was set up, see figure 15. The inputs and outputs were identified by reading specifications for the equipment and by interviewing employees at Siemens.

![Black-box for the SLM container](image)

Figure 15: Black-box for the SLM container

6.3 Machines and Equipment

To identify what equipment and machines are needed in the RaBuTiR container an analysis of the process as well as of the functions were performed. The process analysis resulted in a flow chart and the function analysis resulted in a Function-Method Breakdown Structure.

6.3.1 Process Analysis

Breakdown of the RaBuTiR process to identify the necessary equipment, see figure 16. Details of how to operate the machine have been collected from (Siemens Industrial Turbomachinery AB, 2016a), (Siemens Industrial Turbomachinery AB, 2016b) and (Siemens Industrial Turbomachinery AB, 2016c).
6.3.2 Function Analysis

To analyze the functional part of the RaBuTiR process, for use in a container, a method based on Function / Method Trees, explained in 3.3.1. Function-Method Breakdown Structure, were used.

An overview diagram of the RaBuTiR container can bee seen in figure 17. The deeper analysis, attached in Appendix A. Function / Method Tree, shows both the method with which the functions are fulfilled and the need for implementation in the container as well as the need for research to know the systems. An explanation of designations is found in table 1 in 3.3.1. Function-Method Breakdown Structure.
6.3.3 Identified Equipment

Based on the process analysis, in 6.3.1. Process Analysis, and the function analysis, in 6.3.2. Function Analysis, a list of equipment that is needed for the RaBuTiR process has been compiled, see table 4.
Table 4: *Identified equipment needed in the RaBuTiR process.*

<table>
<thead>
<tr>
<th>Category</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLM</td>
<td>SLM Machine, Filter Unit, Heat Exchanger, Camera Vision System</td>
</tr>
<tr>
<td>Powder Handling</td>
<td>Conveying Module, Sieving Module, Filling Module, Vacuum Cleaner (Wet Separator)</td>
</tr>
<tr>
<td>Burner Handling</td>
<td>Lifting Tool, Jig and Jack, Fixture, Computer, Milling Machine, Ultrasonic Washing Machine</td>
</tr>
<tr>
<td>Climate</td>
<td>Air Lock, Sticky Matt, Anti Static Floor, Heating / Cooling System, (De)humidifier, Argon Alarm, Locker</td>
</tr>
<tr>
<td>Testing</td>
<td>Measuring Tool, Flow Test Unit, Calibration Unit, Area Measure Unit</td>
</tr>
</tbody>
</table>

A short description of the equipment can be found in Appendix C.

### 6.3.4 Lifting Tool

Evaluation of the need for a new lifting tool, instead of the *Electrical Lifting Truck*, ELT, that are used in the current workshop. The identified work tasks, identified in 6.3.2. *Function Analysis*, requiring a device for lifting and the ELT’s capability are presented in *table 5.*
Table 5: Identified work task with a need for a lifting tool and the capacity of the Electrical Lifting Truck, ELT, currently in use.

<table>
<thead>
<tr>
<th>Identified Tasks</th>
<th>ELT Capable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Powder (hold powder container over sieve)</td>
<td>Yes</td>
</tr>
<tr>
<td>Refill powder into machine</td>
<td>Yes</td>
</tr>
<tr>
<td>Take in/out burner for repair</td>
<td>No</td>
</tr>
<tr>
<td>Lift burner in/out of SLM machine</td>
<td>Yes</td>
</tr>
<tr>
<td>Lift burner in/out of powder removal system</td>
<td>Yes</td>
</tr>
<tr>
<td>Allow lifting even though floor is obstructed</td>
<td>No</td>
</tr>
</tbody>
</table>

Further the lifting device needs to be

- Easy to maneuver in a confined space, by one operator
- Easy to be kept out of the way
- Not risk injuring operator or damaging equipment
- Reach all positions to perform its task

The main disadvantages with the ELT is the way it is moved and the amount of manual work needed. It has four wheels which of only the two front wheels has steering capability. This makes the ELT not optimal for moving in a confined space. The wheels can easily be changed, but when the operator is needed for all tasks it is not ideal.

6.3.5 Media Connections

Following the list in 6.3.3, Identified Equipment a list of media connections has been set up, see Appendix B, with the media as starting point.

6.4 Analysis of SLM Container

The Fish Bone Analysis resulted in a diagram with 21 ribs, see figure 18 which has been broken down to a level suitable for the specific subject. The magnification of each rib can be found in Appendix D. Fish Bone Analysis.
Figure 18: Main diagram as a result of the Fish Bone Analysis

6.5 Climate Conditions

To make sure the container is suited to be placed in as many likely places as possible a set of extreme conditions are chosen as starting point. One solution is to make the container work in all climate conditions to maximize the possibility of moving it. On the other hand, it may be beneficial to focus the container on one type of climate and keep the container stationed there.
Hot and Dry  Typical climate close to deserts. A suitable example is Dubai with its oil industry.

Hot and Humid  Common climate of southern Asia. Singapore is suitable due to its central location in Asia and the shortage of land. This is also the case in big cities in Asia.

Extreme Cold  Typical climate of northern Russia and Canada. Alaska is a suitable example with its oil industry and remote location.

Close to Sea  Common location for gas turbines are on oil platforms, which have to withstand both cold and wet conditions. Barents Sea, north of Norway, is a good example.

To identify the most extreme weather conditions from these places some major factors are compared: maximum and minimum Temperatures, the most Precipitation and the strongest Wind, over the last 3 years. The collected data is not enough to be used as design conditions. But it shows that it is important to take into consideration, and what climates are to be considered.

The weather data is collected from (The Weather Company, 2016) and the climate zone information is collected from (European Commission, 2010).

6.5.1 Climate in Dubai

Dubai, United Arab Emirates, is known for its hot and dry weather conditions. It is also a very sandy place with sandstorms commonly occurring.

6.5.2 Climate in Singapore

Singapore has a central position in Asia. The climate is warm and humid, commonly with high amounts of rain.

6.5.3 Climate in Alaska

Barrow's, Alaska - USA, remoteness makes it a good place for PLANT-IN-THE-BOX. The climate can be extremely cold.

6.5.4 Climate in the Barents Sea

Hammerfest, northern Norway is the closest point of data collection for Barents sea. The climate is characterized by its closeness to sea. This means the place is exposed to sea water as well as windy and wet weather conditions.

6.5.5 Weather Data

Collection of weather data for the four places can be seen in figure 19.
Figure 19: Weather data for the four places. Data collected from (The Weather Company, 2016)

The four places represents four different climate zones, see table 6.

Table 6: Climate zones for the four places. (The Weather Company, 2016), (European Commission, 2010)

<table>
<thead>
<tr>
<th>Place</th>
<th>Climate Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>Polar, dry</td>
</tr>
<tr>
<td>Dubai</td>
<td>Tropical, dry</td>
</tr>
<tr>
<td>Hammerfest</td>
<td>Polar, moist</td>
</tr>
<tr>
<td>Singapore</td>
<td>Tropical, wet</td>
</tr>
</tbody>
</table>

6.6 Transportation

The main ways of transporting the containers will be by ship and by truck. Since it is rather heavy and includes sensitive equipment it is not suitable for flying. During transport, power can be supplied to the container from the ship and truck, (DHL, 2016). This makes it possible to keep a specific atmosphere within the container to ensure machinery and equipment are not damaged due to varying temperatures, humidity etc.
6.7 Container Model

The container must be of standard size to allow for easy transportation, thus following ISO 668. The length of the container is chosen to be a 40-foot container to ensure enough room for equipment and that the container is still transportable. 40-foot is the longest regular container even if there are longer available. A 40-foot container means a container designated, by ISO 668, as 1AAA, 1AA, 1A or 1AX. 1AAA is the highest standardized container and the 1A the lowest, while 1AX is of special type. The 1AAA container must be of gooseneck type, thus resulting in a lower height on a part of the container. The choice of container size, in this master thesis, is a 1AA container, according to ISO 668. See table 7 and figure 20 for outer dimensions of the container.

**Table 7: Outer dimensions of a 1AA ISO container**

<table>
<thead>
<tr>
<th>Dimension</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, L</td>
<td>12 192mm (40')</td>
</tr>
<tr>
<td>Width, W</td>
<td>2438mm (8')</td>
</tr>
<tr>
<td>Height, H</td>
<td>2591mm (8'6&quot;)</td>
</tr>
</tbody>
</table>

*Note: some countries have limitations of vehicle load and overall height. This must be taken into consideration, but not in this master thesis.*
7 SLM Container Analysis

Description of the subjects identified during the Fish Bone analysis in 6.4.

7.1 SLM Process

The SLM process is the core of the SLM container. It mainly consists of the SLM machine and the support equipment needed for the SLM process. This is what will need the most space in the SLM container, in combination with the equipment for powder handling.

7.2 Powder Handling

Powder handling is the most vital support process to the SLM process and it is the main cause of health and safety hazards, see 2.2.1. The purpose is to deliver powder of an appropriate grain size to the SLM machine and to remove powder and metal condensate from the machine. In between removing and refilling it handles the addition of new powder and the removal of unwanted powder particles.

7.3 Media

Media refers to the materials needed by the SLM container. Mainly the need of the SLM process and the powder handling: inert gas (Argon), pressurized air and metal powder. In addition ventilation is also needed. To be observed is that data connection and power supply has been excluded from media due to their importance.

7.4 IT Network

As part of the container an IT network will be needed to manage file transfers, monitor the process and for the physical access control of the container. It is important to not let anyone without permission into the IT systems as well as into the containers. To manage the health and safety aspects it is of importance to make continuous measurements of the atmosphere in the container. With respect to the SLM process it is necessary to monitor conditions that can affect the quality of the process.

7.5 Power Supply

Supply of electricity to the machinery and equipment in the SLM container. This includes machines directly connected to the SLM process as well as climate conditioning and for a lifting tool. There is a need to provide power to the machines corresponding to the individual specifications as well as to take into consideration the on site available power supply.
7.6 Inspection

The inspection that can be performed within the SLM container has two aims.

The first is to measure if the burner is straight or not. This is important to make sure the burner is placed correctly in the SLM machine. If the burner is not straight enough there is a need to straighten it and to control measure it once more.

The second inspection is to make sure that the repaired part of the burner is centered on top of the original burner. This is to make sure the connection is good between the materials as well as making sure the flow through the burner can be guaranteed. The inspection tool can be rather simple as long as it is able to detect how well the parts coincides.

Other types of inspection of the burners are not considered to be placed in the SLM container.

7.7 Cleaning

The cleaning of the container is different from regular cleaning in the way that it deals with an environment with risk of powder spillage. The common cleaning methods for these types of environment are 1. using the Wet Separator, and 2. wet mopping. Another alternative is to use some kind of robotic cleaning, which could be a robotic vacuum cleaner deployed during night time.

An important aspect of the cleaning is the way the waste is taken care of; water in the wet separator and when mopping and a filter of special kind in the vacuum cleaning process, due to the presence of fine metal powder.

7.8 Computer Station

By the computer station the operator can assess work related files, prepare the job files for the SLM machines, report his work and assess the manufacturing execution system. By the computer station there should also be available documentation about machines, equipment and work processes.

The computer station may be in the traditional form of a desk, or in an alternative way which is more space efficient.

7.9 Maintenance

The SLM machine, and the other equipment have a need for maintenance, by maintenance personnel, in regular time intervals as well as continuous maintenance by the operators. It is of importance that all service points can be reached and that there is enough room for the maintenance personnel and the maintenance equipment, see 2.6.
7.10 Lifting Tool

The lifting tool is used to load and unload burners from the SLM machine, as well as to lift powder containers during the process of filling the SLM machine and sieving the metal powder. Traditionally a small Electrical Lifting Truck is used, but for the container concept there are many opportunities of incorporating a semi or fully automatic lifting tool, or a manual lifting tool that is designed to work better in the constrained environment of a container.

7.11 Storage

Storage is needed in the container to make sure materials, such as burners and powder, are acclimatized when they are used in the SLM process. It is also important to have personal protective equipment, consumables and filters close by to make the work more efficient. Some of the personal protective equipment do need a special storage space which is powder free, to make sure they do not get contaminated. There are also hazardous materials needed for the process, such as pure alcohol, T-red and the metal powder which need special storage.

7.12 Accessibility

The function of the container is dependent on the ability of an operator, or a robot, to perform work tasks to keep the process going. This requires room to operate machinery and maneuver lifting tools, see 2.6.

7.13 Simple Hand Tools and Consumables

There are a few hand tools needed for the operation of, and operator maintenance of, the SLM machine as well as preparation of the burners. The tools are mainly screw drivers and Allen keys.

7.14 Climate

It is of great importance to keep a well defined climate in the container to ensure the machinery and equipment can operate appropriately, with maintained accuracy and without breaking, in different outdoor climates. The internal climate is also important to the operator. To maintain the internal climate an air conditioning unit is needed to heat and or cool the air as well as to maintain the humidity level. The temperature and humidity level are critical since they have an effect on the behavior of the metal powder. Another important thing is to not let the climate from outside disturb the internal climate when entering and exiting the container.
7.15 First Installation at AM CoC

Before shipping the container to a customer it is necessary to do testing locally, with predefined checklists, to ensure the function, as well as to provide an opportunity for customer pre-acceptance tests. To do this testing a fully operational rack is needed which can supply the connections that would be available at a customer site. Before running the tests it is important to let the container acclimatize to its operational conditions.

7.16 Commissioning on Site

The commissioning on site has the same needs as First Installation at AM CoC except for the need for a long time installation. The installation should not be of permanent nature, as of a traditional workshop, but still provide complete connections and functionality. It is important that the container is easy to remove and it should be easy to put in a new container.

7.17 Transport of Container to Site

During transportation of the container it is important to make sure the internal climate is within the specifications of the machinery and equipment. It is also important to reduce the risk of damaging sensitive equipment with vibrations. There is a need for a good weight distribution within the container, fastening of equipment and conditions monitoring during the transport. To ensure nothing exceeding the specification has occurred during the transport it is important to monitor conditions as temperature, humidity, vibration and GPS position.

7.18 Environment, Health & Safety

The Environment, Health and Safety, EHS, aspect of the container is one of the main subjects of the container workshop. In the SLM container one needs to consider protecting the operator from metal powder, making sure it is not stirred into the air, see 2.2.1. As well as making sure the oxygen level is sufficient. Due to the confined space the risks of suffocation due to argon leakage is greater than in an open space workshop, see 2.2.3. It is important to take care of risks regarding working alone in a confined space, and making it possible to exit the container in an emergency without unnecessary risk, see 2.2.2. Some metal powders, and especially filters full of metal condensate, are very sensitive to static electricity making it necessary to electrically ground all equipment. Since it otherwise can start a fire. There is a need of fire extinguishing. Last but not least the working environment is a subject to consider.
7.19 Ingoing Logistics

There are many things needed to pass into the container without disturbing the climate. First and foremost damaged burners, metal powder and manpower has to pass into the container. Then there is the need of media connections, and consumables to be brought.

7.20 Outgoing Logistics

Repaired burners, waste metal powder and heat dissipation are the main logistics going out from the container. It is important to have a system to take care of gas and waste from the container.

7.21 Physical Design of Container

The physical container is the casing of the process. It has to provide all functionality in the form of structural support, allowing things in and out of the container, insulating the internal climate from the external, allowing the equipment to be fastened during transport and stationary placement. The container does need to provide access-control, to be a certified structure and to have an interface to connect with the Vertical Workshop rack.
8 Focus Areas

To focus the master thesis on the most important parts of the container some focus areas has been identified and further defined.

8.1 Identification of Focus Areas

Identification of subjects of the greatest importance to the project, to distribute work on the right tasks. To identify the most important subjects the method “Multi-Topic Subject Weighing” defined in 3.4. Multi-Topic Subject Weighing was used. The topics Work Environment, Function and Cost were chosen to be of the greatest importance in this initial stage of the project. The resulting graph can be seen in figure 21, and the table with values can be found in Appendix E. Focus Areas where the individual scores can be seen. The scores where set to 1-10 where 1 is the lowest, equaling no effect/degree of freedom, and 10 is the highest, equaling high effect/degree of freedom. The scores were first set by intuition, what felt reasonable from personal judgment, and then checked by a college with experience in power plant design.

Figure 21: Multi-Topic Subject Weighing of subjects from the Fish Bone Analysis with respect to Layout and Work Environment

The analysis concludes which are the most important subjects. As a starting point the five subjects with the highest score
1. Physical Design of Container
2. Powder Handling
3. Environment, Health & Safety
4. Accessibility
5. Lifting Tool

are chosen for further definition and development.

8.2 Further Definition of Focus Areas

Based on the previous Fish Bone Analysis, in 6.4. Analysis of SLM Container, a further definition of the five focus areas have been done. The resulting diagram can be seen in figure 22 and the magnifications can be found in Appendix F. Further Definition of Focus Areas.

Figure 22: Focus areas of the RaBuTiR container
9 Layout Planning

The planning process of the RaBuTiR AM container layout. By analyzing the internal interactions of the AM container - what enters/exits the container, what equipment interacts with each other and what the interaction is focused around - charts describing the relations were established. See 3.5. Work Process and System Function Analysis for description of the method. First of the interactions focused around the main entrance were analyzed, resulting in figure 23. Then the internal relations were investigated, resulting in figure 24.

![Diagram](image)

**Figure 23:** Interactions between what enters/exits the container and their first contact point.
The relations and interactions described in figures 23 and 24 gives a good clue of what equipment that needs to be located close to each other to enhance the operation from a technical and operational point of view.
Chapter III

Result - Requirements and Concept Generation

The chapter presents the requirement specification set up for the container and the concepts resulting from concept generation, where the requirements were kept in mind.
10 Requirement Specifications

The requirement specification for the AM container, PLANT-IN-THE-BOX, as part of the Vertical Workshop concept was set up based on the fish bone analysis in 6.4 Analysis of SLM Container. The resulting document can be seen in Appendix G.

The requirement specification document is divided into four sections:

**Introduction** - Short note about the structure and purpose of the document

**Requirement Specification - General** - general requirements on the container

**Requirement Specification - Equipment** - requirements put on the container based on the machines and equipment to be placed in the container

**Requirement Specification - Operations** - requirements based on operations which has not been covered by Equipment and Operations
11 Concept

Concepts generated with the requirement specification in mind. The concept generation process with multiple alternatives and a basic evaluation of concepts can be found in Appendix H. Concept Generation.

11.1 Frame

The main purposes of the container frame are:
1. Conform with standards regarding shipping containers - size, weight, strength etc. - to make it easy to transport the container with commonly available modes of transport, see 2.4.2.
2. Provide a structure on which the rest of the container, including equipment, can be installed in. See figure 25 for an overview of the frame.

![Figure 25: The framework of the container, which is a fixed part of the construction](image)

11.1.1 Beams

The beams with names corresponding to ISO 838 - Freight containers - Vocabulary

- **Corner post**: Vertical beam in corner of container
- **End transverse**: Horizontal beam at the short end of the container (top and bottom)
- **Side rail**: Horizontal beam at the side of the container (top and bottom)

Functions as the structure of the container and allows for the walls to be attached with a bolted connection. Together with the roof and the floor, the beams forms the bearing structure of the container.

11.1.2 Corner Fittings

The eight corner fittings are to conform with ISO 1161 - Series 1 freight containers - Corner fittings - Specification. This is to allow lifting tools and fastening of the container with standard equipment.
11.1.3 Roof and Floor

The roof and floor is regarded as a part of the frame structure since they will be fixed to the beams and not be removable. They shall provide

- Climate proofing
- Support at load zones
- Fastening capabilities of machines, pipes, cables etc.

11.1.4 Rails

Multiple rails run across the floor, where machines and equipment will be installed. The idea is to put the equipment on “rail carts” which will allow them to be moved when there is a need to reach the back of the machines for maintenance. It is very important that the carts can be securely fastened to the floor during operation and transportation to avoid any movement of equipment. The rails shall be designed to minimize the risk of powder collection. The rails runs across the width of the container, making it possible to move the equipment as much as possible as well as allowing insertion/removal from both sides. The reason for running across the width instead of along the length of the container is that it allows one piece of equipment to be removed or installed without the need of moving other equipment.

One possibility is to use a rail extension when installing and removing equipment. This extension makes it possible for a forklift to place the machine on the rail outside of the container and then roll it into the container and vice versa.

Note: The ideas of rails and rail extension comes from (CassaMobile Project, 2013). Before implementing such a solution it is recommended that a search for patents are done.

11.2 Walls

The wall system is focused on providing a modular and flexible solution, with easy exchange and access. The wall pieces can easily be removed with their bolted connection, to allow for insertion of big pieces of equipment and provide the possibility to connect multiple containers together to form a bigger workshop. When necessary the set up of wall sections can be changed to suit different uses of the container. The modular walls are displayed in figure 26. During transport the windows and doors are covered by protective plates. This is to prevent anyone from seeing what is inside the container.
The walls are to provide

- Climate proofing
- Structural support
- Entrances to container, including emergency exit
- Modular and flexible setup
- Easy removal and exchange

11.2.1 End Wall

The end walls are designed to have a sliding door, providing an entrance/exit in both ends of the container. Both the doors are installed towards the same side to allow the lifting tool to extend through the container and to reach through the doors when lifting things in and out of the container. The modular setup makes it easy to change the setup of the container. Thanks to the equal entrances at both ends of the container, it can be “mirrored” - turned the other direction - which is efficient when combining or connecting multiple containers in a set up.

The doors are made in glass to make it possible to see the status of the container and operator without entering the container. This is very important during work with powder since one then needs protective equipment to enter the cell, as well as in the case of fire. It does also allow the operator to see what is happening outside without stepping out.

11.2.2 Side Wall - Front

The front side wall consists of two panels. The panels have a supporting structure of a frame and framework, and a whole side window. This is beneficial when working in the container, since it will make the working space feel less enclosed, and it makes it possible to see the status of the equipment and the operator from outside. The panels are easy to remove and can be exchanged to suit different needs or to allow equipment being installed in or removed from the container.
11.2.3 Side Wall - Back

The back side wall consists of ten panel pieces, see figure 26. The pieces can individually be removed and exchanged if one would like to have a window, door etc. on a specific place. It does also make it possible to remove only the segments where access is needed, disregarding if it is for installation of equipment or a partial opening between two connected containers. One of the segments have a connection point for media as well as the possibility to mount a cabinet for transformation of electricity.

11.3 Doors

The doors are of the sliding type to reduce the amount of space taken ant to reduce the forced airflow when opening and closing the doors. Sliding doors are easy to make electrically operated without the risk of hurting the person using the door.

11.4 Airlock

To reduce the risk of disturbing the internal climate of the container when opening the doors there is an airlock at both ends of the container. This is to prevent air from outside to rush into the container and vise versa. When stepping in and out of the container only one of the sliding doors can be opened at the same time. The internal airlock wall and door is made of glass to provide visibility. See figure 27 for more information.

![Figure 27: Airlock setup in both ends of the container](image)

To make use of the space in the airlocks they are used for storage and as a desktop space. The main entrance is used for storage of protective equipment and powder free storage with a locker. By the secondary exit there is a small desktop with space for a computer and machine documentation.

11.5 Lifting Tool

The lifting tool is a light crane system, running on a rail attached to the ceiling, and two wall mounted cranes. The light crane system is to be able to retrieve burners from the wall
mounted crane and to deliver them to the burner storage, the work bench, the shake-blower and to the SLM machine. It shall be able to lift the burners both when they are mounted in a fixture and not. The wall mounted cranes are positioned in the airlocks and are capable of reaching through the sliding doors to retrieve burners from outside of the container and to deliver them in the work cell. This makes it possible to open one sliding door at a time to minimize the flow of air between the controlled environment in the container and the outside.

The light crane systems main rail, for example a Dematek - KBK 100, runs close enough to the burner storage to be able to place and retrieve burners in the stand. It is connected to perpendicular rails to be able to reach to the workbench and shake blower. The rail connection can be done with a Dematek - Turntable for KBK 100 which is a space efficient hand powered rail gear.

11.6 Storage

There is a need for storing burners, metal powder and disposables, protective equipment and tools in the container.

11.6.1 Burners

Burners are stored in a stand hanging on the wall. The concept is similar to what is traditionally used in the current workshop, except that this solution is mounted on the wall instead of on wheels. The stand holds six burners, which is suitable since they come in sets of 18 or 30 depending on the turbine.

11.6.2 Powder and Disposables

There is a locker for storage of powder, filters and other disposables in the container. The locker must be graded to store small amounts of flammable goods such as pure alcohol and T-Red spirits.

11.6.3 Protective Equipment

Protective equipment and things that need to be stored in a powder free environment can be stored in a locker which is put in the airlock at the main entrance.

11.6.4 Tools

The tools that are commonly used when working with the SLM machine are hung on the tool board on the opposing wall from the SLM machine. Tools that are needed by the work bench are hung on another board close to the work bench.
11.7 Air Condition and Ventilation

Description of the air conditioning and ventilation system concepts.

11.7.1 AC Unit

There is need of an AC unit which is dimensioned for the climates where the container are to be used. The cooled or heated air are not to be ejected directly towards the SLM machine and therefore it should be in the other end of the container.

11.7.2 Ventilation

The flow of air in the container must be such that it is slow enough to not stir up powder. The air stream should reduce the risk of powder spreading through and out of the container. The air exiting from the container must pass through a filter to make sure powder is not spread. The air enters from a high position and exits on a low position in the other end of the container to force spilled powder downwards.

11.8 Media

The media that need to be provided to the equipment in the container is electricity, pressurized air and Argon. The internal media providing system of the container can be seen in figure 28.

![Figure 28: Internal media providing system of the container.](image)

11.8.1 Connection Socket

There are connection sockets for input of Argon, pressurized air and electricity on the outside of the container. The connections are recessed into the wall and covered by a plate
during transport. The connection point shall be standardized and on a known position to make sure it is easy to prepare the infrastructure where the container is going to be placed and making it easy to attach and detach the container.

11.8.2 Media Supply to Equipment

The media pipes and cables are drawn from the connection socket up to the ceiling where it follows the length of the container. The main supply line branches of to the respective points of use. It is important that the ends of the branches are flexible and of adequate length for the equipment to be moved on the rails without straining the supply line.

11.9 Modes of Use

The container has two modes of use. 1. The operational mode and 2. the transport mode.

11.9.1 Operational Mode

During the operational mode media are connected to the container, the container has a controlled climate and the covers has been removed. The openness of the container - glass windows and doors - are utilized to make the atmosphere in the container feel less enclosed. This puts less strain on the operator from a work environment perspective. It does also increase the safety when one can clearly see what is happening in the container from a distance and vice verse.

During operation of the machines and equipment the rail carts are fastened to the floor to ensure steady positions. When maintenance is to be carried out the rail carts can be unfastened and rolled forward to allow access to the back of the machines.

11.9.2 Transport Mode

During transport all sensitive and translucent parts of the container are covered by protective covers to reduce the risk of damages and to restrict unauthorized personnel to see into the container. This includes covering all windows and doors as well as the media connection socket.

During transport it is necessary to keep the temperature and humidity, in the container, within certain limits to protect machines, metal powder etc. Depending on the weather conditions it may be necessary to connect the container to a power source to be able to run the AC unit during transport.

11.10 Equipment

Description of the powder handling unit and the workbench.
11.10.1 Powder Handling Unit

A closed powder system has been chosen, including the functionality of both the conveying and sieving modules, to make the work environment safer, see 2.2.1. The system connects directly to the SLM machine which it feeds with fresh powder, and removes dirty powder from. The system will, to start with, be operated manually, while in the future the system can be run automatically.

11.10.2 Work Bench

The work bench can be used when a table is needed for regular work, when doing maintenance and when removing powder from parts produced in the SLM machine. The work bench is equipped with an extraction hood - a hood to enclose the powder, using a negative pressure - to improve the work environment. Close to the work bench there is a tool board and the lifting system can be used to transport things to and from the bench.
In this chapter the generation of 2D and 3D layouts are described. Furthermore improvements that have been identified, for the equipment in the container as well as the container itself, are presented.
12 Layout

Setup of the 2D- and 3D-layout for the AM container.

12.1 2D-Layout

Based on the interaction charts in 9. Layout Planning a 2D layout were set up. The layout takes into account the floor space occupied by each piece of equipment - to confirm the setup would fit within the container - while making sure the interactions between equipment and operator is plausible.

The expected floor area to be available in the container is based on the external dimensions of a container stated in ISO 668, plus a wall thickness of 100 mm to take into account the wall structure and insulation.

12.1.1 Description of 2D-Layout

The container has two entrances with a respective airlock. Even though one entrance is regarded as the main entrance and the other as a secondary entrance or emergency exit, the containers setup and flexibility allows for easy changes. If there is a need to put the container facing the opposite direction the doors are designed equally to allow for full flexibility. This includes the lifting system which is symmetrical and can serve both ends of the container. See figure 29 for the 2D-layout drawing.

When entering the main entrance there is a locker in the airlock where protective equipment can be stored. Entering the machine cell there is first a work bench and storage for burners as well as filters, powder and disposables. This makes sure the operator does not need to transport goods through the whole container, during loading and delivering of goods.

Next to the storage area the powder handling area begins. The closest machine is the shake-blower, to make it easy to transport the repaired burner from the SLM machine to the shake-blower and further to the work bench and burner storage. The second half of the container is dedicated to the SLM machine and the support equipment. Facing the front of the SLM machine the closed powder handling system is to the right, including the sieving and conveying function. To the left there is a wet separator, for cleaning of the process chamber, and the filter unit and heat exchanger. On the opposite wall from the SLM machine there is a tool board for the tools that are regularly used when operating the SLM machine.

In the second airlock, in the back of the container, there is a desktop station.

The layout is beneficial from a work flow perspective and it concentrates the main powder handling to the back of the container, which reduces the amount of powder reaching the airlock at the main entrance.
12.2 3D-Layout

Based on the 2D-layout in 12.1.1. Description of 2D-Layout a 3D-layout were set up. The 3D-layout - a 3D CAD-model - takes into consideration the volumetric needs as well as the media supply of the equipment. The CAD model shows the basic concepts for most functions, as door types, wall segments, machines on rails etc.

12.2.1 Description of 3D-Layout

The 3D-layout is displayed in figure 30 and it shows the conceptual layout of the AM container on a boxes stapled on boxes level. The concept of modular wall sections are displayed by a two pieced front wall of glass and a ten pieced back wall. This is one possible way of set up. Depending on the needs there are multiple opportunities to easily implement other wall sections, also during the container's life cycle. The media supply, entering by the desktop station in the back of the container, runs along the ceiling and branches to the points of use by the wall behind the equipment. The lines must be flexible to allow the equipment to be moved forward when accessing their back. More figures can be found in Appendix H.1.
**Figure 30:** Annotated 3D-layout for the AM container. The green arrow corresponds to the main entrance and the red arrow to the secondary entrance.
13 Development of Equipment and Concept

Proposals of improvements to be done to the equipment and the container.

13.1 Equipment

Machine doors The current doors which swings out takes too much space when opened. There is a need to redesign the door mechanism to make it possible to fully open the doors without obstructing the walkway in front of the machines too much. An alternative is to have sliding doors.

Buttons, Switches and Dials Some of the controls are mounted on the back and sides of machines, especially the SLM machine, including main power switches. These need to be re-positioned so that they can be reached without moving any equipment.

Powder Handling System In the layout the powder handling system is depicted as one unit, which corresponds to the plan of a closed powder handling system. The system is currently under development and it may have to be reconfigured to fit in the container since it is being developed to be used in a conventional workshop.

Size The size of some equipment, especially the Shake-Blower and the Powder Handling systems, are too big. The mentioned are currently too high to fit in the container, and they take much space. Even though they fit, from a floor area perspective, the space could be used more efficiently.

13.2 Container Concept

Fire Extinguishing System It might be possible to implement a central fire extinguishing system. The main problem is that there are multiple different fire types involved; such as metal condensate fire, electronics fire, flammable goods fire.

Floor and roof - insulation The floor and roof are fixed parts of the container frame and they need to provide good insulation. In addition the floor needs to provide structural support to the equipment in the container.
14 Installation

Installation process in the container.

14.1 Order of installation

The order of installation is rather flexible when it comes to the machines and equipment. What has to be in place first is the container structure and media provision. See list for order of installation:

1. Build the container frame, including floor, roof and rails on floor
2. Install air locks
3. Install media provision - cables, piping etc.
4. Install machines and equipment - order is not critical except it might be hard to reach some attachment points
5. Attach walls
6. Test run of functionality
7. Packing and closing with cover plates
8. Shipping

The benefit with not permanently installing the machines is that they can be removed from the container. Another good thing from installation/removing point of view are that the rails run across the container and that the walls can be removed section wise. This means it is easy to move a single piece of equipment without the need to unload the whole container to remove something that is placed in the back.
Chapter V
Discussion and Conclusion

The final chapter of the report provides a discussion of the work and results, as well as conclusions regarding the concept.
15 Discussion

Applied methods and achieved results are discussed, as well as my view of the future of the PLANT-IN-THE-BOX AM concept and what I would like to have done differently.

15.1 Discussion of Methods

Discussion of methods applied during the master thesis.

15.1.1 Work Process

The work process described in section 3.1 gives a good overview of the master thesis work. It shows the fact that there are many parts of the container concept, to many to thoroughly study in one master thesis. By identifying the most important subjects there is a possibility to focus on the areas that will be the most useful in the continued work. This approach do give the opportunity to review the project based on information about the most important or most critical parts. One problem is how to identify these critical parts.

15.1.2 Function-Method Breakdown Structure

Section 3.3.1 describes a method based on Ulrich and Eppingers description of a Function / Method Tree. In addition to the regular tree, information about the project is added. This gives a good overview about what needs to be done during the project and what functions to include in the product.

15.1.3 Fish Bone Analysis

The Fish Bone analysis were a great way of breaking down the concept into smaller and graspable parts, even though I did not realize the benefits of the method when it was first recommended. The analysis made it a lot easier to identify the parts of the container and then what information was necessary in the requirement specification. Since the method starts with the main subject and branches out to more detailed information one can stop the process on a level that is suitable for the specific case. One problem with this is that you may not know how deeply to analyze the subject. In this case I focused on making sure the depth of analysis did go to a level where the information was still useful within the scope of the project. Another part of my approach was to analyze all subjects one step at a time. This makes sure a consistent level of detail is reached on all subjects, without the risk of spending to much time on the first few subjects and not being able to finish the last ones.

15.1.4 Multi-Topic Subject Weighing

When facing the task of choosing focus areas within the project, to narrow down the scope, it was realized that a method was needed to make it possible to weigh multiple subjects
against each other with respect to a set of topics. This was to be done in a time efficient manner with a limited amount of detailed knowledge about the subjects.

To perform this analysis a systematic method is needed to be able to quickly judge subjects, based on the current knowledge, and decide if they are of greater or lower level of importance. The analysis could be performed with any number of topics, but adding topics result in a trade-off between efficiency of analysis and the ability to identify the most important subjects.

In this case three topics were chosen; work environment, function and cost. The choice of topics were based on what have the greatest affect on the layout.

15.1.5 Work Process and Systems Function Analysis

To create an efficient work process it is important, when deciding the layout, how the operator will work with the equipment and how subsystems work together. This is important to minimize the distance to move objects and to make the work flow natural. It is not desired for the operator to move from one end of the container to the other for two consecutive operations.

The resulting chart can be used to decide the placement of a piece of equipment with respect to the other pieces, by graphically describing the interactions.

15.1.6 Product Development Strategy

The Product Development Strategy, PDS, have been useful by creating a structured review plan. Even if this project have been to small to implement a significant part of the PDS it has been interesting to get a better view of how Siemens works with development projects. It has, by the review structure, been a great way of continuously reviewing the progress and results, as well as to get feedback and constructive criticism.

Since the PDS is very extensive, it is important to choose the parts that are relevant and suitable for each type of project, big as small. In my case it was suitable with four reviews, of which two has been of the more formal kind. R0 were held at Siemens with representatives from LiU and R3 will be held at LiU in the form of the final presentation. R1 and R2 has been smaller reviews with discussions at Siemens.

The Siemens and Ulrich & Eppinger processes are basically the same with minor structural differences. They do both build on the general idea of creating a structured work and review process to ensure problems can be discovered and resolved as soon as possible. The Siemens processes is a bit more detailed since the Ulrich & Eppinger process is not intended to be a complete work process but rather a compilation of multiple processes found in the industry.
15.2 Discussion of Results

Discussion of results achieved within the master thesis.

15.2.1 State of the Art

During the state of the art analysis some interesting ideas and functions were identified. By combining a set of them an overall description of what I believe is important for the concept can be set up.

The container concept utilizes the idea of plug and produce, where it allows the industry to easily adapt to new requirements with a minimal investment in time and infrastructure. By packaging the workshop in an ISO, standard sized, container one can achieve a fast and comparatively cheap world-wide shipping. The setup time at arrival is minimal since the workshop is shipped in a close to operational state without the need of extensive installation and configuration at arrival. The container is easy to adapt thanks to its removable sides. They allow easy exchange of equipment and the possibility to connect multiple containers to form a bigger workshop. By letting the equipment slide on rails it can easily be moved within the container to allow access to their maintenance doors.

I believe the container concept will be used as in this case for modular and flexible workshops as well as for other usage areas where mobility is of great importance. The AM container benefits greatly from the fact that the health and safety aspects, especially connected to powder handling, can be well defined even though the container will be used in different locations. This can make the design of the container more complicated as regulations from many countries will have to be taken into consideration. At the same time a customer from a country with less though restrictions may not want to pay for things he does not need to take into consideration. On the other hand Siemens as company have responsibility of their products, meaning they want to deliver safe products even though the local regulation may not require the same standards.

15.2.2 Distributed Manufacturing

Burner tip repair may require to much equipment to be beneficial on a wide spread market. While, centralized units closer to customer groups may be efficient, similar to the standardized and replicable model factory concept described in 2.3. Other AM based production has a better potential since the market is bigger and not focused on a few products. The general AM containers may be spread in a bigger number of small clusters/workshops, corresponding to factory on site - fully functional small scale mobile facilities temporarily placed on a customer site.

The clusters may benefit from the shift towards mass customization, with the AM technology, and the need for small, flexible and scalable manufacturing units. A possible business model is to let the customer rent the container and then, corresponding to Production labs of additive manufacturing, purchase the production data for manufacturing a specific part.
There are many benefits with distributed manufacturing as described in 2.3.1, where mobility, flexibility and on demand forms the backbone of the container concept. On the same time there are risks with DM. To minimize the risks there is a need to clearly specify the work processes and to ensure there is an organization that can support such wide spread manufacturing plants - both from a logistics perspective and a technological and support perspective. It is important that the benefits outweigh the risks and extra costs of small scale production.

15.2.3 Vertical Workshop

The vertical workshop enables smart usage of production capacity on a world wide scale - meaning that it is possible to use the same capacity in many different locations with a relatively short time schedule. The concept do allow quick changes in setup of containers to adjust the capacity to the current needs. A vertical workshop benefits in comparison with a fixed workshop, by not requiring an economical justification of the same level. Since the containers can easily be moved during their lifetime, the cost can be spread on many different users. This is similar to a rental car where the single user do not benefit economically corresponding to the purchase price of the car.

By combining multiple containers of different equipment setup it is possible to focus some of the containers on one main task. For example; if there is an office container and a central powder handling container, the office space and powder handling system in the AM container are not needed. Thus, one may fit another AM machine in the AM container, resulting in a higher production capacity and lower cost. The specialized containers are applicable if the vertical workshop, or other setup of containers, are big enough to justify the capacity need of such specialized containers.

15.2.4 Confined Space

As described in 2.2.3, confined spaces are an area of discussion. One could look at it in a strict way, concluding that the container is not a confined space since it is designed for people to work in it. At the same time, depending on the design and setup of the container, the access to enter and exit from the container, as well as to see in and out of the container may be very limited, meaning it would definitely raise the risk level of working in the container. There are also the risk of hazardous conditions to arise; such as Argon leakage - which the operator by himself hardly can notice, and work with machinery and lasers. The organization is obliged to manage the risks associated with the work environment - thus the container workshop - which makes it relevant to look into the restrictions of confined spaces when designing the containers, as well as when working in them.

As a way of making the container behave less like an confined space it has been designed with two entrances, see 11.2.1, which must be easy to use. It is also of great importance to have sensors and alarm signals monitoring the atmosphere in the container. Argon, which is used by the SLM machine, is a dangerous gas since it displaces Oxygen, which could
cause a lack of oxygen in the container.

15.2.5 Solitary Work

The restrictions of solitary work, as described in 2.2.2, depends on the work environment. Solitary work in combination with confined spaces are not desirable, and it may require at least a second person to be present. Thus, increasing the need of considering the design of the containers to reduce the risks of confined spaces. When working alone with machinery, without a second person permanently around, it is of great importance to be able to send an alarm signal in case of an emergency. Letting persons passing by have the opportunity to make visual contact with the operator is very beneficial from a safety perspective.

To make the operation of a container less solitary, where the operator would work separated from the surroundings, the front wall is designed as a big window, see 11.2.2, and the sliding doors are proposed to be in a see-through material, see 11.2.1. This enables a person from outside to see the status of the operator, in the container, and vice versa. Two examples would be: (1) someone is passing by during his work; and (2) two containers are placed facing each other, with the window walls, allowing the two operators to see one another during their work.

15.2.6 Mobile Manufacturing

Mobile manufacturing, see 2.4, is a very important part of the PLANT-IN-THE-BOX concept. It enables the production capacity to easily be shipped to new locations and to place the production capacity at the site which needs it. When dealing with mobile manufacturing capacity there are some points that needs to be considered:

1. Securing and distributing equipment during transport - make sure no damages to the equipment or the container occurs, and that the weight distribution of the container is sufficient for the transport system.

2. Standardized connections - there is a need for a standardized way of connecting the containers on site, to make it easier to prepare the site before the container arrives.

3. Standardized setup - there must be requirements put on the site of installation, as example; the properties of the ground at the site of erection.

Mobile manufacturing does allow the use of functional sales, where the production capacity provider rather supplies a function than a production machine. This means that the customer can choose a function, which then the supplier provides in a working condition, and then are able to use it “out of the box”, instead of having to struggle with the setup of his plant. If this is done with a rent/lease approach; the customer can easily use the capacity as long as it is needed, while not having to worry about finding a new use of the equipment, as the capacity provider takes it back.
15.2.7 Modularity

By using modular production capacity units, as described in 2.5, it is easy to set up a complex plant by combining any set of sub-functions. By using modular “building blocks” it is easy to manufacture them separately, while being sure they will fit together. This does also allow for easy changes in the setup as one module can be removed and another installed.

Modularity may be used in many levels of the Plant-in-the-box and Vertical Workshop concepts. First of when considering one container as a module which can be exchanged in the Vertical Workshop setup. Second when looking at the container itself as a product; the container can be divided into different systems, which in them self can be designed in a modular fashion. This has been utilized in the wall design, for both the side and end walls, as described in 11.2.

15.2.8 Maintainability

Maintainability, as a design and layout creation criterion, is something that may have great impact on the easy of use of a production facility. As described in 2.6 the available and needed space for maintenance is very important to consider. In this thesis a container is considered while in comparison Lou, (Luo et al., 2014), looks at the case of a ship cabin. Both the cases are heavily restricted by the available space, and have a great need to a person to perform maintenance on machines.

15.2.9 Metal Powder Health Effects

By considering the possible health effects described in 2.2.1, it can be concluded that there is a need to take the health aspect into consideration. In the design of the container it is important to include systems that reduces the spreading of powder, eg. air conditioning/-ventilation and a closed powder handling system. When the container has been built and tested, the need of protective equipment can be evaluated. Since the need for protective equipment, in today’s fixed workshop, is dependent on the risk of powder spillage connected to each work task, a new evaluation would be needed with this container based workshop.

15.2.10 Fish Bone Analysis

Ishikawa / Fishbone Analysis were used to get a systems overview by breaking down the the RaBuTr IR SLM container into subjects and sub-subjects. The analysis gives a good understanding of the different parts that are to be included in the RaBuTr IR SLM container and what purpose every part plays. With the help of the analysis it is easier to make a requirement specification, and later on, perform the detailed design work of the container, meanwhile minimizing the risk of forgetting any part. The analysis can be performed to various levels of depth, and the depth of this analysis were adjusted to the need of detail for this master thesis.
To take into consideration is that the diagram can be rather complex, with many levels of depth, when handling complex systems with advanced equipment. On the same time the map can be easy to overview as long as a good structure is maintained. Another benefit is that one can look at one section, fish bone, at the time since they are independent. In some cases there are parts of the analysis that fit into multiple bones. This may require some caution during the analysis, while the benefit is that it can show the connection between multiple subsystems.

In the master thesis the graphical diagram was of great help when setting up the requirement specification as it made it easy to see which parts of information where needed, and where.

15.2.11 Climate

The collected climate data is based on data from the last three years. This gives a clue about the values, but it does not give the full picture. It was considered to be enough for this thesis as it shows the general idea, to take into consideration a wide range of climate conditions. Due to the extreme conditions it may be beneficial to design containers for different usage climates. For example one for the range between -50°C and +10°C, and one for the range of -10°C to +60°C.

The containers will most likely be very similar, except the heating and cooling units and possibly some specific things as weather sealing with regards to the icy respective sandy climates.

15.2.12 Requirement Specification

The requirement specification gives a good idea about the container concept but it is not meant to be a complete document ready for designers and engineers to start the design process. With the help of the requirement specification the designer will get a good idea about what he or she will need to research further and what is the main requirements on the container concept.

The specification is focused around the equipment that are to be installed in the container and the general functionality of different systems.

15.2.13 Concepts

In general it is very important that all equipment and parts of the container are designed to withstand the strains of transportation and operation.

Frame The frame consists of the roof, floor, beams and the rails on the floor. The roof and floor will need to be well insulated as they have a big surface area. The floor does also need to be structurally strong to provide a stable base for the equipment. There are some alternatives regarding ways of insulating, some more common than
others. The simplest is to use a glass wool insulation. A more complex solution would be to make the roof and floor air tight containers and pump a vacuum in them creating a very good insulation. This would on the other hand make it necessary with reinforcements to prevent the plates from buckling. Since the concept does not utilize any media supply or such that runs in the floor or roof there is no need to make them possible to open. They do need to provide a weather proof solution which does not risk getting infested by insects or mold.

**Walls** The walls needs to be well insulated while not being to heavy to move. A tricky part with the sectioned walls are to get them to seal well between each other and not to allow heat dissipation, moisture leakage or access for insects. They do need to provide structural integrity to the container when mounted.

**Airlock** The airlocks provide a good way of entering and exiting the container without disturbing the internal atmosphere to much. It is of importance to make the door systems work well - give a tight seal - and that it is not taking too long to enter and exit for the operator. In the case of installing the containers within an existing building with a controlled environment it might not be necessary from a temperature and moisture level perspective to use airlocks. The airlocks do on the other hand reduce the risk of spreading powder out of the container. They do as well allow the use of some less powder contaminated space within the container, for storage of protective equipment and a desktop station.

**Lifting Tool** The lifting tool must be easy to use and put minimal strain on the operator, while not being in the way. There shall be no risk that the operator hits the rail mounted in the ceiling and the part hanging down must be possible to put in a place where it is not in the way. It is beneficial if the lifting tool is capable of lifting other things than the burners; such as powder bins, building plates etc. A future development would be to use some kind of an industrial robot to automatically do the lifting within the container.

The lifting tool, or tools, must be designed in such a way that they can reach out of the container ends without the need of keeping both the doors in the airlock open at the same time. One solution would be to have a telescopic function from the airlock, in both directions. Thus, making sure the door can shut at the side where the lifting tool does not momentarily extend.

Another way would be to use a 2 or 3 sectioned wall mounted crane in the airlock, which can reach through the doors and hand the load to the other lifting tool. This may be a technically simple solution, to skip the telescope function, while it may face difficulties in the hand over of the load. In the case of lifting burners the crane can be designed so that it can reach the burner stand and thus delivering the burners directly.

Another question is how to get the lifting tool to reach the workbench and shake blower. This could be done by branching the ceiling mounted rail. Such a branch can
be done with the suggested turntable from Dematek, which is a space efficient hand turned direction changer.

**Ventilation** The ventilation is an important part of the EHS system in the container. Apart from providing fresh air in the container it can be used to direct powder particles that have escaped downwards. They will then either end up on the floor or in a filter at the ventilation outlet. The direction of the air stream may be directed such that it pushes the powder in a certain direction. It is important to not point the air stream at the SLM machine, and that it is not strong enough to stir up powder into the air. The placement and flow of the ventilation and air conditioning system must be further researched to ensure good functionality.

**Media** The media provision system must not be in the way of moving equipment or the operators work. A very important thing is that there must be main switches, both within and outside the container, to allow turning of the flow of gas, pressurized air and electricity into the container in the case of an emergency. Since the container is mobile it is important that the system do not risk getting damaged during transport.

**Powder Handling Unit** The most practical and safe way is to use an enclosed powder handling unit to reduce the risk of powder spreading within the container. Such a system is also easier to operate than the conventional equipment and to use with an automated solution.

### 15.2.14 Layout

**Planning** The diagrams in 9. describes the work process connections between the different pieces of equipment - ex. the operator moves something from one work station to another. This chart gives a good overview of work flow within the container and makes it easier to decide on the placement of equipment. There are other restrictions to take into consideration, as size, risk of spreading powder etc., while the work process of the operator must be kept as the central decision basis. As the container provides a very limited amount of space it is of importance to consider the amount of space needed for certain operations. It must be possible to move from one station to the next, in an ergonomic way, without the need of strenuous maneuvers.

**2D-Layout** The basic structure of the container is symmetric in the lengthwise direction. This makes it possible to turn the container 180°to face the other direction without loosing accessibility. The ability to be turned the other direction does allow multiple containers to be connected to each other in a “mirrored” fashion. The layout does take into consideration how the powder will tend to spread in the container. The focus is to keep the contamination in one end, and with the help of the ventilation system blowing it in that direction. Something that has to be taken into consideration during the further development is the fact that some equipment are quite big, resulting in the impossibility to open some doors. This may result in the risk of not being able to operate the machines, as well as posing a safety risk when the passage is blocked.
Therefore, it is of importance considering a redesign of the machine door mechanisms to reduce the depth of the opened doors. From a work process point of view it may be necessary to say that it is not allowed to open two machine doors at the same time. This to ensure that the operator is not trapped in the container. At the same time it would be beneficial if opening a machine door does not block the passageway, thus ensuring that the operator can reach both exits at all times.

3D-Layout The detail level of the 3D-layout, “Boxes stapled on boxes”, were chosen since the main purpose of the layout is to make sure there is enough room in the container to house all equipment. This means it was not requested to spend the time on modeling details. The box layout takes into account the widest parts of the equipment, meaning that the final result will be perceived as less dense. The extra space ensures that there is some margin included in the model.

The floor area were assumed to reflect the outer dimensions of an ISO container, see 6.7, minus 100mm of wall thickness. The wall thickness may not be completely accurate, as it were not desired to look into the detailed construction of the supporting structure and insulation of the walls.

The 3D-layout shows that it is plausible to fit the SLM machine and the necessary supportive equipment for powder handling in the container. In the case of using the AM container for other purposes than RaBuTiR it is likely that the Shake-Blower unit is removed. Perhaps it is exchanged for a similar unit that is built to remove powder from a wide range of products while they are still fixed to the building plate.

The front wall, with a full window side may not be suitable for every destination or use case. Thanks to the modular design the wall can easily be exchanged for another wall setup. The same regards the back wall with 10 wall segments. The size of the segments gives a high grade of customization without implying a massive rebuild. The segments can individually be exchanged, making it possible to install a door or window across the whole length of the container.

Since the container workshop will be used for other types of manufacturing it is important to consider a modular and flexible setup, and thus enabling easy implementation in other use cases.

15.2.15 Installation

Implementation of the removable side walls and the rail system on the floor makes it possible to install and remove any piece of the equipment without moving the others. To make it easier to install and remove equipment CassaMobile uses a rail extension. The extension connects to the container side allowing the equipment to be rolled in or out of the container. This makes it a lot easier for a forklift or crane to place equipment on the rail extension as there are less obstructions.

Since the equipment is not permanently installed it can easily be exchanged. This requires
a way of locking them into position during operation and transportation.

15.2.16 SWOT

The SWOT analysis provides a good way of identifying the advantages and disadvantages of, in this case, a concept. This makes it easier in the development process as one can try to find solutions to weaknesses and threats while benefiting from the strengths and opportunities. In this way the SWOT analysis gives a good overview of the development project.

15.3 Discussion of Future

**Future potential** Vertical Workshop is one of the use cases for PLANT-IN-THE-BOX. The likely user of a Vertical Workshop is in need of more than a couple of containers and to use them on a location where space is scarce. The user does not necessarily have any other workshops locally.

The container can be used as a stand alone miniature workshop that can compliment the machinery of another production facility. In this case the container can be placed outdoors, or inside another workshop if there is available space. With the benefit of enclosing the powder process within the container. In need of multiple containers, and not the flexibility of a Vertical Workshop, they can be stacked on top of each other. Or, they could be docked to a fixed workshop, as extension cells, to increase the capacity of the workshop.

A different use of the container is to use it as a display container, which easily can be shipped to a new location. Since AM and the PLANT-IN-THE-BOX are new technologies/solutions, on an emerging market, they make up a good show case scenario for fairs - both at university and manufacturer fairs. Plant-in-a-box provides an opportunity to spread AM of metals on a world wide scale with the benefit of a controlled workshop environment - reducing the health and safety risks - while maintaining a predictable process behavior with known results.

**Further Work** To realize Plant-in-a-box Siemens needs to go through a detail design phase, including research of laws and requirements of the market. They need to build one or multiple prototypes to verify the concept and make evaluations to find further improvements. Then it is time for product launch and production. In the mean time, while developing the container, it is important to develop the surrounding systems, such as vertical workshop and the digital network that will provide the container and Siemens with data in a secure way.

Another aspect of the continued project are to analyze the market and do calculations to justify the concept economically. Without a market or with an too expensive product the container concept will not be realizable.
15.4 What I Would Have Done Differently

The main thing I would liked to have done differently is to have focused on a general SLM or AM container, without the RaBuTiR focus. In the beginning RaBuTiR seemed like a good starting point since it is the furthest developed product for AM at Siemens. Later it was concluded that the RaBuTiR process uses a lot of other equipment to perform the complete repair. This means that there is a need to have multiple other containers with different setups to complete the process. There may be a possibility to make use of local suppliers. This might not be possible on all locations, both with respect to availability and quality.

At the same time; the customization of a SLM container for the RaBuTiR purpose is very brief. This means that the developed concept can easily be adjusted to be used as a general SLM container. Another possibility would be to, with this AM container as a starting point, create a generic container that can be used for a variety of machine setups.
16 Conclusion

Mobility, flexibility and on demand forms the backbone of the container concept. The Vertical Workshop concept do allow quick changes in setup of containers to adjust the capacity to the current needs. Since the containers can easily be moved during their lifetime, the cost can be spread on many different users. This means that a single user do not need to pay and benefit economically corresponding to the purchase price of the container.

The container concept utilizes the idea of plug and produce, where it allows the industry to easily adapt to new requirements with a minimal investment in time and infrastructure. By packaging the workshop in an ISO, standard sized, container one can achieve a fast and comparatively cheap world-wide shipping. The setup time at arrival is minimal since the workshop is shipped in a close to operational state without the need of extensive installation and configuration at arrival. The container is easy to adapt thanks to its removable sides. The sides allow easy exchange of equipment and the possibility to connect multiple containers to form a bigger workshop. By letting the equipment slide on rails it can easily be moved within the container to allow access to their maintenance doors.

The layout was set up with focus on health and safety. The use of a closed loop powder handling system - to minimize the leakage of powder - in combination with airlocks and a directed airflow through the container - to minimize the spreading of powder - the exposure to powder will be minimal. Since the layout is on boxes-stapled-on-boxes level, with less detail, the further work needs to ensure that the work stations are ergonomically designed.

To protect the intellectual property the openings are completely covered during transportation to make sure that no one can look into the container. During operation the external doors provides access control to ensure that only authorized personnel can enter. The data network in the container is wired to reduce the risk of unauthorized access. By combining this with a secure access to the Siemens network, over the internet, the risks are minimized.

The master thesis has been successful in considering the additive manufacturing workshop in Finspång as a fixed process and utilizing that knowledge to create the layout of the PLANT-IN-THE-BOX. It was important to not reinvent the process, and to focus on making it mobile.

The state of the art study shows that there are multiple other initiatives that utilizes the mobility of ISO containers. The use cases are widely spread, and CassaMobile’s idea of a mobile workshop is the most similar to the PLANT-IN-THE-BOX concept.

The requirement specification gives a good understanding of the concept and supplies detailed information about the needs of the machines and equipment that are needed for the RaBuTiR SLM process.

The 2D- and 3D-layouts shows that it is plausible, from an area and volumetric perspective, to place the equipment in a 40’ ISO container, in a workshop setup.
The resulting container solution is setup for the specific case of RaBuTiR. Since the studied container will only include the SLM part of the RaBuTiR process it is very similar to a container built for the general SLM case. This means that the container, with a few changes, can be redesigned to work as a general SLM container. The container solution could be used for other manufacturing technologies as the general parts of this container solution can easily be implemented for any other type of container workshop.

16.1 SWOT

How does the container concept apply to the SWOT analysis in 1.2. Industrial Challenge.

Strengths

**Modularization of production capacity** The container concept is based on modular concepts on multiple levels. First of the container can be a workshop cell that can be combined with any number of other containers to form a cluster. Secondary, the design of the container is modular; the modular wall sections provide flexibility of setup and allows containers to be connected directly to each other or docked to a building.

**Flexible manufacturing capacity** AM do provide a great flexibility to build parts with new geometry. The production capacity is flexible in the meaning of size of workshop since any number of containers can be combined in a Vertical Workshop. The number of containers can quickly be changed to correspond to the current needs.

**Repair close to customer** The PLANT-IN-THE-BOX concept provides a good way of setting up repair workshops closer to customers. To begin with it is suitable to have centralized units supplying a larger number of customers. In the future it might be that there are more decentralized units in places with high customer density, or if a customer have got a big amount of turbines. Being close to customers reduces the lead time of repair and it gives the opportunity to hire local personnel to the benefit of the local economy.

Weaknesses

**Small scale production units** With this kind of small scale production units it may be necessary to rethink the supply chain. There is a need to provide materials, in relatively small amounts, to many small production sites. These sites are mobile which means they may be moved to new locations within a short period of time. This implies other difficulties as one either needs to ship materials to the new location or find local suppliers.

**Spread competence** When distributing the production into many small scale units it is likely that all units cannot have all competences locally. This makes it important to collaborate with a central system and between different units. As
an example, all units cannot have their own service technicians since there will not be enough work locally.

**Long distance between manufacturing units** The organization will be spread over a large portion of the world, with many small units. This will take new ways of organization to manage a wide verity of production units on world wide scale. Siemens will be responsible for the function of the containers. They will need a Manufacturing Execution System, MES, that helps them managing data transfer and data storage. The containers must be connected to the system to guarantee the production quality.

**Opportunities**

**Increase quality of burner tip repair** Since the RaBuTiR Plant-in-a-box containers are designed for one purpose - repair burners - the equipment and processes can be optimized for a single use case. The Vertical Workshop can then be setup in a way to benefit the process of the cluster to minimize waiting times etc. This includes choosing the number of each type of container and then how to place them in the rack.

**Increase the performance of burners in existing and new gas turbines** Thanks to the AM technology it will be possible to implement new designs in the burner tips that are repaired. To make this a secure process it is very important that Siemens has full control of what is being printed, how many times, by whom, when and where it is printed. This is part of the functionality of the MES system that Siemens are developing.

**Threats**

**Increased competition** In the modern industrial world it is important to continuously, not only, develop the products but also to improve the ways we think about and use manufacturing to keep an advantage towards competitors. The Plant-in-a-box concept is a new way of setting up workshops in a flexible way that provides new opportunities to grow as a business. The AM technology, on the same time, provides many new opportunities to create products that was not physically possible to manufacture before.

**Rapidly changing market needs** The AM technology in combination with the modular workshops gives great opportunities to follow the rapidly changing market needs with a reduced risk of locking resources to a single location. The container concept may as well change the conditions of modern industry to another level of industrialization.
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Chapter VI

Appendix Collection

Appendix

A Function / Method Tree

Branches of the function method three presented in 6.3.2. Function Analysis. The branches represents different parts of the Rapid Burner Tip Repair, RaBuTiR, process.

A.1 SLM Tree

Function / method tree for the SLM process.

A.2 Powder Handling Tree

Function / method tree for the powder handling.
A.3 Lift / Transport Burner Tree

Function / method tree for lifting and transportation of burners.
A.4 Cleaning Tree

Function / method tree for the cleaning of the Plant-in-the-box container.

A.5 Container Tree

Function / method tree for the container itself.
A.6 Burner Preparation Tree

Function / method tree for the burner preparation process.
A.7 Logistics Tree

Function / method tree for logistics part of the Plant-in-the-box.
B Media Connections

List of supplied media and the machines and equipment in need of media.
### Table B-1: Media Connections to Equipment

<table>
<thead>
<tr>
<th>Media</th>
<th>Machine / Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground</td>
<td>SLM Machine</td>
</tr>
<tr>
<td></td>
<td>Filter Unit</td>
</tr>
<tr>
<td></td>
<td>Heat Exchanger</td>
</tr>
<tr>
<td></td>
<td>Lifting Tool</td>
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<tr>
<td></td>
<td>Conveying Module</td>
</tr>
<tr>
<td></td>
<td>Sieve Module</td>
</tr>
<tr>
<td></td>
<td>Filling Module (temporarily)</td>
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<td></td>
<td>Jig</td>
</tr>
<tr>
<td></td>
<td>Vacuum Cleaner</td>
</tr>
<tr>
<td></td>
<td>Sticky Matt ??</td>
</tr>
<tr>
<td></td>
<td>Anti Static Floor</td>
</tr>
<tr>
<td></td>
<td>Heating / Cooling System</td>
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<tr>
<td></td>
<td>Dehumidifier</td>
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<tr>
<td></td>
<td>Milling Machine</td>
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<tr>
<td></td>
<td>Argon Alarm</td>
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<tr>
<td></td>
<td>Camera Vision System ??</td>
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<tr>
<td></td>
<td>Flow Test Unit</td>
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<tr>
<td></td>
<td>Calibration Unit</td>
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<tr>
<td></td>
<td>Area Measure Unit ??</td>
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<tr>
<td></td>
<td>Ultrasonic Washing Machine</td>
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<tr>
<td>Pressurized Air</td>
<td>SLM Machine</td>
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<tr>
<td></td>
<td>Filter Unit ??</td>
</tr>
<tr>
<td></td>
<td>Conveying Module</td>
</tr>
<tr>
<td></td>
<td>Milling Machine</td>
</tr>
<tr>
<td></td>
<td>Ultrasonic Washing Machine??</td>
</tr>
<tr>
<td>Gas</td>
<td>SLM Machine</td>
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<tr>
<td>Electricity</td>
<td>SLM Machine</td>
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<td></td>
<td>Filter Unit</td>
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<tr>
<td></td>
<td>Heat Exchanger</td>
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<tr>
<td></td>
<td>Lifting Tool</td>
</tr>
<tr>
<td></td>
<td>Sieve Module</td>
</tr>
<tr>
<td></td>
<td>Vacuum Cleaner (Wet Separator)</td>
</tr>
<tr>
<td></td>
<td>Heating / Cooling System</td>
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<tr>
<td></td>
<td>Dehumidifier</td>
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<td></td>
<td>Milling Machine</td>
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<td></td>
<td>Argon Alarm</td>
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<tr>
<td></td>
<td>Computer</td>
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<tr>
<td></td>
<td>Camera Vision System</td>
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<td></td>
<td>Calibration Unit</td>
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<tr>
<td></td>
<td>Area Measure Unit</td>
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<tr>
<td></td>
<td>Ultrasonic Washing Machine</td>
</tr>
<tr>
<td>Data (network)</td>
<td>SLM Machine</td>
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<tr>
<td></td>
<td>Argon Alarm</td>
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<tr>
<td></td>
<td>Computer</td>
</tr>
<tr>
<td>Cutting Fluid</td>
<td>Milling Machine</td>
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<tr>
<td>Water</td>
<td>Flow Test Unit</td>
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<tr>
<td></td>
<td>Ultrasonic Washing Machine</td>
</tr>
</tbody>
</table>
C Equipment Description

Description of equipment identified in the RaBuTiR process.

**SLM Machine**  Selective Laser Sintering machine for additive manufacturing. Uses a laser to melt layer by later of a fine metal powder.

**Filter Unit**  Unit connected to the SLM machine, used to filter the recirculating gas from dust and ash particles.

**Heat Exchanger**  Connected to the SLM machine and used to cool the laser etc.

**Camera Vision System**  Camera mounted in the SLM machine, connected to an external computer to measure the position and angle of the burner when mounted in the SLM machine.

**Conveying Module**  Machine used to suck powder out of the SLM machine. Also used to empty new powder containers when adding powder to the process. Fills a stainless steel bottle at the its base.

**Sieve Module**  Used to sieve the contaminated powder to remove ashes and dust. The bottle from the Conveying Module is lifted and held above the Sieving Module, connected with a hose and the powder is led through the sieve and into another stainless steel bottle.

**Filling Module**  Piece of equipment used when filling clean powder to the SLM machine. It is mounted in the SLM machine, a bottle of clean powder is lifted and connected with a hose to the Filling Module and the powder is led into the machine.

**Vacuum Cleaner (Wet Separator)**  Apparatus used to remove ashes from the SLM machine, the Sieving module and for cleaning the workshop space. Works as a vacuum cleaner, except that it uses water to filter out the metal particles from the air.

**Lifting Tool**  Tool used to do the heavy lifting of burner, powder filled bottles etc. The current tool is a Electrical Lifting Truck, which is a small hand guided truck on wheels.

**Jig and Jack**  Setup used to straighten crocked burners before they are repaired. Currently a manual lathe is used as a jig, but the only needed parts are two rotating tailstock centers. Then a small hydraulic jack is used to push in the middle of the burner to make it straight, using a dial indicator to measure the camming.

**Fixture**  A fixture mounted to the burner to make it possible to lift it, and to mount it in the SLM machine. The fixture does also prevent metal powder from seeping from the process chamber.

**Computer**  A computer station used to prepare the job files for the SLM machine.
Milling Machine  CNC milling machine used cut of the damaged tip of the burner as well as machine the surface of the repaired burner tip.

Ultrasonic Washing Machine  Machine used to clean the burner before the repair process can start. The burners does not come clean out of the gas turbine.

Air Lock  Preventive measure at the entrance of the container to reduce the risk of letting warm/cold or damp air into the container. The SLM process is sensitive to both temperature and moisture level.

Sticky Matt  Doormat with a sticky surface to remove powder from the operators shoes when leaving the workshop.

Anti Static Floor  Floor construction preventing the build up of static electricity. Static electricity is particularly dangerous when working with metal powder and powder condensate due to its flammability.

Heating / Cooling System  Equipment used to preserve the temperature in the container when the surrounding climate is not optimal for the building process.

(De)humidifier  Equipment to preserve a god humidity level within the container.

Argon Alarm  When repairing burners Argon is used as a protective gas in the SLM process chamber. Argon (for some materials Nitrogen can be used) is a suffocating, non-visible, non-smelling tasteless gas, and in the case of a leak it is important to detect its presence, especially in a small and enclosed environment as a container.

Locker  Storage space for personal equipment in the office, and for storing powder, filters and disposable materials as well as tools in the workshop.

Measuring Tool  Tool to measure the the placement of the repaired tip on the burner. It is necessary to make sure it is centered to know it is fully functional.

Flow Test Unit  Testing unit to make sure the flow through the burner with a repaired tip is satisfactory.

Function Testing Unit  ?????????????????????
D  Fish Bone Analysis

Extension of fish bone analysis performed in 6.4. Analysis of SLM Container.

D.1  SLM Process - Fish Bone Analysis

Fish bone analysis of the SLM process.

D.2  Powder Handling - Fish Bone Analysis

Fish bone analysis of the powder handling system.
D.3 Media - Fish Bone Analysis

Fish bone analysis of media.

D.4 IT - Fish Bone Analysis

Fish bone analysis of the IT system.
D.5 Power Supply - Fish Bone Analysis

Fish bone analysis of the power supply.

D.6 Inspection - Fish Bone Analysis

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Fish bone analysis of the outgoing logistics.
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<table>
<thead>
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<th>Nr</th>
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<th>Function</th>
<th>Cost</th>
<th>Total Relevance R1+R2+R3</th>
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</tr>
</tbody>
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Requirement Specification of AM Plant-in-the-box Container
Part of Thesis: Conceptual Design of AM Container for “3D-Printer Cloud” Close to Customer Site

Vincent Sidenvall – 2016
Linköping University
Siemens Industrial Turbomachinery AB
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3.1.3 Heat Exchanger

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3.2 Powder Handling

3.2.1 Conveying Module

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3.2.1.2 Media

3.2.2 Sieving Module

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3.2.2.3 Vibrations

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1 Introduction

This is an initial requirement specification for the Additive Manufacturing, AM, container with intention of being used as part of the Vertical Workshop concept. The AM container is based on the Plant-in-the-box concept.

1.1 Overview

The requirement specification is divided into three parts

1. General – general requirements on the container
2. Equipment – requirements put on the container based on the machines and equipment to be placed in the container
3. Operation – requirements based on operations that has not been covered by the 2 first parts

1.2 Important Notes

1. This document is meant to be a supporting document for further work with a detailed requirement specification.
2. The requirement specification may need to be adapted to local laws and standards as well as conditions.
3. In this document a powder handling system consisting of two units (Conveying Module and Sieving Module) are described. This would preferably be exchanged for a closed loop powder handling system.

1.3 Delimitations

1. Laws and standards have not, in general, been taken into consideration as a basis for this document.
2 Requirement Specification – General

General requirements regarding the AM container itself

2.1 Physical Design of Container

The container shall provide structural support and attachment of machines and equipment during transportation with
- Truck
- Ship
- Lifting crane

and when installed at its stationary placement. It shall also support the machines and equipment during operation and be able to connect to the Vertical Workshop rack. In the case of equipment installed on the outside of the container the equipment shall be supported by the container.

During installation and replacement of equipment the container shall support the weight of lifting equipment used to install machines etc.

The container must perform as a standardized ISO container in the regards of strains, stresses, weight distribution.

Important standards regarding ISO container:
- ISO 668: Series 1 freight containers – Classification, dimensioning and ratings
- ISO 838: Freight Containers – Vocabulary
- ISO 1161: Corner Fittings
- ISO 1496-1: Series 1 freight containers – Specification and testing – part 1: general cargo containers for general purposes
- ISO 3874: Series 1 freight containers – Handling and securing
- ISO 6346: Freight Containers – Coding, identification and marking

2.1.1 Layout

The layout must allow the operator to perform all operations and move in the container without increased risk.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Minimum Width of Walkway [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator</td>
<td>0.8</td>
</tr>
</tbody>
</table>
The layout shall contribute positively to the operators work. It shall be easy to
- Reach controls
- See indicators
- See what you are doing (not reaching behind)
- Minimize the risk of powder collecting in certain areas by reducing the number of tight corners, narrow spaces etc.

2.1.1.1 Risks
The layout must reduce the risk of
- The operator hitting objects that are
  - Sticking out
  - Out of sight
- The operator getting stuck
  - Behind machinery and equipment
- The operator getting clamped / obstructed by
  - Open machine doors
  - Entrance doors
  - Movable equipment
- Obstruction of
  - Operations and movement of equipment
  - Escape ways
  - Entrances / exits
  - Windows
  - Ventilation inlet & outlet
  - Work station by
    - SLM machine
    - Powder handling
    - Jig and jack (tool for straightening burners)
    - Computer station
  - Valves and switches
    - Inert gas (Argon)
    - Pressurized air
    - Ventilation
    - Electricity
  - Controls
    - SLM machine
    - Powder handling
      - Sieving Module
      - Conveying module
    - Shake-blower module
    - Filter unit
    - Heat exchanger
    - Camera vision system
    - Wet separator
    - Lifting tool
    - Jig and jack
    - Air conditioning
    - Oxygen alarm
• Equipment being in the way during work.
• The operator climbing on equipment or goods to reach something
• The operator falling due to
  o Cables
  o Piping
  o Steps
  o Temporarily placed things

2.1.1.2 Operations
There shall be room to
• Use the lifting tool
• Handle burner
  o Mount / dismount in fixture
  o Mount in SLM machine
  o Inspection of burner dimensions
• Change the filter in the Filter Module
• Perform sieving operation
• Refill powder into SLM machine
• Remove powder from SLM machine
• Clean process chamber in SLM machine

2.1.1.3 Heat Dissipation
There shall be room for heat dissipation from
• SLM machine
• Heat exchanger
• Air Conditioning

2.1.2 Floor
Requirements put on the floor, from an inside and outside perspective of the container.

2.1.2.1 Inside
Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Floor Loading by SLM Machine</th>
<th>4 screw feet, diameter 80 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor Planeness</td>
<td>&lt;5 mm/m² difference</td>
</tr>
<tr>
<td>Vibrations</td>
<td>No vibrations are allowed to be transmitted from heavy machinery</td>
</tr>
<tr>
<td>Anti-Static</td>
<td>The floor is electrically conductive, e.g. anti-static floor</td>
</tr>
</tbody>
</table>
Surface
- Powder do not stick to the surface
- Surface is easy to clean
- Surface must be suitable for mopping so that no hazardous powder is stirred up to the air while cleaning
- Surface is not slippery
- Surface withstands solvents
- No gaps are allowed where powder and dust can collect
- Must not be a hindrance for the operator or equipment

2.1.2.2 Outside
The floor shall withstand

<table>
<thead>
<tr>
<th>Weather</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td>Moisture</td>
</tr>
<tr>
<td></td>
<td>Salt</td>
</tr>
<tr>
<td></td>
<td>Abrasion from sand</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infestation</th>
<th>Animals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insects</td>
</tr>
<tr>
<td></td>
<td>Plants</td>
</tr>
</tbody>
</table>

The floor shall reduce the heat transfer between the container and the surroundings due to temperature difference.

2.1.3 Walls
Requirements put on the walls, from an inside and outside perspective of the container.

2.1.3.1 Inside
The walls shall contribute to noise reduction in the container.

2.1.3.2 Outside
The floor shall withstand

<table>
<thead>
<tr>
<th>Weather</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td>Moisture</td>
</tr>
<tr>
<td></td>
<td>Salt</td>
</tr>
<tr>
<td></td>
<td>Abrasion from sand</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infestation</th>
<th>Animals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insects</td>
</tr>
<tr>
<td></td>
<td>Plants</td>
</tr>
</tbody>
</table>

The walls shall reduce the heat transfer between the container and the surroundings due to sun light and temperature difference.

2.1.4 Ceiling and Roof
Requirements put on the ceiling and roof, from an inside and outside perspective of the container.
2.1.4.1 **Inside**

The ceiling shall contribute to noise reduction in the container.

2.1.4.2 **Outside**

The roof shall withstand

<table>
<thead>
<tr>
<th>Weather</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td>Moisture</td>
</tr>
<tr>
<td></td>
<td>Salt</td>
</tr>
<tr>
<td></td>
<td>Abrasion from sand</td>
</tr>
<tr>
<td></td>
<td>Sun</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infestation</th>
<th>Animals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insects</td>
</tr>
<tr>
<td></td>
<td>Plants</td>
</tr>
</tbody>
</table>

The roof shall reduce the heat transfer between the container and the surroundings due to sun light and temperature difference.

In the case of equipment mounted on the outside of the container there must be sufficient weather protection.

2.1.5 **Windows**

Windows are to

- Provide the possibility of visual contact between the operator and the surroundings outside.
- Make sure it is possible to look into the container, without stepping inside, to see
  - state of machinery
  - if there is a fire
  - the state of the operator inside

The windows shall provide

- Reduction of light and heat let into the container

Protective covers are needed to protect the windows from breaking and to prevent unauthorized persons to see into the container during transport.
The windows shall withstand

<table>
<thead>
<tr>
<th>Weather</th>
<th>Precipitation</th>
<th>Wind</th>
<th>Moisture</th>
<th>Salt</th>
<th>Abrasion from sand</th>
<th>Sun</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Infestation</th>
<th>Animals</th>
<th>Insects</th>
<th>Plants</th>
</tr>
</thead>
</table>

The windows shall reduce the heat transfer between the container and the surroundings due to sun light and temperature difference.

2.1.6 Doors and Openings

Requirements put on doors and openings, from an inside and outside perspective of the container. Note that some doors and or openings may coincide.

2.1.6.1 Installation

There shall be an opening in the container, possibly temporary, to allow installation of machinery, equipment etc. during first installation and exchanging of machinery or equipment. See table for references to dimensions.

<table>
<thead>
<tr>
<th>Machinery &amp; Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLM Machine</td>
<td>3.1.1</td>
</tr>
<tr>
<td>Filter Unit</td>
<td>3.1.2</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>3.1.3</td>
</tr>
<tr>
<td>Camera Vision System</td>
<td>3.1.4</td>
</tr>
<tr>
<td>Conveying Module</td>
<td>3.2.1</td>
</tr>
<tr>
<td>Sieving Module</td>
<td>3.2.2</td>
</tr>
<tr>
<td>Filling Module</td>
<td>3.2.3</td>
</tr>
<tr>
<td>Shake-Blower Module</td>
<td>3.2.4</td>
</tr>
<tr>
<td>Wet Separator</td>
<td>3.2.5</td>
</tr>
</tbody>
</table>

2.1.6.2 Main Entrance

The main entrance shall allow the operator to enter and exit the container. The general guideline of the minimal door width is 80 cm. There must be a sticky mat at entrance, to remove powder from operator shoes.

2.1.6.3 Emergency Exit

The emergency exit must provide an easy way of evacuating the container in the case of an emergency. It shall allow the operator to exit from the container when he/she is not close to or cannot reach the main entrance. The emergency exit door must be easy to open. The general guideline of the minimal door width is 80 cm.

2.1.6.4 Logistics Entrance / Exit

Allow input and output of...
2.1.6.5 Service Doors
In the case of fixed installation of SLM machine, close to the wall, one or several service doors must be provided, in the container wall, to enable the service technician to open the back of the machine.

2.1.6.6 Media Inlet
Allow connection of tubes, pipes and lines to connect into the container without allowing air to seep between inside and outside of container. Media to be connected:
- Argon
- Pressurized air
- Electrical power supply
- Data connection

2.1.7 Insulation
The insulation shall be sufficient, following standards, for the temperature difference between internal and external climate described in 2.5.3 Internal and 2.5.2 External.

The insulation must be of a non-organic material to prevent infestation of animals, insects, plants, and mold.

<table>
<thead>
<tr>
<th>Infestation</th>
<th>Animals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insects</td>
</tr>
<tr>
<td></td>
<td>Plants</td>
</tr>
<tr>
<td></td>
<td>Mold</td>
</tr>
</tbody>
</table>

2.1.8 Sun Protection
The container in combination with the Vertical workshop rack must provide sufficient sun protection of all equipment, mounted both in the container and outside the container. It may be of interest to see to that the placement of the vertical workshop is beneficial from a solar-radiation perspective.

2.1.9 Fastening of Equipment
The machinery and equipment in the container must be fastened to the container to withstand the dynamic loading of transportation. The equipment that do not need to move during operation may be fastened in a semi-permanent manner which allow them to be moved for service purposes and removed for exchange of equipment.

2.1.10 Certification
The container must be certified according to applicable laws and standards. Initially identified areas of interest
- Laser - even though the SLM machine is certified the container may need a separate certification in some countries.
- Electronics – the electronics system must be designed according to standards and directives (Low Voltage Directive etc.)
- Pressurized air & gas – tanks of pressurized air and gas are needed. Not likely supplied in the SLM container. More likely supplied by either a separate container or the Vertical Workshop rack. The system must be designed according to standards and directives (Pressurized Equipment Directive etc.)
- Hazardous materials / chemicals – metal powder, 99% alcohol, T-Red (spirits) etc. must be used according to local regulations
- Working alone in a confined /enclosed space – needs investigation
- Work environment - Ventilation, lightning, sound levels, emergency exits etc. must be installed according to standards

2.1.11 Access Control

There shall be an access control system to make sure that only authorized personnel can enter the container.

2.1.12 Vibrations

The container including its attachment to the Vertical Workshop shall be designed in a way that it reduces the effect of vibrations caused by sources in the
- Surroundings,
- Vertical Workshop and
- Container.

There is to be a monitoring system according to 3.4.3 Conditions Monitoring to make sure the container has not been vibrated in such a way that may have effects on the AM process.

2.1.13 Work Station

There shall be a work bench where workshop classified work can be performed and where powder can be removed from parts. An extraction hood with powder collection is necessary for powder removal.
2.2 **Power Supply**

- There shall be an external power supply during operation and transport.
- The connection points must be placed such that the cords to the SLM machine can be installed along the floor.
- All cords and hoses must be installed such that they are protected from damages, e.g., caused by abrasion, bending, squeezing etc.
- There shall be 230V, or according to local variations, wall sockets to supply power to hand tools.

### 2.2.1 Power

Power supply needed for SLM process machinery and equipment (excluding air conditioning, lifting tool etc.)

<table>
<thead>
<tr>
<th>Machine / Equipment</th>
<th>Specification</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLM Machine</td>
<td>400V 3~/N/PE</td>
<td>3.1.1.2.1</td>
</tr>
<tr>
<td>Filter Unit</td>
<td>230V 1~/N/PE</td>
<td>3.1.2.1.1</td>
</tr>
<tr>
<td>Wet Separator</td>
<td>380-420V 3~/N/PE</td>
<td>3.2.5.1.1</td>
</tr>
<tr>
<td>Sieving Module</td>
<td>400V 3~/N/PE</td>
<td>3.2.2.1.1</td>
</tr>
<tr>
<td>Camera System</td>
<td>230V 1~/N/PE</td>
<td>3.1.4.1.1</td>
</tr>
<tr>
<td>Shake-Blower Module</td>
<td>400V 3~/N/PE</td>
<td>3.2.4.1.1</td>
</tr>
</tbody>
</table>

### 2.2.2 Ground

- All machinery and equipment must be grounded.
- The container itself must be grounded.
- The floor must be of antistatic type, without obstructing the work or processes.

The Vertical Workshop rack in combination with the container must provide lightning strike protection.

### 2.2.3 Battery Backup

There must be a battery backup, or equivalent, to ensure that a sudden power loss does not damage the SLM machine, by letting it power off in a controlled manner.
2.3 **Securing Container to Rack**

The connection between the container and the Vertical Workshop rack must provide:

- Installation of / removal of container – the container shall be able to be slid in and out
- Locking – the container must be locked to the rack without risk of falling out
- Fastening device – must be weather proof and earthquake proof
- Connection – shall reduce the transferring of vibration between containers and between ground and containers

2.3.1 **Fastening of Container**

The container must be fastened to the Vertical Workshop rack in such a manner that there is no risk of the container to slide out. The locking mechanism must allow for easy installation and removal of container while being able to withstand live loads, such as wind, earthquakes etc.
2.4 Environment, Health and Safety

Environment, health and safety related matters.

2.4.1 Personal Protective Equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Stored in Container</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regular Storage</td>
</tr>
<tr>
<td>Coat</td>
<td>X</td>
</tr>
<tr>
<td>Overall</td>
<td>X</td>
</tr>
<tr>
<td>Fresh Air Helmet</td>
<td></td>
</tr>
<tr>
<td>Filter Mask</td>
<td></td>
</tr>
<tr>
<td>Vinyl Gloves</td>
<td>X</td>
</tr>
<tr>
<td>Shoe Protection</td>
<td>X</td>
</tr>
<tr>
<td>Welding Gloves</td>
<td></td>
</tr>
</tbody>
</table>

(*) – Stored close to filter unit, easy to collect in case of fire when changing filters

2.4.2 Emergency stop circuit

There must be easy to reach emergency stop buttons for
- The SLM machine
- Electrically powered equipment
- The power supply to the container
and shut of valves for
- Argon
- Pressurized air

2.4.3 Emergency Signaling

In: There must be an emergency signaling device in the container signaling
- to the security department
- outside of the container

Out: There must be a signaling device to alert the operator of alarms from outside the container

2.4.4 Oxygen Level Alarm

Reference: Operation, EOSINT M280 Custom, Siemens RaBuTiR

The oxygen level is to be measured at floor level, in the container. The alarm should monitor the oxygen level and signal according to table below.

<table>
<thead>
<tr>
<th>Oxygen Level</th>
<th>In Container</th>
<th>At Entrance of Container (outside)</th>
<th>Security Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;19% Oxygen</td>
<td>Light</td>
<td>Light</td>
<td>Alert</td>
</tr>
<tr>
<td>&lt;17% Oxygen</td>
<td>Light, sound</td>
<td>Light</td>
<td>Alert</td>
</tr>
</tbody>
</table>

2.4.5 Fire Prevention

Fire preventive matters
2.4.5.1 Detection
There must be a fire detection system and a signaling unit in the container. It shall signal in the container with
- Sound
- Light
Outside the container with
- Sound
- Light
- Signal to security department

2.4.5.2 Extinguishing
There must be available fire extinguishers for
- Electronics fire
- Waste materials fire
- Filter and metal powder/metal condensate fire

2.4.5.3 Protection of chemical goods
Supply to be stored in a cabinet for chemicals
- Metal powder
- 99% alcohol
- T-Red (spirits)
Small amounts for use may be stored in safety containers
- 99% alcohol
- T-Red (spirits)

There must be general ventilation enough to counteract accumulation of fumes.

2.4.6 Argon Release
See 3.1.1.3 Exhaust

2.4.7 Static Electricity
See 2.2.2
2.4.8 Working Environment

2.4.8.1 Air Conditioning & Ventilation

Ventilation supply and connection

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

- Keep temperature and humidity level as specified in 2.5.3
- Ventilation inlet (in container) directed so that
  - it does not blow directly at a machine
  - it does not stir powder into the air
    - Low flow rate
    - Not directed towards the floor
- Ventilation inlet placed high
- Ventilation outlet placed low
- Air filter
  - Inlet: do not let particles, insects etc. into the container
  - Outlet: do not let powder and condensate out of the container

2.4.8.2 Lighting

Work stations must be designed to provide industrial standard lighting in the container. European standard DIN EN 12079-1" Light and lighting - Lighting of work places - Part 1: Indoor work places” is of importance.

2.4.8.3 Noise Levels

The design of the container must reduce the noise level in the container.

2.4.8.4 Ergonomics

Work stations must be designed to provide ergonomic work positions for operators. Ex. In front of the SLM machine a risen platform is suitable when operators are expected to be shorter than the standard of the machine installation.

There must be a lifting tool providing sufficient amount of help to reduce the loadings put on the operator. See 0 Lifting Tool
2.5 Climate

Requirements on the container considering the climate inside and outside of the container

2.5.1 In and Out Passage

It is important to not let the external climate have an effect on the internal climate due to the opening of doors and removable covers. This means it is of interest to limit the flow of air between the container and its surroundings. A solution similar to an air lock is of interest for the main entrance.

2.5.2 External

Values based on data from www.wunderground.com for a period of 3 year. OBS! Three years are a too short time, but the collected data gives the general idea.

<table>
<thead>
<tr>
<th>Place</th>
<th>Climate</th>
<th>Temperature Range [°C]</th>
<th>Wind [m/s]</th>
<th>Precipitation [mm/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>Polar dry</td>
<td>-39 - 19</td>
<td>20</td>
<td>217</td>
</tr>
<tr>
<td>Dubai</td>
<td>Tropical dry</td>
<td>12 - 49</td>
<td>46</td>
<td>58</td>
</tr>
<tr>
<td>Hammerfest</td>
<td>Polar moist</td>
<td>-17 - 28</td>
<td>26</td>
<td>483</td>
</tr>
<tr>
<td>Singapore</td>
<td>Tropical wet</td>
<td>21 - 35</td>
<td>12</td>
<td>2222</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>-39 - 49</strong></td>
<td><strong>46</strong></td>
<td><strong>2222</strong></td>
</tr>
</tbody>
</table>

2.5.3 Internal

Requirements on the internal climate of the container

<table>
<thead>
<tr>
<th>Equipment</th>
<th>During Transport</th>
<th>During Operation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLM Machine</td>
<td>10-40 °C, max 20-80% rel. humidity (non-condensing)</td>
<td>15-20 °C, max 80% rel. humidity &gt;20-25 °C, max 60% rel. humidity &gt;25-30 °C, max 45% rel. humidity</td>
<td>3.1.1.1</td>
</tr>
<tr>
<td>Powder</td>
<td>15-25 °C, max 40% rel. humidity</td>
<td>-</td>
<td>3.7.5.1</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>-25-70 °C, max 20-95% rel. humidity (non-condensing)</td>
<td>5-40 °C, max 20-95% rel. humidity (non-condensing)</td>
<td>3.1.3.1</td>
</tr>
<tr>
<td>Filter Unit</td>
<td>-25-55 °C humidity - non condensing</td>
<td>15-30 °C, humidity - non condensing</td>
<td>3.1.2.2</td>
</tr>
<tr>
<td>Wet Separator</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Conveying Module</td>
<td>-</td>
<td>-20-60 °C</td>
<td>3.2.1.1</td>
</tr>
<tr>
<td>Sieving Module</td>
<td>-</td>
<td>10-40 °C</td>
<td>3.2.2.2</td>
</tr>
<tr>
<td>Filling Module</td>
<td>-</td>
<td>10-40 °C</td>
<td>3.2.3.1</td>
</tr>
<tr>
<td><strong>SLM Process Condition</strong></td>
<td>15-25 °C, max 40% rel. humidity</td>
<td>15-25 °C, max 40% rel. humidity</td>
<td></td>
</tr>
</tbody>
</table>

2.6 First Installation at AM CoC & Commissioning on Site

The container is to be installed in a Vertical Workshop rack at the AM CoC to ensure...
all systems are working,
it produced good quality parts and
to perform a pre acceptance test with the customer.

2.7 Transport of Container

During transport of the container it is important that:

- The mass is centered mass
- The weight is within specification
- Conditions are monitored
- There is a power supply for climate conditioning
Requirements specification connected to the equipment to be installed in the AM container.

### 3.1 SLM Process

Requirements on the AM container based on the SLM process.

#### 3.1.1 SLM Machine – M280

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

- The SLM machine corresponds to, in operational state (with closed covers above optics and scanner), a laser device of class 1

<table>
<thead>
<tr>
<th>Mass</th>
<th>Weight (in operation, fully loaded)</th>
<th>1557 kg</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>2200 mm</td>
<td>4350 mm</td>
</tr>
<tr>
<td>Width</td>
<td>1260 mm</td>
<td>2560 mm</td>
</tr>
<tr>
<td>Height</td>
<td>1940 mm</td>
<td>2540 mm</td>
</tr>
</tbody>
</table>

#### 3.1.1.1 Surroundings

**Temperatures and Humidity**

<table>
<thead>
<tr>
<th>Operation</th>
<th>15-20 °C, max 80% rel. humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;20-25 °C, max 60% rel. humidity</td>
</tr>
<tr>
<td></td>
<td>&gt;25-30 °C, max 45% rel. humidity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transport</th>
<th>10-40 °C, max 20-80% rel. humidity (non-condensing)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Additional</th>
<th>Machine is not allowed to be heated or cooled from one side, e.g. by element, air conditioning, insolation or by drafts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No visible condense are allowed on the cooler system for the laser</td>
</tr>
<tr>
<td></td>
<td>The temperature difference between the inert gas (argon) and the surrounding air, at input, are within +/- 3.5 °C</td>
</tr>
</tbody>
</table>

**Emitted Noise Level**

<table>
<thead>
<tr>
<th>Sound Pressure Level</th>
<th>63 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>68 dB (short period of time)</td>
</tr>
</tbody>
</table>
Electromagnetic Compatibility, EMC

<table>
<thead>
<tr>
<th>EMC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No equipment emitting high frequency radiation are allowed close</td>
<td>to the SLM Machine</td>
</tr>
<tr>
<td>Electrical installations that can cause electrical interference are</td>
<td>not allowed in the machine hall</td>
</tr>
<tr>
<td>The SLM machine is classified as an ISM-instrument, class A,</td>
<td>group 1 following EN55011</td>
</tr>
</tbody>
</table>

3.1.1.2 Connections

The SLM machine needs to be connected to electrical power, media and data.

3.1.1.2.1 Electrical Power

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

- The connection points must be placed such that the cords to the SLM machine can be installed along the floor
- Connect the machine and equipment to a 400 V TN-C-S three phase power supply including fuse protection
- Connect the machine to an uninterruptible power source (USV), contact EOS-hotline
- No electrical motors of moderate size are allowed to be connected to the same electrical circuit as the SLM machine, since this may disrupt the power supply to the laser
- If the SLM machine is not integrated in a protective conductor system, a potential equalization line can be connected to the M6 bolt behind the installation cover to the FI-housing

<table>
<thead>
<tr>
<th>Connection</th>
<th>CEE-socket 400 V / 32 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>400 V 3~/N/PE</td>
</tr>
<tr>
<td>Voltage Deviations</td>
<td>+6% to -10%</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 / 60 Hz</td>
</tr>
<tr>
<td>Short-Circuit Current</td>
<td>5 kA</td>
</tr>
<tr>
<td>Rated Power</td>
<td>8,5 kW (incl. Heat Exchanger and Filter Unit)</td>
</tr>
<tr>
<td>Rated Amperage</td>
<td>Max. 17.5 A (incl. Heat Exchanger and Filter Unit)</td>
</tr>
<tr>
<td>Fuse Protection</td>
<td>3x 32 A</td>
</tr>
</tbody>
</table>

3.1.1.2.2 Media

There must be connections to the AM container from the Vertical Workshop providing pressurized air and Argon.
Pressurized Air

- Quality according to ISO 8573
- No liquid water allowed in the pressurized air

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Consumption (with external inert gas)</th>
<th>About 1 m³/h at 7 bar pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Pressure</td>
<td>7 bar</td>
</tr>
<tr>
<td>Min. Pressure</td>
<td>6 bar</td>
</tr>
<tr>
<td>Max. Pressure</td>
<td>10</td>
</tr>
<tr>
<td>Temperature</td>
<td>Max. 10 °C above surrounding air</td>
</tr>
<tr>
<td>ISO 8573</td>
<td></td>
</tr>
<tr>
<td>1. Solid Particles</td>
<td>Class 1 (particle size &lt;0.1 micrometer, particle density &lt;0.1 mg/m³)</td>
</tr>
<tr>
<td>2. Humidity Purity</td>
<td>Class 4 (pressure dew point &lt;3 °C)</td>
</tr>
<tr>
<td>3. Oil Purity</td>
<td>Class 1 (oil concentration &lt;0.01 mg/m³)</td>
</tr>
</tbody>
</table>

The pipes for pressurized air supply, in the container, shall be placed so that they are not in the way of the operator or any movable machinery.

**Reference:** Operation, EOSINT M280 Custom, Siemens RaBuTiR

**Argon Usage**

- 0.6 m³/h (average operation)

### 3.1.1.2.3 Data Connection

- The process computer in the SLM machine is permanently connected to the network by a data cable that has been connected through the bottom of the SLM machine

<table>
<thead>
<tr>
<th>Specification</th>
<th>Ethernet Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Protocol</td>
<td>TCP/IP</td>
</tr>
<tr>
<td>Network Connection</td>
<td>10/100 Base-TX</td>
</tr>
</tbody>
</table>

### 3.1.1.3 Exhaust

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

- The SLM machine be run together with a, by EOS delivered, Filter Unit
- Exhaust gases from the Filter Unit must pass through the Exhaust Filter
- The exhaust gases must be discharged outdoors, either directly or by an dedicated exhaust air system
- The exhaust gases are not allowed to be recirculated into to workshop
- The exhaust pipe must be equipped with a check valve to ensure the exhaust gas is not flowing backwards
- No stagnation of flow are allowed in the exhaust pipe
- If an dedicated exhaust air system is used, it must guarantee that all exhaust gases are completely and continuously aspirated
- There must not be any lower ground, eg. a pit or shaft, under the exhaust exit outdoors, where Argon can collect
Specification of the direct exhaust pipe outdoors
- Gas tight connections
- Check valve to counteract backwards flow
- Maximum hose length: 10m

Specification of connection to an exhaust air system
- Connection without leakage
- Check valve to counteract backwards flow
- Maximum hose length: 10m
- A guaranteed operation of the exhaust air system as long as there is an exhaust flow
- Exhaust air flow: >10m³/h
- Maximum pressure difference to the surrounding, at point of connection: +/-5 mbar

3.1.1.4 Controls and Indicators
Position of Controls and Indicators

<table>
<thead>
<tr>
<th>Main Controls</th>
<th>Front of machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Switch and Indicators</td>
<td>Back of the machine (propose redesign)</td>
</tr>
</tbody>
</table>
3.1.2 Filter Unit and Exhaust Filter

Including exhaust filter

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Mass</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (in operation, plus exhaust filter)</td>
<td>225+19=244 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>650 mm</td>
<td>1460 mm</td>
</tr>
<tr>
<td>Width</td>
<td>690 mm</td>
<td>1840 mm</td>
</tr>
<tr>
<td>Height</td>
<td>1560 mm</td>
<td>1715 mm</td>
</tr>
</tbody>
</table>

3.1.2.1 Connections

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

3.1.2.1.1 Electrical Power

<table>
<thead>
<tr>
<th>Connection</th>
<th>In the SLM machine, by a Schuko 230 V connector (3.19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>230 V 1~/N/PE</td>
</tr>
<tr>
<td>Voltage Deviations</td>
<td>+6% to -10%</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Rated Power</td>
<td>2x 1 kW</td>
</tr>
<tr>
<td>Fuse Protection</td>
<td>1x 16 A</td>
</tr>
</tbody>
</table>

3.1.2.2 Surroundings

<table>
<thead>
<tr>
<th>Operation</th>
<th>15-30 °C, humidity – non-condensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>-25-55 °C humidity – non-condensing</td>
</tr>
<tr>
<td>Emitted Noise Level</td>
<td>60 dB(A)</td>
</tr>
</tbody>
</table>

3.1.2.3 Controls and Indicators

Position of Controls and Indicators

<table>
<thead>
<tr>
<th>Main Controls</th>
<th>Front of unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Switch and Indicators</td>
<td>Front of unit</td>
</tr>
</tbody>
</table>
3.1.3 Heat Exchanger

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

- If you decide not to use the heat exchanger provided by EOS, contact EOS/hotline
- There is two choices of heat exchangers
  - Air-Water (standard), dissipates heat with a fan to the surrounding air
  - Water-Water, dissipates heat to a separate flow of water
- Do not connect the cooling circuit directly to an in house cooler. The internal cooling elements in the SLM machine may corrode or get damaged
- The hose length of the cooling water circuit, between the SLM machine and the heat exchanger is about 15 m. This may not be altered, especially not making them shorter
- There must be sufficient space around the Heat Exchanger to allow the heat to be radiated

<table>
<thead>
<tr>
<th>Cooling Media</th>
<th>Distilled or deionized water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount</td>
<td>About 10 liters</td>
</tr>
<tr>
<td>Corrosion Protection</td>
<td>Addition of 27.5% +/-2.5% DOWCAL N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (in operation)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>405 mm</td>
<td>1005 mm</td>
</tr>
<tr>
<td>Width</td>
<td>600 mm</td>
<td>1200 mm</td>
</tr>
<tr>
<td>Height</td>
<td>850 mm</td>
<td>850 mm</td>
</tr>
</tbody>
</table>

3.1.3.1 Surroundings

| Operation | 5-40 °C, max 20-95% rel. humidity (non-condensing) |
| Transport (empty) | -25-70 °C, max 20-95% rel. humidity (non-condensing) |
3.1.4 Camera Vision System

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Mass</th>
<th>Weight (empty)</th>
<th>30 kg</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dimensions Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length 680 mm</td>
<td>680 mm</td>
</tr>
<tr>
<td>Width 1220 mm</td>
<td>1220 mm</td>
</tr>
<tr>
<td>Height 430 mm</td>
<td>430 mm</td>
</tr>
</tbody>
</table>

3.1.4.1 Connections

The Camera Vision System needs to be connected to power, see blow, and to the data network.

3.1.4.1.1 Electrical Connections

<table>
<thead>
<tr>
<th>Connection</th>
<th>Schuko socket 230 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>230 V 1~/N/PE</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Rated Power</td>
<td>2x 1.0 kW</td>
</tr>
<tr>
<td>Fuse Protection</td>
<td>1x 16 A</td>
</tr>
</tbody>
</table>
3.2 Powder Handling

Requirements based on the powder handling of the AM process.

3.2.1 Conveying Module

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Mass</th>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (empty, plus max. powder load)</td>
<td>139+100=239 kg</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>790 mm</td>
<td>790 mm</td>
</tr>
<tr>
<td>Width</td>
<td>800 mm</td>
<td>2600 mm</td>
</tr>
<tr>
<td>Height</td>
<td>1710 mm</td>
<td>1710 mm</td>
</tr>
</tbody>
</table>

3.2.1.1 Surroundings

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

The Conveying Module must be connected to ground during operation

<table>
<thead>
<tr>
<th>Operation</th>
<th>-20-60 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitted Noise Level</td>
<td>&lt; 70 dB(A)</td>
</tr>
</tbody>
</table>

3.2.1.2 Media

Pressurized Air

- Quality according to ISO 8573

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Consumption (with external inert gas)</th>
<th>Max. 0.5 m³/h at 6 bar pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Pressure</td>
<td>6 bar</td>
</tr>
<tr>
<td>Min. Pressure</td>
<td>5.5 bar</td>
</tr>
<tr>
<td>Max. Pressure</td>
<td>12</td>
</tr>
<tr>
<td>Temperature</td>
<td>Max. 10 °C above surrounding air</td>
</tr>
<tr>
<td>ISO 8573</td>
<td>1. Humidity purity Class 4 (pressure dew point &lt;+3 °C)</td>
</tr>
<tr>
<td>ISO 8573</td>
<td>3. Oil purity Class 2 (oil concentration &lt;0.1 mg/m³)</td>
</tr>
</tbody>
</table>
3.2.2 Sieving Module

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Mass</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (empty, plus max. powder load)</td>
<td>145+100=245 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>790 mm</td>
<td>790 mm</td>
</tr>
<tr>
<td>Width</td>
<td>750 mm</td>
<td>2550 mm</td>
</tr>
<tr>
<td>Height</td>
<td>1420 mm</td>
<td>2350 mm</td>
</tr>
</tbody>
</table>

3.2.2.1 Connections

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

The Sieving Module must be connected to ground during operation.

3.2.2.1.1 Electrical Power

| Connection       | CEE-socket 400 V / 16 A |
| Voltage          | 400 V 3~/N/PE          |
| Frequency        | 50 Hz                  |
| Rated Power      | 0.15 kW                |
| Rated Amperage   | 0.6 A                  |
| Fuse Protection  | 3x 16 A                |

3.2.2.2 Surroundings

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

| Operation | 10-40 °C |
| Emitted Noise Level | < 70 dB(A) |

3.2.2.3 Vibrations

The Sieving Module vibrates during operation. The installation of the Sieving Module must be such that it ensures that vibrations that may cause problems for the SLM machine is not transmitted to the container.
3.2.3 Filling Module

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Mass</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>7 kg</td>
</tr>
</tbody>
</table>

### Dimensions

<table>
<thead>
<tr>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>530 mm</td>
</tr>
<tr>
<td>Width</td>
<td>240 mm</td>
</tr>
<tr>
<td>Height</td>
<td>300 mm</td>
</tr>
</tbody>
</table>

#### 3.2.3.1 Surroundings

Reference: Jan Lundin, RLM Mekaniska AB, www.rlm.se (machine developer)

**Operation**: 10-40 °C

3.2.4 Shake-Blower Module

<table>
<thead>
<tr>
<th>Mass</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>kg</td>
</tr>
</tbody>
</table>

### Dimensions

<table>
<thead>
<tr>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1100 mm</td>
</tr>
<tr>
<td>Width</td>
<td>2400 mm</td>
</tr>
<tr>
<td>Height</td>
<td>2400 mm (*)</td>
</tr>
</tbody>
</table>

(*) Possible to reduce height

#### 3.2.4.1 Connections

Reference: Jan Lundin, RLM Mekaniska AB, www.rlm.se (machine developer)

The Shake-Blower Module must be connected to ground during operation

**3.2.4.1.1 Electrical Power**

<table>
<thead>
<tr>
<th>Connection</th>
<th>CEE-socket 400 V / 16 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>400 V 3~/N/PE</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Rated Power</td>
<td>Depending on program cycle kW</td>
</tr>
<tr>
<td>Rated Current</td>
<td>Depending on program cycle A</td>
</tr>
<tr>
<td>Fuse Protection</td>
<td>16 A</td>
</tr>
</tbody>
</table>

**3.2.4.1.2 Media**

There must be connections to the AM container from the Vertical Workshop providing pressurized air and Argon.

**Pressurized Air**

- Quality according to ISO 8573 – *specification needed*
- No liquid water allowed in the pressurized air

Reference: Jan Lundin, RLM Mekaniska AB, www.rlm.se (machine developer)

<table>
<thead>
<tr>
<th>Consumption</th>
<th>About 0.8 m³/min at 6 bar pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Pressure</td>
<td>6 bar</td>
</tr>
</tbody>
</table>
Min. Pressure | 5 bar
Max. Pressure | 7 bar

### 3.2.4.2 Surroundings

**Reference:** Jan Lundin, RLM Mekaniska AB, [www.rlm.se](http://www.rlm.se) (machine developer)

<table>
<thead>
<tr>
<th>Operation</th>
<th>Specification as for metal powder, see 3.7.5.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitted Noise Level</td>
<td>(unknown) dB(A)</td>
</tr>
</tbody>
</table>

### 3.2.4.3 Vibrations

The Shake-Blower Module vibrates during operation. The installation of the Sieving Module must be such that it ensures that vibrations that may cause problems for the SLM machine is not transmitted to the container.

### 3.2.5 Wet Separator

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Mass</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (in operation)</td>
<td>135 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Of Machine</th>
<th>Used Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>480 mm</td>
<td>480 mm</td>
</tr>
<tr>
<td>Width</td>
<td>850 mm</td>
<td>850 mm</td>
</tr>
<tr>
<td>Height</td>
<td>1460 mm</td>
<td>1460 mm</td>
</tr>
</tbody>
</table>

#### 3.2.5.1 Connections

**3.2.5.1.1 Electrical Connections**

- Must be connected to the socket in the back of the SLM machine
- Must be connected with a potential equalization line to the SLM machine

<table>
<thead>
<tr>
<th>Electrical Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection</td>
</tr>
<tr>
<td>Voltage</td>
</tr>
<tr>
<td>Voltage Deviations</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Rated Power</td>
</tr>
<tr>
<td>Rated Amperage</td>
</tr>
</tbody>
</table>

#### 3.2.5.2 Water

A water supply is needed when cleaning and refilling the wet separator.

#### 3.2.5.3 Surroundings

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

| Emitted Noise Level | 64 dB(A) |
3.3 Media

Compilation of media requirements

3.3.1 Argon Supply

Argon must be supplied to the SLM machine. Data collected from 3.1.1.2.2.

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR
- The connecting hose which is drawn to the connection point must have an connection piece with external thread of G ½”
- Normal condition: 25 °C, 1013 hPa

<table>
<thead>
<tr>
<th>Min. Provided Flow</th>
<th>6 m³/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Flow</td>
<td>0-6 m³/h</td>
</tr>
<tr>
<td>Usage at Process Startup</td>
<td>Max. 3 m³</td>
</tr>
<tr>
<td>Flow During Process</td>
<td>About 0.6 m³/h</td>
</tr>
<tr>
<td>Min. Pressure</td>
<td>4 bar</td>
</tr>
<tr>
<td>Max. Pressure</td>
<td>5 bar</td>
</tr>
<tr>
<td>Min. Argon Purity</td>
<td>Argon 4.8 (99.998% Argon)</td>
</tr>
</tbody>
</table>

The pipes for Argon supply, in the container, shall be placed so that they are not in the way of the operator or any movable machinery.

<table>
<thead>
<tr>
<th>Machine / Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLM Machine</td>
<td>3.1.1.2.2</td>
</tr>
<tr>
<td>Conveying Module</td>
<td>3.2.1.2</td>
</tr>
</tbody>
</table>

3.3.2 Argon Exhaust

See 3.1.1.3

3.3.3 Pressurized Air

Pressurized air must be supplied to the SLM machine, data collected from 3.1.1.2.2, and for the Conveying Module, data from 3.2.1.2.

3.3.3.1 SLM Machine
- Quality according to ISO 8573
- No liquid water allowed in the pressurized air

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Consumption (with external inert gas)</th>
<th>About 1 m³/h at 7 bar pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Pressure</td>
<td>7 bar</td>
</tr>
<tr>
<td>Min. Pressure</td>
<td>6 bar</td>
</tr>
<tr>
<td>Max. Pressure</td>
<td>10</td>
</tr>
<tr>
<td>Temperature</td>
<td>Max. 10 °C above surrounding air</td>
</tr>
<tr>
<td>ISO 8573</td>
<td>1. Solid Particles</td>
</tr>
</tbody>
</table>
3.3.3.2 **Conveying Module**

- Quality according to ISO 8573

**Reference:** Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidity Purity</td>
<td>Class 4 (pressure dew point &lt; 3 °C)</td>
</tr>
<tr>
<td>Oil Purity</td>
<td>Class 1 (oil concentration &lt; 0.01 mg/m³³)</td>
</tr>
</tbody>
</table>

3.3.3.3 **Shake-Blower Module**

- Quality according to ISO 8573 – *specification needed*
- No liquid water allowed in the pressurized air

**Reference:** Jan Lundin, RLM Mekaniska AB, [www.rlm.se](http://www.rlm.se) (machine developer)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption (with external inert gas)</td>
<td>Max. 0.5 m³/h at 6 bar pressure</td>
</tr>
<tr>
<td>Rated Pressure</td>
<td>6 bar</td>
</tr>
<tr>
<td>Min. Pressure</td>
<td>5.5 bar</td>
</tr>
<tr>
<td>Max. Pressure</td>
<td>12</td>
</tr>
<tr>
<td>Temperature</td>
<td>Max. 10 °C above surrounding air</td>
</tr>
<tr>
<td>ISO 8573</td>
<td>1. Humidity purity Class 4 (pressure dew point &lt; +3 °C)</td>
</tr>
<tr>
<td></td>
<td>3. Oil purity Class 2 (oil concentration &lt; 0.1 mg/m³³)</td>
</tr>
</tbody>
</table>

3.3.4 **Supply Line**

Flexible connection to allow machines to be moved in the container
3.4 **IT**

Requirements regarding the IT systems of the AM container

3.4.1 **It Security**

The IT security of the AM container is very important, especially to protect Intellectual Property.

3.4.1.1 **Fire wall**

There must be a firewall between the data network in the container and the internet.

3.4.1.2 **Wired network**

The data network in the container shall be wired to ensure data transferring rates and reduce the risk of non-authorized access.

3.4.1.3 **Manufacturing Execution System**

The Manufacturing Execution System shall provide a safe way of data communication for 3D models and job files.

3.4.2 **Data Connection**

Pieces of hardware that need a data connection

- SLM machine – see specification in 3.1.1.2.3 Data Connection
- Computer
- Camera vision system
- Argon alarm
- Condition monitoring system

3.4.3 **Conditions Monitoring**

There shall be a conditions monitoring system that monitors the physical conditions of the container during transportation and operation. Data that are of interest:

- Vibrations
- Temperature
- Humidity level
- Oxygen level
- GPS coordinates, during transport

This is of interest to ensure a qualitative process as well as to monitor how the container is transported. The data can be used to monitor if the conditions are met for a qualitative building process and to make decisions regarding the quality of the AM process. In case of damages during transport the data can be used to identify the cause.

The data shall be stored and sent to Siemens during operation and transport.

3.4.4 **Access Control**

The container shall provide a system for letting only authorized personnel into the container. It shall include

- Card reader or equivalent – access control
- Locking mechanism
• Alarm – protection against break in
• Camera surveillance
  o According to local laws

3.4.5 Computer Station

There shall be a computer station where the operator can report the work performed and where build jobs can be prepared. This system shall connect to the Manufacturing Execution System, MES. There shall be available documentation and manuals for the work process and the equipment available for information to operators.
3.5 Inspection

Inspection operations of burners that can be performed in the AM container, or in a separate container

3.5.1 Straightening of burner – Jig and Jack

The burners must be straightened before they are put into the milling/turning machine to be prepared for SLM repair. This needs a jig where the burner can be spun slowly, while measuring how bent it is. With the measurement as base a jack can be used to press the burner to be straight. This is to be repeated until the burner is within tolerances for repair.

3.5.2 Measuring Tool

A tool is used to measure how centered the repaired burner tip is on the burner. This must read on three point on the burner tip and three points on the burner.
3.6 Lifting Tool

A lifting tool is needed to reduce the heavy lifting for operators.

3.6.1 Lifting Capacity

Be able to lift

- burner with fixture to and from
  - the SLM machine
  - the Shake-Blower module
- Building plate with SLM parts on top
  - Building plate
    - EOS M280 RaBuTiR: ~ Ø160x25mm steel plate (4 kg + part)
    - EOS M290: ~250x250x36mm steel plate (17.8 kg + part)
- Powder Bottles (**) – 120kg (full) to and from
  - Conveyor Module
  - Sieving Module
- Powder bottle (**) – 120kg (full)
  - Hold above Sieving Module
  - In front of SLM Machine

(**) – Applicable for a not closed powder handling system.

3.6.2 Maneuverable in Confined Space

It should be easy to perform all operations without trouble
3.7 Storage

There shall be room for storage of

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
<th>In AM Container</th>
<th>May be in Separate Container</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burners (repaired and damaged)</td>
<td>~5</td>
<td>Y</td>
<td>The rest of the set</td>
</tr>
<tr>
<td>Metal Powder</td>
<td>~100 kg</td>
<td>Y</td>
<td>Supply</td>
</tr>
<tr>
<td>Filters (Filter Unit)</td>
<td>1</td>
<td>Y</td>
<td>O</td>
</tr>
<tr>
<td>Filter (Sieving Module)</td>
<td>1</td>
<td>Y</td>
<td>O</td>
</tr>
<tr>
<td>Filling Module</td>
<td>1</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Personal Protective Equipment</td>
<td>See 3.7.4</td>
<td>Y</td>
<td>Supply</td>
</tr>
<tr>
<td>Chemicals</td>
<td>See 3.7.5</td>
<td>Y</td>
<td>O</td>
</tr>
<tr>
<td>Consumables</td>
<td>See 3.7.3</td>
<td>Y</td>
<td>Supply</td>
</tr>
<tr>
<td>Hand Tools</td>
<td>See 3.7.7</td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

Y denotes item is to be stored in AM container. O denotes optional

3.7.1 Burners

Burners primarily need to be stored in an indoor environment with a low level of particles. Before the burners can be repaired in the AM container they must have been acclimatized to be at the same temperature and humidity as the climate in the AM container. This is important to ensure a good repair process.

3.7.2 Filters

Filters for the Sieving Module and the Filter Unit.

3.7.2.1 Filter Unit

A spare set of filters must be available in the AM container, or in a container close by. Used filters are to be sprayed with water, encapsulated and sent to the waste management. Used filters are sensitive to static electricity, sparks, open flames and high temperatures.

3.7.2.2 Sieving Module

There is to be a spare filter for the sieving module stored in the AM container.

3.7.3 Consumables

Consumables such as cleaning tissues, disposable gloves etc. needs to be placed in an easy to reach place in the AM container, to be used by the operator. Extra supply can be stored in a separate container.
3.7.4 Personal Protective Equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Stored in Container</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coat</td>
<td>Regular Storage: X</td>
</tr>
<tr>
<td>Overall</td>
<td>Powder Free Storage: X</td>
</tr>
<tr>
<td>Fresh Air Helmet</td>
<td>Other: X</td>
</tr>
<tr>
<td>Filter Mask</td>
<td></td>
</tr>
<tr>
<td>Vinyl Gloves</td>
<td></td>
</tr>
<tr>
<td>Shoe Protection</td>
<td></td>
</tr>
<tr>
<td>Welding Gloves</td>
<td></td>
</tr>
</tbody>
</table>

(*) – Stored close to filter unit, easy to collect in case of fire when changing filters

3.7.5 Hazardous Goods

99% alcohol (*may be regulated by local regulations*) , T-Red (spirits), powder

3.7.5.1 Powder

The metal powder is classified as a chemical and it is to be stored in the plastic cans it is delivered in and in a chemical grade locker.

Reference: Installation Manual, EOSINT M280 Custom, Siemens RaBuTiR

<table>
<thead>
<tr>
<th>Storage in Original Container</th>
<th>15-25 °C, max 40% rel. humidity</th>
</tr>
</thead>
</table>

3.7.6 Filling Module

See 3.2.3

3.7.7 Hand Tools

There shall be a tool stand or storage for the hand tools needed in the AM container. The main hand tools that are necessary for the SLM process are

- Allen keys
- Screw drivers
4 Requirement Specification – Operations

Requirements connected to operations which has not been mentioned under other topics.

4.1 Cleaning

It shall be easy to clean all surfaces, including the floor, since there may be powder collecting. A way of cleaning the floor is to let a robotic vacuum cleaner run when it would not disturb the operator. This robotic cleaner would though need to be modified to comply with standards regarding removal of powder particles.

4.2 Maintenance

It must be possible to perform maintenance when machinery and equipment is installed in the container, with minimal disruptions.

4.2.1 Maintenance

It must be possible for service technicians to reach all equipment, including the back of the SLM machine. During service of the equipment in the AM container space is needed for the service equipment. It is also of interest to have a table or work space.

4.2.2 Maintenance Intervals

It is important to establish maintenance intervals and to follow the already defined intervals to ensure a qualitative process.
H Concept Generation
Conceptual Design of AM Container for “3D-Printer Cloud” Close to Customer Site
Vincent Sidenvall – LiU – Siemens

Concept Generation
Documentation of concept generation and weighing of concepts. The concept generation process was focused on finding plausible solutions for the most obvious subjects. The evaluation process may be uncomplete, since the purpose is a conceptual design.

Lifting Tool
 Functions
0. Hold burner when attaching/detaching fixture
1. Lifting burner without fixture in/out of container
2. Lifting burner with fixture in/out of SLM machine and shake-blower
3. Lift powder bottles
   a. To/from conveying module
   b. To/from sieving module
   c. Hold powder bottle when
      i. Sieving (above sieve)
      ii. Refilling SLM machine (above/in front of SLM machine)
4. Lift Building plate in/out of SLM machine (with attached part)

Comments
0. - Depending on work procedure and how the burner stand is designed. Preferable if burner is “fixed” in stand when mounting fixture.
3. - Excluded if a closed loop powder system is used. Closed loop system desired for EHS purposes. (Choose to use a closed loop system)
4. – When performing other builds than RaBuTiR, such as quality verification.

Concept ideas
• Electrical lifting truck – small hand maneuvered truck, used in current workshop
  - Hard to maneuver in tight space
  - Needs much floor space during operation and storage
• Overhead crane on rails – extension out of container
  - Decreases indoor height
  + Space efficient
  + Extends out of container to get/deliver parts
  + Easy to maneuver in confined space
• Robot arm – fixed (on floor/wall/roof) or movable (on rail, wheels etc.). For a part of process such as powder handling.
  - Takes more work to implement
  - Not as flexible as an operator
  + Desired for automation of process in future
  + Reduced contact with powder for operator
  → To complex at the moment, but desired in future
Physical Design of Container
Fastening of equipment/machines to container

<table>
<thead>
<tr>
<th>Fixed (but unpractically movable)</th>
<th>Movable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolted to floor</td>
<td>Rails</td>
</tr>
<tr>
<td>Hung from wall</td>
<td>Wheels</td>
</tr>
<tr>
<td></td>
<td>Lift by crane</td>
</tr>
</tbody>
</table>

Important:
- Rigid attachment
- Possible to clean floor under machines
- Damps vibrations
- Allows maintenance of equipment (to reach maintenance points)

Rails:
+ Easy operation
+ Forklift does not have to drive into the container when installing machinery
+ Stiff support when not moving the equipment
- “Feet” on ground (makes it harder to clean the floor)
- Risk of powder collecting on/around rails
- Risk of machines moving during operation

Wheels:
+ Freely movable
+ Easy operation (when moving)
- Not rigidly attached
- Feet on ground
- Can move in undesired directions

Lifting by crane:
- Needs heavy duty crane
- Not easy to operate (and dangerous to operate in confined space)
- Feet on floor

Bolt to floor:
+ Steady/rigid fastening
- Not movable (gives a need for service doors to access back of machines for maintenance/service)
- Feet on ground

Hung from wall:
+ No feet on ground
- Strong construction needed to hold heavy machinery
- Risk that the construction amplifies vibrations (due to not complete stiffness)

→ Choose rails with locking mechanism/bolt to attach to floor
Rails + locking mechanism to attach to equipment to floor

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Equipment slides in from</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can move machines forward for maintenance</td>
<td>+</td>
</tr>
<tr>
<td>Can move 1 piece of equipment (without the others)</td>
<td>+</td>
</tr>
<tr>
<td>Easy to clean in container (fewer obstacles on the floor)</td>
<td>-</td>
</tr>
</tbody>
</table>

Concept idea: Place machine/equipment on prebuilt “rail carts” with a fastening mechanism. Unlock the fastening mechanism to move the container, then lock it again when it is back in place.
Conceptual Design of AM Container for “3D-Printer Cloud” Close to Customer Site
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Powder Handling

<table>
<thead>
<tr>
<th></th>
<th>Original Setup</th>
<th>Enclosed Powder System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing product</td>
<td>+</td>
<td>- (in development)</td>
</tr>
<tr>
<td>(movable)*</td>
<td>(+)</td>
<td>(-)</td>
</tr>
<tr>
<td>Reduced exposure to powder</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Takes less floor space (combines machine)</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Beneficial from automation perspective</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Can connect directly to the shake-blower</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

*not necessary on a container due to the tight space (movable=currently has wheels)

➔ An enclosed powder system is beneficial. If possible implement
Storage

<table>
<thead>
<tr>
<th></th>
<th>Hang on wall</th>
<th>On floor</th>
<th>In locker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor space Efficient</td>
<td>+</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>In the way of operator</td>
<td>+</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Contact with air (*)</td>
<td>++</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

(*) – beneficial from an acclimatization perspective

➔ Hang the burners on the wall. Simple possible solution is a hanger with similar design as the carts that are used in the conventional workshop.

**Powder + T-Red + 99% Alcohol**
- Store in containers graded for the content, in a locker graded for chemicals.
- Do not store by the entrance of the container.
- Make sure there is sufficient ventilation to remove any fumes
- Powder shall be contained within the AM container

**Filters and consumables**
- Store in locker
- Consumables shall be close at hand

**Powder free storage (certain protective equipment)**
- Locker
- Close to entrance

**Personal protective equipment (other)**
- Close to entrance so that operator can grab them before entering the powder contaminated zone
- Stored in locker or at hanger
Main entrance (door)

Important:
- Tight seal (climate etc.)
- Allow to enter: operator, materials (burners, materials, consumables etc.)

<table>
<thead>
<tr>
<th></th>
<th>Hinged</th>
<th>Sliding sideways</th>
<th>Roll up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single</td>
<td>Double</td>
<td></td>
</tr>
<tr>
<td>Tight seal</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Space efficient</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Ease of opening</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Ease of making</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>automated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Air suction when</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>opening</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

➔ Use sliding doors that slides sideways.

Implement in front and back of container (main entrance and secondary entrance/emergency exit).
Use a modular approach to allow maximum multi purpose / wide user range.

Installation ”entrance”

(Entrance used when installing or changing the equipment of the container. Rarely used.)

<table>
<thead>
<tr>
<th></th>
<th>Removable Wall</th>
<th>Sliding Door</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Efficient</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Climate sealing</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Rigidity/structural</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>support to container</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Whole Side (1 piece)</th>
<th>Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Ease of use</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

➔ Use a sectioned removable wall as installation “entrance”. This is rarely opened and it can be made as a sturdy and well sealed design.
Walls
Modular wall setup desired for all four walls, to maximize the flexibility of the container and provide many opportunities of use.

Front and back end:
- Removable wall with sliding doors. (bolted around edge)
- Air lock section (both ends of container)
  - Main entrance: storage of personal protective equipment
  - Secondary entrance: office space

Side walls:
- Multiple sections
  - Possibility to have windows/doors etc. at suitable places (just change single wall section)
- Must support rigidity of container (when transported and stacked)
- Connection: bolted and possibly hinged
- Possibility to open wall to enable connection of multiple containers
  - Bolted connection
  - Connector including gasket (might need an “extension” to cover gap between containers)
- One glass side (+ transport cover) – good for work environment
Media
Argon, pressurized air, electricity, data

Important:
• Easy to connection when installing the container in Vertical Workshop rack (or other)
• Weather protected during operation and transport
• Run through container without obstructing machines or operator

Concept idea:
Connect media, form outside, at a recessed cabinet. The cabinet can be closed during transport with a cover plate. The cabinet itself forms a tight seal around the media lines. Media runs through the container by the ceiling. Since the ceiling is permanent (in comparison with the walls) it can give continuous support. The risk of obstructing anything is also smaller.

Windows
Mainly on wall opposite of machines.

Ventilation
The ventilation system is to be configured so that
• It keeps powder on the floor (do not stir it up)
• Enters at a high position and exits low, to “trap” lose powder particles
• The air flow is not directed directly on the SLM machine (causing a cold/hot spot)

Work Bench
• Provides an ergonomic work station (height adjustable)
• Has a powder collection functionality (when dealing with parts that may contain metal powder)
• Has a robust construction, (workshop grade)

Lighting
There shall be extra light focused on work stations, such as:
• SLM process chamber
• Work bench
• Burners fixture mounting station

Desktop Station
Useful when there is not a separate dedicated office (/office container).
➔ Put desktop station in the second airlock so that it is in a powder free environment.
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MES (Manufacturing Execution System) access

<table>
<thead>
<tr>
<th></th>
<th>Touchscreen on wall</th>
<th>SLM machine computer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Efficient</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>United System</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Easy to develop</td>
<td>+</td>
<td>0 (*)</td>
</tr>
</tbody>
</table>

(*) – Easy to develop, if the machine supplier allows access to the system

→ Assume MES access can be achieved through the AM machine computer
(the machine itself shall be connected for other purposes as well. Ex. for reading sensor data about the process)

Tools
Tools shall be available close to the place where they will be used:
- By SLM machine
- By work bench
- Where the burner fixtures are mounted
H.1 Container Concept