MASTER

Flamenco tower in ice
an analyses of process optimizations

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An analyses of process optimizations

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Colophon

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Abstract

The Flamenco tower in ice is the next application of fiber reinforced ice in a series of ice projects. After the 'Pykrete dome' (2014) the 'Sagrada in ice' (2015) and the 'Bridge in ice' (2016) the next goal is to attempt to build the highest ice dome with a height of 30 meters in Harbin, China. The tower is constructed of Cellcrete, an ice composite that is reinforced with Cellulose fibers. The purpose of this study is to realize the Flamenco tower in Ice and optimize the production process. Based on previous projects an optimized construction and organization process is proposed. During an experimental field study the improvements in the processes have been implemented and tested.

To successfully realize the tower, two tracks are exposed:

Process optimization

The main recommendations of previous project were the foundation of the improvements of the production process. These recommendations were:

- Speed up the production time;
- A more reliable production process which is less dependent of external factors;
- Automate the production line where possible to exclude human errors;
- Mobilization of the production line to promote (re-)deployment.

To achieve these recommendations two main improvement were made to the production process of previous projects:

- Optimizing and automating of the Cellcrete production process
- Mobilizing one central construction station to operate and coordinate the whole construction process;

These main improvements were combined in the engineering of a mobile Cellcrete factory that coordinates the total construction process.

Organization

The initial design and the structural calculations formed the base of the activities of the construction process. The calculation on the inflatable concluded that total inflation at once was not possible due to deformations. To solve this, the building plan has been modified to a sequence with partitial inflation. This consisted of constructing the legs of the tower first, so the base could function as a stable foundation for the rest of the tower.

The design and calculations resulted in an optimization of the planning and budget.

All described optimizations were tested during the construction of the Flamenco tower in Ice in Harbin in the winter of December 2017. Chapter "Construction management" is an overview of the observations and results of this field experiment.

The experiment shows that the optimizations of the production and construction process led the following results:

- The production time is decreased with 50%;
- Less errors occurs in the production line;
- The production line needs a buffer to function properly;
- The overall functioning of the mobile factory is proved which lead to the conclusion that also the production process has been improved;
- The overall construction process has been improved by
    - The creation of one central standardized station to coordinate the whole process;
    - The monitoring of progress have been improved by the implementation of a monitoring tool.

Based on the experiment, the following recommendations are identified for following research:

- Further engineering of the mobile factory, to develop a full automated process;
- Planning strategies must be including cultural differences and local standards to prevent major delays;
- Further development of the monitoring tool, to generate a more reliable understanding of the progress.

Thus, the production process of ice sculptures is optimized by standardizing the production and construction process in the form of a mobile factory which has resulted in the realization of the Flamenco tower in Ice.

Preface

The presented report contains my master thesis on the optimization of the Flamenco tower in ice project. The project is the next in a series of ice projects.

With this thesis I want to prove that I'm ready to end my career as professional student, and start my career in the building practice.

I had the unique opportunity to be part of all the previous ice project. I always said that I would not be involved as a graduation student, but luckily my weak spine convinced me otherwise. Throughout the years I developed a bond with the research, the people and the material. Or, as the Cursor quoted on Jan the 18, 2017: "You can call me a real ice veteran'.

The projects gave me many opportunities to development myself. Not only on educational level, but also on a social and international scale. Maybe it is because of these opportunities that Heijmans NV. Shared its interest in me. Therefor I'm happy to state that I will start my career on their professional playground.

I want to thank all students and tutors who were connected to the project. Especially I want to thank Arno Pronk, who accompanied me in the many ice adventures we have experienced. His will to achieve difficult goals, and his executive approach inspired me in real life. Not only because it brought us in some interesting situations, but also because I slightly recognized myself in it.

A nomination to Yiling Zhu cannot be missed in this word of thanks. I want to thank her for the many challenges we faced together as a team. This project gave me a friend.

I also want to thank my friends and family. They always supported me in my, sometimes silly decisions. Especially I want to thank Madelon Louwers for always opening her door with a cup of coffee in times of need. And of course her good advice throughout my whole study.

My parents and sister also deserve a special thanks. They always believed in me, no matter what. At last I want to thank Leanne de Jager for the amazing advise, dedication and care. Providing a shoulder when even I did not knew I needed one.

I'm really happy to know the people I know. And I'm gratefully to realize that.

Closing this phase in life, I looking forward to the next. Let me build, fail, learn and build more… I'm ready!

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1. Introduction

This introduction explains the nature of this research by placing it in a wider frame. This new project is placed in a series of previous ice projects. The introduction also describes the path of the performed research.

1.1 Motivation

Since I was a child I have been fascinated by the building industry, and especially the construction phase. Therefor I have never doubted my study choice and I have started in 2011 at the University of Technology Eindhoven. During my first years of this study my interest in this engineering field have been affirmed by practice.

I have noticed that my interest and qualities could be well expressed in the construction phase of the building industry. In 2014 I have had the opportunity to take place in the research group of Structural ice. The first project consisted of building an Ice Dome in Finland. This project was fully executed by students which made it exclusive and gave me the opportunity to discover my ambition in practice.

From that point on I have been intensively involved within the further ice projects. As the research continued, I have noticed that my different positions on the building site presented me a clear insight into the building practice. All the different aspects and facets of the construction phase have motivated my intension to create a wide knowledge in different disciplines. I believe that this is a crucial factor when applying for a future career as project leader.

After my contribution in the different projects as a bachelor and master student, I continued my involvement in the ice projects in the following project as a graduation student. It is a chance to implement my gained knowledge and experience in one final big scale project. Combined with the international approach, the multidisciplinary base, the aspects of process-management and the facets of project management, a solid foundation is created for the start of my career.

Previous involvement in projects (related to Construction technology and Building technology):

- Pykrete Project – 2014
- Sagrada Familia in Ice – 2015
- Bridge in ice – 2016
- Pilot Project Flamenco tower- 2017
- Research project; 3D-printing of Ice – 2017

1.2 Previous research

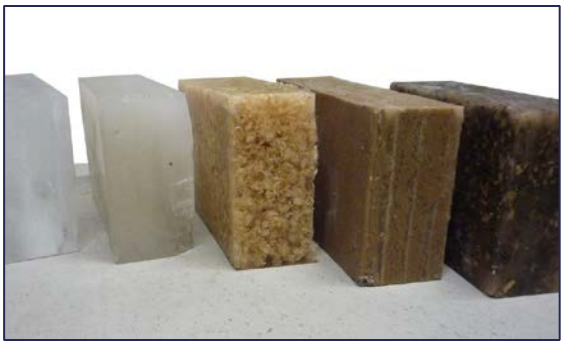


Figure 2; Different samples of reinforce ice (Janssen, et al., 2013)

Figure 3; 'Pykrete dome' during construction; source: Bart van Overbeeke

Figure 4; 'Pykrete dome' inside after completion; source: Bart van Overbeeke

Figure 5; 'Sagrada in ice' during construction; source: (Kern, et al., 2015)

As precursor of this research, several other researches have been performed on the material and building methods.

Material research – 2013 (Janssen, et al., 2013)

Earlier material research has been performed with the addition of different fibers to ice (Janssen, et al., 2013). The material has been tested on compressive strength, tensile strength and ductility (figure 2). The main outcome of this research was founded in the applicable capabilities of a wood fiber reinforced ice type called: 'Pykrete'.

Pykrete dome - 2014 (Hijl, et al., 2014)

The construction of the 'Pykrete dome' has been the first structure of Pykrete (figure 3 and 4). The 'Pykrete dome' consisted of water and wood fibers. The design was based on a geodic dome and was designed with a span of 30 meters. This stated to be the world record of biggest ice dome (in span and height). With a height of 10 meters the dome formed a big hall, capable for all kinds of activities. The dome was build using the same building method as Kokawa did, holding the previous record of 25 meters (Kokawa, 2003).

Sagrada in ice - 2015 (Kern, et al., 2015)

The 'Sagrada in ice' was an attempt to build the highest ice dome in the world. The design was based on a simplified model of the Sagrada del Familia, originally designed by Gaudi. The simplified model consisted of one main tower (30 meter), two medium towers (24 meter), two small towers (19 meter) (figure 5) and a midship (figure 6). The previous record of highest ice dome was set by the previous 'Pykrete dome project' with a height of 10 meters. The four smaller towers, the midship and the base of the main tower were constructed, due to wind problems the rest of the main tower was not constructed. However, the' Sagrada in ice' set a new record of highest ice dome on 24 meters. This project was also realized using Pykrete with wood fibers. First tests of the improved Cellcrete, reinforced ice with a cellulose fiber, were performed during this project.

Figure 6; Midship of completed 'Sagrada in ice'; source (Kern, et al., 2015)

Figure 7; Impression of the 'Bridge in ice'; source: (Koekkoek, et al., 2016)

Figure 8; Collapsed bridge during construction; source: (Koekkoek, et al., 2016)

Bridge in ice -2016 (Koekkoek, et al., 2016)

The last performed project consisted of a bridge made of Cellcrete (figure 7). The bridge was designed after the original design of Leonardo Davinci. He designed a bridge over the Bosporus river in Constantinople. The 'Bridge in Ice' was designed to overcome world's largest ice span, which was set on 30 meters by the 'Pykrete dome' project. The bridge was designed with a span of 40 meters, a height of 10 meters, and a total length of 60 meters.

Due to weather problems, the bridge was not finished (figure 8). A rise in temperature caused the middle part of bridge to melt and eventually collapse. The time schedule and the weather conditions did not make it possible to solve this fatal error.

The bridge in ice was the first time that a cellulose fiber was used in the construction of an ice structure. Material research concluded that Cellcrete is preferred over Pykrete in terms of ice shell constructions.

1.3 Problem area

The overall problem areas are subdivided into three main categories. These categories also form the base of the research model as stated in section 'Research model'. The three main categories are:

- Building and construction process
- Building material
- Structural design

Building and construction process

The building process focusses on the project- and process management during the large scale project. During the previous projects, a specific building process has been developed for building structures in fiber reinforced ice. This building process (further described in 'Literature study') is further improved due to field testing and experience.

All previous projects have had a major error, or partial exclusion of the initial design, after completion. Partially this was caused by shortcomings on management level (production and construction). Therefore, it is important to pre-plan as much as uncertainties upfront, to ensure a successful completion of a new project. The main focus of this research will be improving the production- and the construction process.

Climatic issues form another important influential aspect of the formerly encountered problems. It is stated that improvement of the climatic conditions can only be established by departing to a more stable cold climate (Moonen, 2017). Nevertheless, the extreme cold temperature will heavily influence the building process, and should therefor considered as an essential factor.

Previous projects have proven that organizational factors are essential for a successful completion (Hijl, et al., 2014). The participating team must me of reasonable size and composed in a clear organization.

Building material

Despite several years of research in Cellcrete, the material has not been successfully implemented in a big scale project. The first intended implementation (in the 'Bridge in Ice' project) did not succeed. Therefor this project is an important first field test of the successful application of Cellcrete. However, this research will only expose the processability of Cellcrete and will not go in to further material research.

Structural design

The ambition to realize the world highest ice dome has been chased and achieved earlier by the 'Sagrada in Ice' project (Kern, et al., 2015). Despite setting the new record on 24 meters, the initially plan to build a tower of 30 meters have not been realized.

For this research the ambition remains to build a tower with a height of 30 meters. Therefore, errors and experiences from previous high ice shell structures will be taken into account.

1.4 Goals

Because fiber reinforced ice is a building material with many possibilities, further research in application and processing is preferred. Researching the boundaries of the material can result in a simplification of the building process. This will make it more likely for other parties to use Cellcrete as a building method.

The main goal of the research is to complete the project successfully, and answer the stated research questions.

Minor to the main goal, the following subjects will also be pointed out:

- Researching potential; Research of the capabilities and limitations of the material including improvements to the building method.

- Optimizing processes; Research in the optimization and simplification of the processability of Cellcrete

- Promote use of material; with a big scale project like the 'Flamenco tower in ice', a lot of media attention is generated. This could lead to a broader knowledge of the existence and capabilities of the material. Hopefully this will lead to more applications of the material itself.

- International corporation; these internationally oriented projects forms the base of an international research platform. Good international relations can lead to more efficient research and findings.

1.5 Research questions

The research questions below are focused on the approach in construction technology.

Main question

How to realize the Flamenco tower in Ice and optimize the production process, within stated boundaries?

Research question 1: Construction

How to optimize the current construction methods and processes to realize fiber reinforced ice structures?

- *Sub question 1.1: How does the design influence the building process?*
- *Sub question 1.2: How can the production process be optimized?*
- *Sub question 1.3: How can the construction process be optimized?*

Research question 2: Organization

How to manage and control organizational factors before and during the construction process?

- *Sub question 2.1: How to optimize and manage planning and building speed before and during construction?*
- *Sub question 2.2: How to overview, manage and reduce costs before and during construction?*

1.6 Theoretical framework

The research has been based on two major approaches. The first approach can be found in the design aspect. This aspect includes flexible molding and lightweight structures, to the research area of reinforce ice building, and has been used within the previous projects.

The other approach is orientated on the organizational aspect. This aspect mainly focusses on project management, and the optimization of processes.

The ‘Bridge in Ice’ project was the first project which has combined these approaches focusing on (structural) design, material and construction optimization. In the new project, this mindset will be continued. Figure 9 is a schematic overview of the approaches.

1.7 Boundaries and conditions

For this research, the boundaries and conditions have been stated and summarized below:

- Design:
    - The initial design of the ‘Flamenco tower in Ice’ is designed by Arno Pronk. This design forms the basis for further form finding and engineering.
- Construction:
    - The construction will be based on formal projects using a temporarily inflatable mold. Material will be applied using the same layered principle.
- Materialization:
    - This project will be executed with Cellcrete; a fiber reinforced ice composite. Fiber type is specified to cellulose in a 2% mass ratio.
- Structural components:
    - The design will be optimized using form finding principles and calculated during and after the construction process. H.I.T. and TU/e Master students SD will focus on these examinations.
    - The inflatable will be designed and structurally analyzed to ensure a reliable support during construction. H.I.T. and TU/e Master students SD will focus on these examinations.

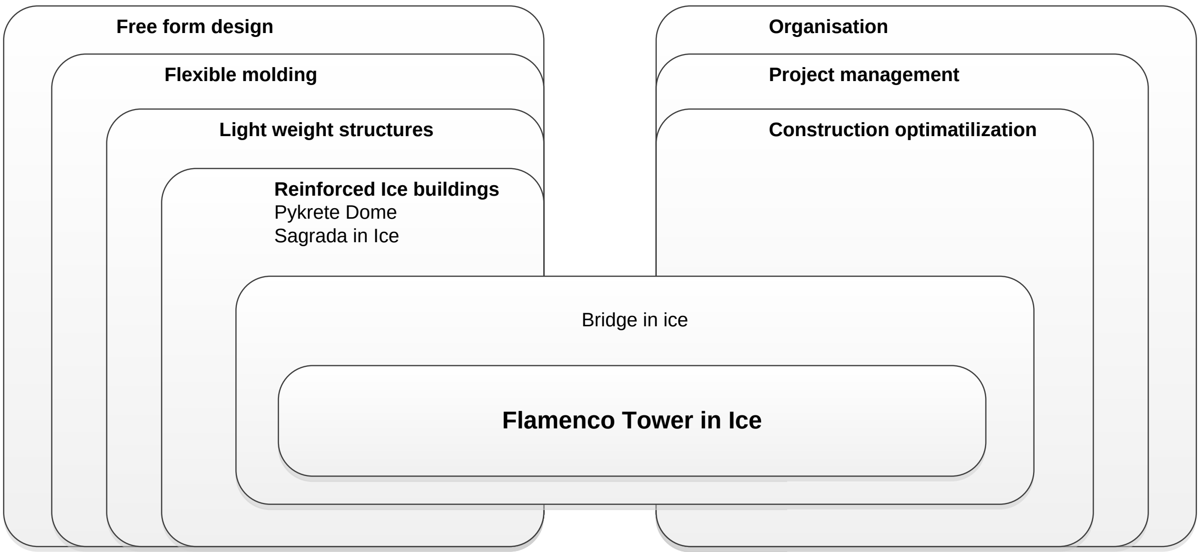


Figure 9; Approach overview

1.8 Research methods and model

The research can be divided in the following approaches:

- Literature research; Analysis of formal projects an publications
- Model research; Modeling for structural analysis, as well as mapping and optimizing internal processes.
- Experimental research; All elements will be combined on site, referring to one big scale field test.

The main research can be divided in three problem areas:

- Building and construction process;
- Building material;
- Structural design.

The main focus will be on the building and construction process. There will be no further research performed on building material during this research. Therefore, this factor is excluded. The diagram (figure 10) shows the deviation of the different research approaches, in relation to the different problem areas.

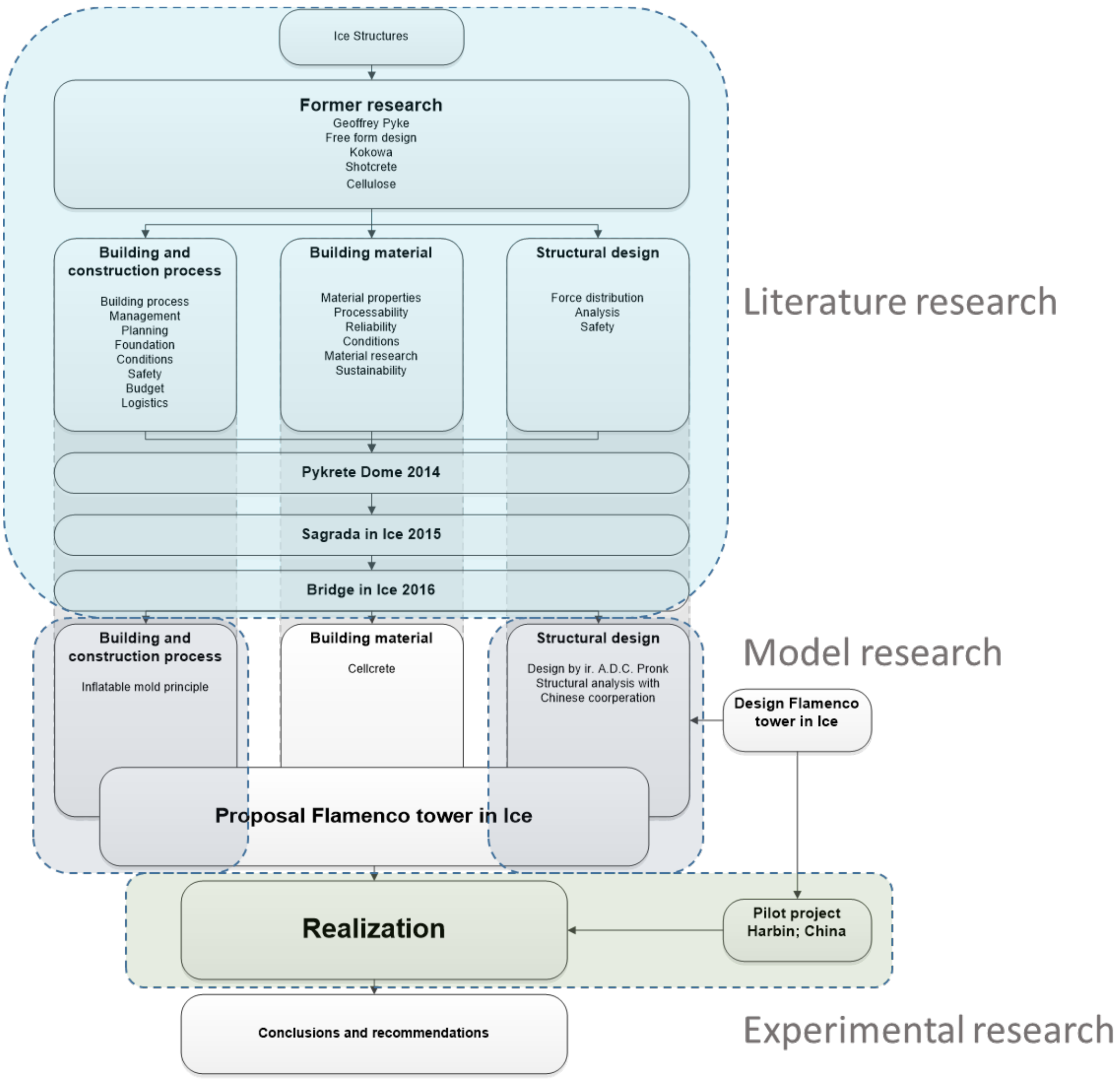


Figure 10; Overview of different research approaches and problem areas

1.9 Structure of thesis

The thesis has been structured as shows in figure 11. Two main tracks can be observed. The first track is focused on the optimization of the construction process. Recommendation of previous projects led to the proposal of optimizations of the construction process. These optimizations have been tested during the realization of the Flamenco tower in Ice. This test resulted in observations and conclusions.

The second track is orientated on the organization. The design determined a certain set of activities which were analyzed. A proposal of the optimization of organizational factors has been tested during the realization of the Flamenco tower in Ice. This test resulted in observations and conclusions.

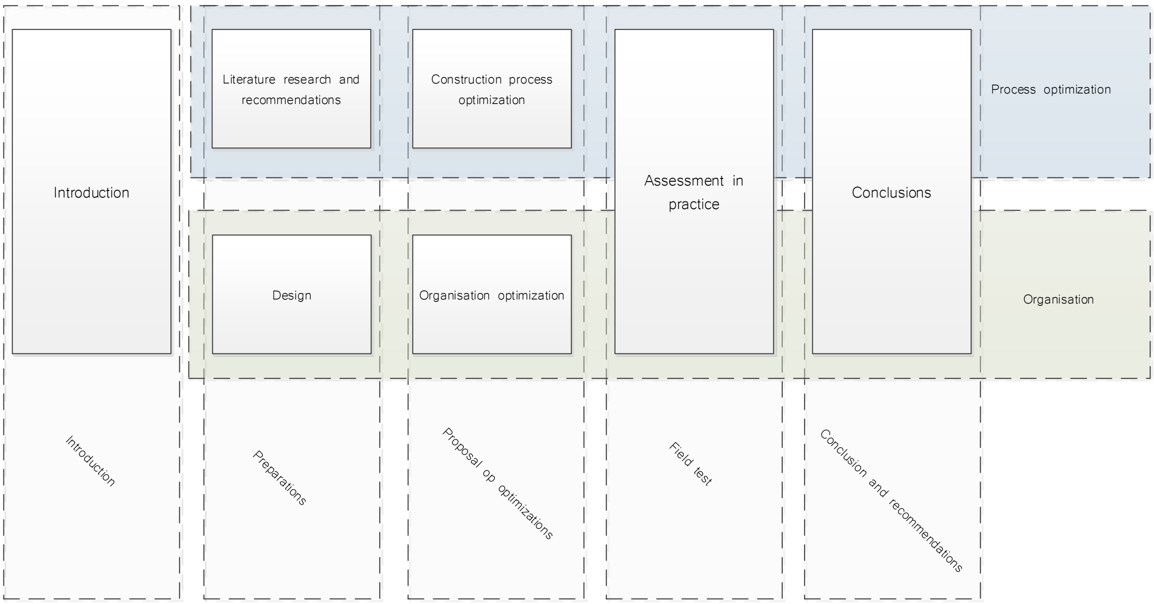


Figure 11; Structure of thesis

1.10 Planning of thesis

The planning of the thesis will be divided in three phases:

Phase 1:

Formation of the project and pre-planning have been done a year before the construction, in the winter (Semester B) of academic year 2016-2017.

Phase 2:

Further preparations and calculations have been performed in semester A of academic year 2017-2018. The travel and construction took place from 12 December 2017 till 3 January 2018. The construction planning will describe this execution phase.

Phase 3:

Phase 3 existed of processing of the conducted construction information and the completion of the final thesis. This was conducted in Semester B academic year 2017-2018.

Figure 12 is shows the time table as result.

Id	Task	Begin date	End date
1	Start pre-project (M3-project)	1-9-2016	1-2-2017
2	Pilot project in Harbin, China	1-12-2016	30-12-2016
3	Phase 1	1-2-2017	1-9-2017
4	Phase 2	1-9-2017	3-1-2018
5	Construction in Harbin, China	11-12-2017	3-1-2018
6	Phase 3	3-1-2018	7-9-2018
7	Begin colloquium	3-5-2018	3-5-2018
8	Midterm colloquium	5-7-2018	5-7-2018
9	Deadline final thesis	1-8-2018	1-8-2018
10	Green light	31-8-2018	31-8-2018
11	Final colloquium	7-9-2018	7-9-2018

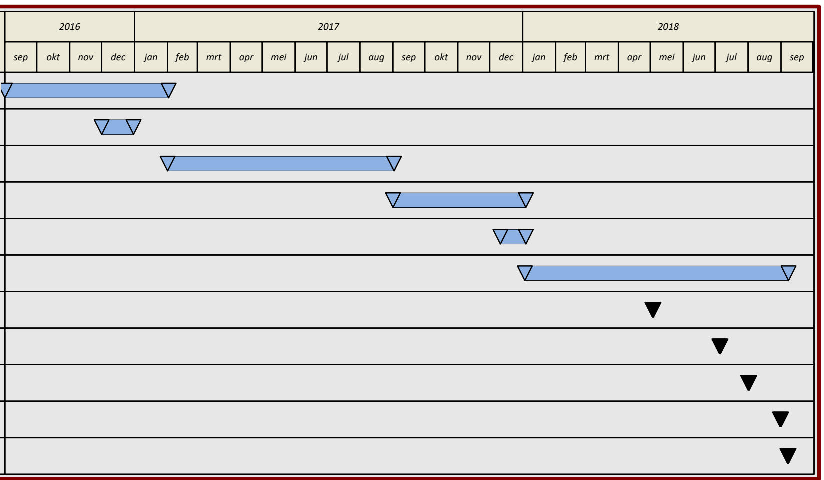


Figure 12; Planning of master thesis

2. Literature research

This chapter will provide theoretical background information as basis for this research. Since the previous ice projects cover the same background knowledge, a selection of the most important findings will be given next to the relevant publications and articles.

Figure 13; Eskimos building an igloo (Source: https://www.loc.gov/pictures/resource/cph.3c35985/)

Figure 14; Traditional Kamakura (Source: https://matcha-jp.com/en/3856

Figure 15; Impression of ice dome by day; source: (Kokawa, 2003)

Figure 16; Impression of ice dome by night; source: (Kokawa, 2003)

2.1 Ice structures

The first known application of ice as a building material, can be found in the structures of igloo's (Pronk, et al., 2016). The construction consisted of building with snow carved blocks stacked in a catenoid shape (figure 13). The spaces between the blocks were filled with more snow. Internally the heat of the human body could raise the temperature to above 0^{0}C resulting in the melt down of the first layer of snow (Koekkoek, et al., 2016). The melted snow froze by the cold surface forming a solid ice layer, optimizing strength and insulation (Pronk, et al., 2016).

A different type of snow structure is the Kamakura, an ancient concept which was based on filling a mold with wet snow, and retrieving the inner part to form a hollow core (Kokawa, et al., 2012). The size of this type of igloo is limited due the relative weak mechanical properties of snow (figure 14).

Tsutomu Kokawa, a Japanese researcher, was the first who researched an ice dome structure in the beginning of 1980 (Kokawa, 1985). He designed and constructed several domes as field tests. His designs were generally based on a geodesic dome, which he used during his attempt to build the Roman Pantheon in ice (Takaya Suzuki, 2010). This geodesic design, and the further field research, led to the execution of the 'Pykrete dome' Project (Hijl, et al., 2014). Figure 15 and 16 shows impressions of Kokawa's ice projects. The continuation of research in ice structures can be found in the formal ice projects as described in paragraph 'Previous research'.

2.2 Reinforced ice

Normal ice has its limitations as building material. Compared with pure concrete, normal ice can relatively withstand more compressive forces, in relation to a low tensile strength (Janssen, et al., 2013). This results in applications where the stapling of blocks is leading. This limits spans and building opportunities. Just like concrete, ice can be reinforced. By the addition of fibers the material properties are changed (Janssen, et al., 2013).

Not only can the added fibers increase the tensile strength, but it also increases the ductility of the material (Hijl, et al., 2014). Relating to a positive influence on the creep behavior of normal ice.

Figure 17; Ice aircraft carrier; source: (Hijl, et al., 2014)

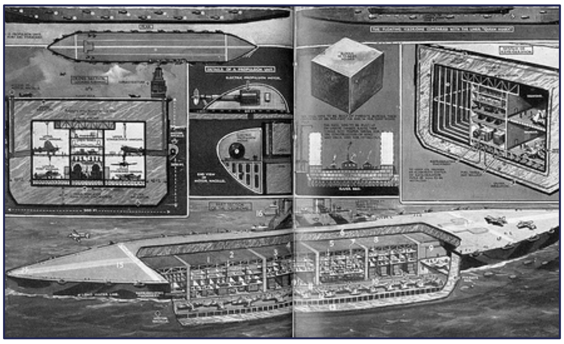


Figure 18; blueprint of ice aircraft carrier; Source: (Hijl, et al., 2014)

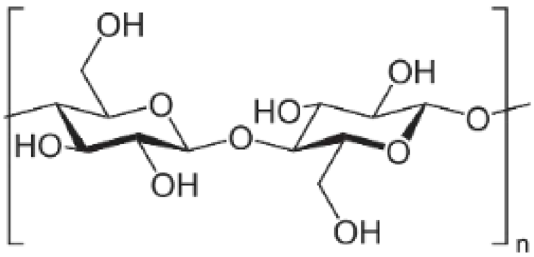


Figure 19; schematic view linguine cellulose molecule (Source: https://en.wikipedia.org/wiki/Cellulose#/media/File:Cellulose_Sessel.svg)

Applications of reinforced ice can already be found in the building of igloos, were moss serves as reinforcement (Hijl, et al., 2014). A First planned big scale application can be found during the second world war (Perutz, 1947), were the first ideas for an aircraft carrier of reinforced ice were planned to be realized (figure 17 and 18). The material had capabilities because of the strengths, relative slow melt rate, easy application and low costs. The project was never fully realized because of the end of the war (Hijl, et al., 2014).

A new research project has started in 2012 at the University of Technology Eindhoven (Janssen, et al., 2013). This research mainly focused on the ratio and type of reinforcement fibers. The research also contained a possible application of the end product.

The addition of the fibers resulted in an increasement of compressive strength (figure 20). The research also pointed out that smaller wood particles resulted in a better performance during the end compression tests. Besides, the increasement of the mass-ratio also had a positive effect on strength.

Not only the compressive strength exhibited this behavior, also the flexural strength of the material increased. The researchers concluded that a Pykrete sample can evolve approximately three times the structural behavior of normal ice (Janssen, et al., 2013). This first implementation of the material was conducted by the 'Pykrete dome' project (Hijl, et al., 2014). Another important material property is the toughness. The typical behavior of Pykrete shows a decrease of crack formations in the structure and allows the material to be flexural. This allows the structure to deform without loss of strength (Kern, et al., 2015). This is related to the more ductile properties of Pykrete. These properties make Pykrete a safe building material to be used in practice (figure 21).
Further research has been performed during the following projects, mainly orientated on processability and alternatives (Kern, et al., 2015) (Koekkoek, et al., 2016). During the 'Bridge in Ice' project the research was oriented to the reinforcement of ice with a cellulose fiber, called: 'Cellcrete'. The results are presented in figure 22.

During the various studies, the method of testing has been optimized. Therefor the properties of the compared Pykrete (10% sawdust ratio) are less positive than given in figure 22. Summarized, it can be concluded that cellulose fibers will result in a stronger end product than wood fibers (Koekkoek, et al., 2016).

Cellcrete does not only has benefits in the strength of the ice, but it does improves the rate of processability and esthetics (Moonen, 2016). Esthetics are improved because of the white fiber color. This results in a better ice appearance then the brown Pykrete. The processability is improved because of the molecular structure of Cellcrete, which unlike wood fibers, is able to form hydrogen bonds with water (Moonen, 2016). These weak bonds are orientated on the OH-groups and the free H2O-molecules. Figure 19 is a schematic view of a linguine cellulose molecule. These bonds result in the fact that it is easier to obtain and preserve a homogeneous distribution in the mass (Moonen, 2016). In practice this means that less mixing and pumping is needed. Also unlike Pykrete, there are no big solid particles present which can obstruct pumps and nozzles.

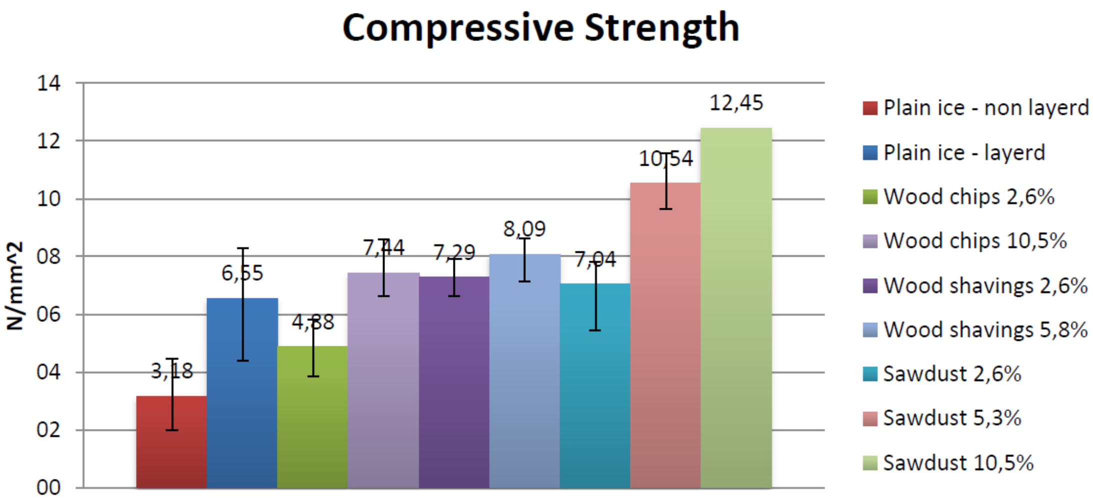


Figure 20; Results of fibers on compressive strength (Source: (Janssen, et al., 2013))

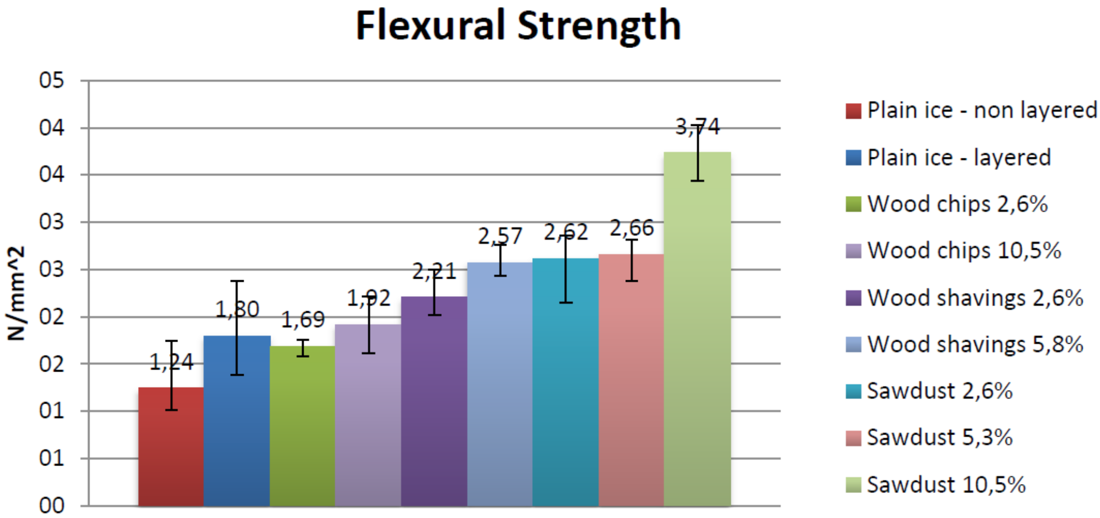


Figure 21; Results of fibers on flexural strength (Source: (Janssen, et al., 2013))

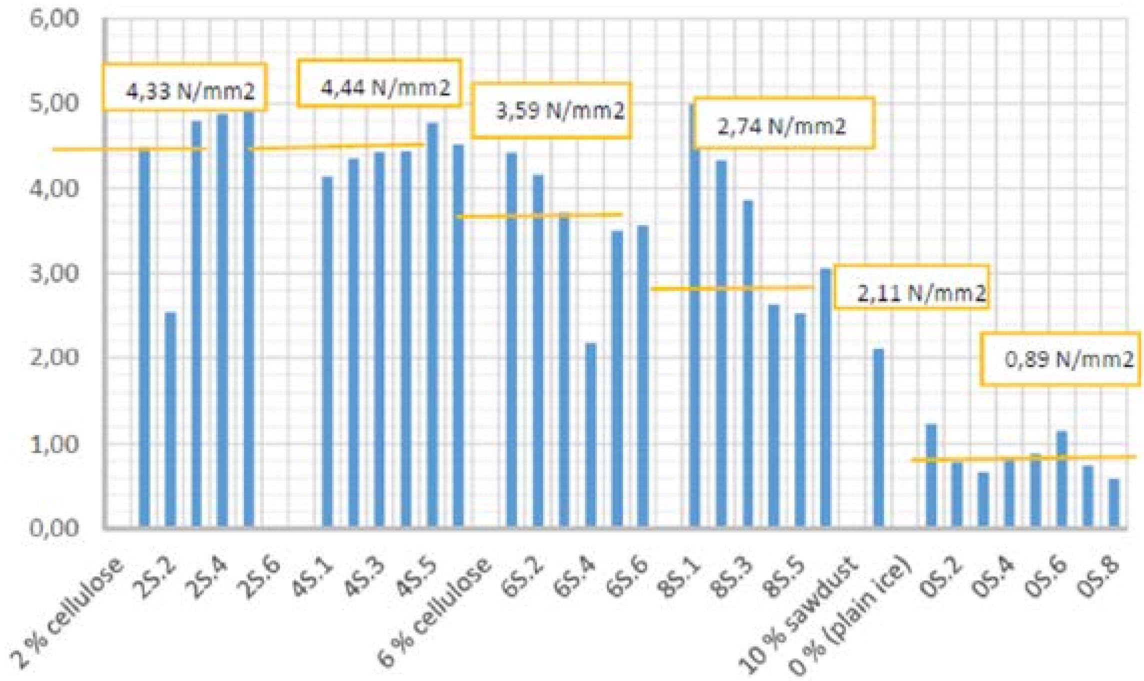


Figure 22; Results of cellulose fibers on strength (Source: (Koekkoek, et al., 2016))

2.3 Building method

The building method of the previous projects has been substantial equal in execution. The original method has been explained by Tsusumin Kokawa (Kokawa, 2003) (Kokawa, 2012). In summary, this method consists of the layered application of ice and snow on a mold. This method is directly applicable when using Pykrete. After the shell is created, the mold is eliminated. A step by step approach of the building method will be described using different projects of Kokawa.

A pre-made inflatable serves as retractable mold. This inflatable is shaped and secured by a rope net. This rope net is fixed to the ground/base (Kokawa, 2012). A section of the full setup is displayed in figure 23.

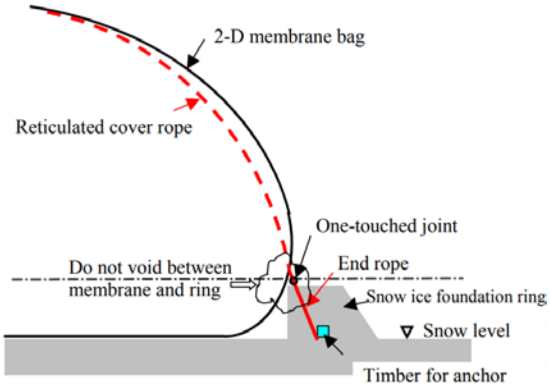


Figure 23; schematic view of building method (Kokawa, 2012)

Figures 24-26; Building an ice ring with the use of a wooden frame work; source: (Kokawa, et al., 2012)

Foundation

By the original method of Kokawa, an ice ring is used as in figure 24 until 26. This ring is constructed by placing a wooden formwork and filling with snow and water. After compression and freezing, an ice ring is formed. This ring acts as radial foundation of all anchor points of the rope net.

Inflatable

After finishing the foundation, the inflatable is positioned in the ring. This is followed by the fixation of the rope net to the foundation. After this connection is established, the inflatable is inflated to a predetermined internal pressure. From this point on the inflatable will serve as a mold for the ice shell, see figure 28 until 30.

Shell construction

The construction of the shell consists of two alternating steps and is explained in figure 27. The first step is the application of snow on the inflatable (figure 31). The second step is the spraying of water (figure 32). The spraying humidifies the snow, which will freeze in a solid ice layer. This layered process continues till the desired shell thickness is achieved.

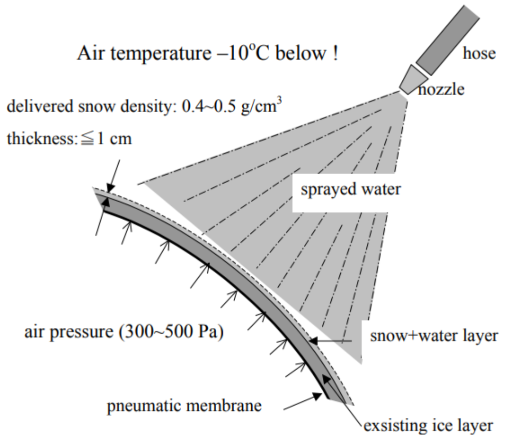


Figure 27; Schematic view of construction of the shell source: (Kokawa, 2012)

Figure 28-30; inflating the inflatable source: (Kokawa, et al., 2012)

Completion

After the shell construction, the inflatable is deflated and removed. The dome is completed after finishing the entrances, and the possible placement of lighting (figure 33 until 35).

Cellulose

The building method of Cellcrete is almost similar to the method of Kokawa. The difference between the two methods is that Cellcrete makes the application of snow superfluous (Moonen, 2016). This simplifies the building process because no additional snow has to be produced and applied.

2.4 Recommendations

In this section the construction and production processes of previous projects will be summarized and analyzed. An overview and comparison of the recommendations will be provided. A clear schematic overview can be found in annex 1.

Pykrete dome (Hijl & Pluijmen, 2014)

The dome was constructed using layers of snow and ice. Only the lower layer was fortified with Pykrete.

Construction

The water was applied using a mobile fire truck from the local fire department. This made it easy to apply water. The refilling of the vehicle's tanks took a significant amount of time, which resulted in a delay of the process.

The snow was produced on a nearby field by a static snow canon. The snow was moved by a shovel and further distributed by an excavator. The distribution of snow on the inflatable occurred sometimes rough, which damaged the developing ice shell.

The application of Pykrete was done by hoses pumping from the production container. A single hose was carried by construction workers to spray the dome. The height of 5/6 meters of Pykrete was easily covered by spraying from the ground.

Figure 31; Application of snow on the inflatable source: (Kokawa, 2012)

Figure 32; Spraying water on the inflatable (Kokawa, 2012)

Production

The Pykrete was produced in an open container in the outdoor climate. The mixing was performed by different submersible pumps which were randomly distributed in the container. The sawdust was manually and mechanically sifted to extract the large particles (avoiding pump obstructions). Eventually one external centrifugal pump was distributing the Pykrete to the inflatable.

The open container was exposed to extreme cold conditions and it was unavoidable that parts of the equipment froze. Thereby, the submergible pumps were randomly distributed which resulted in an inhomogeneous mass. Under water, piles of sawdust were formed which was obstructing the pumps and limiting the movement of the mass. This was stimulated by the ice growth and resulted in an inhomogeneous output.

The pumps were obstructed by the provided sawdust which also contained residues of garbage and large particles. Sieving of the sawdust was performed mechanically. The sawdust was added to the container by estimation, resulting in a variating mass-ratio output.

Recommendations

Recommendations were mainly focused on the application of snow, and a simplification of the construction process. Also the importance of maintaining the power have been mentioned because of an energy shut down, which affected the pressure in the inflatable. Another point covered the dependency of the weather. The existing fluctuations of the temperature affected the planning and the construction process. This must be taken into account by further projects.

Figure 33-35; Removing of the inflatable; source: (Kokawa, et al., 2012)

Sagrada familia in ice (Kern & Verberne, 2015) (Moonen, Uitvoering; Sagrada Familia in Ice, 2015)

The construction of this project was mainly focused on achieving the height of 30 meters. The whole structure was covered in Pykrete.

Construction

The hoses were connected to the boom lifts for the spraying activities of the Pykrete. This resulted in a lot of mobility of the spray nozzles and a simplification of the spraying process.

The snow was produced by a mobile snow cannon and directly applied to the inflatable. This made the distribution of snow unnecessary. It was quite complex to move the snow cannon which resulted in delays and an uneven application of snow on the ice shell.

The size of the project, the different hoses, the boom lifts and the connection of the snow cannon resulted in a lot of hoses and cables on the building site. This often resulted in obstructions and unsafe situations.

Production

The production was comparable with the Pykrete dome project. However, the production was scaled up to twice the output distribution. Two containers were prepared to produce, and distribute. This also meant that the crew was able to operate two different nozzles at the same time.

The submergible pumps were placed strategically in the containers to stimulate a recurring flow, and preventing freezing and accumulation of wood fibers. Despite these measures, the same issues as the year before were faced.

The wood fibers were sieved before transport, and had been packed in batches. This made it possible to simplify the recipe by adding a specific amount of batches to one container. The wood fibers still contained big particles.

Recommendations

The recommendations were mainly focused on the aspect of automation of the construction, as well as the production process. To prevent working in the cold and exclude human error.

Bridge in ice (Koekkoek & Nieuwenhof, 2016) (Moonen, Bridge in Ice- Construction, 2016)

The bridge was the first project to be executed in cellulose fiber reinforced ice. This changed the working method slightly, by excluding the production and application of snow. Reducing the activities to producing, distributing and spraying.

Construction

The process was simplified by excluding the snow layer. The construction was comparable with the previous projects.

Production

During this project, the production line was fully redesigned and improved to optimize the production. The main focus lied on the different production of Cellcrete, and the climate control of the production line. The production of Cellcrete was performed in pre-mix barrels, for soaking and dissolving of the raw cellulose sheets. Afterwards the Cellcrete was distributed to a buffer container to supply the pumps. Multiple external centrifugal pumps (and hoses) have been connected to the buffer container. Throughout the whole process the mass is kept in motion to ensure a homogeneous distribution of fibers.

The whole production line was compacted to make climate control possible. The production line has been placed in a big overlaying tent structure. Heaters were preventing the system and pumps from freezing. This excluded obstructions and delays, creating a more reliable production system.

Overall points of attention and recommendation

- Freezing; freezing of different parts of the production and distribution have resulted in delays, and therefor this needed to be prevented.
- Automation; by automating the construction and production, the risks of errors is minimized. Automation prevents construction workers from working in the cold environment.
- Mobility; the factor of mobility has been important to build up an evenly distributed ice shell. A greater mobility promotes the progress and a fully mobile production line can result in an easy application on different building sites.
- More reliable; the processes need to be more reliable.
- Fasten production time; the dissolvent of the cellulose sheets takes time, this limits the production time.

3.Design

The design has been determined. This resulted in the engineering of a suitable inflatable. The inflatable and the shell have been structurally analyzed. This design forms the base for the further planning of the realization.

3.1 Initial Design

Figure 36; Harbin Ice Festival by day; source: http://www.storiesxp.com/harbin-international-ice-and-snow-festival/

Figure 37; Harbin Ice Festival by night source: https://www.gadventures.com/trips/harbin-ice-festival/ACHH/

Figure 38; Dancer with flamenco dress; source: (Qingpeng LI, 2018)

Location

The construction of previous projects suffered from bad and unstable weather conditions. All previous projects were constructed in Juuka, Finland. After analysis of the weather circumstances, it can be stated that the wind in this region is unpredictable (Koekkoek & Nieuwenhof, 2016) as well as the fluctuating temperate. This obstructed further projects from being constructed.

A new location is found in Harbin, China. Harbin is a city with a stable land climate in the north east of China. It gained recognition due to its yearly Ice Festival (figure 36 and 37). This festival consists of a full ice city which is being build using ice blocks.

The capabilities of these ice structures are limited due to the construction which depends on the stapling of ice blocks. Every ice structure also needs a secondary construction to support the blocks, and prevent deformations.

The Harbin Institute of Technology (H.I.T) designed different ice structures in the past. Because of the previous described limitations, the interest in a new building method rose. In combination with the research of the University of Technology Eindhoven, a symbiotic corporation was formed. The two educational instances planed the future project as presented in this report.

New design

The design has been named: 'Flamenco tower in ice'.

The design of the 'Flamenco tower in ice' was inspired by three different aspects: A traditional Chinese tower (figure 40), a flamenco dress (figure 38) and the Harbin flower (figure 39). Based on these aspects, and the ambition to build the new highest ice dome, the new project is designed by Arno Pronk.

Figure 39; Harbin flower; source: (Qingpeng LI, 2018)

Figure 40; Traditional Chinese tower; source: (Qingpeng LI, 2018)

Figure 41; Initial design Flamenco tower in Ice

The influence of the traditional tower can be related to the height of the design, which covers an altitude of 30 meters. This tower is claiming the world record for being the highest ice shell structure. The characteristics of the flamenco dress are represented in the six cantilevering legs as shown in figure 41. The legs serve as entrances and are positioned in a radial symmetric grid. The entrances are executed with a staircase made of solid clear ice, leading to an internal platform. The traditional Chinese local flower, can be recognized from the top view.

The tower will be constructed using cellulose fiber reinforced ice. The project will be constructed with the same building method as the previous projects.

The purpose of the tower is not only to research the capabilities and possibilities of the material, but also to promote different applications and further international research. After construction the tower will be open to public and serve as attraction.

3.2 Inflatable

The design of the inflatable is examined using the Grasshopper plug-in for the 3D-modelling software package of Rhino. Most of the modeling and form finding is performed by S. Brands (TU/e master-student) and Liu Xiuming (H.I.T. Phd-student).

Main design

In the main design, the inflatable will be approached using different inflatables interacting with each other. In this subdivision, all six legs and the tower are considered as different parts, referring to the same internal pressure (figure 42). To ensure that the internal pressure of all the parts is constant during the construction, the parts are mutually connected to guarantee an even distribution of air (and pressure). The external pressure is considered to be constant on all surfaces. Changes in the external pressure, and additional deformations, are further examined in chapter 'Structural analysis of inflatable'..

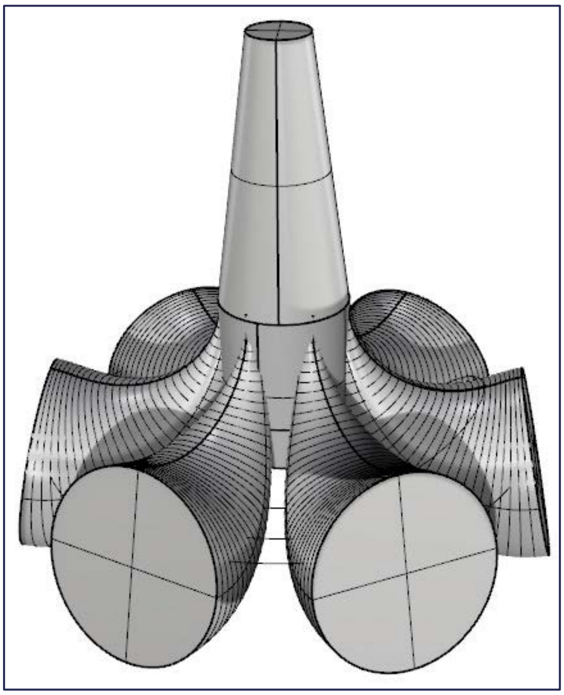


Figure 42; Modeled geometry of tower inflatable; source: (Brands, 2017)

The tower itself is modelled by dividing it in two sections. The under part is a simple cone, and the top part consists of a frustum cone (figure 42). From this point it is expected that the top surface, which is originally designed to be flat (because of the open structure), will shape itself spherically.

Figure 43; Modeling of the inflatable legs; source: (Brands, 2017)

The six legs are observed as a horn shaped cone pointing upwards in z-axis. One leg is designed using different circular sections where the center is positioned on a curved line (figure 43). The sections slowly increase in area. After connecting the different sections, an area is created to form a surface. The end of the horn shaped cone is formed by a basic pointed cone. Later in the process the center of this last cone will be positioned on the ground area with its bottom surface orientated perpendicular to the world.

The connection with the main tower is based on the intersection between the different parts, overserving the tower as primary. All the vertices intersecting the volume of the tower, are positioned on the surface of the tower, ensuring no intersections of volumes.

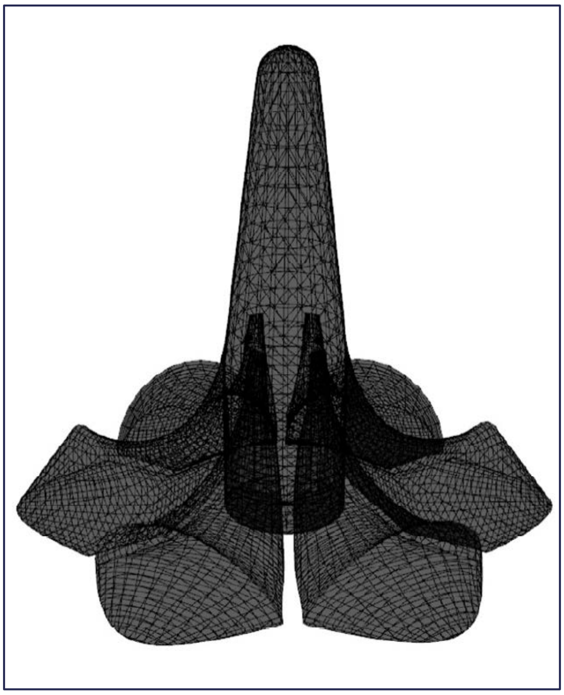


Figure 44; Connection of tower and legs; source: (Brands, 2017)

The connection to the ground area is observed in a similar way, considering the ground area as primary. The vertices of the intersecting volumes are again translated, but now in a horizontal surface as seen on figure 44.

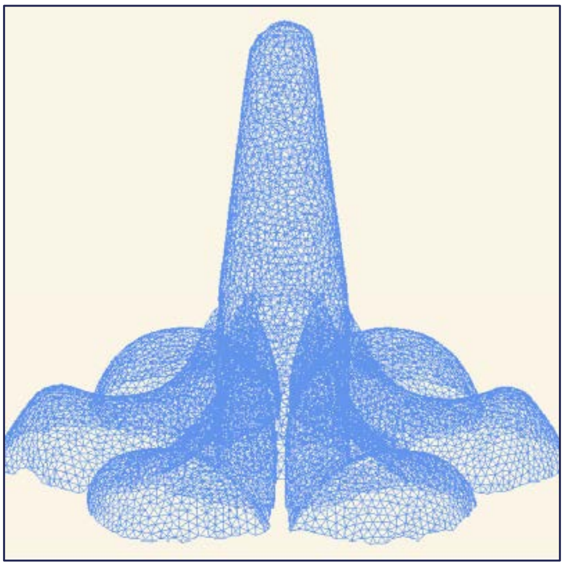


Figure 45; Improved inflatable model by X.Lui; source: (Xiuming, et al., 2017)

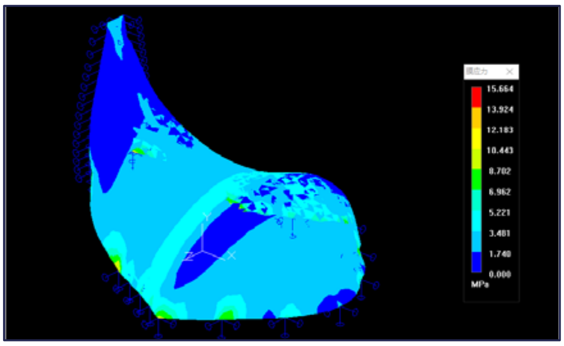


Figure 46; Modelled membrane stress in leg; source: (Xiuming, et al., 2017)

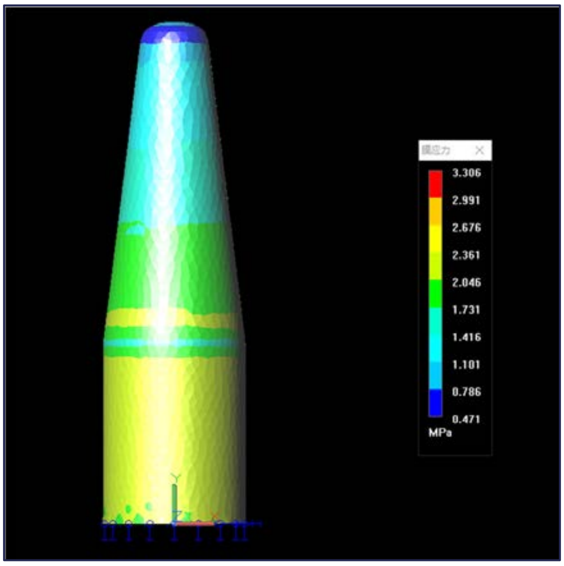


Figure 47; Modelled membrane stress in tower source: (Xiuming, et al., 2017)

To make sure there is no excessive membrane material, which could result in deformations of the total inflatable, the model is improved using the principles of 'form finding' (Brands, 2017).

Modelled inflation

To test the final design, the model has been digitally inflated. X. Lui programmed for this allocation an external plugin for GSA, which indicates a better approach of a real inflatable (Brands, 2017). Resulting in the final model shown in figure 45.

The model shows strange behavior on a few points. However this can be assigned to minor flaws in the design input due to the complex geometry of the tower (Brands, 2017). No wrinkles occurred, indicating no excessive material was present.

Structural analysis of inflatable

To ensure a safe and reliable inflatable, the final design is also tested on structural properties. This is also important to determine the internal pressure that is needed for total inflation, and to minimize deformation during the construction.

To predict the behavior of the inflatable under external factors, the model is analyzed using a software package of GSA. The following factors and parameters are observed. The same parameters are also observed for the structural analysis of the ice shell.

Wind load

Because of the height and the deformational nature of the inflatable, its reaction on (heavy) winds is crucial. A relation can be found in the internal pressure, the wind load, and the deformation of the inflatable. The higher the internal pressure, the more the deformation is minimized when external forces are applied of the surface. It must be mentioned that a high pressure is more problematic to maintain, and is more likely to cause damage to the inflatable itself. The optimum pressure is therefore deviated from the experimental field testing (Hijl, et al., 2014) and experience from other projects. Therefor internal pressure has been stated on 400 Pa (Brands, 2017).

To limit the deformation of the inflatable, it is also possible to radial attach support lines on height. This technic has been used earlier during the construction of the Sagrada in Ice (Kern, et al., 2015).

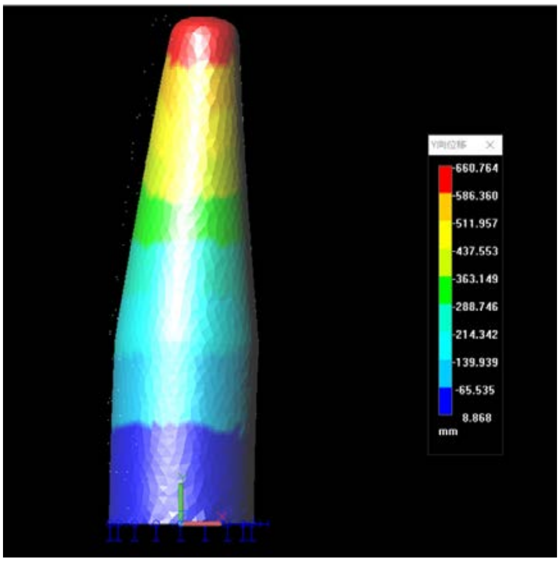


Figure 48; Deformation of membrane; source: (Xiuming, et al., 2017)

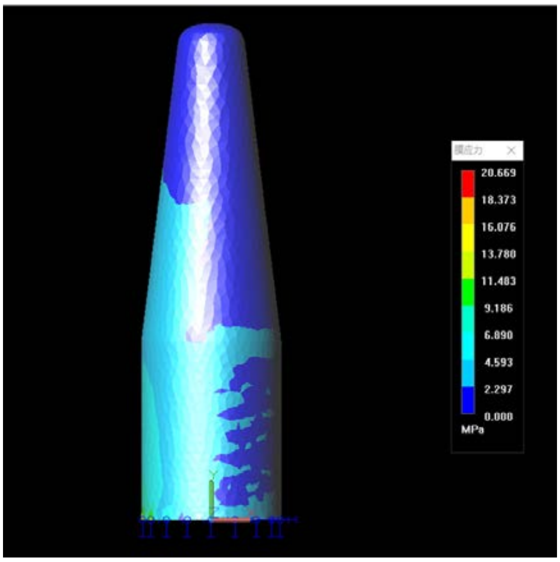


Figure 49; Membrane stress under external factors; source: (Xiuming, et al., 2017)

Despite the extra stability, the lines formed a practical obstruction for boom lifts and other heavy equipment, and are therefore not preferred.

For a reliable approach of the local wind conditions, a Chinese wind code has been consulted referring to a wind load of 0,140 kN/m2 (Brands, 2017).

Snow-load

Due to the overall vertical approach of the design, the snow loads only concentrate on the top of the tower and on top of the legs. Both locations consist of curved surfaces, limiting the influence of the snow. Therefore the snow load can be neglected.

Membrane stress

The tower and the legs are approached individually. In this inflation, only the internal pre-stress is taken into account.

With the internal pressure of 400 Pa, the structural analysis of the tower shows that the pressure is high enough to lift the membrane and fully inflate the inflatable in the top (figure 47). The maximum membrane stress of 3,3 N/mm^2 is located in the bottom. The membrane stress decreases gradually over height.

The separate analysis of one leg shows a more constant distribution of membrane forces. Figure 46 shows a maximum membrane stress of 15.67 N/mm^2 in the leg both tower and legs show no signs of compression, preventing any deformations in of the surface (Xiuming, et al., 2017).

Deformation

Figure 48 and 49 show a resultant analysis of both legs and tower under external factors. To optimize the visibility of the deformation, the legs are hidden from the visual expression. Applying the wind load on the whole tower results in a maximum membrane stress of 20 N/mm^2 and a zero stress surface in the top. This indicates a relaxation of the membrane in the top resulting in wrinkling and losing (local) support. As figure 48 shows the maximum deformation is 660mm.

Unfortunately the deformation in relation to the height does not meet the Chinese CECS regulations (Xiuming, et al., 2017). Therefore the inflatable must be supported during construction, or the construction sequence should be adapted. This will further be described in section 'Planning'.

Production

For this project, the production of the inflatable is outsourced to a specialized company in Beijing. For the production, the company translated the final inflatable model into cutting patterns.

The company produced and folded the total inflatable, to further distribute it to the building site. The final freight consisted of a packings with the dimensions of 6000*2800*3000 mm (l*w*h) with a weight of 4000Kg (Figure 50). In chapter 'Realization' will be described how the inflatable is processed during the construction.

Figure 50; Folded and packed inflatable during arrival on the building site

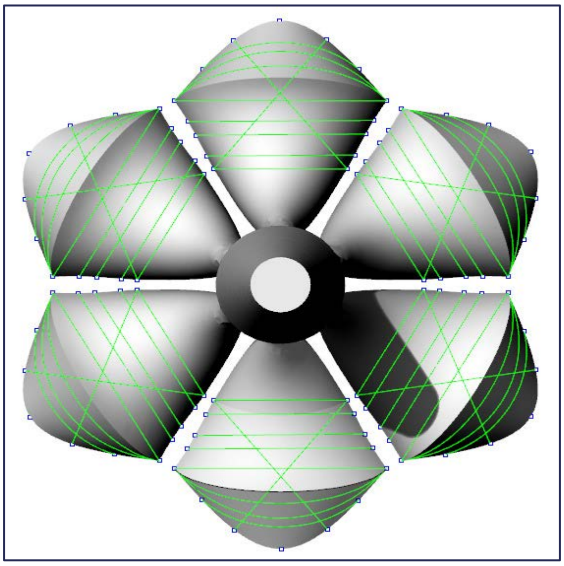


Figure 51; Modelled position of the rope net; source: (Brands, 2017)

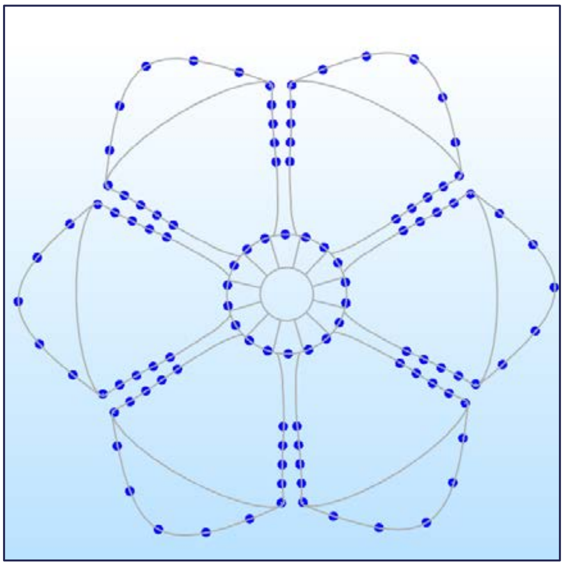


Figure 52; Anchor plan for the fixation of the inflatable; source: (Brands, 2017)

Rope net

In the design, the connection to the ground is approached as being a flat surface. This is only possible when the inflatable is firmly connected to the ground concerning a stiff underground.

In the first project ('Pykrete dome') an external rope net is used for the fixation of the inflatable (Hijl, et al., 2014). Former projects like the Sagrada in Ice and the Bridge in Ice used anchoring which was fixed to the inflatable itself (Kern, et al., 2015) (Koekkoek, et al., 2016).When not performed correctly, fixed anchor points can lead to damage to the inflatable during the inflation process because of local peak stresses. Fixed anchoring also impede the removal of the inflatable, because the rope net and anchor points are enclosed in the ice shell. This leads to forcefully damaging the inflatable to successfully remove it, excluding a re-use. Therefor it is preferred to design an external rope net which makes no use of fixed anchoring to the inflatable itself (figure 51).

It is important to state that the design of the rope net is focused on an easy executable phase in the construction process, limiting as many ropes and connections as possible. Therefore a perpendicular rope approach has been designed. This indicates single perpendicular lines spanning from one anchor point to the other. Because of the double curved surface of the legs, the ropes have a possibility of shearing along the slope of the leg. To prevent this, two diagonals are added to fix the distances between the ropes. To ensure this, every intersection needs to be considered as a fixed connection. These fixed points are connected using U-Bridges m12. The working drawings of the rope net are attached in annex 2.

3.3 Foundation

The foundation consists of two components. The rope net will be directly connected to the ground using an anchor plan. Secondary, to improve stability and create an entrance after completion, an ice base ring is being constructed.

Anchoring

The anchoring in the ground is executed in the floor plan of figure 52. Unlike the desire to eliminate fixed anchor points on the inflatable, some connection of the middle of the tower has been established. This was the result of a measure of security of the H.I.T.

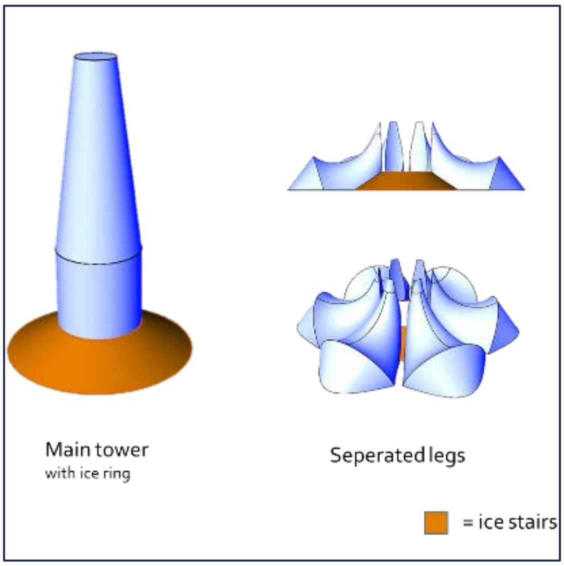


Figure 53; Position of ice ring; source: (Xiuming, et al., 2017)

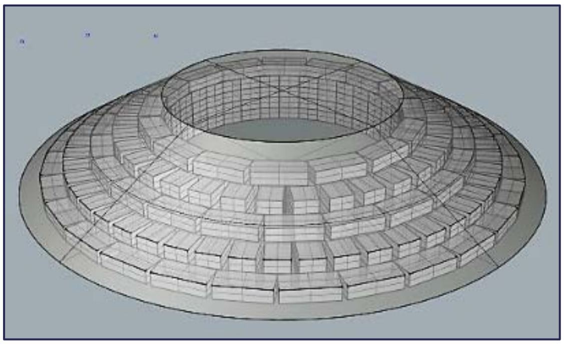


Figure 54; Positioning of ice blocks in ice ring; source: Sjef Brands

The anchoring consists of 18 anchor points for the main tower and 15 points for every leg resulting in a total of 108 anchor points. Anchor points have been executed with small casted concrete poles. This type of pole is not optimal for tensile forces. However, the used poles were capable to withstand a tensile strength of 90 kN (Xiuming, et al., 2017).

Regarding the maximum stress in the rope (and the ground-anchoring), the maximum internal pressure is used leading to a maximum tensile force of 45.6 kN (Brands, 2017). The maximum capacity of the anchors is not exceeded, and therefore complies with the maximum forces with safety factors taken into account.

Ice stairs

After completion, the main level of the tower will be elevated. Because all legs will serve as an entrance, the space underneath the legs needs to be filled. This will also give the tower extra stability during and after construction (Xiuming, et al., 2017).

As can be seen in figure 53, the ice ring is modeled as a frustum cone. To speed up the building process, the ring will not be constructed using snow and water. Instead of that, the cone has been translated in the stapling of ice blocks. An overview of this modeling is displayed in figure 54. The ice blocks are carved out of the local river, and transported to the building site by truck. Every layer has been individually modeled with either a parallel or perpendicular block position. This position is determined when approaching the border of the frustum cone as close as possible. A full overview of the drawings can be found in annex 3.

Another benefit from building with ice blocks apart from the building speed, is the fact that the blocks form an ice stairs. This stairs can be directly implied and used after finishing the structure. The transparency of the blocks also creates esthetic opportunities in relation to lighting.

By executing the ice stairs, the inflated leg will be supported pointwise instead of evenly along the whole surface. This is not considered as a problem, because most of the leg inflatable will be anchored on the ground surface. The ice stairs will support the inflatable enough and fill up the open space under the inflatable, so the ice shell can develop from the ice stairs on.

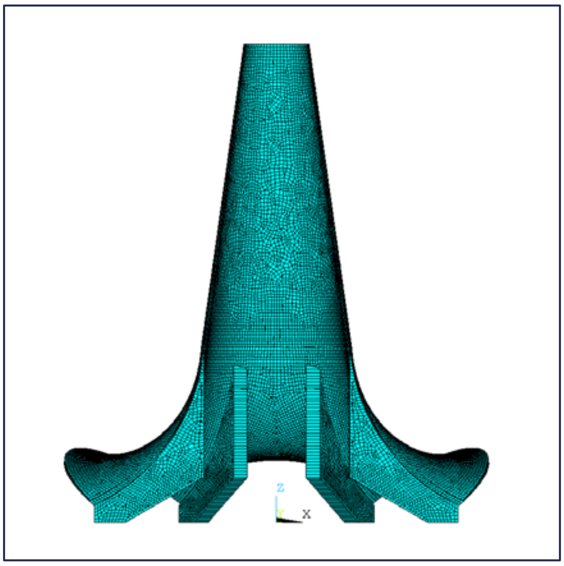


Figure 55; Section of ice shell, showing the position of the internal ice walls; source: (Qingpeng LI, 2018)

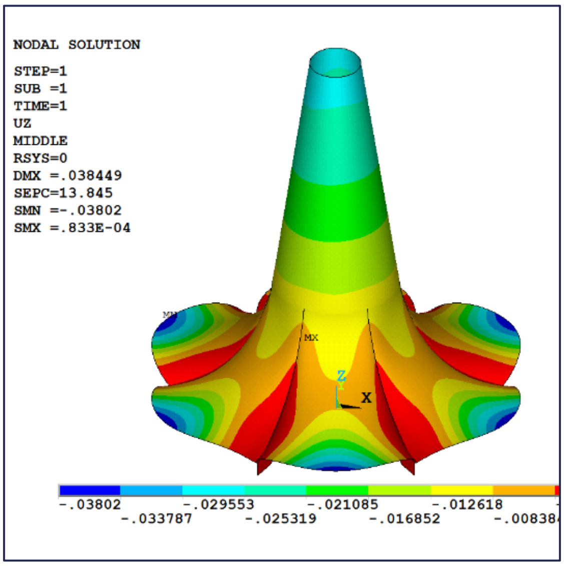


Figure 56; Deformation in Z-direction (m); source: (Qingpeng LI, 2018)

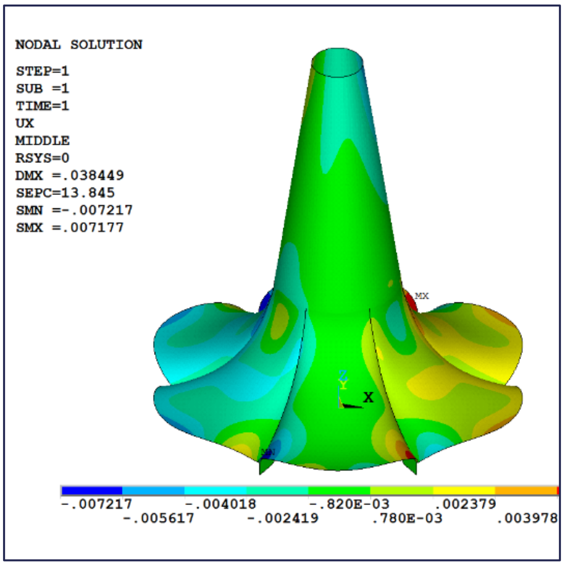


Figure 57; Deformation in X-direction (m); source: (Qingpeng LI, 2018)

3.4 The structural analysis

Structural analysis as presented has been performed by Qingpeng Li (Qingpeng LI, 2018). The analysis focused mainly on the thickness of the shell, and the reaction to external forces. The parameters as in table 1 are used for the modeling.

Mechanical properties Cellcrete	
Young's Modulus	500 N/mm^2
Density	900 kg/m3
Tensile strength	0,5 N/mm^2
Compressive strength	2,0 N/mm^2

Table 1; Parameters used for modeling

Thickness

After modeling a parametric finite element model, based on the original design and the developed inflatable, the model is analyzed with a software package of ANSYS. All six legs and the tower are taken in the calculation.

The main thicknesses can be divided into two parts. The first part, the tower, resembles a thickness that decreases linear over height. The second part, the ice wall of the legs, are designed to carry the own-weight of the tower and the leg shells.

After analyzing own-weight and wind loads, the thickness has been stated to be 400mm at the base, and 70 mm in the top (Qingpeng LI, 2018). Figure 55 shows an overview of a radial section of the tower.

Analysis

The model has been tested under different external factors. The following model represents the structural behavior of the tower under self-weight and wind load (applied in the x-direction), see figure 56 and 57.

The maximum deformation (blue indication) is located at the maximum cantilever of the legs (blue indication)(figure 56). The vertical deformation values approximately 4 cm. The connection of the legs shows the least deformation.

Figure 58 shows the first principle stress at the top surface. The maximum stress (red indication) is located at the upper part of the connection of the legs and values approximately 0,71 N/mm^2.

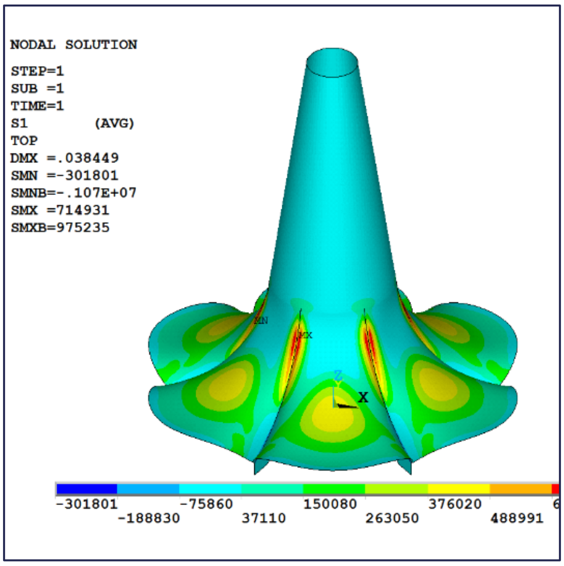


Figure 58; First principal stress at top surface (Pa); source: (Qingpeng LI, 2018)

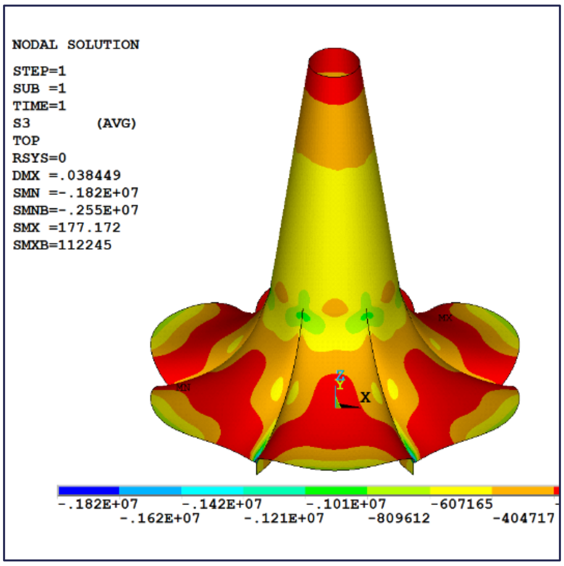


Figure 59; Third principal stress at top surface (Pa); source: (Xiuming, et al., 2017)

The maximum compressive stress (figure 59, blue indication) of 1,82 N/mm^2 can be deviated from the third principles stress and occurs at the bottom junction along the ice wall.

It can be concluded that the tower is theoretically strong enough to withstand self-weight and wind loads. The occurring stresses are lower than the material properties.

Nonetheless it is advised to the crew to specifically focus on the construction of the legs because of stress concentrations that occur at the junction of the legs and the ice walls (Qingpeng LI, 2018).

3.5 Pilot project - (Moonen, 2017)

To define a good preparation for the project, a pilot project has been performed.

This pilot was important to get a better understanding of the local building standards in Harbin as well as sharing knowledge about the construction method.

The activities and goals of this field test were:

Construction of small scale tower; to do some test on the shape of the tower, and the practicability of the shape.
Construction of small dome (10 meters span); researching the local standards and educating the building method to the local construction workers.
Introducing building method with local construction methods; available equipment and materials.
To get a vision on the degree of preparation for the big project.
International corporation and exchange of knowledge.

The pilot was performed together with student and tutors from the H.I.T. and the K.U. Leuven (see figure 60).

Design

Tower

Two tower design were prepared for this pilot. The students from H.I.T. (figure 62) and the students of KU Leuven/Tue (figure 61) made two separate designs. Both were based on the initial design.

The Students from H.I.T further researched the model with form finding concepts. The test inflatables have been constructed by a specialized company using PVC-foil. It was stated that the initial design was already hard to approach. The design established by form finding however showed an even higher complexity in cutting patterns.

Figure 60; Conceptual impression of pilot project; source: H.I.T.

Figure 61; Inflatable of KU Leuven

Figure 62; Inflatable of H.I.T.

Dome

To educate the construction process, a larger dome with a span of 10 meters was also designed and build. The dome, as resembled in figure 63, was inspired by the Harbin flower as well.

The final inflatable was produced by the same company as produces the Chinese version of the tower. In corporation with the company, the design had been changed, and enlarged to reach a height of 3 meters, and a span of 10 meters. Figure 64 shows the inflatable on the building site.

Construction

For the construction all parts has to be ordered and collected locally in front. Unfortunately a lot of equipment had not arrived on time on the building site. That resulted in delay and improvisation.

A temporarily production line was stationed inside a public lavatory. This provided the needed water, and the climate controlled environment to avoid freezing.

Figure 65 shows an overview of the production area. Four containers were used: three in preparation, and one was being pumped and distributed. This system resulted in hoisting the heavy submersible pump in another container when the previous was emptied.

This system made constant movement in the hoses impossible and therefor risked freezing. Because of the fact that the hoses could not be returned in the container (container size was too small), every interruption of spraying lead to a huge delay by emptying the total hoses.

Spraying process

The spraying process is comparable with all the other projects. The inflatables were inflated and sprayed in sequence (see figure 66 and 67). Shells have been inspected to ensure a good forming of an ice shell with an even distribution.

Result

After removing the inflatables and final finishing activities, the ice structures were lightened and officially opened (see figure 68, 69, 70 and 71).

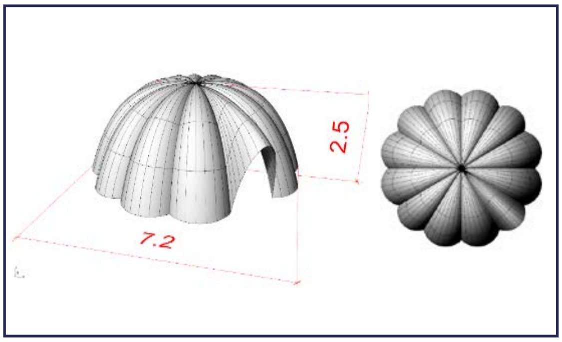


Figure 63; Design and top view of test dome; source: H.I.T.

Figure 64; Inflatable of test dome on building site

Figure 65; Improvised production set up

Figure 66; Crew handling the hoses for the spray process

Figure 67; Spraying of test dome

Figure 68; Result of scale model with form finding

Figure 69; Result of tower and test dome

Figure 70; Official opening of constructed pilot ice structures; source: H.I.T.

Figure 71; Final result of two towers and test dome

Conclusion of pilot project

The realization of the small scale towers, showed some focus points:

- It is import to focus on the connection between the leg and the tower. The ice is likely to build up in the middle of the leg, without creating an evenly distributed shell along the connection. This can result in point loads during the construction.
- Extra attention needs to be given to the side walls of the legs. It is important that they are build up from the bottom, to support the cantilever of the whole leg.

It was concluded that a lot of equipment varied in size, efficiency, connections and reliability. There for it is important to prepare as much as possible in front, for a big scale project.

The internal corporation has been experienced as pleasant by both parties. Both the H.I.T. and the TU/e planned to continue the big scale project of the Flamenco tower in ice.

4.Process optimization

The overview in recommendations of previous projects results in a demand for an optimization of the production of Cellcrete, and of the total construction process. In this chapter the recommendations are translated in process optimizations,

4.1 Starting position

The system as used in the 'Bridge in ice' project is marked as starting point for the optimization (Moonen, Bridge in Ice- Construction, 2016). In this section, the existing system will be fully described.

Setup

For the production of Cellcrete, the cellulose was added in compressed sheets of 98% cellulose. These sheets needed to be soaked and dissolved in water. The dissolvent process took place in the pre-mix container (as is figure 72). This container consisted of a conventional IBC-Tank with a volume of 1m^3, equipped with an adjustable mixer. This mixer was specially designed for this application. The size of the container made it possible to guarantee and control a constant output, instead of a big scale setup.

The production of the Cellcrete was separated from the distribution. This is important to create a constant homogeneous output with the same mass-ratio of cellulose fibers. The setup was equipped with 2 pre-mix tanks (figure 73). After the completion of the dissolvent process, the pre-mix tanks were emptied in the buffer container.

This buffer container was also equipped with adjustable mixers, to keep the mass in motion. External centrifugal pumps were connected to the buffer tank, to distribute the Cellcrete to the inflatable. In case of shut-down of the mixers, extra external pumps were connected to generate circulation in the buffer tank.

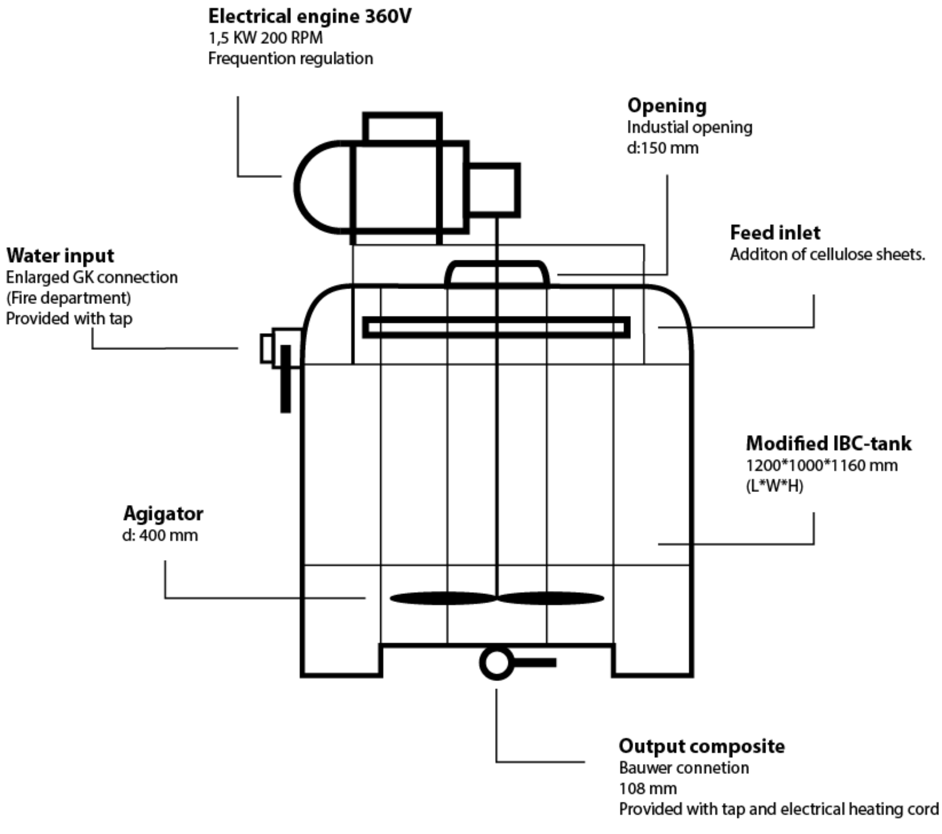


Figure 72; Pre-mix container, modified IBC container; source: (Moonen, 2016)

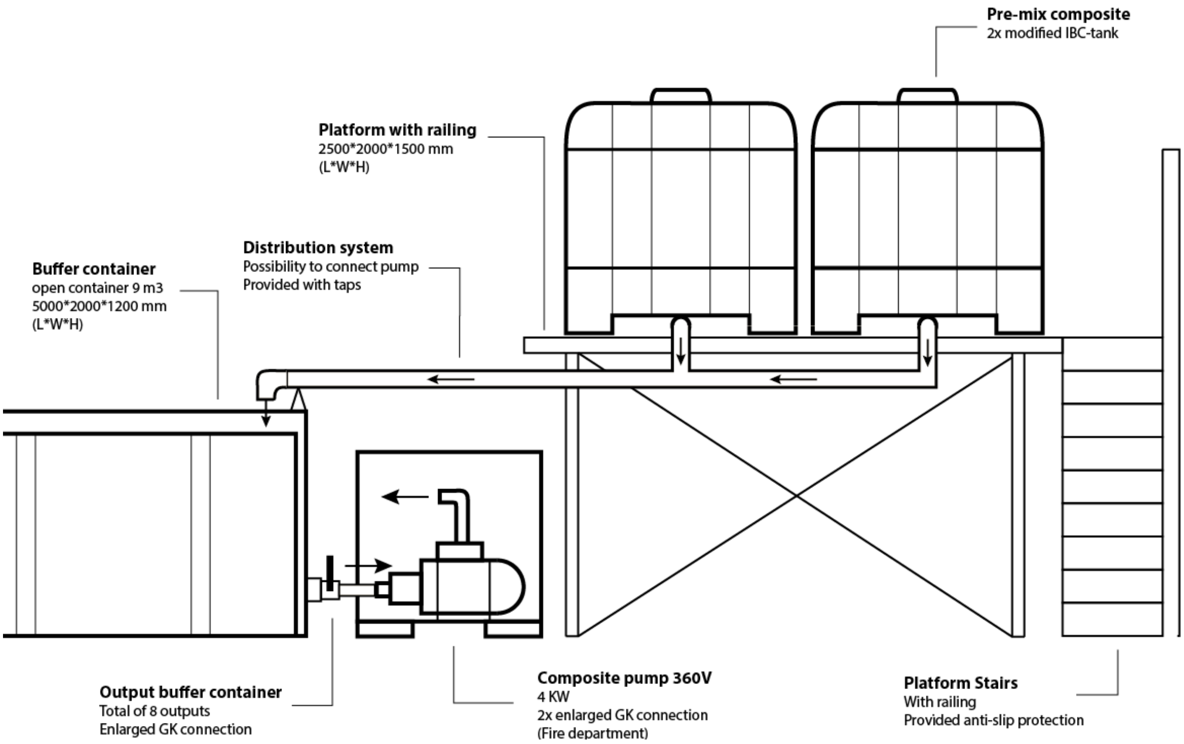


Figure 73; Schematic overview production line; source: (Moonen, 2016)

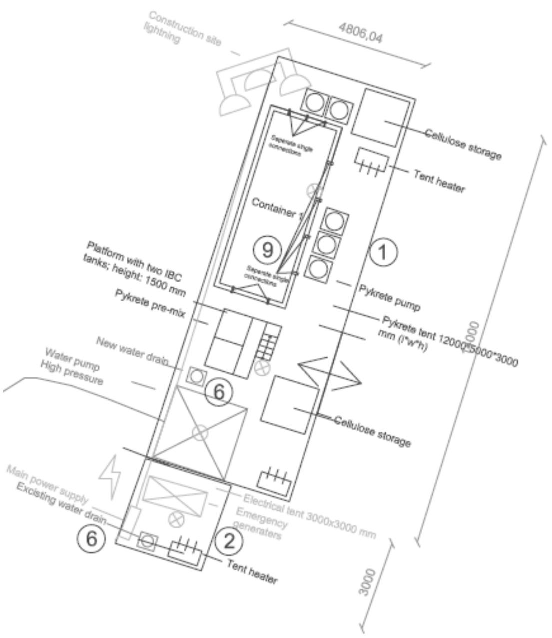


Figure 74; Floor plan of construction tent source: (Moonen, 2016)

The whole setup was placed in a construction tent as shown in figure 74 The tent served as an insulating shell of the production line. This made it possible to control the internal climate of the production line and prevent parts from freezing and obstructing.

The climate control also contributed to better working conditions for the construction workers. Thereby, it simplified the engineering process, because the equipment would not have to be selected by performing in extreme weather conditions of -30°C.

In case of a power shutdown, the production line was also equipped with an emergency generator. This is important to prevent the Cellcrete in the production line from freezing when the heating is disabled.

In practice

The system was first assembled and tested in Juuka, Finland (figure 75 and 76). The system functioned according expectation with minimal errors. Table 2 shows an overview of parameters needed for improvement of the process.

Figure 1; Platform for pre mixing

Figure 76; Overview of production line

Factor	Quantity	Description
Production capacity pre-mix	1m3 every 30 minutes	One batch takes 30 minutes to fully dissolve and process.
Pre-mix containers	2	2 Modified IBC-tanks are included in the production line
Total production capacity	4m3/h	Capability with 2 operating pre-mix tanks. Previous projects asked a demand of 2 m3/h (Moonen, Uitvoering; Sagrada Familia in Ice, 2015).
Buffer capacity	9m3	It takes approximately 2 hours and 30 minutes to fill the entire buffer
Connectable pumps	4	There are 4 external pump connection suited on the buffer container

Table 2; Parameters production line

Concept

As a base for the improvements, the points of attention of previous researches were taken into account. The main attention points are summarized and listed below:

- Fasten production time; speeding up the bottlenecks of the process
- More reliable; engineering of a system which is less dependent of external factors
- Automation; atomize where possible to exclude human errors
- Mobilization; mobilize system to promote (re-)deployment

To prevent malfunctioning and delays, as occurred in the past, it is preferred to prepare and standardize as much as possible of the construction and production beforehand. This results in the engineering of one total construction station, which houses all the activities on the building site. Making this total construction station plug and play, ensures a standardized and independent operating platform. This means that the station only needs a connection to electricity and water, to process from that point on. The last addition is found in mobility. If the total construction station is engineered to be fully mobile, it could be stationed in any cold climate and operated to execute comparable projects. This concept simplifies the use of Cellcrete as a building material, and it stimulates the use within the building practice. The attention points are solved with the implementation of the following factors:

- Total construction station; one central platform to operate and coordinate the whole building sequence.
- Plug and play; making the platform independent for operation, only electricity and water connections needs to be established
- Mobile; by mobilizing such a platform, the station can be deployed all over the world

These factors have been combined by engineering the mobile Cellcrete factory. The mobile factory covers five areas (figure 77):

Figure 2; Schematic overview of mobile factory

The mobile factory houses all main activities of the building site; one central platform that executes, plans and monitors the construction. The factory provides an enclosed space which offers the possibility for internal climate control.

Production:

The mobile factory includes the full production line as described in chapter 'Engineering production line'. To include this line, the production phase needed to be re-engineered to be more efficient and compact. In this redesigning the factor of accelerating the production speed was taken into account.

Monitoring:

Not only the construction process and progress need to be monitored, also the condition and status of the inflatable are crucial for a successful completion of the construction. In a previous project ('Bridge in Ice'), together with the SUMMA college, a system has been engineered to monitor this inflatable status (Moonen, Bridge in Ice-Construction, 2016). This system needed to be re-engineered to make it suitable for this project, and make implantation in the mobile factory possible.

In the factory is also a small office installed to coordinate the construction.

Residence:

Because the Pykrete and Cellcrete structures are always build in extreme cold climates (up to − 30 ^{0}C), it is important to create the most optimal working conditions. By executing the production line internally, unnecessarily outside work is excluded.

Working outside could not fully be excluded and therefor it is important to create a residence, close to the construction area, where construction workers can regain energy and heat. The Mobile factory houses a residence for the workers to rest and heat in between shifts.

Power control:

The factory can be connected to the electricity grid and operates as the main energy hub of the building site. That means that all energy runs through the factories electric cabinets. This created the opportunity to monitor the building site grid, and localize any faults or errors visually. The connection to the electricity grid limits the cabling on the building site.

The factory is also equipped with its own emergency power generator in case of a power shutdown. The power generator is able to provide the most critical parts of electricity to avoid major delays.

Storage

The factory accommodates a storage area. This storage area is not only for the cellulose, but also for equipment and tools. An efficient way of storage needs to be engineered to make optimal use of the limited space inside the factory.

4.2 Engineering

The engineering process has been performed with assistance of students 'Mechatronics' from the SUMMA college in Eindhoven. Their expertise in mechanics and electrical engineering was crucial to engineer a working end product.

Different assignments have been created to instruct the students. A description of the corporation is added in annex 4 and 5.

Bottleneck of Production line

To fasten the production time, the bottleneck in the process has been determined by analyzing the production process (figure 78).

As figure 79 shows, the most time consuming part of the process is the pre-mixing. The cellulose needs to dissolve and fall apart. This is dependent on the compactness of the sheets, the moisture-% of the sheets, and the dimension of the inserted particles (Moonen, Bridge in Ice- Construction, 2016). The smaller the particles the faster the dissolvement process is completed.

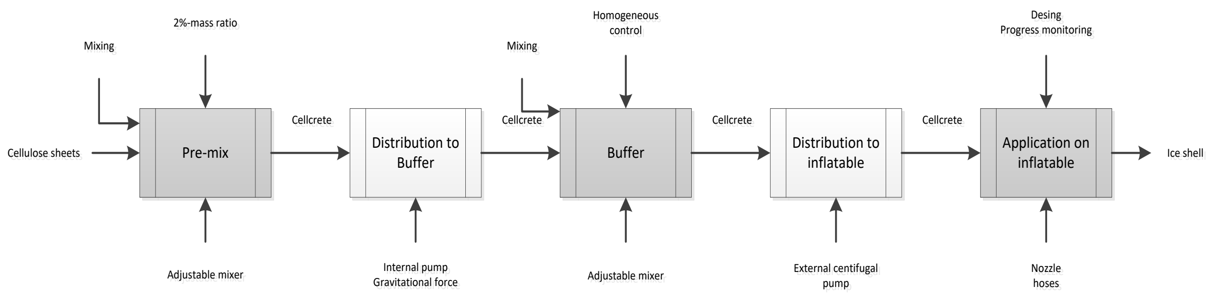
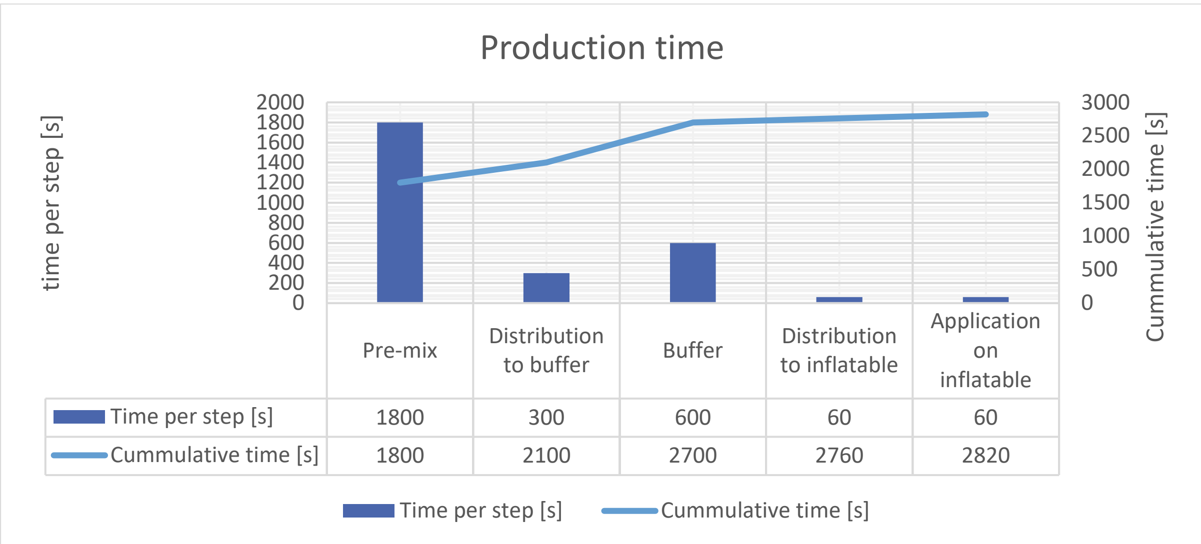


Figure 78; SADT-scheme of production process



	Pre-mix	Distribution to buffer	Buffer	Distribution to inflatable	Application on inflatable
Time per step [s]	1800	300	600	60	60
Cummulative time [s]	1800	2100	2700	2760	2820

Figure 3; Time consumptions per process step

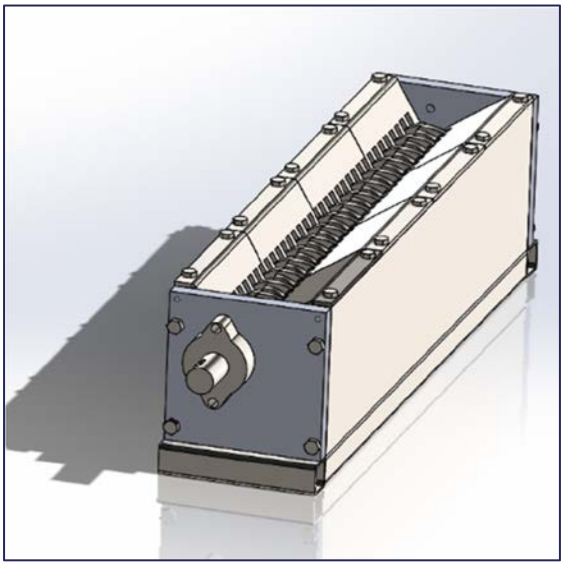


Figure 80; specially engineered shredder, perspective view

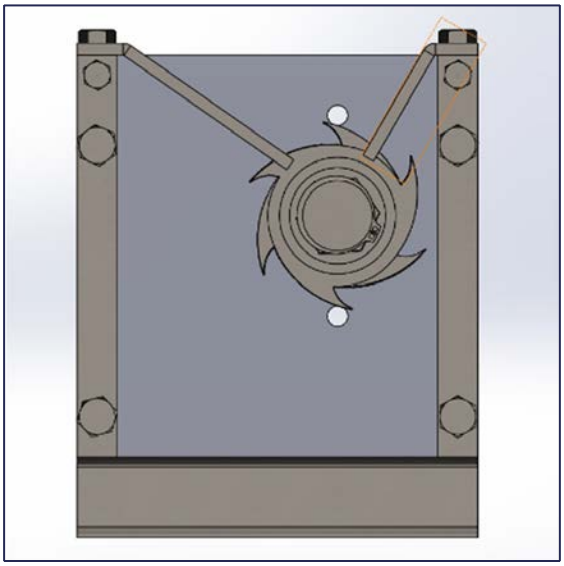


Figure 81; Shredder section

Figure 82; Engineered and watercutted shredder tooth

Improvements

shredder

To accelerate the production process, the pre-mixing had to fastened. Therefore it has been determined to minimize the cellulose particles by using a shredder. Because of the nature of the material, and the toughness, a special designed shredder should be engineered. A plan of requirements has been set up depending on formal projects (Koekkoek & Nieuwenhof, 2016) (Moonen, Bridge in Ice-Construction, 2016).

Requirements of shredder:

- Minimize particle size of cellulose sheets
- Whole sheets input
- Automatic sheet input with counting system*
- Storage for 100 sheets*
- Shredder must distribute output in container
- Speed of at least 3 sheets/minute
- Maximum energy use of 10 kW
- Safe to operate

*: due to financial limitations, these points had to be delayed for further engineering.

The shredder in figure 80 and 81 has been designed. Working drawings can be found in annex 6.

The shredder is designed with a single axil to simplify the connection to the electric motor. As is shown in figure x, the shredder is kept compact to make sure the whole production line stays as compact as possible.

The shredder has been executed and tested. However, the first prototype did not meet the requirements. The designed shredder teeth (figure 82) pulverized the cellulose

sheets by contact. The shredder did not pull the whole sheet in the teeth, resulting in a dangerous manual input of the sheets.

After realizing the first prototype, there was no time left to fully re-engineer the shredder.

To replace the engineered shredder, a secondhand a3 cardboard shredder was installed (figure 83). This shredder was repaired and revised to minimize the change of faults and error during heavy performance.

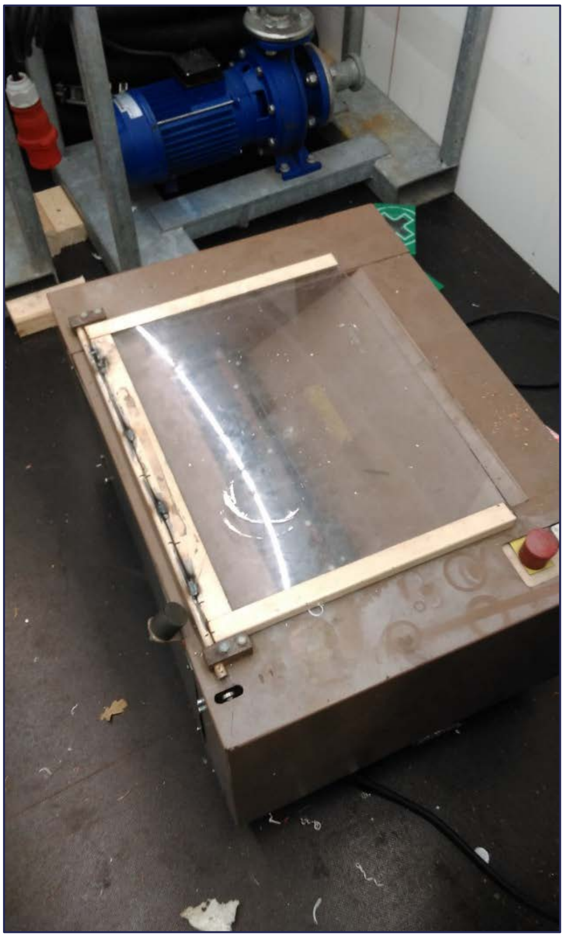


Figure 83; Secondhand replacement shredder

The a3 shredder was not capable of inserting the cellulose sheets as one. This resulted in the addition of a new activity where the sheets need to be folded before insertion.

It is expected that the addition of the shredder will reduce the dissolvement time resulting in an acceleration of the total production time.

Optimization production line

Estimations and small scale tests with smaller particles, predict a dissolvement time of 15 minutes. This would speed up the process of premixing with 200%. Because of this improvement, the same production can be generated using only one premix container, excluding the buffer (figure 84 and table 3).

This reasoning resulted in the exclusion of the buffer tank, and replacing it with a second pre-mix tank. This speeded the production output to a maximum output of 8m3 per hour. This meets the requirements double, and therefore suits capabilities for future projects.

To ensure a constant uninterrupted supply of Cellcrete, the tanks will be operated parallel. Resulting in one tank providing Cellcrete, and the other mixing the following batch. A manifold has been engineered to ensure multiple pumps could be connected to the two tanks. The manifold controls which valves open and close.

The following fully automatic overview is engineered. The system is connected to an external water supply. It is important that the water supply does not interrupt the flow of water. No water flow results in the freezing of the hoses, which will lead to delays (Drijvers, et al., 2015). Therefore a return line should always be engineered to promote the flow of mass.

For the water supply this will result in a bypass which pumps the water back to the supply, or down the local drainage. The distribution of Cellcrete should be approached with the same principle. The spray nozzles will need a return line to prevent the mass from stagnation in the hoses.

The automation is controlled with sensors and automatic valves. Cellulose input is assumed to be manual. All instruments are connected to one central PLC which collect all sensor data, and controls all valves and engines. The sensors detect the water level of the containers, and the status of dissolvement providing the PLC with the demanded data. The PLC will switch valves and pumps to enable distribution.

A connection with an eccentrically worm pump has been engineered, to ensure the possibility to use the mobile factory to 3d-print fiber reinforce ice in the future.

It is expected that the automation will result in less failures, and a more reliable production line.

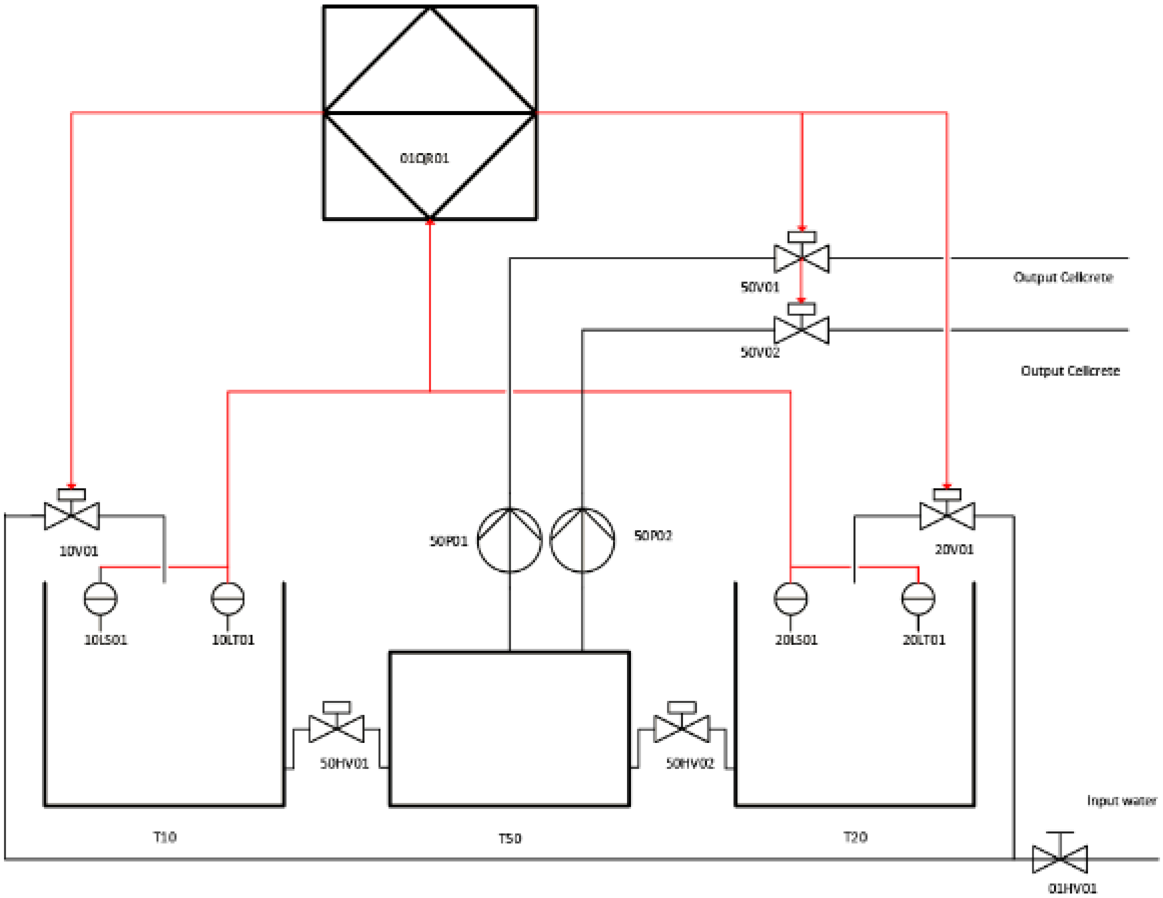


Figure 84; Schematic overview of the automated Cellcrete production line

Item	Description	service	material	model
T10	Mix container 1m3	Pre-mix	HDPE	DN80
T20	Mix container 1m3	Pre-mix	HDPE	DN80
T50	Manifold	Distri-bution	S355	n/a
50P01	Centrifugal pump Manifold > output	Distri-bution	Cast steel	RC 3075 2T
50P02	Centrifugul pump Manifold > output	Distri-bution	Cast steel	RC 3075 2T
01QR01	PLC	Control	n/a	Wago PLC
10LS01	Level switch t10	Digital level control	n/a	Liquiphant FTL31
10LT01	Level transmitter t10	Analog	n/a	Vegapuls WL61
20LS01	Level switch t20	Digital level control	n/a	Liquiphant FTL31
20LT01	Level transmitter t20	Analog	n/a	Vegapuls WL61
01HV01	Main water supply	Manual valve	n/a	Valve 22mm
10V01	Water supply T10	Automatic valve	n/a	BW2-100-AW1
20V01	Water supply T20	Automatic valve	n/a	BW2-100-AW1
50HV01	T10>T50	Automatic valve	n/a	S100*80
50HV02	T20>T50	Automatic valve	n/a	S100*80
50V01	T50>output	Automatic valve	n/a	12576510
50V02	T50>output	Automatic valve	n/a	12576510

Table 3; Explanation of schematic overview of production line

4.3 Mobile factory

Before engineering the interior of the mobile factory, a plan of requirements is stated out of previous recommendations and experiences (see chapter 'Recommendations') (Koekkoek & Nieuwenhof, 2016) (Moonen, Bridge in Ice- Construction, 2016). To make international universal transportation possible, the mobile factory shall be engineered for a 40 ft sea container.

Requirements

General

The container will operate fully independent (except for water and electricity supply). The sea container is standardized and can be transported by truck, train, ship and plane. The factory must be able to operate anywhere in the world. Therefore, an international approach in operation is essential.

- The container must house the whole production line
- The engineered parts of the factory should be executed as compact as possible
- The internal climate of the unit needs to be controlled; temperate and ventilation.
- The unit must be safe to use by all personal and workers of every origin (international approach).
- The unit must only be connected to electricity and water, the rest is internal.
- The production rate must at least process 4M3 Cellcrete every hour.
- A storage area for material and equipment.
- The unit must house a small workspace for reparation purposes.
- The unit must be isolated, and able to operate in temperatures to -30° C.
- Unit will have windows.
- All in- and output will occur through one exchange panel.
- Due to regulations, no permanent connections can be made directly to the sea container. The container will be equipped with in internal construction.
- Production line must be fully automatic equipped with sensors and automatic valves *

Safety

Safety is a primary aspect of the mobile factory. All safety measures must be displayed visually, so all workers and users can follow safety instructions.

- Protection for revolving parts
- Fencing and railing along operating equipment to prevent injury.
- Dangerous components will be highlighted by international stickers
- Fire extinguishers and smoke detectors
- All electric components will be grounded
- Alarm in case of problem (audio and visual)
- First aid kit

Engines (electrical)

An inventory of all electrical engines is needed to determine the total energy usage of the container.

- 2x external centrifugal pump (4kW) for spraying Cellcrete
- 1x eccentrically worm pump (2,2kW) for 3d ice printing
- 1x water pump
- 3x air pumps for inflatable
- 2x Mixer engines for premix

Electric components

All electric components need to be engineered and tested.

- Multiple power outlets
- Electrical cabinet with fuse box
- Emergency generator >7kW
- Central panel for engine control*
- All engines must be frequency regulated

Overall Monitoring System (OMS)

The whole building process and the monitoring of it, can be controlled from one main hub: OMS. This system can not only monitor and manage the status of the inflatable, but the production line can also be controlled from this main hub.

- Real-time pressure of inflatable
- Atomically maintaining the pressure
- Temperature in and outside inflatable
- Program to visualize and control all electrical engies.*
- Communication center (Porto phone base)
- Wifi
- Laptop

Wet compartment

All wet activities are clustered in one compartment to prevent major disruptions with electrical components.

- Production and distribution of Cellcrete; for spraying and 3d-printing.
- Premix will be executed with modified IBC-containers
- Shredder
- Buffer (exclude when possible)

Dry compartment

All dry activities are clustered in one compartment to prevent major disruptions with wet activities.

- Position of electrical components
- Position of OMS
- Position of emergency generator

Storage

Storage space will be designed to be as compact as possible.

- Hoses
- Nozzles
- Cellulose
- Inflatable
- Cabling
- 8 steel shovels
- 8 snow shovels

workplace

The workplace is suited for small repairs and adaptions. By housing it internally, better working conditions are realized for construction workers.

- workbench
- Vice
- Variety of tools
- PVC welding equipment

office/residence

The office and residence are established to coordinate the building process, as well as a place for the construction workers to rest, and regain temperature.

- Coordination of building process.
- Room for rest and heat
- Coffee machine
- Water boiler
- Fridge
- Changing room

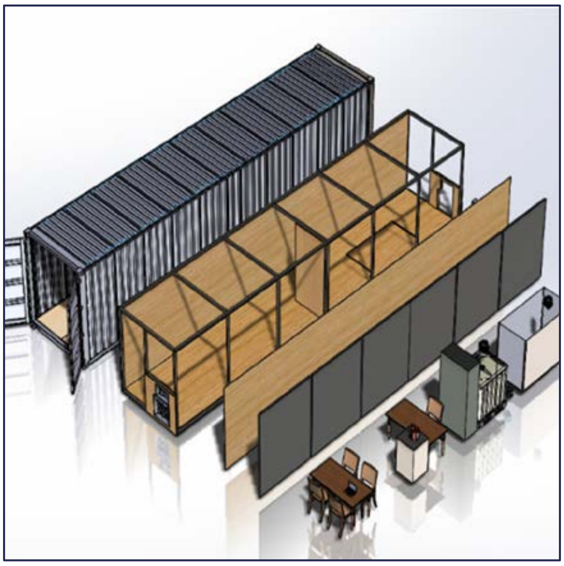


Figure 85; Top view container concept

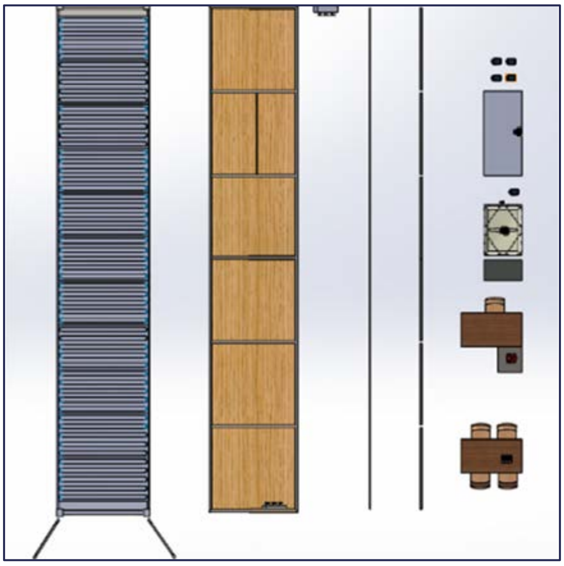


Figure 86; Concept of internal construction in container

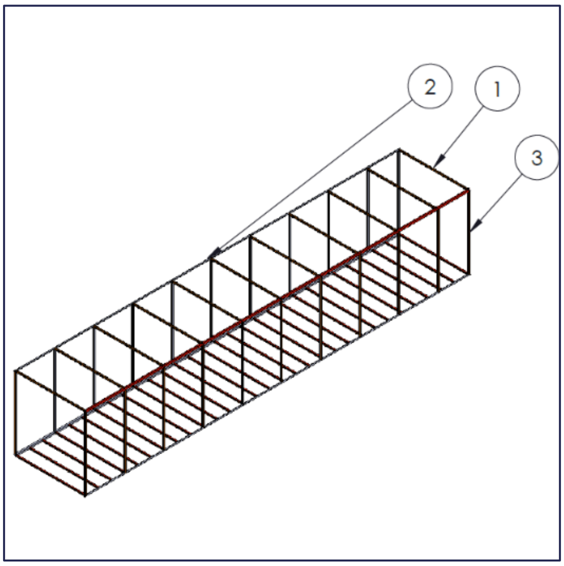


Figure 87; Steel internal frame, numbers represented details

*: due to financial limitations, these points had to be delayed for further engineering.

All needed materials of the design, are summarized in annex 7.

Container design

A first container design is engineered as in annex 8. This design is fully orientated on the pre-stated requirements. However, the scale of the project has become bigger than expected. Not only time based, but also financially. Therefor some simplification of the initial design had to be implemented. This led to the following adjustments:

Inner frame will be executed in wood; faster and cheaper.
Fully automatic production line will be trimmed down to manual control; cheaper, but more sensitive for human error.
Container will house only one opening instead of two; container is sponsored.
Lay-out will be divided in two spaces: a machine room, and an office; saves time and costs, but neglects the preference to separated electricity from wet activities. This results in the application of special splash proof electrical cabinets.

The further descriptions show the final engineering.

To make transportation of the container possible, it is not allowed to directly secure the internal structure to the container (with welding or drilling). Transport operators will only transport a sea container when it is inspected and provided with a seal of approval. To gain this seal, the container must be in original condition.

To bypass this limitation, an inner intendent structure is designed as in figure 85 and 86. By this approach, the whole factory is considered as cargo, and therefore no further seal or examination is necessary.

A separate wooden frame is designed to serve as inner construction. Every addition to the wall structure will be mounted on this inner wooden frame as specified in figure 87. The spaces between the wooden beams will be filled with insulation material and a foil layer, to prevent condensation to the outer (cold) steel wall. Work drawings can be found in annex 9.

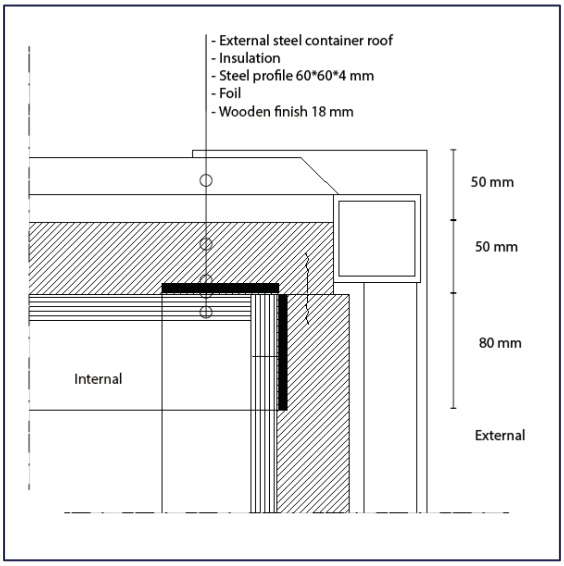


Figure 88; Detail 1; vertical section of the wooden framework at the corner connection

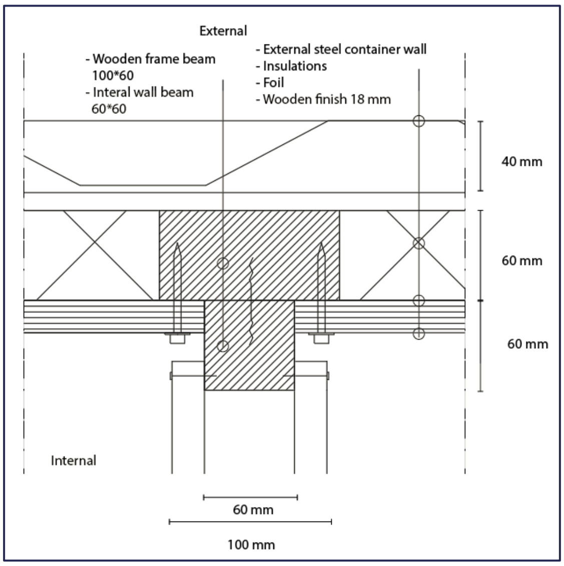


Figure 89; Detail 2; horizontal section of inner wooden structure with inner wall

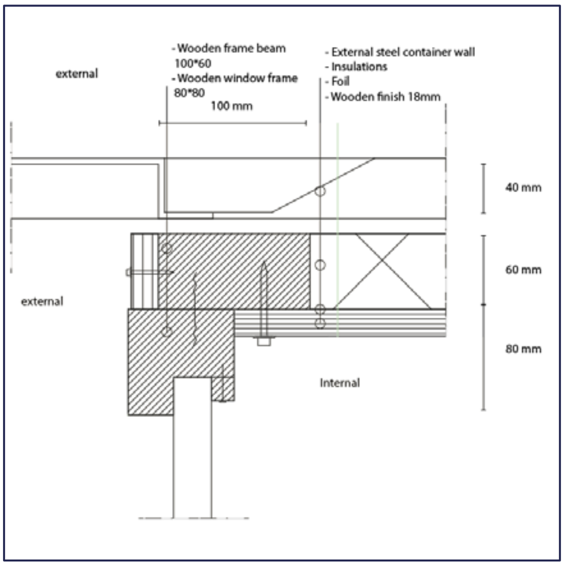


Figure 90; Detail 3; horizontal section of the connection of the wooden frame with the internal facade

The frame will be built totally independent from the container. The connection of the beams will be established using stainless steel screws.

The frame consists of four frameworks which are constructed outside the container.

The choice of wood makes it able to execute the isolated walls as thin as possible. Because the insulation values of wood are acceptable for this purpose, only the thickness of the beam resembles the lost free space. Direct contact with the steel outer wall is therefore no problem. The insulation will be stacked behind the wooden.

The following paragraph show some schematic details of the inner construction of the container. The location of the details can be found in figure 87. The overall drawing can be found in annex 10.

Detail 1 (figure 88) shows the vertical section of the connection of the corner with the inner framework. The different wooden frameworks are connected using steel brackets.

Detail 2 (figure 89) displays a horizontal section of the wooden frame inside the container. At the position of the wooden beam, an inner wall is connected to separate differing internal spaces as defined in the plan of requirements.

The detail shows a total wall thickness of 80 mm. In practice it is expected that the beams will interfere with the outer container wall. But because of the insulation capacity of wood, this is not considered as a problem or thermal bridge.

The insulation is covered with a foil that forms a damp barrier. This is important to avoid condensations and oxidation in the construction. The wall is finished with the mounting of wooden multiplex plates. The distance between the vertical frameworks is set on the standardized dimensions of the multiplex plates. This simplifies the mounting during construction.

As figure 91 shows, the sides of the container will be finished with a second façade behind the container doors. This façade (one-sided) is equipped with a door, windows, and connections for the production. The façade is constructed to maintain the indoor climate, and add daylight to the workplace.

Detail 3 (figure 90) displays a horizontal section at the connection between the wooden framework and the inner façade. The façade is simply constructed of a window and a door frame.

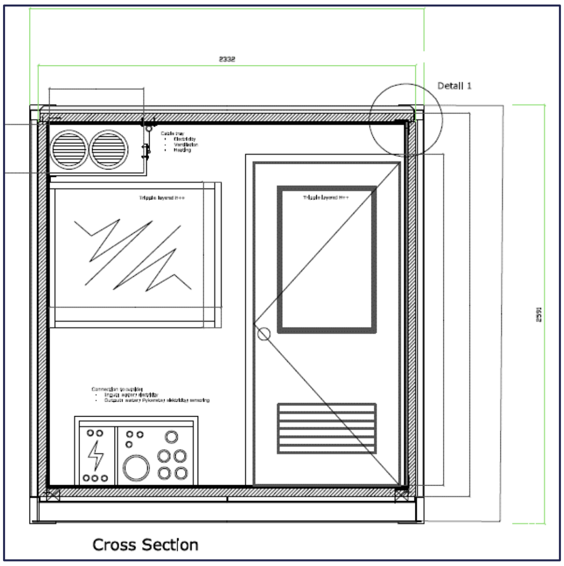


Figure 91; Cross section of container facing the inner façade

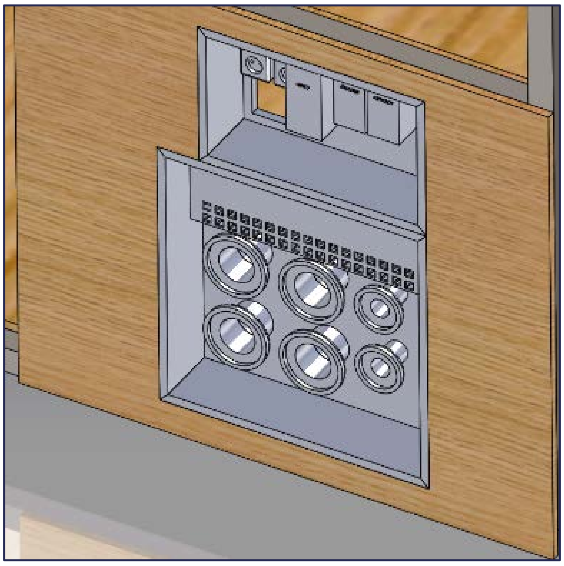


Figure 92; Specially engineered transfer panel for all in- and outputs

Connection	In-/ output	Function	Type
Dry			
Electric socket	Input	Main input container	63 ampere Euro female socket
Electric socket	Output	High power sockets * 2	16 ampere Euro male socket
Electric socket	Output	Main current *2	240 V Euro socket
Wet			
Water connection	Input	Main input container	1" GK connection
Water connection	Output	Water output	1" GK connection
Water connection	Output	Cellcrete output *4	2" GK connection

Table 4; Specification of transfer panel

A special transit panel has been engineered to combine all connections at one central point (figure 92). This prevents hoses and cables from entangling and creating an unworkable environment. The panel is divided in sections for wet connections, and dry connections. The wet connections consist of one water input, one water output, and 4 Cellcrete outputs (capability up to 4 pumps)(see table 4) . This panel is heated with hot air, to prevent ice forming on the connections. The panel will be covered with plastic flaps to optimize heating conditions, and prevent water from splashing. All connection are based on European GK connection of 1"and 2". To make international application possible, the connections can be removed leaving an outer thread 1"or 2" to mount all types of connections.

The dry panel consist of a 63 ampere input, two 16 A output and two 240v output. This panel will be covered with plastic flaps to prevent damage by water splashing. All sockets are based on Europe standards. Modifications can easily be made by adding adapters to the sockets.

The glass in the window and door is established with insulating h++ glass, to guarantee a good insulation.

Practice

The execution of the container has been assisted by the SUMMA Klusbus (figure 93,94,95 and 96). This is an educational project to connect students with real-life projects. The full wooden isolated frame, with façade and inner wall, is constructed by the students of the SUMMA klusbus.

Figure 97 shows the façade. The final execution is based on a simplified model of the engineered design. Due to financial and planning limitations, the façade had to be modified. This resulted in the elimination of the separate window, the exchange panel and a reduction of the door window.

Figure 93; Construction of inner insulated wooden frame

Figure 94; Sponsored 40ft container by Mammoet

Figure 95; Finished interal walls

Figrue 96; Finished internal walls, faced to internal façade

Figure 97; Inner façade in container

Production line

The system as engineered in chapter 'Improvements' resulted in a high financial investment. At the moment of execution, there was no budget to realize the system. Therefore, some modification has been made to reduce costs and time. This involved all automatic valves to be replaced with manual alternatives. This means that an operation crew needed to be trained to operate the production line. The drawings of the new production line can be found in annex 10.

The whole production line has been engineered on a steel frame, and elevated 30 cm (figure 98). This creates a space for the positioning of hoses and cables, improving accessibility and compactness. Also the whole floor of the wet room has been coated with a watertight sealing, to make sure no water is seeping in the wooden structure. By doubling the pre-mix tanks, one shredder should provide the cellulose supply of two tanks instead of one. Therefor a special rail has been engineered, so the shredder could slide between the two mix tanks (figure 99 and 100). The production line has been executed as compact as possible resulting in a total dimension of 3500*1100*2200 mm (l*w*h).

Figure 98; Steel frame for movement of shredder

Figure 99; Engineered manifold to connect pumps to pre-mix tanks

Figure 100; Realization and programming of production line

Electrical engineering

To engineer the electric circuit, it is important to overview the total consumption. A full overview of the electronics has been analyzed and can be examined in annex 10. Table 5 and 6 shows an estimation of the energy consumption

This estimation gives a clear view on the energy consumptions when all the different components are simultaneously active. It has to be stated that all electronic parts are assumed to run at full capacity. A total consumption is calculated of 11+21 = 33 kW with an amperage of 77,4 A. This resembles a high demand of electricity which need to be distributed properly.

Figure 101 shows an electric distribution where different current categories were made. The electronic distribution has been established by considering electronic elements with comparable consumptions, and probability to activate fuses (wet compartment). All electric motors are equipped with a frequency regulator to control the engines speed. The energy consumption is displayed by the regulator when the electric motor runs at the optimal operation speed. These values seems to be lower than the values of table 5. The input energy can therefore be stated on a multiple phase 63 A line. Realizing that not all components will be active at the same time, and not at full capacity, this power input need to be sufficient. The choice for the 63 A input also simplifies the availability of an electrical connection on a building site, because of the standardized international load connection.

.

Item	Consumption (kW)	Quantity	Total	Amperage
Coffee machine	2	1	2	8,7 A
Cooking plate	1,5	1	1,5	6,5 A
Heater	1	4	4	17,4 A
Lighting led	0,036	12	0,432	1,9 A
Fridge	0,1	1	0,1	0,4 A
Water boiler	2,4	1	2,4	11,3 A
Laptop	0,5	1	0,5	2,3 A
		total	10,9	kw
		I=p/u	47,53	A

Table 5; Estimation energy consumption of 1-phase consumers

Item	Consumption (kW)	Quantity	Total	Amperage
Centrifugal pump	4,5	2	9	13 A
Wormpump	2,2	1	2,2	3,2 A
Mixer	1,5	2	3	4,3A
Shredder	1,5	1	1,5	2,2 A
Control air system	5	1	5	7,2 A
		total	20,7	kw
		I=p/u/√3	29,89	A

Table 6; Estimation energy consumption of 3-phase consumers

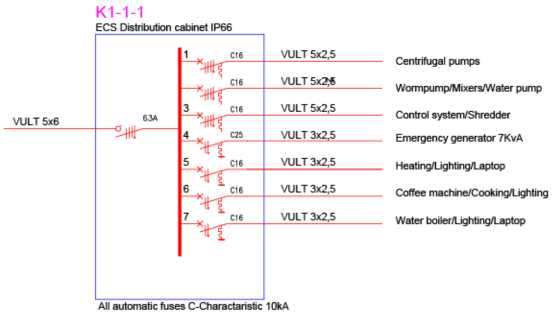
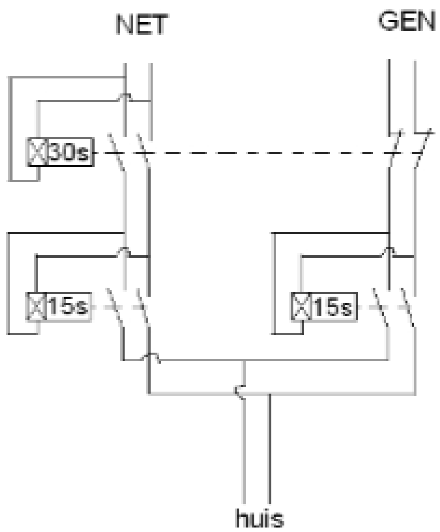


Figure 101; Scheme of electricity distribution

Figure 102; Emergency generator 7KVA sponsored by Valkenpower



1Figure 103; Electric circuit of the automatic take over of the emergency generator

The system will be equipped with an emergency generator (figure 102). The capacity of the emergency generator has been selected on the most critical components of the system. Maintaining the pressure in the inflatable is primary. Secondary is the heating of the container to prevent freezing of Cellcrete in the system. The consumption of the air pump control is listed in table 6 and stated on approximately 5 kW. Due to financial aspects, and limited space, it is important that the generator is limited in dimensions (and with that its output). A standardized generator of 7 KVA resembles a load output of approximately 5,6 kW. This will be enough to power the control system of the inflatable, and some LED emergency lights.

It is important that the emergency generator is automatically started when there is a power shutdown, to minimize the time no electricity is provided. The control system is executed with an UPS to intercept the power shutdown and the current peaks. Figure 103 shows the automatic takeover circuit of the container. When electricity is not provided by the net, a check will send a signal to the relay of the starting engine of the generator. The generator will take over the power supply. In this system, the generator should be shut down manually when the public power net is restored again. See figure 105 and 106 for the implementation of the electricity.

The electricity is mounted following the electric circuit overview as presented is annex 10. All sockets are executed with European sockets. Adapters will be available for different internal sockets.

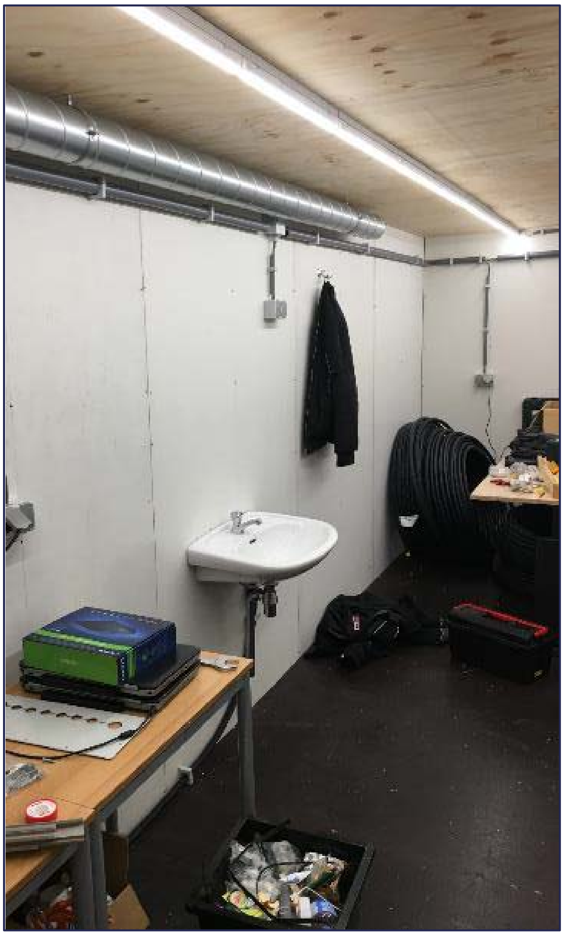


Figure 104; Electric sockets are connected as engineered in the electric circuit

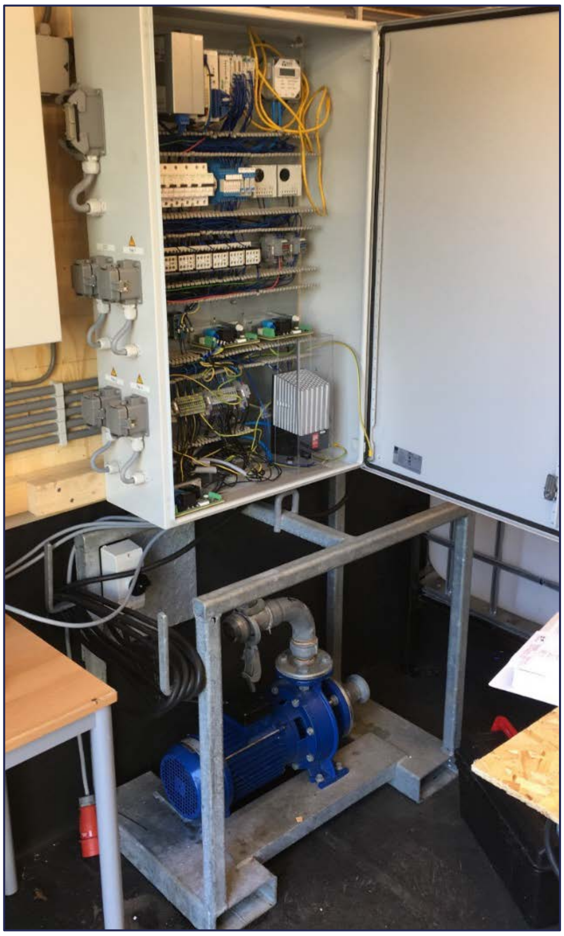


Figure 105; Electrical cabinet during installation

Figure 106; Ventilation scheme

Figure 107; Vventilation unit of mobile factory

Figure 108; System in operation, signaling an error with acoustic and visual notifications

Figure 109; Test of the air monitoring system with acoustic and visual alarms

Ventilation

Because of the activity of construction workers in the mobile factory, it is important to create an environment with good working conditions. Not only heating, but also the provision of fresh air is essential to achieve a pleasant working space.

Because the extreme difference in temperature, the loss of heat by refreshing the air should be limited. Therefor a heat exchanger system is selected as a ventilation option. An estimation of the capacity is made in the following calculation. Assumed is that the inner temperature should just be above freezing point (0°C). A big difference with the outside temperature is experienced as unpleasant (Drijvers, et al., 2015). When the outside temperature is -30°C, the difference in temperature results in ΔT= 30 at max. To select an air distribution capacity, the NEN standard of 25m3/h of air distribution per person is stated. With a total of 10 construction workers this add up to an air distribution of 250 m3/h.

$Q=c*m*\Delta T$
c air= 1 (J/kg*K)
m= 1,29 Kg/M3 1,29 *250= 323 kg
$\Delta T1$= 30 °

Q = 1 * 323 * 30
Q= 9690 watt per hour
9690/ 3600 = 2,7 KW

It can be concluded that a heat exchanging system with a distribution of 250 m3/h and 2,7 kW is needed.

Due to time and financial limitation also this component is simplified. This resulted in the following ventilation plan (figure 107).

The ventilation has been simplified to a mechanical extraction system. The air will be extracted in the back of the container. The front panel, will be executed with grids to ensure a natural air input. Heating will be provided by separate air heaters. This modification is not as effective and efficient as the original design, but it covers the minimal requirements of 250 m3/h air distribution. This solution will need extra capacity of the heaters due to the input of cold air.

Figure 110; Testing of monitoring system

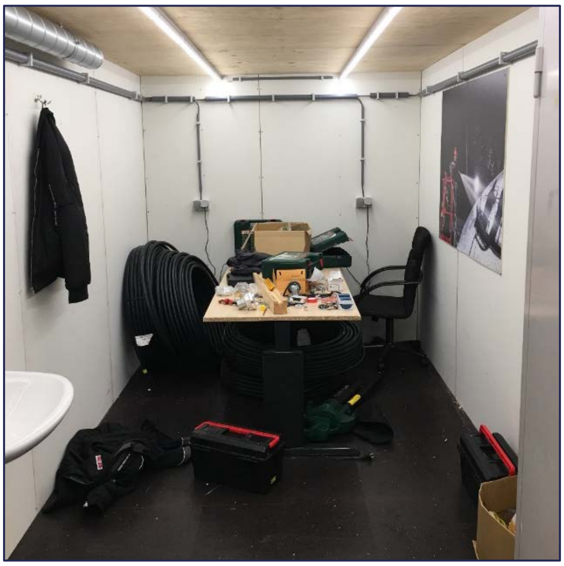


Figure 111; Internal office

Overall Monitoring system

The initial engineering concept was to fully automate the production line and the inflation of the inflatable. Both could be monitored and controlled from one main platform. Due to the simplifications of the production line, the OMS only needed to control the status and inflation of the inflatable.

During the 'Bridge in ice' project, a system has been engineered to monitor and control the status of the inflatable (see figure 108, 109 and 110). The systems controls the air pumps on a predetermined pressure. Pressure sensors measure the pressure and control the capacity of the air pumps to maintain the internal pressure.

The system is also equipped with distance sensors, to measure deformations in the inflatable. As well as for pressure, as deformations, boundary conditions can be programmed in the system. Dependent of the priority of the problem, the system will report errors or failures with acoustic and visual notification.

The monitoring system will be integrated in the monitoring area of the mobile factory. The visualization is adapted to the current project. Also new, more efficient air pumps have been connected to the system. Every air pump is equipped with its own visual error indicator as displayed in figure 109.

Figure 112 shows the electrical scheme of the monitoring system. No hardware adaption had to be made to ensure a good working system in the new project.

Completion of Mobile factory

After the final installations and testing, the container is transported by train to the building site in Harbin. See figure 111, 113 and 114 for an indication of the container.

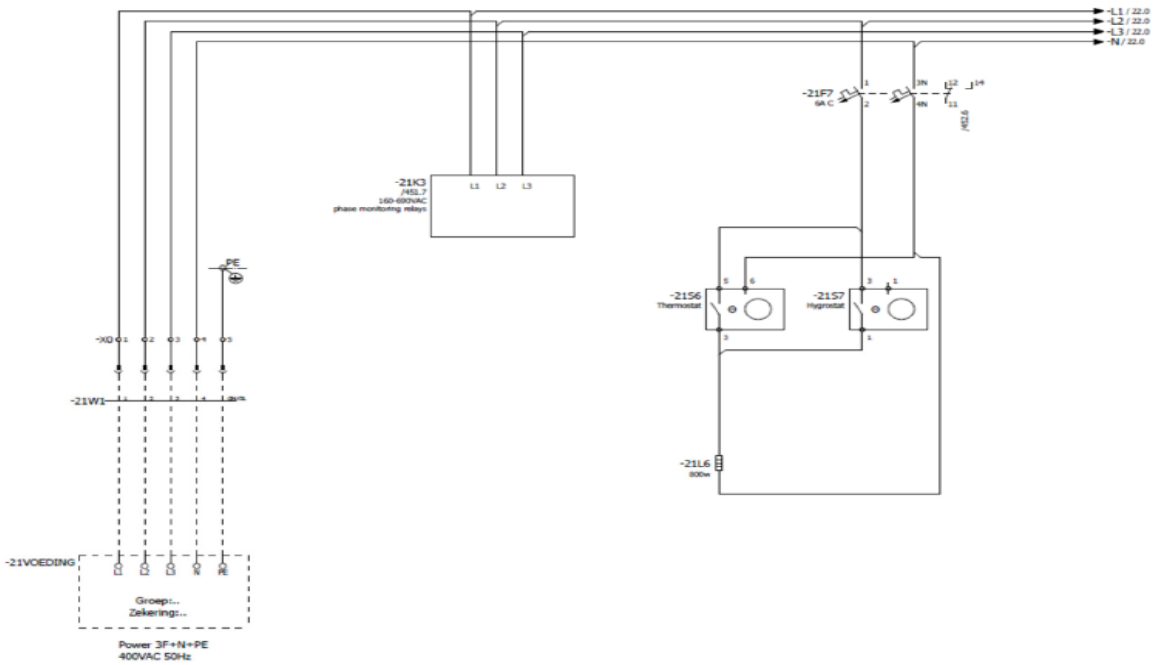


Figure 112; Electrical circuit of the air monitoring system, where the PLC controlls the capacity of all three airpumps. source: (Moonen, 2016)

Figure 113; Completed production line

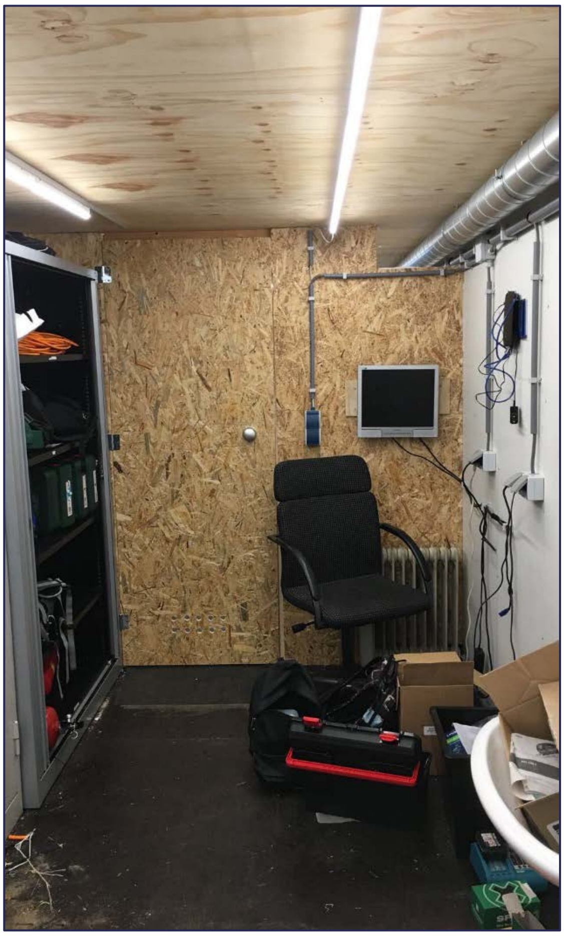


Figure 114; Monitoring corner

5.Orginazation optimizing

The design resulted in the execution of different activities. In this chapter, the different activities are analyzed on mutual relations. This resulted in a proposal of the most optimal organizational approach.

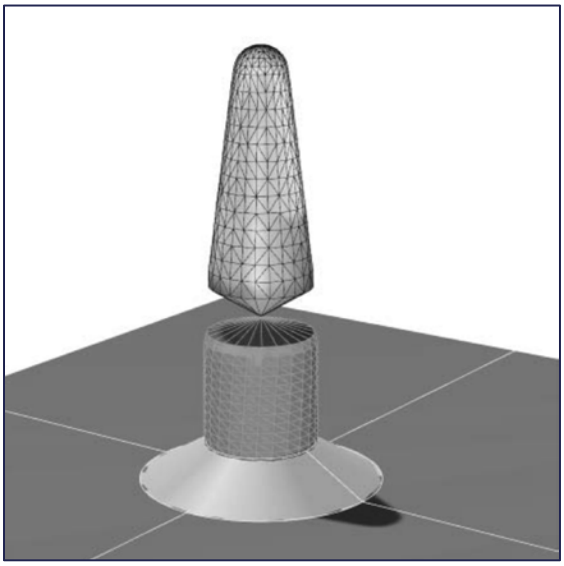


Figure 115; Construction of ice stairs and placement of inflatable.

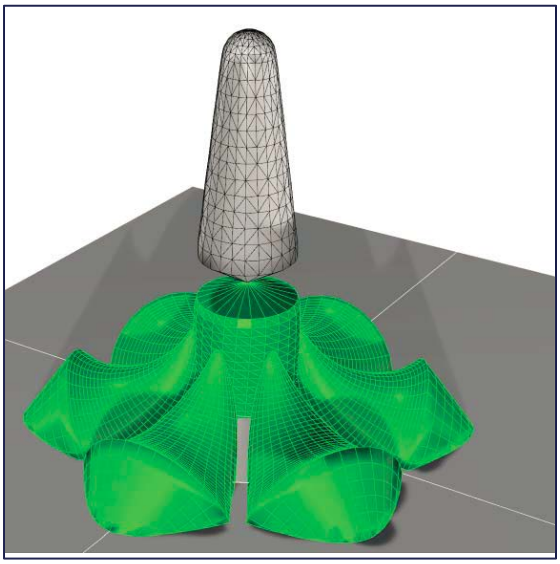


Figure 116; Leg inflation

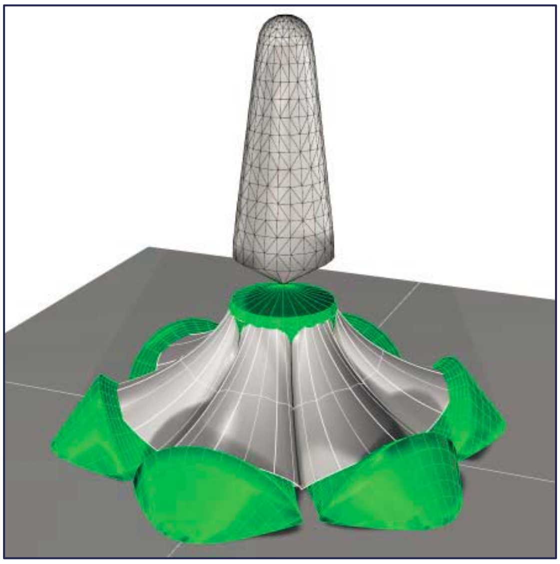


Figure 117; Base shell construction

5.1 Building sequence

As concluded in the paragrah 'preparation-inflatable', the inflatable would not be stable enough to be fully inflated at once. Full inflation would led to excessive influence of the wind what could result in a deformation. This deformation could led to damaging the developing ice shell and even to the inflatable itself (Kern, et al., 2015). To prevent a major fault like the 'Sagrada Familia in Ice' project, where the wind deformated the 30 meter high inflatable until rupture, another approach needed to be preprared.

The inflatble could be supported midway using ropes but, as stated before, this was not prefered due to limited movement and accessibility on the building site (Drijvers, et al., 2015). Therefor, a solution has been found in partially inflatalion. In the folowing paragragh all steps in the building sequence will be discribed. The green coloring will indicate the inflated part of the inflatable. The grey part will indicate the excessive uninflated material. The execution of the sequance will start when the building site preparation has been completed, which includes the drilling and mounting of the ground anchors.

Construction of ice stairs

To stabilize the inflatable, the ice ring will be prepared in this first phase (figure 115). By postponing the positioning of the inflatable, the accessibility to the middle part of the tower will be optimized and the chances to damage the inflatable will be excluded. The grey colored inflatable shows the position where the tower will be after hoisting the inflatable in the completed ice ring.

Before finishing the ice ring, ropes will be attached to the middle anchor points on the ground, so they could be attached to the inflatable later in the process.

Positioning of inflatable

The following step will focus on the positioning of the inflatable in the ice ring, according to the anchor pattern (already completed). The inflatable will be folded and packed when it arrives on the building site. It will be folded out, and hoisted in the ice ring (figure 115). The inflatable will be orientated and measured so the legs will meet the ground anchoring.

When the inflatable is in position, the tower will be fixed to the middle anchor points.

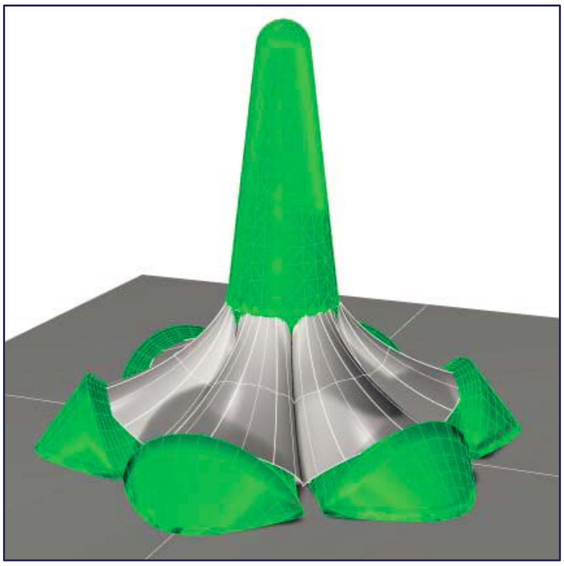


Figure 118; Full inflation and spray activities

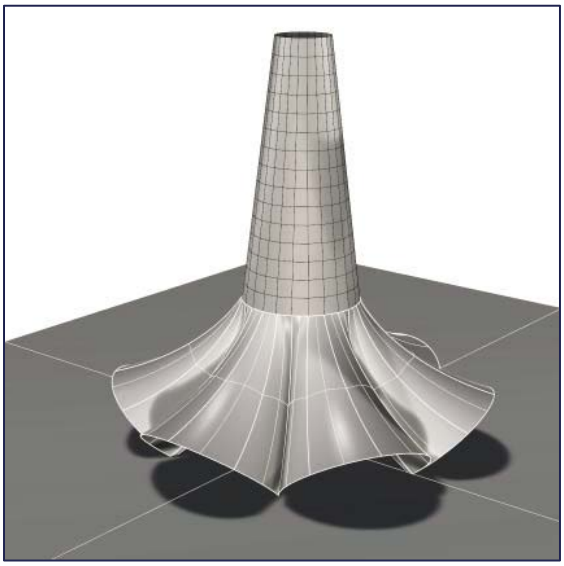


Figure 119; Completion of tower

Leg inflation

In the third step, the legs will be inflated and secured (figure 116). The connection of the ropenet will also take place in this phase. The upper part of the inflatable will be tied to close, so no inflation will take place in this part. First, the legs will be inflated to minimum pressure, where modification to positioning is still possible. Full inflation without the rope net will lead to a vertical rise of the inflated legs which could result in rupture or deformations.

By minimal pressure inflation, the ropes of the ropenet can be positioned and mounted properly on predetermined dimensions. The ropes will offer an option for adjustment, to compensate for any dimensional deviations. After securing the rope net, the legs will be inflated on the predetermined inflatable pressure. The weight of the uninflated tower part can be carried by the base, but is preferred to be hoisted by crane.

Base shell

After securing the inflated legs, the first spraying activities will start. These activities will consist of the ice shell development of the legs and the bottom part of the tower (figure 117).

The constructed ice base will act as a stabilizer for the rest of the tower, ensuring a more stable inflatable.

Full inflation

When half of the bottom shell thickness is reached, the tower will be fully inflated (figure 118). Because of the reduced length of the tower (from 30 meters to 20 meters) the stability of the inflatable will be improved. Compared with previous projects (where towers of 24 meters are constructed), the inflation steps will lead to a stable inflatable during construction (Kern, et al., 2015).

After full inflation, the spraying will be continued. It will be important to develop the ice shell from the bottom to the top so the shell will be strong enough to carry the increasing self-weight (Hijl, et al., 2014).

Completion

When the final thickness is reached, the inflatable could be deflated (figure 119). It will be important to measure the thickness of the ice shell during the construction on different places to ensure an evenly distributed development of the ice shell.

After deflation, the inflatable will be removed. Because of the expectation that the mounted anchor points of the inflatable will be covered in the ice base, full removal of the inflatable would lead to deliberately damaging inflatable and ice base. Therefore, the full inflatable will be positioned in the middle of the ice ring. Water will be added layer by layer to freeze the inflatable within the tower base and create an elevated platform. After the melting process of the tower, the inflatable could be re-used.

The last activities will consist of finishing the leg cantilevers, the ice stairs and placing lighting in- and outside the tower.

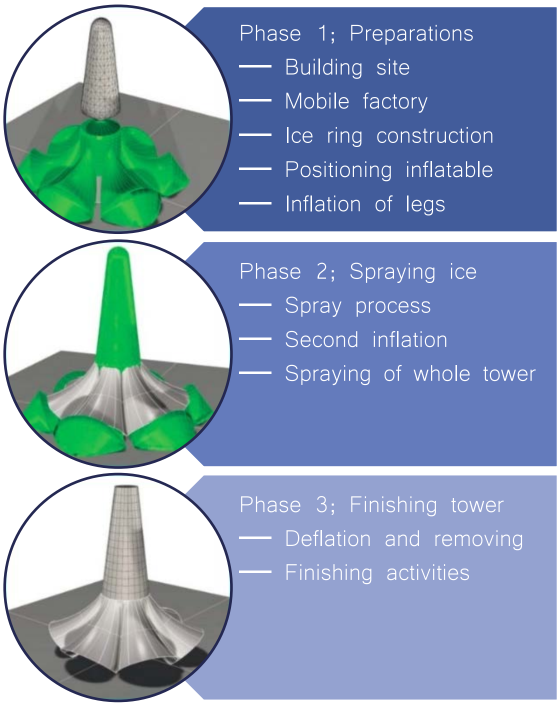


Figure 120; Phased including activities

5.2 Planning

The planning during the construction is divided in three main parts of the construction. A full overview of the construction planning will be given in annex 11. The three different phases and the corresponding activities will be described (figure 120). Activities, and mutual relations will be further analyzed with SADT-schemes. Construction steps and estimated time are based on previous ice projects (Drijvers, et al., 2015) (Borsboom, 2015), and the experiences of the pilot project (Moonen, 2017). The planning is only based on the construction of the tower. Side projects are not taken into account.

Phase 0: anchoring; before 8-dec-2017

In the period before the construction starts, the anchors will needed to be drilled and casted in the ground. Figure 121 is a schematic overview of phase 0. It is important to execute this before the ground is frozen solid. A frozen ground will obstruct the hole drilling as well as the hardening of the concrete. Therefor this activity should be performed before the extreme cold starts. Table 7 is an overview of the description of the activity and the needed labor, time and equipment of phase 0.

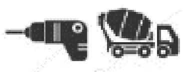
Activity	Description	Workers	Estimated duration	Equipment
Equalizing terrain	Equalizing terrain to enable construction	1 shovel driver	4 hours; 0.5 day	 Shovel
Executing floor anchors	Mounting the floor anchors for the attachment of the inflatable	2 construction workers 1 drill operator 1 truck driver	24 hours; 3 days; hardening time excluded	 Drilling installation Concrete truck

Table 7; Overview of phase 0

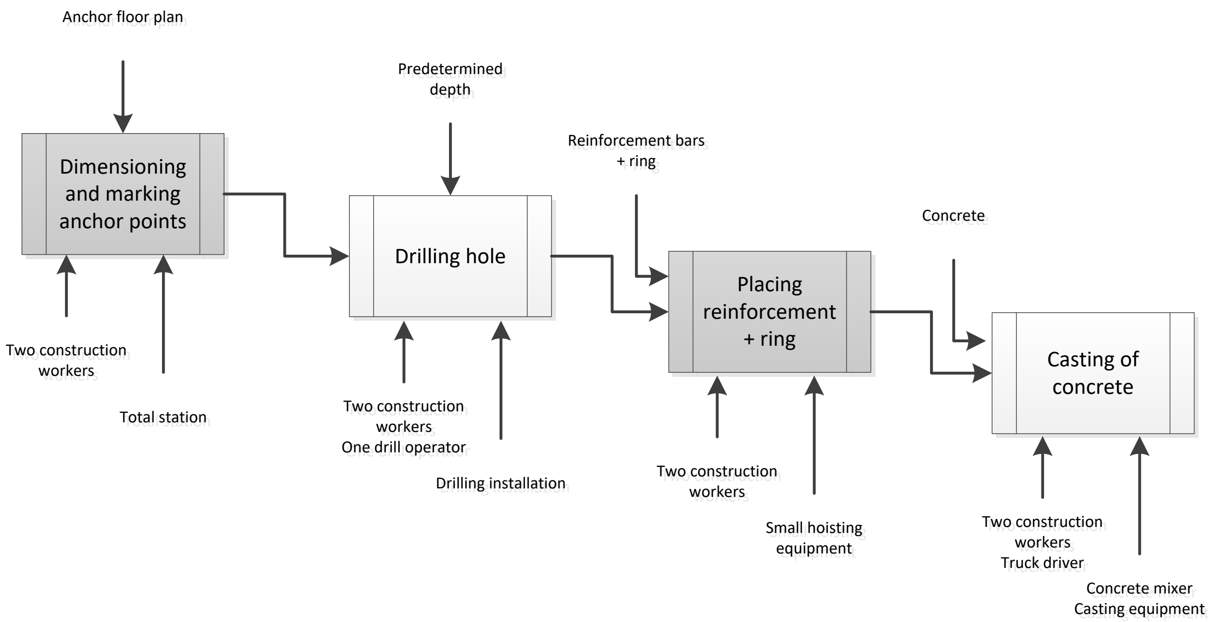


Figure 121; Schematic overview of phase 0

Phase 1: preparations; 8-dec-2017 till 15-dec-2017

Phase 1 will be separated in three steps. The first step will consist mainly of the preparation of the building site, the measurements and the first inflation. This phase is distinguished because a normal work schedule (of 10 hours) is maintained. Table 8 is an overview of the description of the activity and the needed labor, time and equipment of phase 1, step 1.

Activity	Description	Workers	Estimated duration	Equipment
Enclosing Building site	Fencing building site Arranging security 24h	4 construction workers	8 hours; 1 day	 Truck
Applying electricity for building site	Connecting electrical cabinets Connecting Mobile factory Connect lighting building site	2 construction workers 2 Electrical engineers	16 hours; 2 days	n/a
Applying water lines for building site	Placing waterline for Mobile factory Placing reserve waterline Applying heating cord to waterlines to prevent freezing	4 construction workers	16 hours; 2 days	n/a
Positioning of Mobile factory	Positioning mobile factory Connecting container to electricity and water	2 construction workers 2 electrical engineers 1 crane operator	8 hours; 1 day	  Truck Crane

Table 8; Overview of phase 1, step 1

As the building sequence shows, the next step will be the construction of the foundational ice ring. Most blocks will be stacked as they are delivered, without customizing. The open gaps between the blocks will be filled with customized blocks and snow.

The building speed of the ice ring has been estimated by the movement time of one ice block. Table 9 is an overview of the description of the activity and the needed labor, time and equipment of phase 1, step 2 and figure 122 is a schematic overview of phase 1 step 2.

Activity	Description	Workers	Estimated duration	Equipment
Construction ice ring	Measuring position Stapling ice blocks Fill gaps	6 construction workers 1 truck driver 1 shovel operator	20 hours; 2,5 day	 Shovel Truck

Table 9; Overview of phase 1, step 2

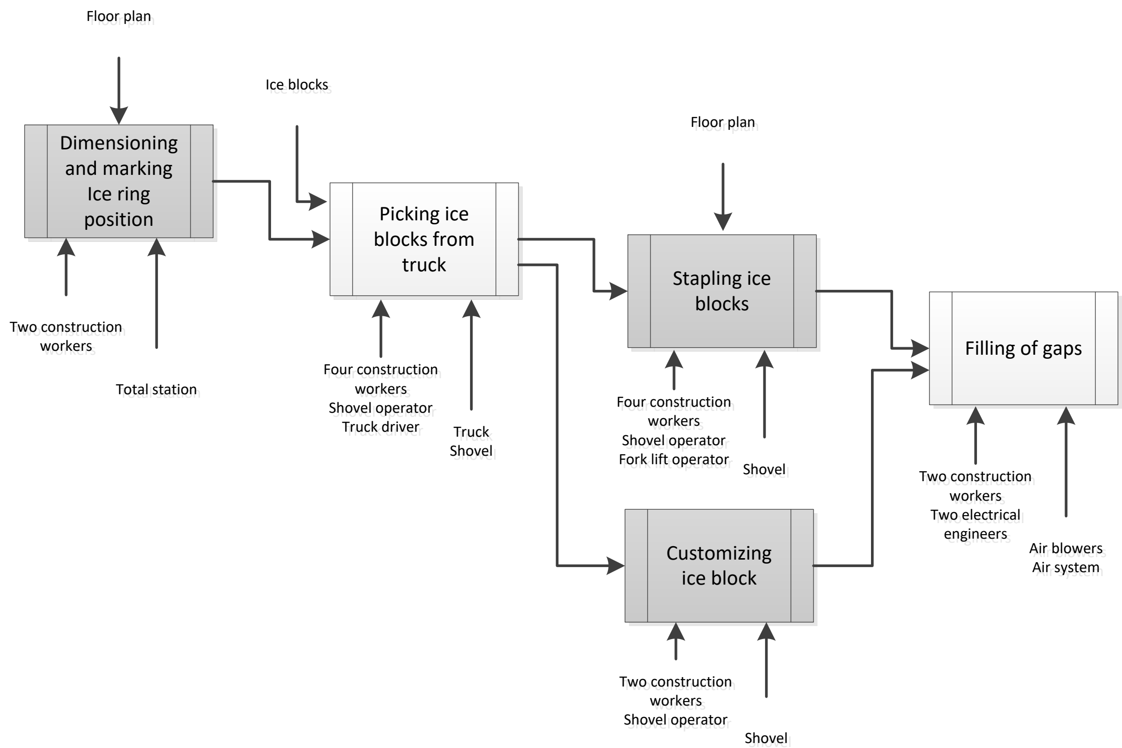


Figure 122; Schematic overview of phase 1, step 2

Activity	Description	Workers	Estimated duration	Equipment
Positioning inflatable	Measuring position Hoisting inflatable in place Attaching tower middle anchors	6 construction workers 1 crane operator 1 truck driver	8 hours; 1 day	 Truck Crane
First inflation	Tying down of non-inflating parts Connecting of air system Attaching ropenet Inflating process	4 construction workers 2 electrical engineers 1 crane operator 2 boom lift operators	24 hours; 3 days	 Crane Boom lift  Air monitoring system

Table 10; Overview of phase 1, step 3

After the construction of the ice ring, the positioning of the inflatable will be performed. The inflatable will be delivered in a folded package by truck. This package needs to be unfolded and hoisted in place. After securing and connecting the air system, the first inflation will take place. The attaching of the ropenet will be done while the underpart of the inflatable is slightly inflated. This will simplify the positioning of the ropes, and holding them into place. Table 10 is an overview of the description of the activity and the needed labor, time and equipment of phase 1, step 3 and figure 123 is a schematic overview of phase 1 step 3

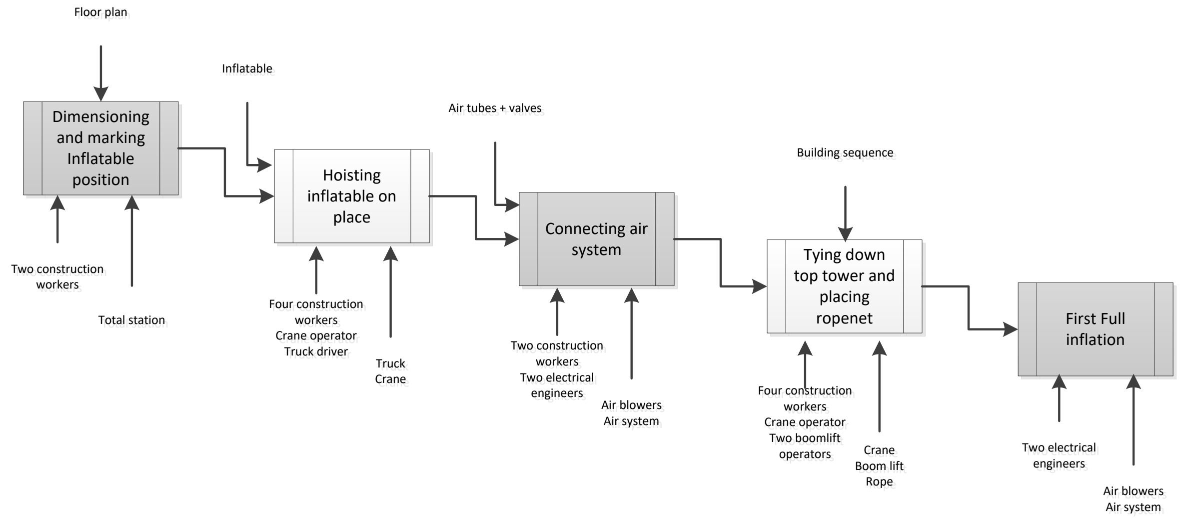


Figure 123; Schematic overview of phase 1, step 3

Phase 2: spraying ice 16-dec-2017 till 27-dec-2017

Phase 2 will be fully oriented on the spraying activities This phase will be the first time the mobile factory will run the production line on full capacity. To avoid freezing of hoses and nozzles, a 24/7 schedule will be stated in this phase to prevent an interruption in the Cellcrete flow. Because starting and stopping the spraying activities will take a lot of time, it is preferred to continue the spraying activity without interruption (Drijvers, et al., 2015).

The spraying sequence will consist of two parts: the base construction, and the full tower construction. During spraying, the progress will be monitored due to measurements. This consists of drilling holes on predetermined locations and measure the depth. The first spraying part will be performed with two spraying teams. One spraying team will spray from a ground position, the second team will connect the spray activities to the boom lift, to spray from an elevated position. This will not only create a wider range of spraying, but it will also guarantee that all spots will be reached. The first spraying part will be completed when the thickness of the legs has reached 50% of the total thickness after completion. Measuring activities will minimally delay the spray activities, because the activities can be executed in parallel.

After the first part, the whole tower will be fully inflated. From this point on the tower will be fully covered in ice (build up from the bottom). To support the progress, a second boom lift will be used. Both spraying teams will spray from a boom lift. It is expected that the base thickness will grow evenly with the tower while the spraying activities are focused on height gaining (Kern, et al., 2015).

The building speed is based on previous projects, where in the most optimal situation of 1 cm of ice shell will be constructed every hour (Drijvers, et al., 2015). A more reliable building speed can be determined by the comparison of completed structures. This will state a building speed of 0,5 cm/hour when constructing with a well trained and experienced crew (Koekkoek, et al., 2016) (Moonen, 2016). Within the estimated time an error rate, and extra spray time will be included to cover unforeseen delays. Table 11 is an overview of the description of the activity and the needed labor, time and equipment of phase 2 and figure 124 is a schematic overview of phase 2.

Activity	Description	Workers	Estimated duration	Equipment
Cellcrete production	Operation of Mobile factory Monitoring of process Start of 24 hour schedule	3 production line operators 1 monitor operator 1 supervisor	Continously	Mobile factory
Spraying Cellcrete part 1	Spraying of the legs and base of the tower. 1 spray team consists of: 1 nozzle operator 3/4 hose carriers	2 spray teams 2 boom lift operators	84 hours; 3,5 day	Boom lift Mobile factory
Measuring	Predetermined measuring locations Thickness of shell is monitored	2 construction workers 2 boom lift operators	4 hours; 1/6 day	Drilling equipment Boom lift
Full inflation	Releasing tied down top section Fully inflation	4 construction workers 2 boom lift operators	4 hours; 1/6 day	Boom lift Air monitoring system
Spraying Cellcrete part 2	Spraying of whole tower 1 spray team consists of: 1 nozzle operator 3/4 hose carriers	2 spray teams 4 boom lift operators	168 hours; 7 day	2 Boom lifts Mobile factory

Table 11; Overview of phase 2

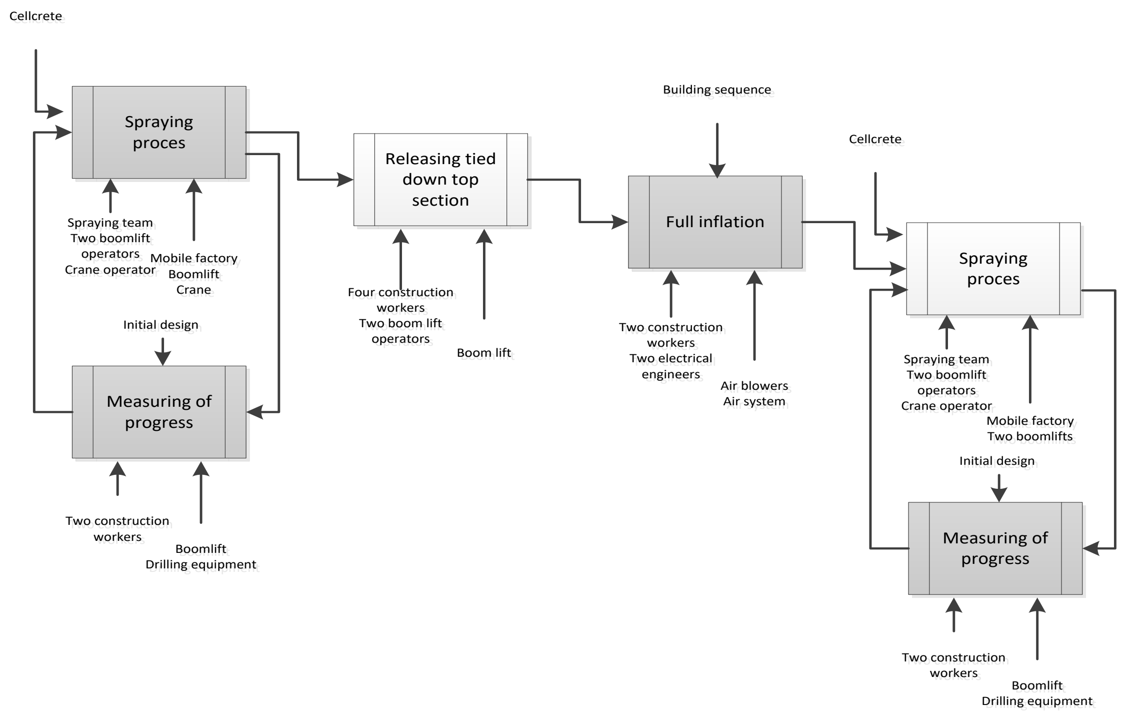


Figure 124; Schematic overview of phase 2

Phase 3: Finishing tower; 27-dec-2017 till 01-jan-2018

After reaching the predetermined thickness of the tower, the inflatable will be deflated using the air system. The inflatable will be removed from the inner walls of the tower. Experience from previous projects states that this activity can be assisted by the pulling strength of a shovel (Drijvers, et al., 2015).

The inflatable will be folded in the ice ring, and frozen in water till the platform is completed. The finishing of the tower will consist of removing excessive material, and finishing the ice stairs. An external company will provide lighting according a pre-designed light plan. Table 12 is an overview of the description of the activity and the needed labor, time and equipment of phase 3 and figure 125 is a schematic overview of phase 3

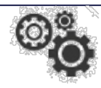
Activity	Description	Workers	Estimated duration	Equipment
Deflation	Deflation of inflatable	2 construction workers 2 electrical engineers		 Air monitoring system
Removing inflatable	Inflatable is positioned in the middle of the ice ring and frozen by layered water	8 construction workers 1 shovel operator	8 hours; 1 day	  Shovel Mobile factory
Finishing	Removing excessive material Completing ice stairs Placing lighting	4 construction workers 2 boom lift operators 2 electrical engineers		 Boom lift

Table 12; Overview of phase 3

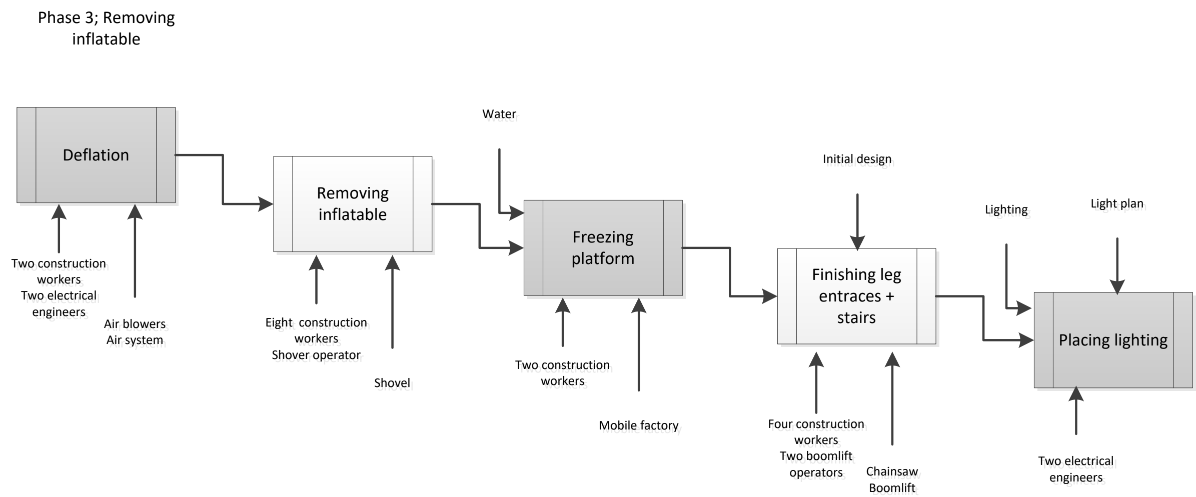


Figure 125; Schematic overview of phase 3

Opening ceremony

After finishing phase 3 of building the Flamenco tower in ice, the opening of the tower will be at the first of January 2018. From this moment on the tower will be transferred to the MLV and opened for public during predefined opening hours. Together with H.I.T. the tower will be monitored during this period to detect any deformations or excessive creep behavior.

During the construction of the tower there will also be an Ice pavilion contest. This contest consist of six small ice structures which will serve as extra attraction by the public opening of the Flamenco tower in ice.

Labor

Previous projects stated that the most optimal and efficient ice building method, is based on a continuous construction without interruptions (Hijl, et al., 2014). Since this schedule is not preferred because of night and evening shifts, the building phases will be organized along this scheduling. Phase 1 and 3 will conduct using a normal day shift, while phase 2 will be executed using a 24 hour schedule.

The schedule in phase 2 will be based on the spraying activities and will consist of three shifts. Every shift will have a full occupation, and will consist of Dutch and Chinese members. Because project management will be performed by the Dutch team, every shift will be led by a Dutch supervisor. This supervision will be supported by a Dutch engineer and a Chinese engineer who could also act as a translator.

For the three shifts of the 24 hour schedule, shifts of 8 hours will be arranged (table 13). A working day contains one day shift, one evening shift and on night shift. previous construction reports state that continually working in the same shift is experienced as pleasant, instead of shifting between shifts (Kern, et al., 2015).

The planning has been optimized referred to the activities and demanded labor. Figure 126 shows a clear overview of the needed labor in every phase. The graphs shows the labor demand per shift.

The activities in the planning are analyzed for serial and parallel execution in relation to each other. Afterwards the activities are planned in a way that the labor demand is proportionally equalized per phase (see line 'Total labor per shift). This resulted in the most efficient approach of the construction planning which can be found in annex 12.

Figure 126 shows an average labor demand of 15 workers in the first phase. A peak occurs on the 11th of December. On this date the Mobile factory will arrive. This results in more crane activity and demand for establishing the connections of the factory.

The second phase is calculated on an average of 20 workers per shift. This houses, among others, two spraying teams, and one production team. Because three shifts fill the 24 hour schedule, the line 'Total labor per 24 hours' show the total amount of workers per day. This average is a factor three of a single shift resulting in 60 workers per day.

The third phase averagely contains 17 workers in a full day shift. This only houses the finishing of the tower.

Team	Leader	Working hours	Engineer (CH)	Engineer (NL)
Shift 1	Arno Pronk	22:00-6:00	Fang Fang/ Xiuming Liu	Qingpeng Li
Shift 2	Yaron Moonen	6:00-14:00	Boxuan Chen	Gavin van Turnhout
Shift 3	Gilles Ide	14:0-22:00	Yiling Zhu	Bart Rodriquez de Miranda

Table 13; Overview of

Figure 126; Overview of needed labor per day

5.3 Budget

The budget of the project has been divided in 2 parts: the mobile factory and the overall construction budget. Many different parties and sponsors were involved. Not all expenses are public. Therefor some costs will be estimated through the costs of previous projects.

Before the start of this projects, the estimated budgets of the pre projects are analyzed in table 14. In the billing of the 'Pykrete dome' project, a lot of costs were covered by the municipality of Juuka, therefor not all costs have been taken into account (Hijl, et al., 2014). The expenses of the 'Sagrada in ice' project have not been shared at all (Kern, et al., 2015). The costs overview of the 'Bridge in ice' project shows an extended overview of the estimated costs (Koekkoek, et al., 2016).

This project budget also covers the total expenses of the whole surrounding ice event. Therefor the costs are relatively high.

Together with the H.I.T., the project has found a local partner: Maple Leaf Village Outlet Centre (MLV). This is a local mall which was interested in the project, and its publicity. The MLV will cover most of the production costs as stated in annex 13. H.I.T. will cover the further design and the costs of the inflatable. TU/e will cover the costs of the mobile factory and the overall management.

Due to different interests on the project, some prices and costs will be considered as confidential. This will result in unknown costs. To still obtain a clear overview, an estimation of every cost category will be made.

Project	Year	Estimated budget [€]	Sponsoring [€]	Percentage sponsoring [%]
Pykrete dome*	2014	19.446	6.500	33,4
Sagrada in Ice*	2015	-	-	-
Bridge in Ice	2016	401.392	370.506	92,3

Table 14; Overview of budget of previous projects (*: none, or limited information is shared)

Overall

For this project, only the construction of the tower will be taken into account. Extra expenses for a second Chinese production line, the ice contest and an overall event will be excluded from this costs overview.

As compared to previous project, an important difference is related to the costs of labor. Previous projects are executed using volunteers. All previous costs overview describe an accommodational aspect for all volunteers, which was a considerably part of the total costs. For the build of the Flamenco, the locations has been changed. Due to the high travel and Visum costs of the volunteers, related to costs of labor in China, it was decided to hire local professional construction workers to assist during the construction.

During preparations, all engineering have been performed by students and sponsoring companies. Therefor no engineering costs were calculated.

Total costs	€ 176.971,40
Total Sponsoring in goods	€ 154.983,97
Total Remaining costs	€ 21.987,43
Total gainings	€ 22.500,00
Overall project balance	**€ 512,57**

Table 15; Overview of budget Flamenco tower;

Because the expenses will be partially done in the Netherlands and not all Chinese prices can be derived with certainty, all costs overviews are related to European pricing. The benefit of this approach will be that the overview stays comparable with previous projects. Where possible, typical Chinese pricing will be taken into account (like labor). It is expected that overall costs in China will be lower.

The total costs estimations are displayed in table 15, the full overview can be examined in annex 7.

As the balance show, the outcome is positive. Though no unforeseen delays or errors are taken into account by this calculation. All prices are excluded of taxes.

Mobile factory

The construction and transportation of the Mobile factory covers the most of unsponsored expenses. Although most items are obtained by sponsoring by companies. Table 16 is an overview of the bill of material

The cost overview of the mobile factory also houses all normal equipment costs of the building site. Because the factory is standard equipped with a full building site deployment, these costs are excluded from the overall budget.

	Total price	Sponsoring	price after sponsoring
Construction	€ 8.303,35	€ 2.396,40	€ 5.906,95
Electricity	€ 9.382,02	€ 7.135,43	€ 2.246,59
Air	€ 1.195,00	€ 700,00	€ 495,00
Water	€ 3.996,85	€ 3.376,75	€ 620,10
Inventory	€ 2.522,06	€ 1.903,27	€ 618,79
Tools on the container	€ 3.755,52	€ 3.755,52	€ 0,00
Tools in the container	€ 398,00	€ 398,00	€ 0,00
Control system	€ 1.125,00	€ 1.125,00	€ 0,00
Total	€ 30.677,80	€ 20.790,37	€ 9.887,43

Table 16; Bill of material: Overview

Sponsors

TU/e Technische Universiteit Eindhoven University of Technology
Where innovation starts

2018 Harbin
WWW.STRUCTURALICE.COM
STRUCTURALICE
FLAMENCO ICE TOWER & COMPETITIONS
Presented by
IASS-WORKINGGOURP 21
TU/e & H.I.T

哈爾濱工業大學
Harbin Institute of Technology

SUMMA College

KU LEUVEN

MAPLE LEAF VILLAGE
枫叶小镇

MAMMOET

VERHUUR easy cool KOELING

PEETERS TECHNICAL SOLUTIONS

SUMMA Bouw

MCB

IsoBouw
Innovatie in isolatie

Café d'n Ekker

engie

Dakenshop

VALKENPOWER

WAGO®

VAN DOREN ENGINEERS BV

5.4 Monitoring of progress

The best way of controlling and overviewing the production process and the construction process, is the assessment of the progression. A stagnation in the progress will be the direct result of insufficient operational functioning of the production/construction process. The progression can easily be monitored by the measurement of the developing ice shell. Two major point need to be taken into account by this monitoring:

- The measurements must result in the thickness of the ice shell of different heights/locations; final dimensions are predetermined.
- The distribution of the development of the ice shell must be analyzed; an even distribution is essential for a reliable ice structure.

Tool

Previous projects used a simple progress sheet as in annex 14 (Koekkoek, et al., 2016). However, this sheet only offered limited understanding of the development, and did not show a clear visual representation of the progress. Thereby, it only measures progress in one-section (2-Dimensions) while progress along the other axis (3-Dimensions) is essential for a clear understanding of the development of the ice shell

Therefor a uniform tool is development for the monitoring progress of the construction of ice shells. This tool consists of an modeled representation of the progress.

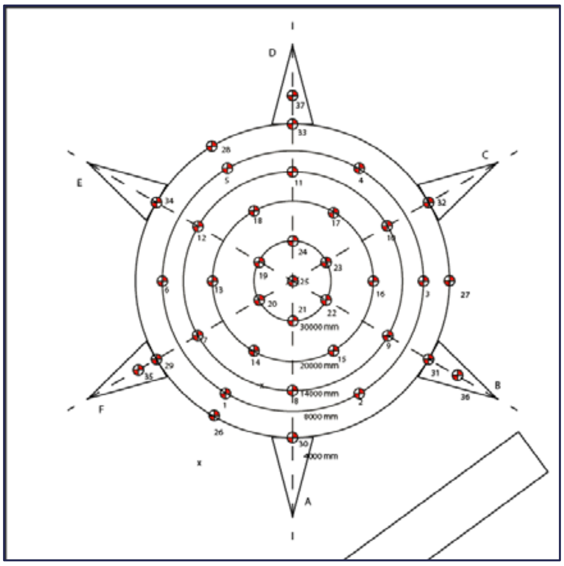


Figure 127; most optimal measuring pattern

The first step of the implementation of the tool is to predetermine measuring points. Figure 127 shows the most optimal measuring pattern by a radial symmetrical model. With this model, the thickness is measured at 37 points, divided over five heights. Every height ring consists of 6 measurement point. Also the connections of the legs with the tower are measured, as well as the thickness between and on top of the legs.

By determining the amount of measure point, the practicality of the measuring has been taken into account. Too much points would take too much time, and may provide excessive information. Nonetheless too less points would result in an incomplete overview of the progress. The optimum is found by field testing and experience.

The model only displays the ice shell at a specific time t. A single measurement moment gives information of the distribution of the ice shell along the height rings at that specific moment. More measurements are needed to overview the overall building speed. Multiple measurements can be combined to a development model. The measurements moments can be planned in advance.

After measuring, the thicknesses [mm] can be imported in the excel sheet in annex 15. The tool compares the imported values per height ring and calculates the average thickness per ring. Because the evenly distribution of the ice ring is considered more important than the overall developments, the local thickness is compared with the average of the ring instead of the planned progress. The average thickness also gives an impression of the overall progress.

The average thickness per ring is considered as zero point. Measurements that indicate a thinner thickness are resembled as negative, and vice versa. Different thicknesses are indicated with color codes at which different codes represent a variation of 10 mm of difference to the zero point. A maximum spread of 200 mm (-100 to +100 mm) has been set. This maximum value has been selected because a value above this shell thickness difference is considered extremely problematic and cannot be ignored (Borsboom, 2015).

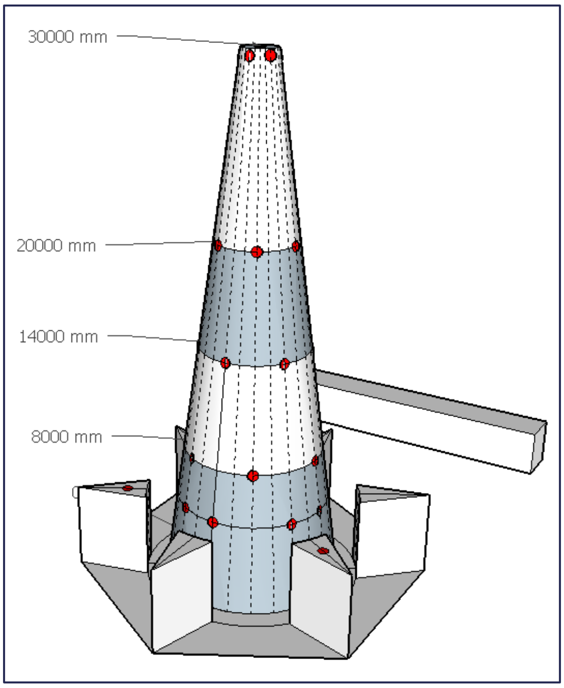


Figure 128; model of the tower;

The color codes are implemented on a project specific model as in figure 128. The measurement points resemble an area which is colored along the color code. The areas between measuring points are linearly approached and colored by this estimation. This results in a visual overview of shell thickness.

The tool can be used as a monitoring concept of the building process of ice shells. Modifications have to be made in the measurement pattern (as in figure 128) and the model, to specify the tool on a particular ice project. By standardizing the monitoring aspect, comparisons in building speed between different projects can be made.

6. Construction management

The proposed optimizations are tested in reality. The realization of the Flamenco tower in ice, will act as field test for the Mobile factory and the organizational optimizations.

6.1 Team

For this project, the project team consisted of students and tutors from the University of Technology Eindhoven and the H.I.T.

Arno Pronk, Project leader TU/e, and Peng Luo, Project leader H.I.T. managed the project before and during construction. For the TU/e Yiling Zhu and Yaron Moonen managed the project. For the H.I.T. this position has been filled by Yuan Luna. Mr Wong, director of the Maple Leaf Village center, mainly focused on the financial management (figure 129).

During construction of the tower, main operations were performed by the TU/e and the Chinese construction crew. Later in the process, students from H.I.T. joined the construction process and eventually adopted the management.

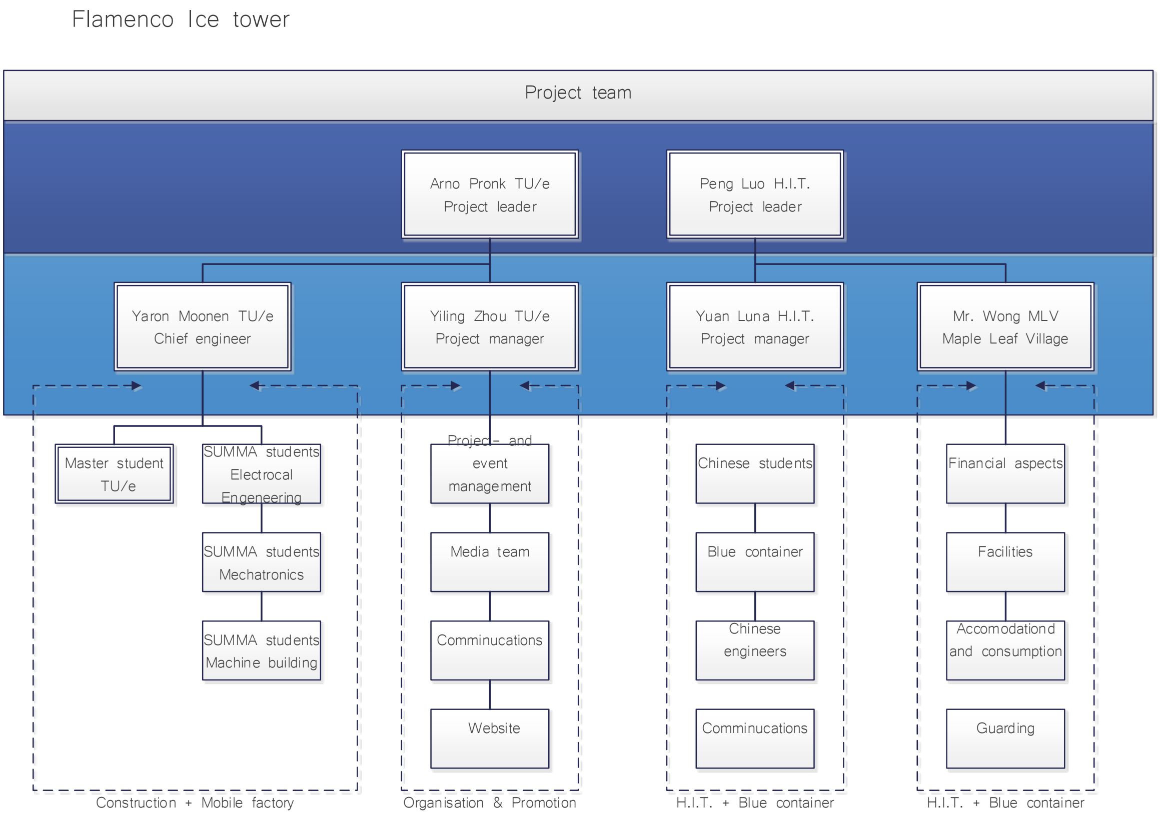


Figure 129; Organizational overview

6.2 Realization

This section will discuss the realization process step by step. According to the planning, the construction started at 8th of December 2017. At this moment, the building site was already equalized and the anchors were finished. No further preparations were performed on the building site.

All steps are described by the procedures and difficulties.

Figure 130; Building site in front of the Maple Leaf Village

Figure 131; Building site is cleaned from snow

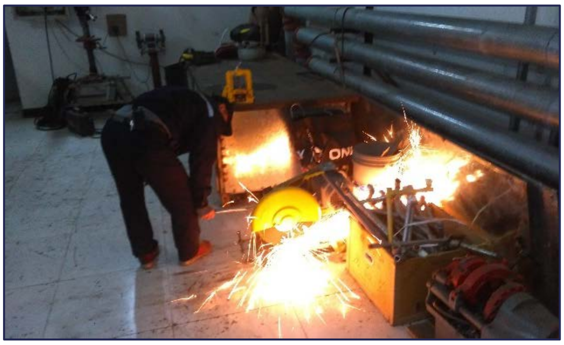
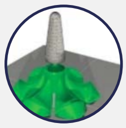


Figure 132; Steel workshop with machinery for steelworks

Figure 133; Steel workshop with welding equipment

Building site

Planned activity + duration
8-dec-2017 – 12-dec-2017 4 days
Executed activity + duration
11-dec-2017 – 15-dec-2017 4 days



the start of the project was directly postponed for four days which resulted in a delay.

The building site was located in front of the main sponsor: The maple leaf village outlet center (figure 130). The building site was situated at a part of the parking lot. For the construction, the site was cleaned of snow and enclosed using small fences and blockades (figure 131).

The underground of the parking lot consisted of casted asphalt were all anchors had been constructed through. The parking lot ensured a stable straight underground for the project.

For repairing activities, a steel workshop was furnished to support the construction (figure 132). This workshop was located next to the project in the mall and consisted of a welding machine, and different machinery for steelworks (figure 133).

The preparations for the construction also consisted of the installation of electrical cabinets, lighting and heated water pipes (see figure 134).

Figure 134; Installation of electrical cabinets

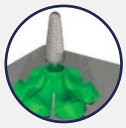
Figure 135; Guards on the building site

The heated water pipes raised some concerns. In previous projects, this method was tested and found insufficient (Hijl, et al., 2014). Therefor a return waterline was engineered in the beginning. However, due to extra insulation of the heated waterline, and some tests, the functioning of the heated water pipes was proved and applied.

Also a 24/7 guard shift of the building site was set up (figure 135). Presence of guards was essential because of the valuable equipment on the building site. Thereby, this construction phase did not had a night shift, remaining the building site unattended at night.

Mobile factory

Planned activity + duration
11-dec-2017 – 12-dec-2017 1 days
Executed activity + duration
12-dec-2017 – 17-dec-2017 6 days



An important part of the preparations was the installation of the Mobile factory. This factory was directly sent by train to the building site and arrived at the 12th of December (see figure 136). The position of the container was measured and placed using two cranes. In advance only one crane was ordered, but differences in cultural work habits resulted in the addition of the second crane.

Figure 136; Positioning of Mobile factory

After arrival, the Mobile factory was unpacked and connected to water and electricity (figure 137). Due to time shortage and the fact that some equipment was ordered in China at the building site, the whole system was not yet tested. All different aspects of the factory were only tested individually. Therefore a total test was needed to ensure a good functioning of the production (see figure 138).

Figure 137; Connecting the Mobile factory to the electricity grid

The tests consisted of the running production line, and spray activities. The production line was connected to the Chinese hoses and connections.

The tests showed that the ordered and the brought connections did not fit. This resulted in delay due to the manufacturing of new connections for the pumps.

Figure 138; Installation and testing of the Cellcrete production line

Also the switching between the pre-mix tanks did not occur fast enough, resulting in an insufficient supply of Cellcrete. To solve this an extern buffer container has been improvised (figure 139). The buffer was positioned next to the container and roofed, to enable an internal climate control.

The buffer consisted of a heated room with two (hand) mixers, and two external centrifugal pumps. The production line was directly connected to the buffer using one external centrifugal pump (one outlet of the container).

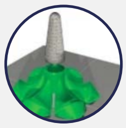
Figure 139; The improvised heated buffer room with a buffer capacity of 9 m^3

The improved buffer room did not function optimally due to insufficient equipment. However, combined with the mobile factory, the total setup was able to produce and spray. The total setup caused a relatively large delay due to unforeseen defects.

The connection of the air system would be performed later in the process.

Ice ring

Planned activity + duration
10-dec-2017 – 13-dec-2017 2,5 days
Executed activity + duration
13-dec-2017 – 18-dec-2017 5 days



The execution of the ice ring was slightly delayed due to overall delay. The ice ring was constructed conform the design.

Trucks delivered the ice blocks on site. The blocks were unloaded with a shovel and stacked on location (figure 140) where some blocks were modified by chainsaw (figure 141).

During the construction of the ring, ropes were attached to the anchors of the middle part of the tower to simplify the connection later in the process (figure 142).

Because the surrounding projects also needed ice blocks and construction workers, the construction of the ice ring was delayed. Thereby, the supply of ice blocks was insufficient. This resulted in a temporarily shut down of the process, due to insufficient material.

To speed up the further process, an extra forklift had been arranged to help with the unloading of the trucks and movement of the blocks (figure 143).

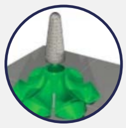
Figure 140; Stapling of ice blocks

Figure 141; Modification of ice blocks by chainsaw

Figure 142; First layer of ice blocks with ropes attached to the middle anchors

Figure 143; Stapling of ice blocks on fourth layer

Positioning inflatable



	Planned activity + duration
13-dec-2017 – 15-dec-2017	2 days
	Executed activity + duration
19-dec-2017 – 22-dec-2017	3 days

Figure 144; Arrival of inflatable on building site

Figure 145; Unfolding the inflatable using a shovel

Figure 146; Hoisting of inflatable by leg

Figure 147; Hoisting inflatable in position

The inflatable was delivered to the building site packed on a truck with mobile crane (figure 144). Despite the request, the fabric factory did not provide a folding pattern. This made the unfolding process complicated (figure 145).

The inflatable weighted over 4000 Kg which made it hard to transport. No recognizable markings were implemented on the inflatable, resulting in difficulties in the orientation. Also no hoisting provisions had been mounted on the fabric, which complicated the hoisting activities.

During movement of the inflatable to understand the orientation, the first rupture developed. The inflatable was dragged by a leg, instead of the tower which resulted in a point load in the fabric (figure 146). The rupture of approximately two meters was directly repaired using PVC welding equipment.

After reparation, the tower has been found and connected to the crane using ropes. This connection was performed at the point where half of the inflatable was tied, to prevent full inflation. Afterwards it was hoisted on the right position (see figure 147 and 148). The legs were positioned corresponding to the anchor pattern on the ground.

Because the middle anchors of the tower were not assessable, and the positioning of the inflatable already caused a lot of delay, it was decided to exclude the connections of the middle anchors. It was expected that the influence of these anchors relating to the inflatable's stability was minimal.

Figure 148; Positioning of inflatable in ice ring

Figure 149; Connection of air pumps to the inflatable

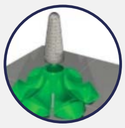
Figure 150; Minimal inflation of the legs

Figure 151; Connection of the rope net

Figure 152; Connection of the rope net

First inflation

Planned activity + duration
15-dec-2017 – 15-dec-2017 1 days
Executed activity + duration
22-dec-2017 – 24-dec-2017 2 days



By the hoisting of the inflatable, the upper part of the tower was already tight down. To support and position the inflatable correctly, it was decided to not disconnect the crane.

The air system was connected to inflatable (figure 149). Unlike requested, no air tubes were connected to the inflatable. Therefore, air tubes had to be connected by hand resulting in a short delay. Because the model of the inflatable showed a full connection between separate air rooms in the inflatable, two air pumps were connected to leg B, and one to leg A. Afterwards minimal inflation was started, the work on the ropenet was finished (see figure 150).

After repositioning and multiple in- and deflations, the final position of the inflatable and the ropenet were secured (figure 151 and 152). Resulting in the first attempt to fully inflate the base.

The full inflation did not proceed as planned. Instead of the whole tower, only one leg (B) inflated. Combined with the fact that the ropenet of this leg was slightly to loose, it resulted in a second rupture of five meter at the bottom connection of the leg and the tower (see figure 153). During repairing activities, construction workers noticed that the different air compartments were just minimally connected by a small hole (diameter of 100 mm) which complicated the internal air distribution. Two workers entered the inflatable to provide all air compartments with an opening. After the reparation was completed, the first inflation could take place (figure 154).

The first part of the inflation of the legs was complicated. Due to a misunderstanding by the crane operator, the top tower was disconnected from the crane. This resulted the untying of the top section of the tower.

The air monitoring system directly responded to the loss of internal pressure and announced an error (visual and acoustic). The system directly controlled all air pumps to operate at full capacity resulting in full inflation of the whole tower (see figure 155 and 156).

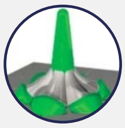
Figure 153; Developed rupture of inflatable under leg

Figure 154; Partially inflation

Figure 155; Full inflation after the untying of the top section

Unlike the building sequence stated, it was decided to continue the construction. This decision was made after discussions with structural engineers and weather forecasters. Because no wind was expected, the inflatable was fixed securely, and the already existing delay, it was decided to continue the construction process from this point on. This excluded phase 2.1 in the process, and resulted in directly spraying the whole tower.

Spraying of the whole tower



Planned activity + duration
16-dec-2017 – 27-dec-2017   11 days
Executed activity + duration
24-dec-2017 – 7-jan-2018   14 days

Figure 157; Spraying process of tower from boom lift

Figure 158; Addition of snow and ice between the legs the stimulate the shell development

Figure 159 ; Correction of inflatable position

After a delay of eight days (on a total building time of 23 days) the spraying activities started at the 24th of December. Originally these days were planned free for all workers due to Christmas. However, the massive delay resulted in overwork during holidays to compensate the lost time.

Spraying activities started with two spraying teams spraying 24 hours a day. Starting with one spraying team on the ground, and one spraying from a boom lift (see figure 157, 160, 161, 162, 163 and 164). Two boom lifts were positioned opposite to each other referring the tower. The positions of the boom lifts were regularly changed to guarantee an even shell development.

The shell has been constructed from the bottom up as instructed in the work method. Extra snow and ice were moved between the legs to stimulate the leg growth (see figure 158).

Originally three shifts for this schedule were planned. At the moment of construction, not enough workers were available (20 instead of 60). Cultural standards in construction work stated no exception in working 24 hours. Because no more workers were available, a schedule has been constructed in which two workers could rest, and the rest operated the spraying process for 22 hours. This resulted in an inefficient crew limited by restlessness and demotivation. This schedule only lasted two days, when more construction workers were available.

During the fixation of the inflatable, a slight dislocation has been neglected. During the construction of the tower, it was tried to correct this dislocation using the crane to consciously deform the inflatable to the opposite direction (see figure 159). After the development of the underlying ice shell, the crane has been removed.

Figure 160; Spraying activities

During the progress of the construction, different measurements of the tower have been performed to monitor the progress. This part is specified in the chapter: ‘Monitoring of progress’.

First measurements resulted in the delay of the opening. Because the spraying activities started relatively late, and there were not sufficient construction workers available, the new opening was set on the 10th of January 2018.

The Dutch crew left on 5th of January which forced the transfer of the management of the building site to the H.I.T. Therefore, no Dutch team members were present by the forthcoming steps, except for the opening.

During the spraying process the importance of motivational factors was revealed. In the beginning, the Chinese crew simply carried out assignments without supervising the entire construction. Together with the language barrier this has led to a limitation of their motivation. By socializing and directly involving the Chinese crew in the progress, the motivation of the team was increased. By setting a collective and understandable goal, the commitment of all of the team members has resulted in an increased progression. This supports the importance of motivation and rate of involvement, when operating in a team.

Figure 161; Progression on ice shell

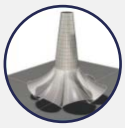
Figure 162; Spraying form boom lift and the ground

Figure 163: Spraying activities with two boom lifts


Figure 164; Spraying activities from boom lift

Deflation and removing

Planned activity + duration
27-dec-2017 – 27-dec-2017 1 days
Executed activity + duration
07-Jan-2018 – 07-jan-2018 1 days



After the final measurement, and the conformation that the predetermined shell thickness was reached, phase 3 could be started.

The air system was set on the deflation mode and the air pumps were disconnected. During deflation the tower showed no deformations. After full deflation the inflatable was loosened from the ice walls by construction workers (figure 165 and 166). Because the bottom of the tower was frozen in the base, the inflatable was moved in the middle of the ice ring (figure 167 and 168).

Originally the inflatable was planned to be frozen by layers of water to create an ice platform. But through concerns of the Chinese engineers on damaging the inflatable, this step was excluded from the finishing activities.

Figure 165; Removal of inflatable

Figure 166; Removal of inflatable and pushing it inside

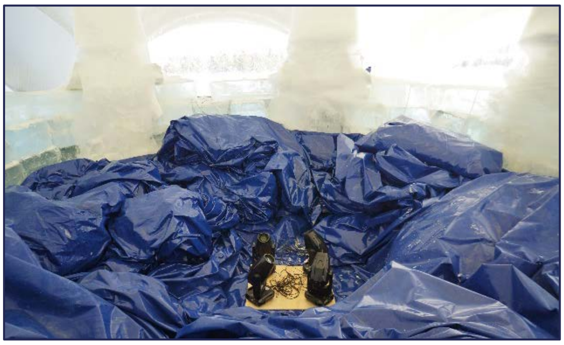


Figure 167; The inflatable is positioned in the middle

Figure 168; Ice stairs remain after the removal of the inflatable

Figure 169; Placing of lighting at the outside of the tower

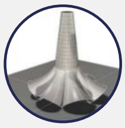
Figure 170; The removal of excessive material and snow

Figure 171; Finishing activities on the tower

Figure 172; Inside tower during finishing activities

Finishing activities

Planned activity + duration
28-dec-2017 – 30-dec-2017 3 days
Executed activity + duration
07-Jan-2018 – 09-jan-2018 2 days



The finishing of the tower consisted of removing the excess ice shell at the legs and top (see figure 170 and 171). The legs showed an curvature in the shell that needed to be removed. However, the Chinese crew only removed the thin parts of the ice leaving the vertical curvature. That difference is pure esthetic and did not have an influence on structural behavior.

In the initial design, the tower had an open top. During the construction the local effects of sublimation were noticed. The extremely dry air in Harbin resulted in a slow sublimation of the ice shell, leaving only cellulose fibers. Removing the top would result in an chimney effect of the tower, creating an upwards airflow. It was expected that this airflow would stimulate the sublimation on the inner ice wall. Therefor is has been decided not to open the top of the tower.

This same sublimation was the reason that the tower has to be sprayed from the outside every two to three days for two hours. This should counteract the effect of the sublimation

An external company has designed a light plan for the final opening of the tower. The lasts step consisted of the positioning of lights and fences for the entrances (see figure 169).

Final result

The following figures show the final result of the tower (figure 172 until 180)

At the 10^{th} of December the tower was officially opened (see figure 181). The Dutch embassy in China, and the local governor assisted this opening. Together with TU/e and H.I.T. the tower was officially opened and transferred to the Malple Leaf Village.

Figure 173; Final result

Figure 174; Final result top view with MLV

Figure 175; Final result top view

Figure 176; Final result by dawn

Figure 177; Tower by night

Figure 178;, Top view on legs

Figure 179; Inside of tower

Figure 180;, Official opening of tower

Figure 181: Final result after official opening

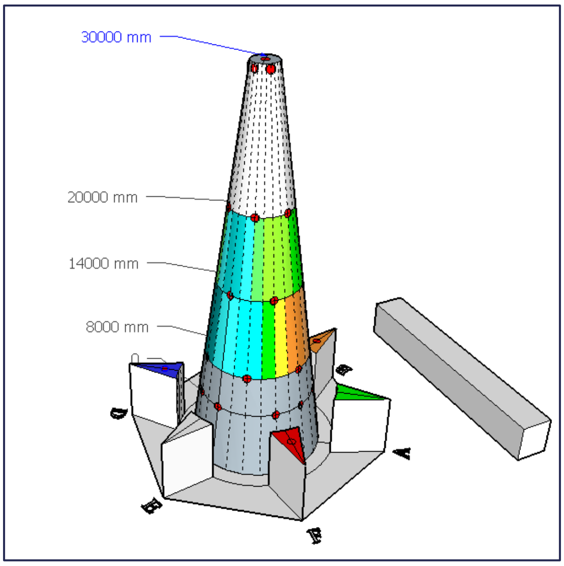


Figure 182; Development of ice shell, measurement 1, side 1

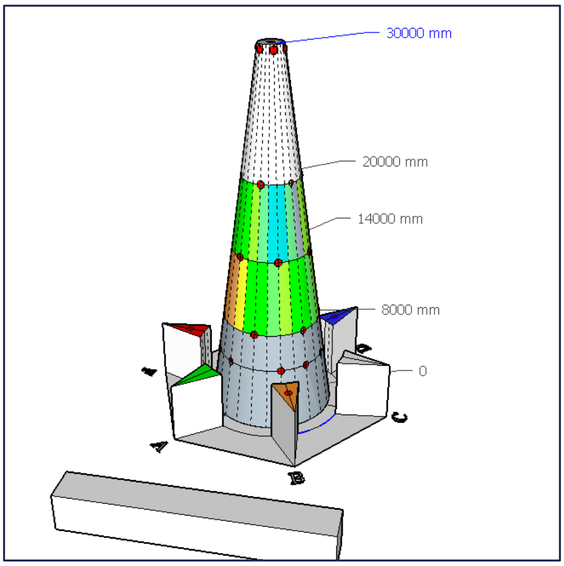


Figure 183; Development of ice shell, measurement 1, side 2

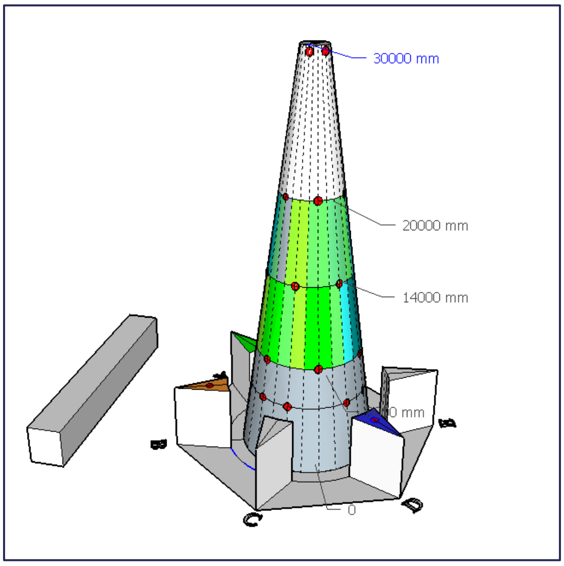


Figure 184; Development of ice shell, measurement 1, side 3

6.3 Monitoring in practice

For this project, the following measuring moments are planned:

19-dec-2017: End of phase 2.1; Full inflation of tower
23-dec-2017: Before Christmas: Dutch team will be absent for one day
25-dec-2017: After Christmas: During process
27-dec-2017: End of phase 2.2; Confirmation before deflation

Because of the changes in the building process, the first measurement did not take place. There was no second inflation and therefor this measurement was unnecessary. Other measurements took place on different times because of the delay of the construction. Three full measurements were conducted.

Measurement procedure

The points were measured using a boom lift and electrical drilling equipment. After drilling the depth of the holes was measured and noted.

Difficulties

The equipment was detached to an electrical line. This electrical line limited the reach of the boom lift and it obstructed work on the ground resulting in delay. To reach all spots, the boom lift needed to be depleted and rearranged. This took more time than estimated in the initial planning. To compensate this delay, not all measurements have been performed. A simplified approach has been executed where only half of the points were measured.

Measurements

Despite the planned measurement moments, measurements were postponed and executed at other moments due to delay.

Between the following three measurement moments, small measurements were performed. These measurements were randomly performed on spots of interest.

Not all measurements have been performed by the same workers, this resulted in different measurement locations.

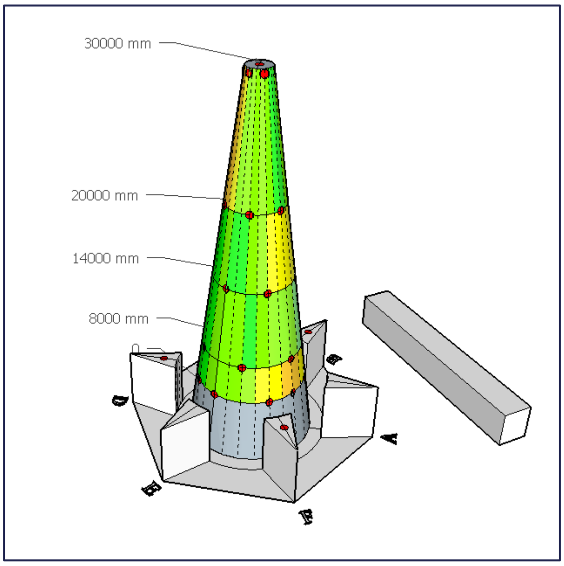


Figure 185; Development of ice shell, measurement 2, side 1

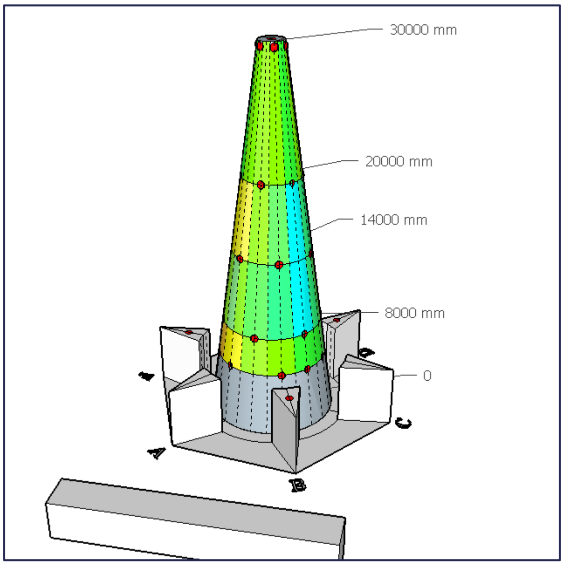


Figure 186; Development of ice shell, measurement 2, side 2

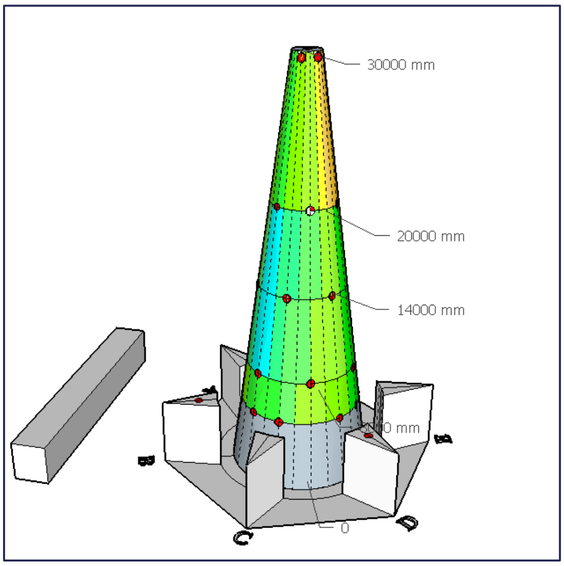


Figure 187; Development of ice shell, measurement 2, side 3

Measurement 1: 24-dec-2017

The first measurement consisted of the base of the tower. The top was not yet in development and therefor point 18 till 32 were excluded. A full overview of the measurements can be found in annex 15. Due to the delay, not all points have been measured according the original measure pattern.

Figure 182, 183 and 184 show a disproportionate distribution of the shell thickness. It can be concluded that the development of the shell was minimal at the opposing site of the mobile factory. This was confirmed by the fact that the uneven distribution occurs on all height rings, and de legs. This indicated that the focus must be oriented at the opposing site of the tower, to gain an evenly distributed shell thickness.

It was expected that the spraying paths (which were always starting near the entrance of the container) pass the container side (leg A,B and C) more than the opposite site (Leg D,E and F). However, the most shell development was located between leg F and A. It was expected that the boom lift's locations have not been changed enough, causing a thicker shell.

The slightly diagonal positioning of the tower is also expected to affect the development of the ice shell. The tower was orientated slightly towards leg B. This resulted in a less steep slope between leg E and F. Further spray activities were focused on the thin shell parts.

Measurement 2: 3-jan-2017

This measurement was planned to be the last measurement before deflation. The results of this measurement was not as positive as expected (figure 185, 186 and 187). The shell showed an insufficient overall thickness with several weak points. To prevent further delay, the team has decided not to execute all measurements. Therefor the measurements of height ring two and the leg connection to the tower have been excluded.

After consultation with structural designers, it has been decided to delay the opening to develop more shell thickness. A clear underdevelopment could be seen between leg B and C. During further construction, the expectation of the first measurement has been taken account during spraying. This has resulted in the underdevelopment of this side. More attention has been paid to the opposite site of the tower.

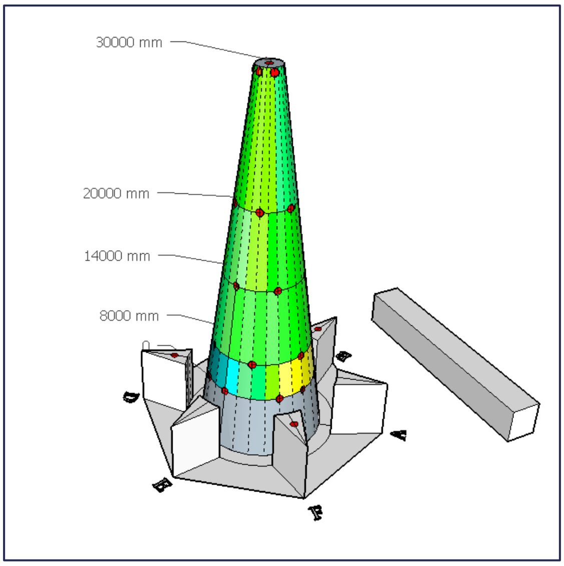


Figure 188; Development of ice shell, measurement 3, side 1

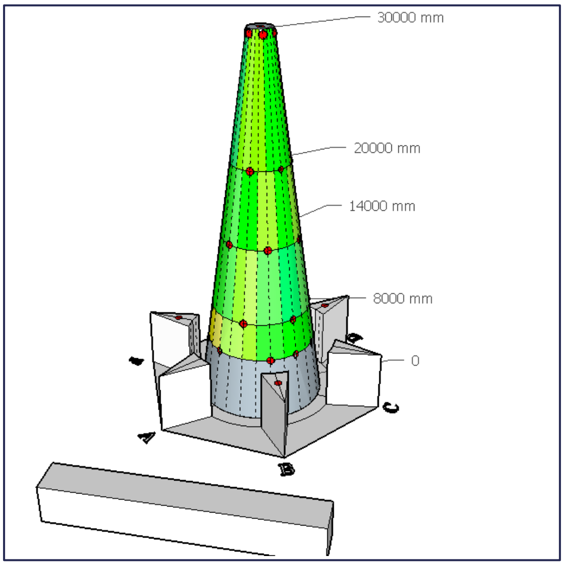


Figure 189; Development of ice shell, measurement 3, side 2

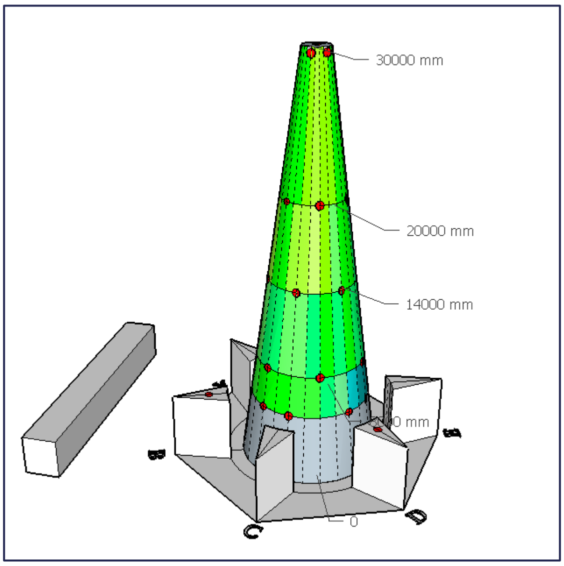


Figure 190; Development of ice shell, measurement 3, side 3

As figures 185, 186 and 187 show, this focus resulted in a more even distributed shell development.

This was also the first time thicknesses between the legs were measured. It could be concluded that the total base was underdevelopment, in relation to the total ice thickness of 400 mm.

Measurement 3: 6-jan-2017

These last measurement was conducted after departure of the Dutch crew. The Chinese crew supervised this last measurement. Not all measurement points have been measured at this moment. Due to misunderstandings, just a minimal selection of the points have been measured. Also not all positions are equal to previous measurements. To complete the table, additional values have been estimated according the previous measurements and findings of the Chinese crew.

The overall model showed an acceptable even distribution of shell thickness (see figure 188, 189 and 190). A bigger difference could be stated in the shell between the legs. Even though the differences in shell thickness were significant, the thinnest section met the predetermined requirements.

By this measurement it was stated that the predetermined thicknesses were reached, and that deflation could be started safely.

Due to delay and miscommunications, not enough measurements have been performed to provide a substantiated base for the test of the tool. There has been insufficient reliable data to model a clear overview of the distribution. Especially the development of the legs is often neglected, or minimally measured. Since the working of the tool is not proven, it can be tested and further developed in future projects.

The measurements itself were considered as an obstruction of the progress. The electricity lines, the occupation of one boom lift, and the rearranging of the boom lift, disrupted the normal spraying activities. This resulted that not all points have been constantly measured.

7.Conclusion and discussion

In conclusion, the research question will be answered as well as the sub questions, and a recap on the process optimization and organization will be given in the form of main observations.

7.1 Organization

International cooperation

The international corporation between Dutch and Chinese parties was not succeeding without hesitation. This is primary related to a lack in communication which has led to misunderstanding and delay.

During the preparation of the project, the communication was limited due to e-mail conversations, and video conferences. Due to the time difference, the communication was taking a long time.

In this pre-partial phase it was stated that both H.I.T. and TU/e would work on the same design. However, due to miscommunication, some modifications to the design were not reported, which resulted in more misunderstanding. The miscommunications has been a result of an absent clear division of tasks and responsibilities in the beginning. The field test concluded that this division of tasks was important. Therefor a clear overview was composed in July 2017

During construction, the cultural differences has been noticeable in interaction, working methods, safety standards and overall living standard. This has led to misunderstandings and irritations. The cultural differences have influenced the progress more than expected.

Despite the turbulent surround and the cultural differences, the internal corporation is considered successful. A new research branch has been set up at the H.I.T. which contributes to the overall research and application of reinforced ice.

Blue container.

During preparations, the H.I.T. team decided to build a second mobile production line. This (blue) container was not implemented in the planning. In spite of that, it would assist by the construction of the ice tower by covering the shell development at the opposite side of the tower. Unfortunately, the blue container could not be deployed for the construction of the tower due to the use of the Cellcrete production for side projects.

This resulted in the fact that only the mobile factory (red) has been used to construct the tower. The blue container has been excluded from the construction planning. However, the assistance of a second production line would have limited the delay of construction.

Location

The appearance of accumulation by the dry air, must be taken into account by construction and maintaining the tower. Thereby, air pollution can results in an esthetic grey layer of ice.

It can be state that the location of the building site is an improvement compared to previous projects. The temperature was stable and cold with minimal wind speeds.

Preparation

To complete this project, a preparation period of two years preceded the construction. Because of errors and recommendations of previous projects, this period has been planned to ensure a good preparation.

To overview this period, a time planning has been made. The preparations consisted of modeling the design, engineering the mobile factory, a field test, and planning activities for the realization.

It can be concluded that this time frame was absolutely relevant. Even with two years of preparations, not all calculations and tests were performed before realization.

Field test

In the winter of 2016, a small team of the TU/e was visiting Harbin to build a small scale model of the tower, and ice dome. The main goal of the field test was to research the validation of the realization of the Flamenco tower in Ice.

The main observations were related to cultural differences. These differences were noticed in interaction, working methods, safety standards and overall living standard. This observations have influenced the preparations for the final construction.

Structural analysis.

The design of the Flamenco Ice tower consisted of different curved shapes. This was making modeling of the inflatable and shell complicated. Therefor the modeling was taking more time than expected.

The H.I.T was performing and verifying most of the structural calculations.

The final calculations were showing another thickness distribution of the ice shell. Just before, and during the construction, a new calculation resulted in the possibility for a thinner overall ice shell. However in this stadium, it was complicated to change the total planning according to the new results.

It can be concluded that the final calculation has been provided too late, to adapt in in the construction planning accordingly.

Building sequence

The building sequence was adjusted on the calculation of the initial design. It was including a partial inflation where the bottom of the tower was inflated and sprayed first and the rest of the tower would be inflated second.

Due to a miscommunication with the crane operator, the tying between two air compartments was loosened, which was resulting in a total inflation at once. After a discussion with professionals, it was decided to continue the process and excluding the partially inflation.

This mistake conducted through human errors. Due to miscommunication and misunderstandings, the crane operator dismantled the crane and left the building site. It was not clear of the miscommunication is the result of translating failures, or inattention of the crew.

Team

The team was consisting of Chinese and Dutch team members. The construction workers were hired by a local construction company.

To supervise this construction workers, cultural standard state that a clear hierarchy was demanding. This would promote clarity by the workers and increase efficiency of activities.

Inflatable

The final design and the production of the inflatable was the responsibility of the H.I.T. They have decided to outsource the production of the inflatable to a specialized company. Unfortunately, no final cutting patterns have been shared before the outsourced production. This was resulting in a few shortcomings in the inflatable.

The overall quality of the inflatable was high since the seams were welded professionally and the overall shape approached the design correctly.

The inflatable was securely folded and packed and transported to the building site by truck. Despite the recommendation, the inflatable was not provided with a folding instruction or recognizable markings. This made it hard to orientate and position the inflatable.

The exclusion of hoisting provisions influenced the orientation and positioning also negative. To hoist the inflatable, ropes were used to form a loop. This method of hoisting was not preferred, because of the risk of damaging the inflatable. A first rupture has been created during this process. Repairs by hand caused delay, and a weak point in the inflatable. After the reparation the process continued.

The inflatable was produced in different components (1 tower, and six legs). These components were later attached and connected to the internal air compartments. The connections consisted of small holes with a diameter of 100 mm. This diameter was not able to distribute the air pressure evenly in the whole inflatable which led to local high pressures. This resulted in the second rupture. This observation has been concluded during reparations of this rupture.

The fabric company provided a high quality inflatable. The lack of hoisting provision, air tubes and a folding plan complicated the processing of the inflatable.

7.2 Process optimization

The process optimization consisted of improving the production line, and the engineering of the mobile factory. This engineering has been performed along with students and tutors of the SUMMA college.

During the project, the students within the team of the SUMMA college changed due to educational time boundaries. The change within the team to new students caused delay in the engineering phase.

The most optimal production process would have resulted in a fully automated line. Due to limitations in time and financial resources, the automated design has simplified. The limitations in time and financial resources have also resulted in a simplified design of the Mobile factory. Nonetheless the production speed is increased with 200%. Also the reliability of the production line is improved.

Mobile factory

The mobile factory was built in the Netherlands on the campus of the TU/e. This location housed all needed facilities and equipment. Transportation of the mobile factory was conducted by train and was lasting 28 days.

Because a part of the equipment was ordered on the building site in China, a full scale test in the Netherlands was not possible. Therefore, all components have been tested individually. The first real life test occurred on the building site after the factory was installed.

First tests concluded that a buffer container was essential for a continuous supply of Cellcrete. On site, an addition to the mobile factory resulted in an improvised heated buffer room. Because of a shortage of equipment, the buffer container was not mixing properly, resulting in partially accumulations of the cellulose fibers. These fibers did not led to blockages of the hoses or nozzles.

Also the improved roofing of the buffer container did not insulate the room accordingly. Resulting in the freezing of hose connection. This was complicating and delaying the normal spray activities.

It can be concluded that further projects need a buffer to ensure a continuous Cellcrete supply. However, the Mobile factory did improve the work standards and the overall construction process.

Spraying

The spraying actives were comparable with previous project. After simple instructions by the Dutch crew, Chinese construction workers took over these activities.

The amount of workers was not sufficient during the whole construction process. Especially during the second phase (24 hour schedule), 20 workers have been supplied instead of 60. Thereby, the conducted planning and labor overview were only applicable on the tower construction. No constructions on side projects were included.

A part of the supplied workers were assigned to the construction of these side project, which resulted in a understaffing of the tower construction team.

Due to the understaffing, and the Chinese work standards, excessive working hours of 24 hours were demanded of the Chinese construction workers by the construction company. This resulted in inefficient work procedures due to restlessness and demotivation. These excessive hours were solved after two days when more workers were available.

Independent form the understaffing, it is observed that the crew was not trained enough for the spraying activities. Too much simple human errors were made which was resulted in frozen hoses and nozzles. These human errors were caused by a lack of experiences, and resulted in large delays and irritations. More focusing on training of the crew could have led to a more efficient spraying process and less delay.

Organization

The organization from the Netherlands started with one professor and one graduation student of the TU/e. During the preparation of the project it was hard to assign students to the Flamenco ice tower project. At the end of the preparations, a limited student team has been composed to assist the project. Nonetheless the team did not possess sufficient members to elaborate all phases of the preparation and realization.

Also during realization, the Dutch staff was not sufficient to be divided over the different shifts. This resulted in excessive work hours for the project leading team.

It can be concluded that the preparation was not sufficient for modeling, calculations and engineering due to understaffing of the team. Composing a bigger team beforehand, with a clear hierarchy, could prevent a project from these issues.

Realization

The construction process was slowed down by many errors and limitations. This is mostly caused by cultural differences and miscommunications. Thereby, not all activities have been planned correctly in advance. Experience and recommendations of previous projects were analyzed to overview the total building time, and possible delay. These factors have been considered composing the project planning. During the building of the projects some others issues occurred which has led to a delay on the planning which resulted in extra days of construction.

It can be concluded that the construction process was delayed with eight days, which is 44% of the total construction time. New experiences and observations can lead to a more reliable planning in the future.

Safety

Chinese safety standard do not meet the European standards. This could result in unsafe situations.

In the ‘Bridge in Ice’ project a standardized safety plan for ice structures has been developed. It was intentioned to fully apply this safety plan on this project. Therefore, the fully plan was translated and specified on this project.

However, this safety plan did not meet the full implantation. The attempts to force European safety standards on the building site resulted in incomprehension and dissatisfaction of the Chinse crew. Understaffing complicated the positioning of a full time safety coordinator.

For further projects in other cultures, the safety standard must be standardized to guarantee a safe building process.

Monitoring tool

A tool has been developed to monitor the progress on the tower. The measurement of the inflatable showed that another approach was needed for an even distribution of the ice shell.

It was important to focus on the other side of the tower because the shell was not developing evenly. This was caused by the fact that the tower was slightly out of position. This side was also the side which was fulltime exposed to the sun. This had also affected the shell development.

Not enough measures have been conducted to fully test the developed tool. The tool shows promising possibilities, but needs to be examined more.

It can be concluded that a lot of measurements are needed for a good reliable model. The procedure of drilling and measuring thickness is efficient, but time consuming.

7.3 Research questions

The process main observations from the optimization and organization will results in the answering of the research questions.

Research question 1: Construction

Sub question 1.1: How does the design influence the building process?

The design of the Flamenco ice tower was influenced in such way that inflating it at one was not possible. This is concluded after the structural calculation of the inflatable which showed too much deformation. Therefor the sequence is building sequence is modified. The inflation is divided in two parts of partial inflation to create a stable ice base for the rest of the tower.

Sub question 1.2: How can the production process be optimized?

The production process is optimized by pointing out the bottlenecks which are leading to an increase in throughput time. The dissolvent time of cellulose sheets is the bottleneck and causing an increasement in throughput time. By adding a shredder to the process the throughput time is decreased with 50%.

The engineering of the Mobile factory mobilized the production line. This made the production operate independently form external factors such as power shutdowns.

Sub question 1.3: How can the construction process be optimized?

Because the Mobile factory houses all equipment for production and processing of Cellcrete, all activities are prepared at front in one platform. This decreases the needed time on site to install the production line with local equipment. Also the preparations ensure the reliability of the factory.

By adding a monitoring system in the container, the status of the inflatable can be tracked. This results in a real time status which made it possible to directly intervention when some errors occurred during the building of the Flamenco ice tower.

<u>How to optimize the current construction methods and processes to realize fiber reinforced ice structures?</u>

The implementation of one mobile total construction platform simplifies the realization of ice projects. An engineered mobile factory forms a uniform standard to construct ice structures all over the world. The mobile factory operates as independent as possible and the monitoring system enables to directly intervene when needed.

Research question 2: Organization

Sub question 2.1: How to optimize and manage planning and building speed before and during construction?

The developed tool makes it possible to measure the progress of the ice shell development. The tool compared the planning and building speed on different measure points. These insights result in interventions to optimize the building during the construction.

Sub question 2.2: How to overview, manage and reduce costs before and during construction?

The overall financial statement is composed by the Maple Leaf Village. Due to confidential information, this information is not shared and no conclusions can be given on how to overview, manage and reduce costs.

The expenses of specifically the mobile container are described and tracked. Most of financial input has been realized by sponsors. It can be concluded that the realization of the mobile factory is an investment for further projects, reducing costs in the future.

<u>How to manage and control organizational factors before and during the construction process?</u>

Organization factors are derived of the total building progression. With the development and use of a uniform tool for ice shell structures, this building progression is monitored.

Main question

<u>How to realize the Flamenco tower in Ice and optimize the production process, within stated boundaries?</u>

After a successful international corporation, the tower is constructed. The production and building processes are optimized by engineering a mobile factory within a container. This container houses the production line, and all facets to monitor the building progress and inflatable conditions.

Addition to science

This research continued where previous research ended. By the engineering of the Mobile factory, an optimization and simplification or the process have been obtained. The Mobile factory sets the first steps to a fully automated construction process on building Ice sculptures.

Thereby, the points of attention and options for improvement will be given in the next chapter to continue optimizing the process of building ice sculptures in further ice projects.

8.Recommendations

The performed project resulted in different points of attention and options for improvement. The following chapter states the recommendation for further ice projects.

Team

The ambition for a considered and extensive preparation was the base of the success of the project. However this can be simply improved in further projects.

It is essential to compose a big enough team early in the process. This must be accompanied by a clear hierarchy and division of responsibilities. A project leading team should also be appointed in the beginning and control the progression of the preparations.

It is recommended to bring a big team to the construction place. It is more efficient to work with engineers who know the background of the project and it will simplify the communication.

Communication

Communication is essential for the successful progress of a comparable projects.

If future project are performed on an international base where English is not a native language, it is important to always make use of translators to avoid misunderstandings.

During the preparations, meetings must take place at least once a week to update the whole team about the progressions. This promotes the involvement and efficiency of all team members.

During construction, daily meetings are recommended to update the whole team of the progress and difficulties. Previous ice projects commenced these daily meetings, but due to time shortage the meetings were expelled in this project. It is recommended to, even dough time shortage, continue this daily meetings.

Planning

To compose a reliable planning, it is important to plan slack time for unforeseen delays. For this project, already more time was planned for delays in comparing to previous projects. Despite this planning, a delay of the total construction time still occurred.

Inflatable

Outsourcing the production of the inflatable resulted in a high quality inflatable. However, important elements were missing on the inflatable. Therefore, it is important to specify the addition of hoisting provisions, position markers, air tubes and a folding plan.

Without these additions, the positioning and inflation of the inflatable it unnecessarily complicated.

Mobile factory

The mobile factory can be improved by extra research and engineering. Due to financial and time limitations, some functions are simplified which limited the atomization of the mobile factory.

Processes to automate the factory are already partially engineered. Further engineering and implementation will result in a more efficient production, and construction progress which will eliminate human errors.

Monitoring tool

The monitoring tool needs additional development to allow a direct implementation in the visualized model. This simplifies the use and the reliability of the tool.

Thereby, the way of measuring can be improved. Because of the importance of the development of the ice shell, and the amount of time it takes, it is recommended to assign a full-time engineer to monitoring the shell. During this project the lack of engineers and supervisors, often led to a minimal execution of the measurements.

Continuous measurement via wireless depth sensors on the inflatable shell will result in a real time model of progression. The real time model will make direct interventions possible to solve impurities in the shell.

Safety

It is recommended to establish clear arrangements beforehand about safety. Because the ice projects are mostly internationally oriented, safety standards differ per country. A uniform agreement must solve these uncertainties and ensure a safe construction process.

9.Annex

1- Overview of recommendations

2- Rope net plan

3- Ice ring floor plan

4- Assignment 1: SUMMA-Structural-Ice-Shredder

5- Assignment 2:SUMMA- Structural-Ice-Mobile factory

6- Shredder working drawings

7- Cost overview BOM mobile factory

8- First container design + electrical circuit

9- Frame container working drawings

10- Final container design + electrical circuit

11- Overall construction planning

12- Schedule labor overview

13- Cost overview Flamenco tower in Ice 2018

14- Example of report log

15- Monitoring tool for progression on ice shell structures

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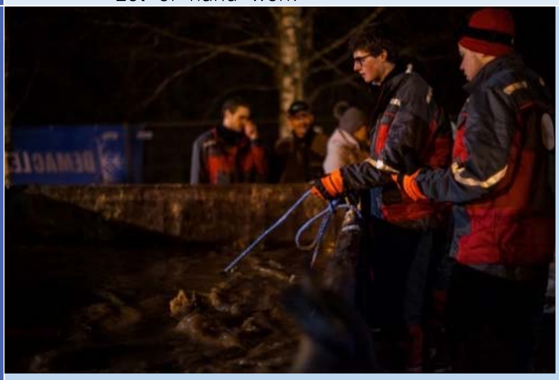
Annex 1; Overview of recommendations

Project:	Pykrete Dome – 2014	Sagrada Familia in Ice – 2015	Bridge in Ice – 2016
			
Construction process			
- Description	- Pykrete was sprayed with fixed hoses - Water was sprayed by mobile vehicle (fire department) - Snow application by static snow canon.	- Pykrete was sprayed with fixed hoses - Pykrete was spayed out of boom lifts to reach height - Snow application by mobile snow canon	- Pykrete was spayed by fixed hoses - Pykrete was spayed out of boom lifts to reach height - No snow application was needed.
- Construction issues	- Slow snow production - Snow needed to be transported and distributed - Pykrete spraying not mobile - Lot of hand work	- Mobile snow canon was hard to move - Too much hoses and cables on building site - Pykrete spraying not mobile	- Pykrete spraying not mobile
Production process			
- Description	- Outside production - Loose pumps in container - No buffer	- Outside production - Strategically placed pumps in container - No buffer - Upscaled production x2	- Inside production - Pre-production - Buffer - Controlled climat
- Production issues	- No consistant output - Freezing of material and equipment - No reliable system	- No consistant output - Freezing of material and equipment - No reliable system	- Long preparation time - Long production time - No ventilation
Recommendations	- Improvement in the application of snow - Emergency measures due to electricity - More reliable planning, depending on weather - Better sieving of saw dust	- Simplify work outside - Automatization of production and construction - Better sieving of saw dust	- Container consisted of slippery steel grids - Ventilation improvement - Mobile spraying system is preferred
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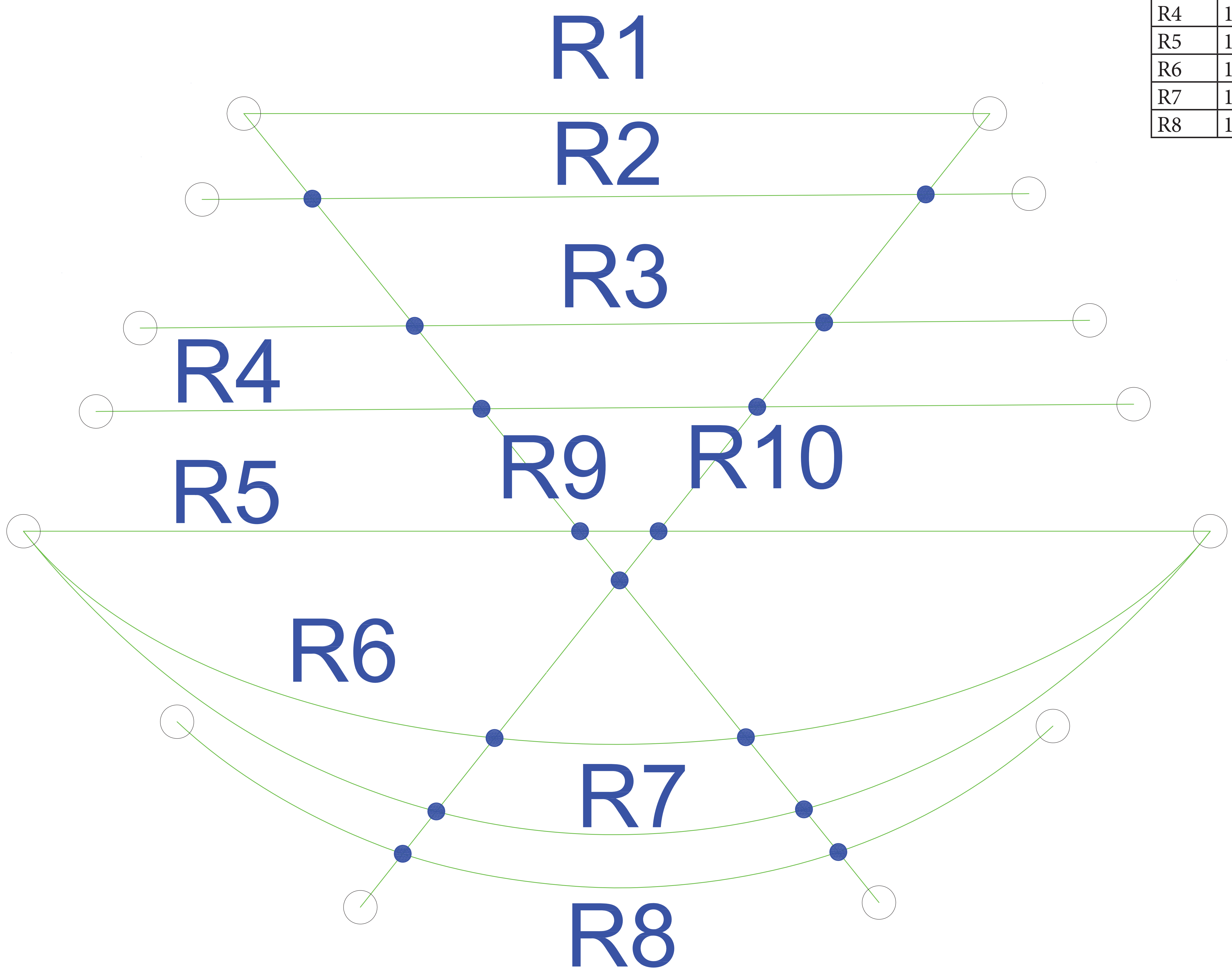


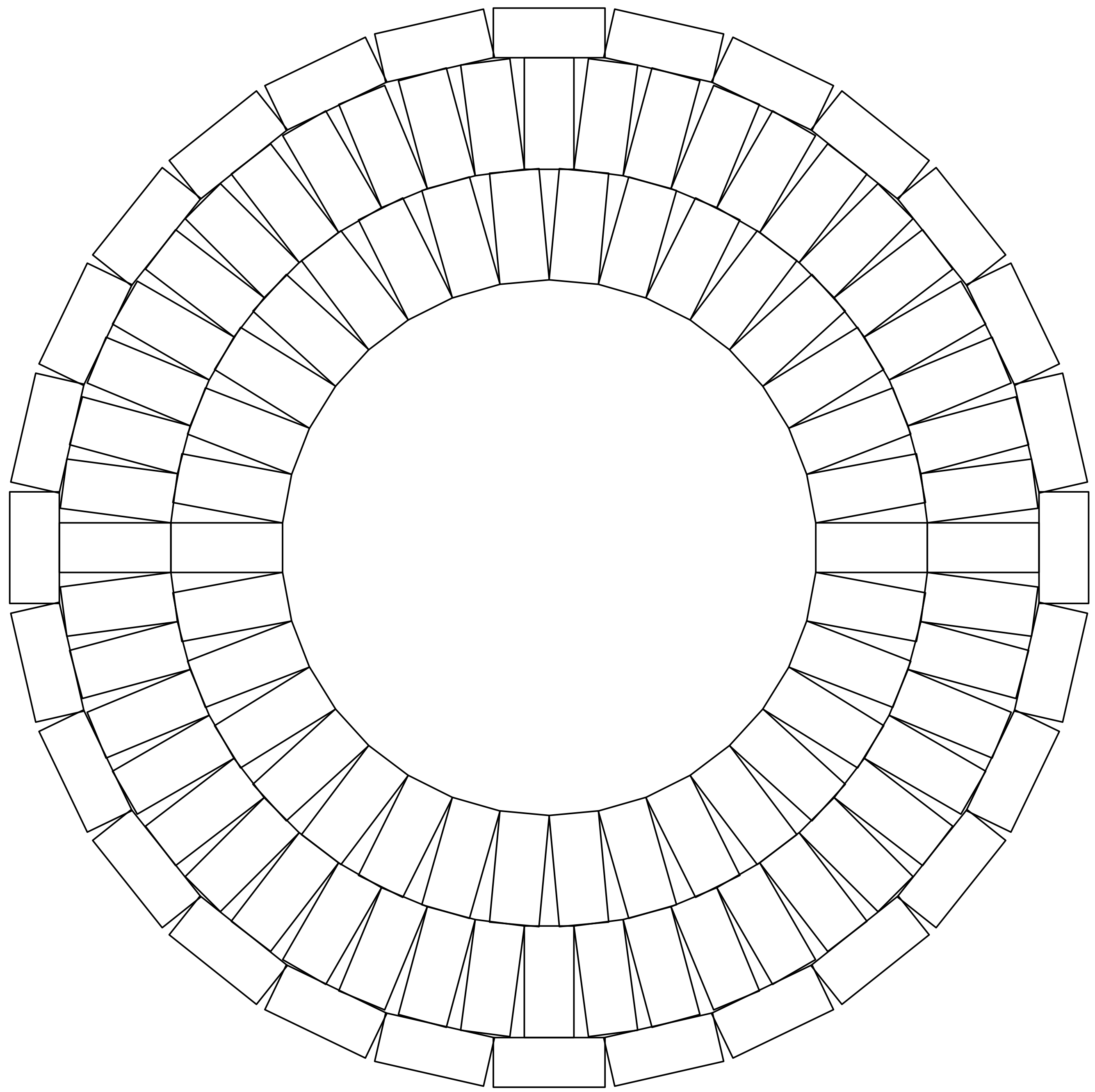
Rope	Total lenght	lenght 1	lenght 2	lenght3
R1	14.7 m	14.7 m	0 m	0 m
R2	14.6 m	3.0 m	8.5 m	3.0 m
R3	15.2 m	5.1 m	5.0 m	5.1 m
R4	16.0 m	6.4 m	3.2 m	6.4 m
R5	17.8 m	8.5 m	0.9 m	8.5 m
R6	18.4 m	7.7 m	3.1 m	7.7 m
R7	17.7 m	6.6 m	4.5 m	6.6 m
R8	12.3 m	3.4 m	5.5 m	3.4 m

Rope	R9	R10
Total lenght	17.3 m	17.3 m
lenght 1	3.0 m	3.0 m
lenght 2	2.2 m	2.2 m
lenght 3	1.3 m	1.3 m
lenght 4	1.9 m	1.9 m
lenght 5	0.8 m	0.8 m
lenght 6	3.1 m	3.1 m
lenght 7	1.9 m	1.9 m
lenght 8	1.2 m	1.2 m
lenght 9	1.8 m	1.8 m

Flamenco ice Tower

Rope-net plan

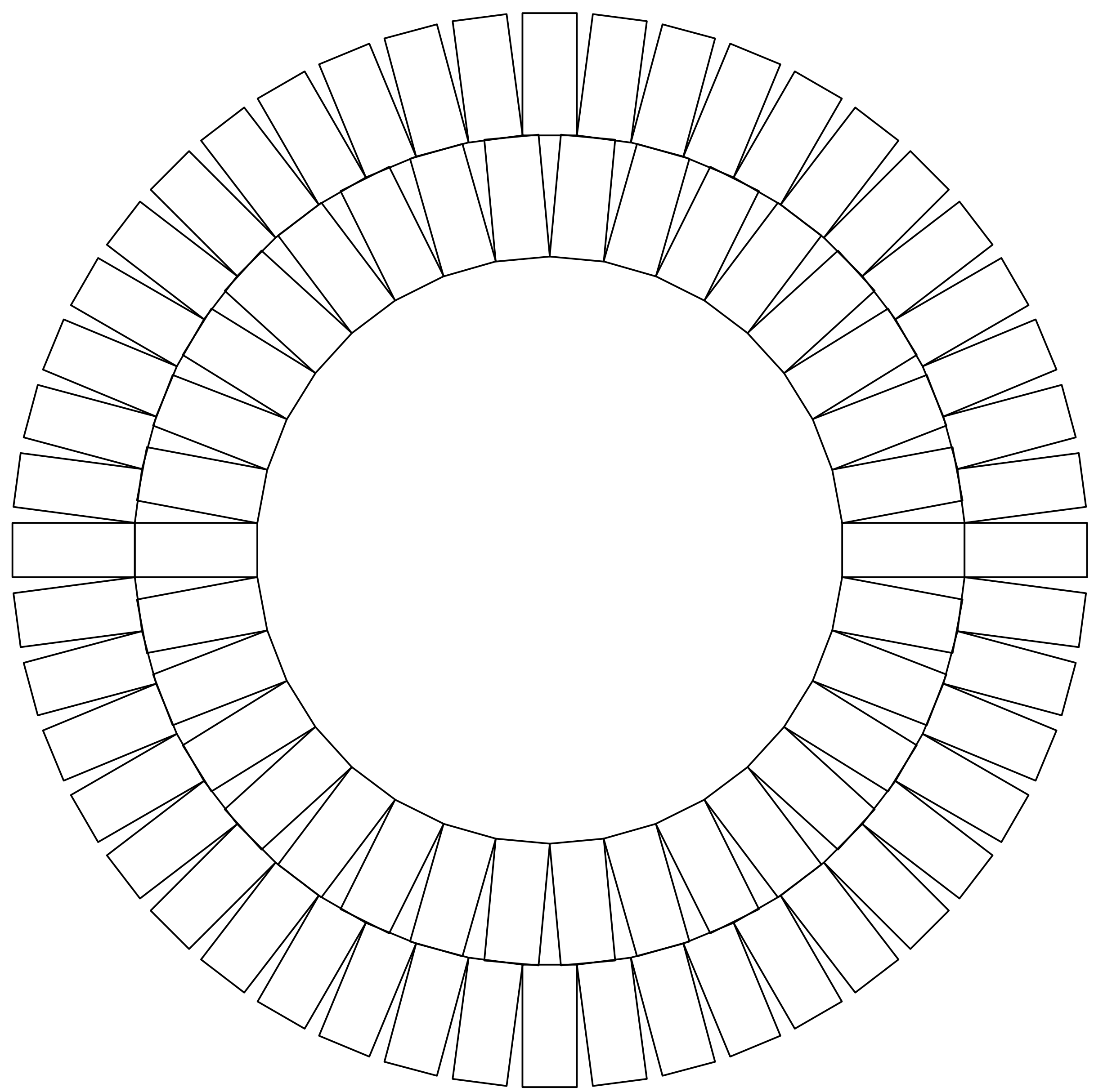
All in meter!!!



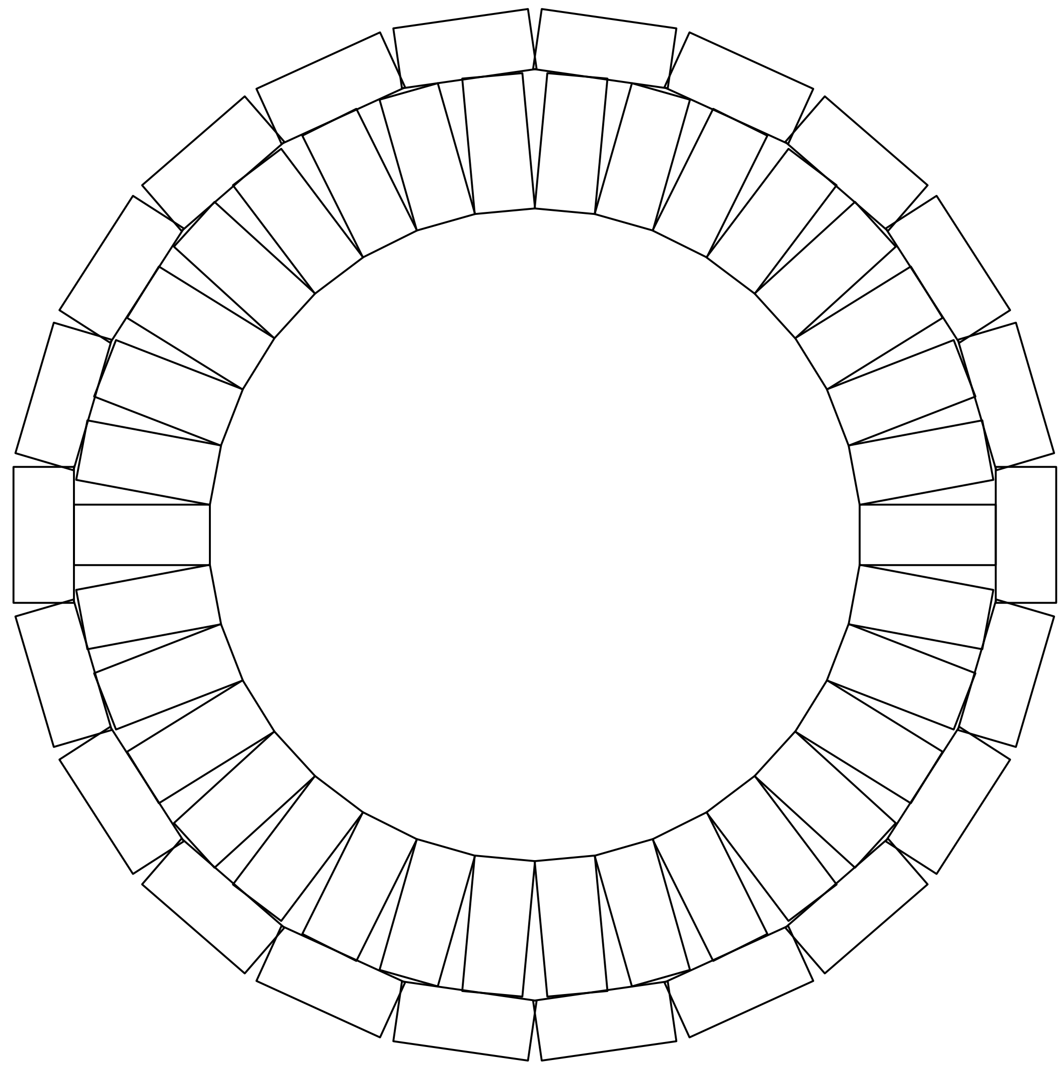
Project
Flamenco Ice tower

Scale
1:100

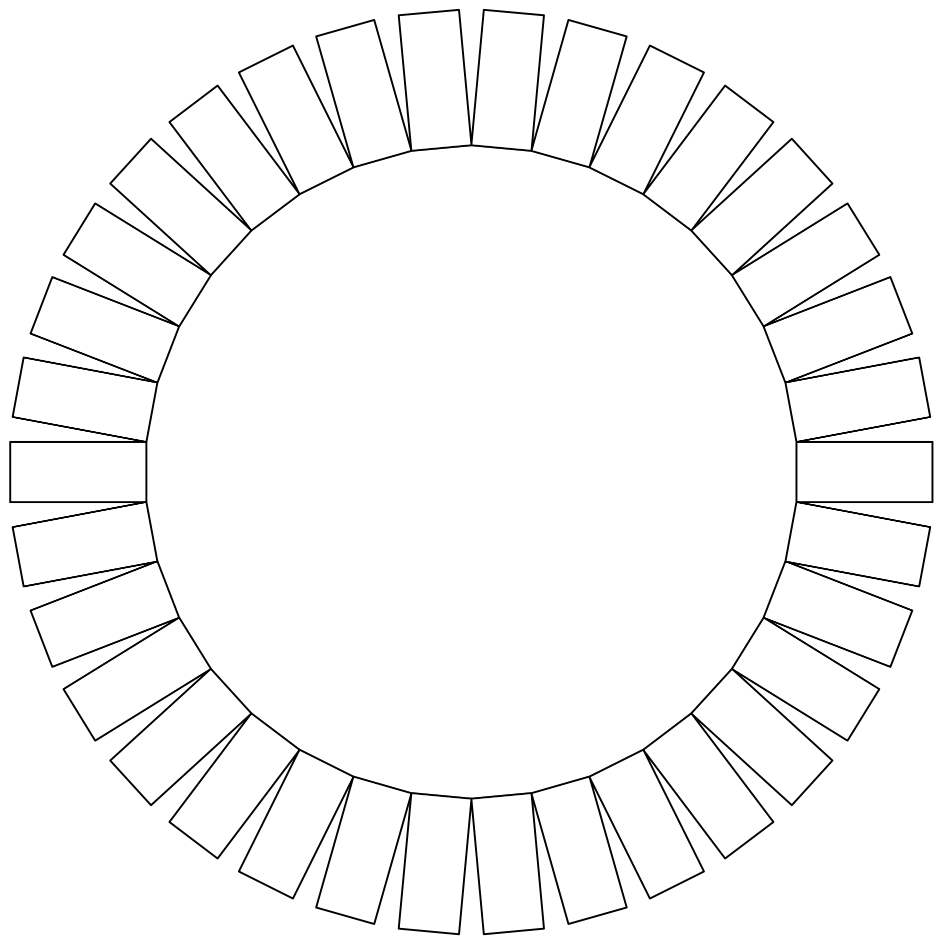
Beschrijving
Plan Ice blocks ice hill - layer 1



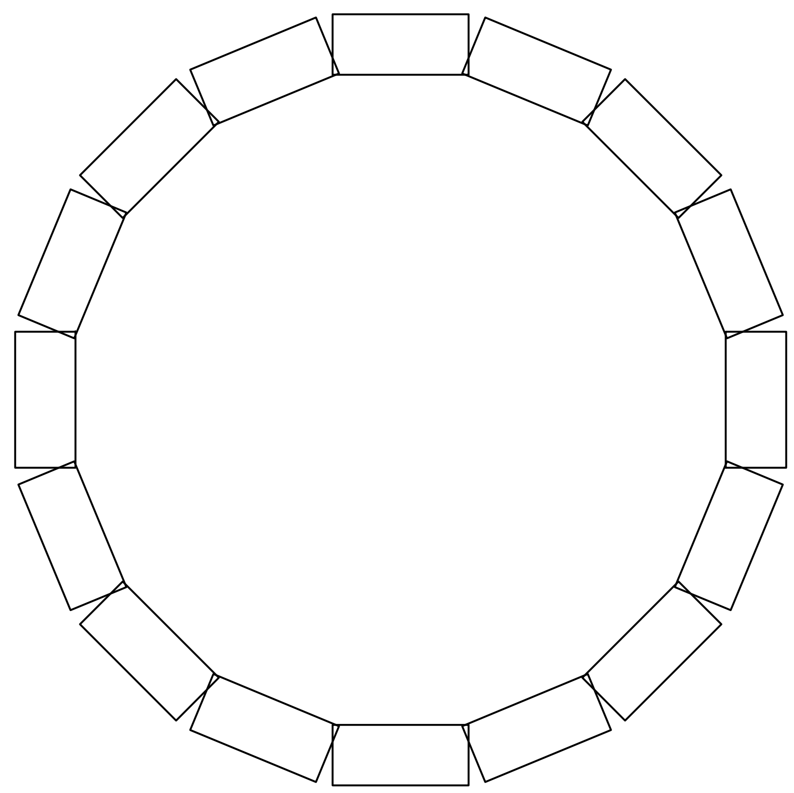
Project Flamenco Ice tower	Scale 1:100
Beschrijving Plan Ice blocks ice hill - layer 2	



Project	Scale
Flamenco Ice tower	1:100
Beschrijving	
Plan Ice blocks ice hill - layer 3	



Project	Scale
Flamenco Ice tower	1:100
Beschrijving	
Plan Ice blocks ice hill - layer 4	



Project	Scale
Flamenco Ice tower	1:100
Beschrijving	
Plan Ice blocks ice hill - layer 5	

Summa college: Structural Ice
Opdracht 1: Schredder

Project omschrijving:

In het project wordt er gebruik gemaakt van Cellkrete. Dit is een ijs soort welke is verstevigd door het gebruik van cellulose vezels (papier-vezels). Het materiaal wordt doorgaans gebruikt met bv. 5 of 2 massa-% cellulose. Door de vezels in het ijs, is het matriaal in staat om veel meer trekkrachten te kunnen verwerken. Ook wordt het materiaal een stuk taaier. Beide zijn positieve eigenschappen voor het bouwen met ijs.

Probleem omschrijving:

Het Cellkrete wordt aangemaakt m.b.v. vellen cellulose. Deze vellen bestaan voor 98% uit pure cellose. Deze vellen worden voor de productie verscheurd en geweekt in een bad met water. Door het weken vallen de gescheurde vellen uit elkaar en ontstaat een composiet, Cellkrete.

Het weken van het cellkrete duurt echter zeer lang en het scheuren van de vellen is erg arbeidsintensief en tijdrovend.

Probleem stelling:

Er is een manier gewenst om het scheuren en toevoegen van de vellen te automatiseren. Hierbij kan een schredder uitkomst bieden.

Er moet worden uitgezocht in hoeverre de toevoeging van cellulose kan worden geautomatiseerd.

Het systeem moet in staat zijn om zelf deze vellen te 'pakken', uit te tellen, en zoveel mogelijk te verkleinen om het productieproces te versnellen.

Criterea:

- Schredder moet in staat zijn de cellulose vellen zo klein mogelijk te verwerken
- De mate van automatisering moet in overleg worden bepaald
- Het systeem moet zelf de vellen, en daarmee het massa-% cellulose kunnen bepalen.
- Het systeem moet veilig zijn in gebruik voor iedereen.
- Het systeem moet een ruime voorraad capaciteit hebben, en een melding geven wanneer deze op dreigt te raken.
- De vellen kunnen per fabrikant van afmeting verschillen, hiermee dient rekening te worden gehouden.

Aanvullend:

Een ontworpen en uitgevoerd systeem zal worden ingebouwd in een mobiele productie unit zoals in opdracht 2.

Summa college: Structural Ice
Opdracht 2: Container

Project omschrijving:

In het project wordt er gebruik gemaakt van Cellkrete. Dit is een ijs soort welke is verstevigd door het gebruik van cellulose vezels (papier-vezels). Het materiaal wordt doorgaans gebruikt met bv. 5 of 2 massa-% cellulose. Door de vezels in het ijs, is het matriaal in staat om veel meer trekkrachten te kunnen verwerken. Ook wordt het materiaal een stuk taaier. Beide zijn positieve eigenschappen voor het bouwen met ijs.

Probleem omschrijving:

Het Cellkrete wordt aangemaakt m.b.v. vellen cellulose. Deze vellen bestaan voor 98% uit pure cellose. Deze vellen worden voor de productie verscheurd en geweekt in een bad met water. Door het weken vallen de gescheurde vellen uit elkaar en ontstaat een composiet, Cellkrete.

Vanwege de internatiole aard van de projecten zal op meerdere plaatsen een bouwwerken worden gerealiseerd. Om de productie omstandigheden zo optimaal mogelijk te houden moet hier een oplossing voor gevonden worden

Probleem stelling:

Er dient een mobiele productie lijn te worden ontworpen en gerealiseerd. De unit zal worden ingebouwd in een zee-container en bestaat uit 3 ruimten: natte ruimte, droge ruimte/opslag, keet.

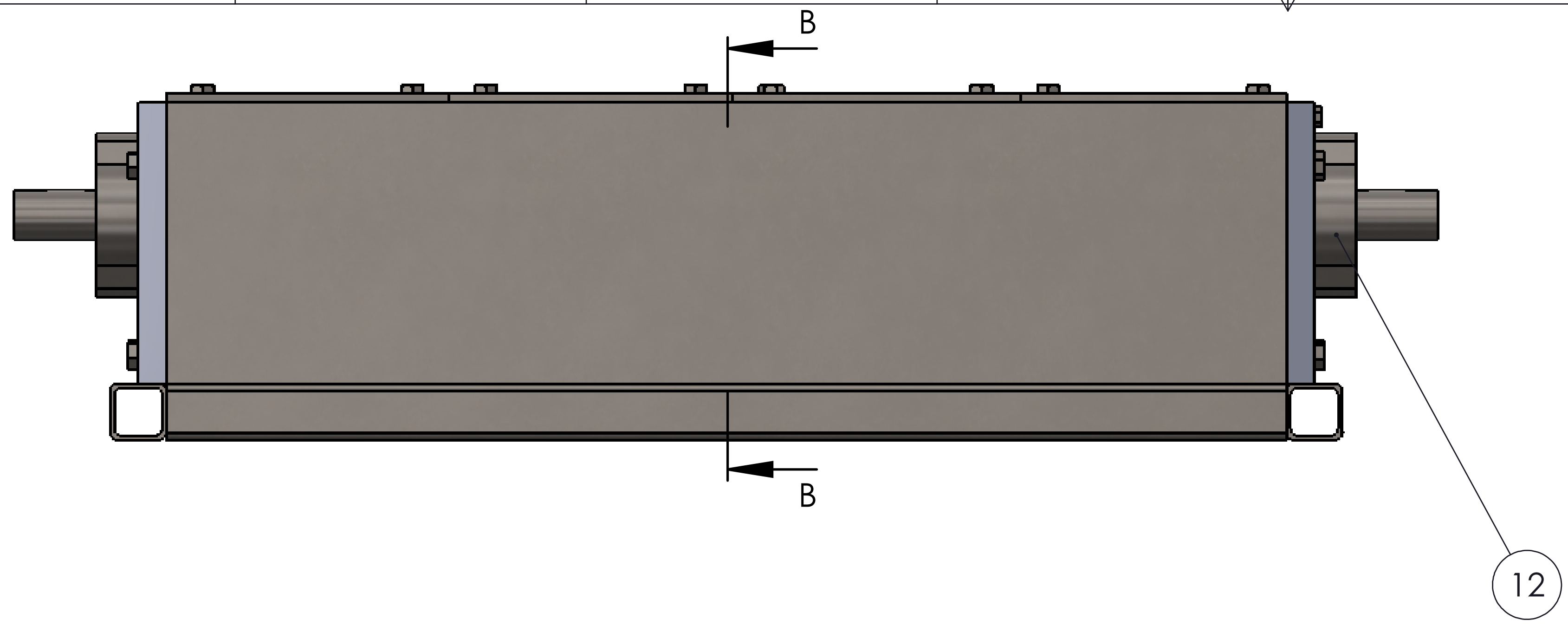
De container dient alleen te worden aangesloten aan de waterleiding, en het electranet. Vervolgens moet de container in staat zijn om het bouwproces te coordineren.

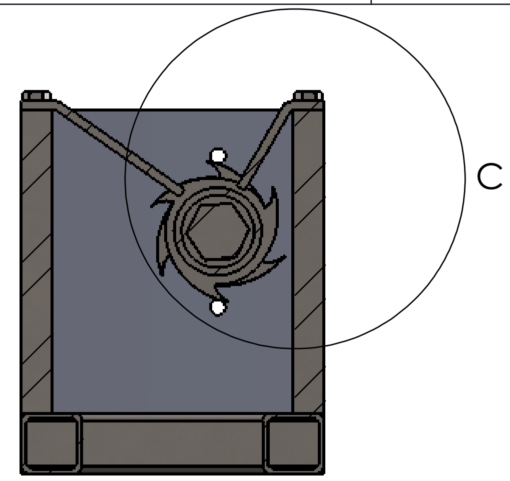
Criterea:

- De productielijn dient in een mobiele unit te worden in een zeecontainer.
- Natte ruimte: productie cellulose en verpompen; zowel voor spuiten als 3d-printen.
- Droge ruimte: electriceitsaansluiting en besturing, noodaggegraat, mogelijkheid tot opslag.
- Keet: ruimte voor monitoren en coordineren van het bouwproces, ruimte voor bouwvakker om te pauzeren
- Unit moet zo compact mogelijk worden
- Unit moet klimaatgeregeld zijn; zowel vochtigheid, temperatuur als ventilatie.
- Unit moet veilig zijn voor gebruik door iedereen
- Unit moet ter plaatse van keet en natte ruimte voorzien worden van ramen.

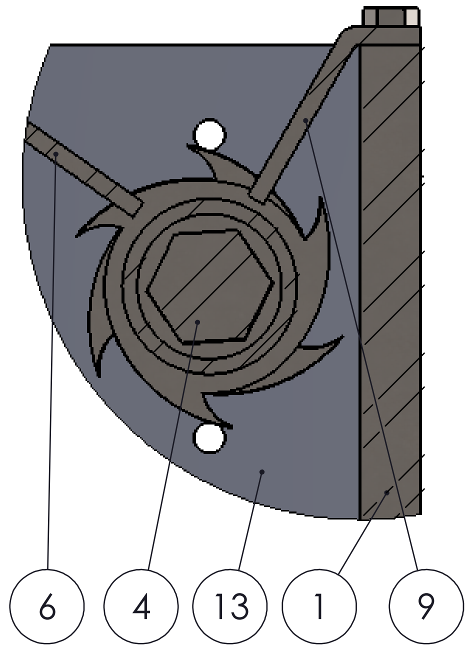
Aanvullend:

In opdracht 1 wordt een schredder ontworpen welke deel zal uitmaken van het productieproces dat wordt verwerkt in de container.

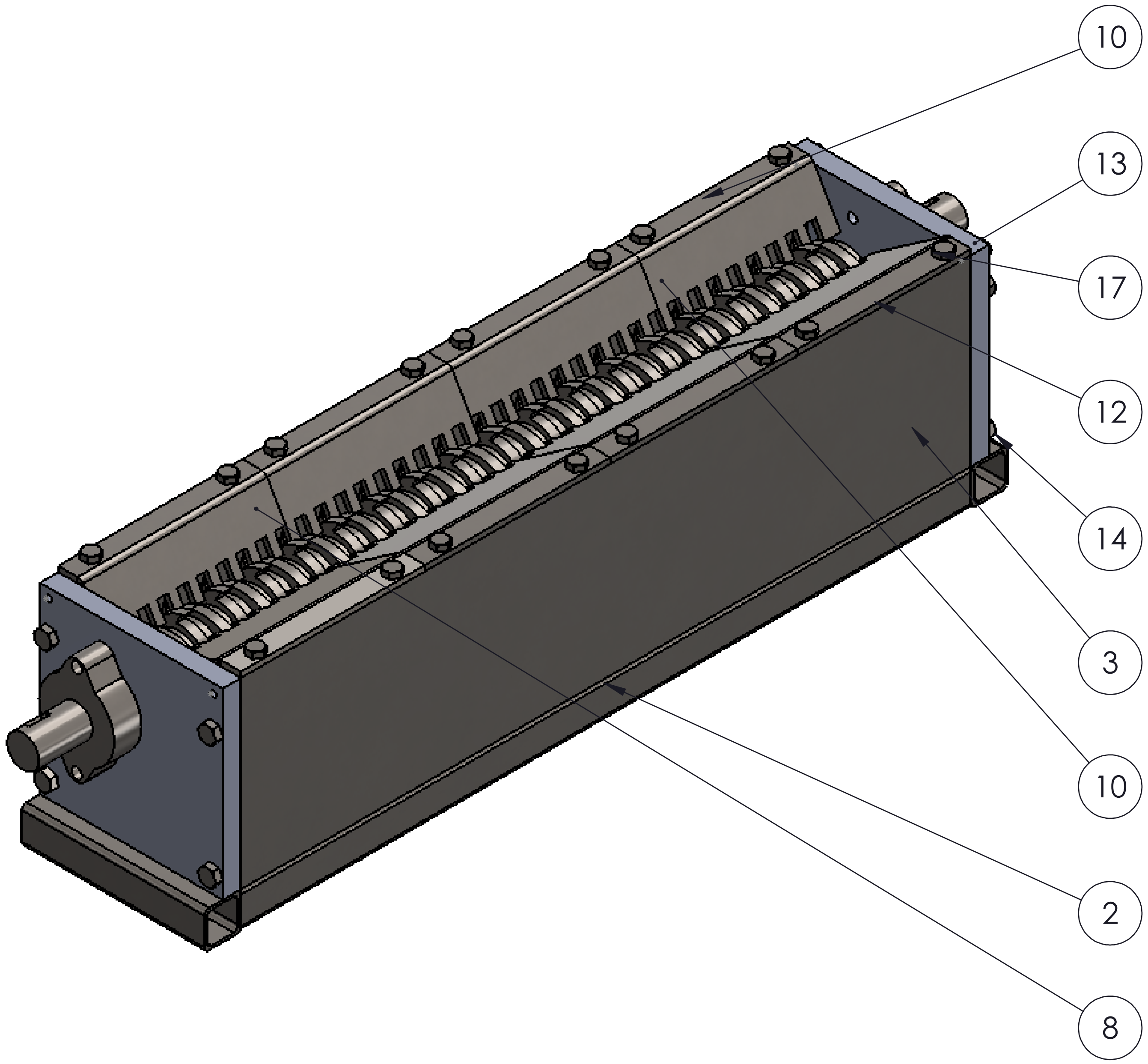




SECTION B-B
SCALE 1 : 5

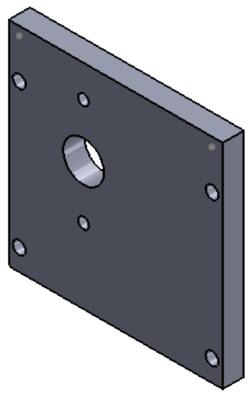


DETAIL C
SCALE 2 : 5

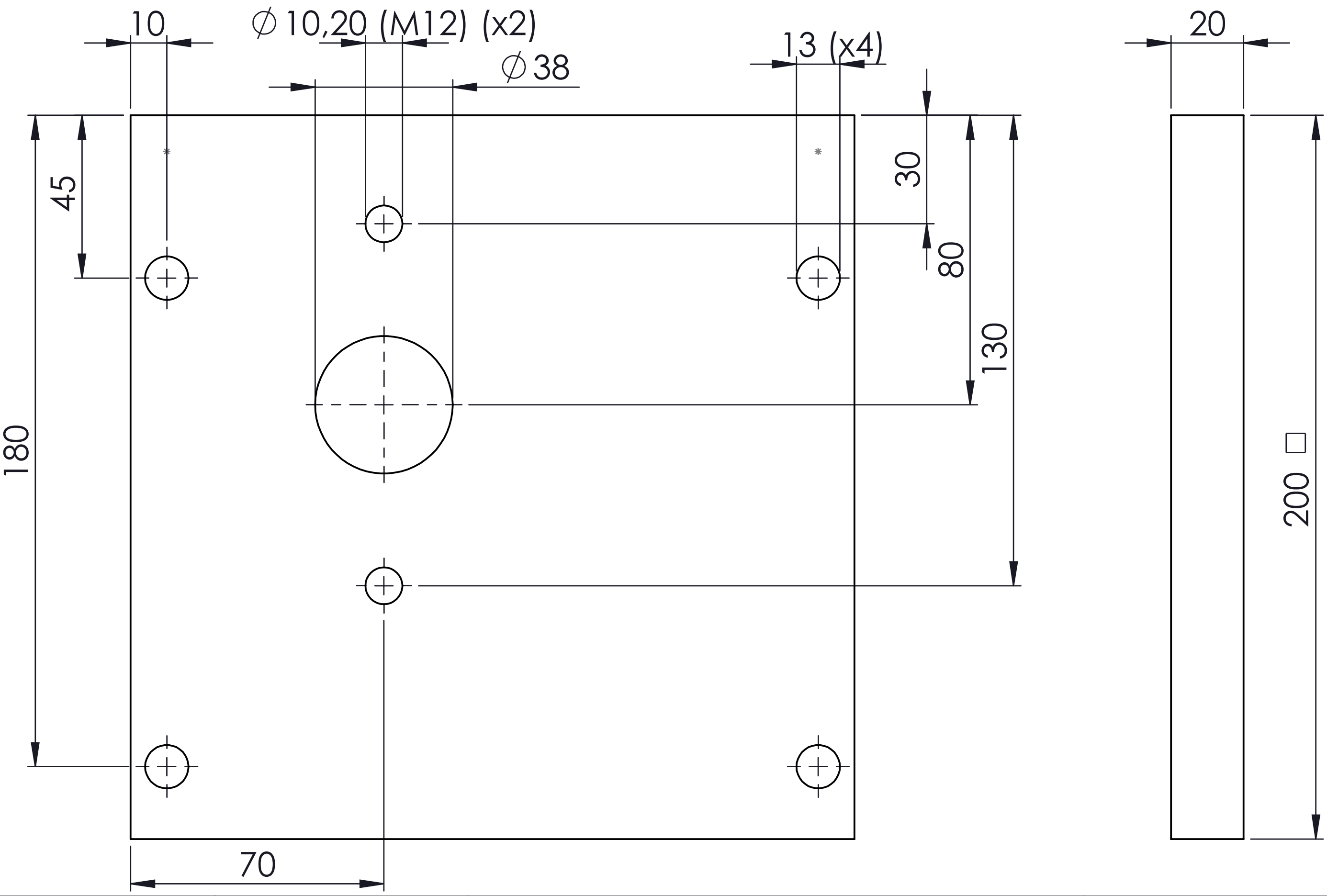


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PART11SHREDDER		2
2	koker		2
3	kokerkort		2
4	as assembly		1
5	PART4SHREDDER		1
6	PART6SHREDDER		1
7	PART7SHREDDER		1
8	PART3SHREDDER		1
9	PART5SHREDDER		1
10	PART8SSHREDDER		1
11	PART10SHREDDER		1
12	lagerblok		2
13	Part1		2
14	ISO 4015 - M12 x 45 x 30-N		8
15	ISO 4015 - M8 x 45 x 22-N		2
16	PART9SHREDDER		1
17	DIN EN 24015 - M10 x 40 x 26-N		16

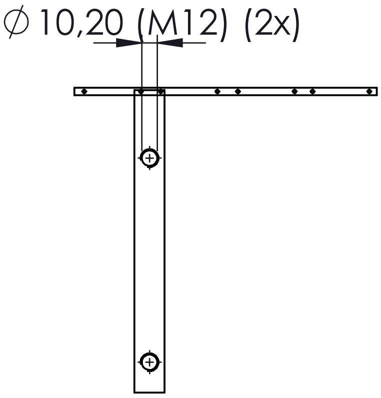
Opp. ruwheid (zie NEN 3634)	Maattoleranties NEN-ISO 2768-	MATERIAAL: staal	Vorm- en plaatstol. (zie NEN-ISO11010)
	SCHAAL: 1:10	GETEKEND: Michiel Vrijsen	OPMERKING:expl. view expl. view
	MAATEENHEID: mm	KLAS: MTM3B4	
	DATUM: 15-6-2017	GEZIEN:	
SUMMA Engineering		BENAMING: Assembly shredder	NUMMER: A3

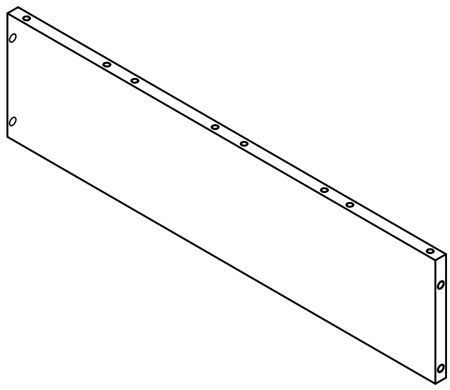


schaal 1:5

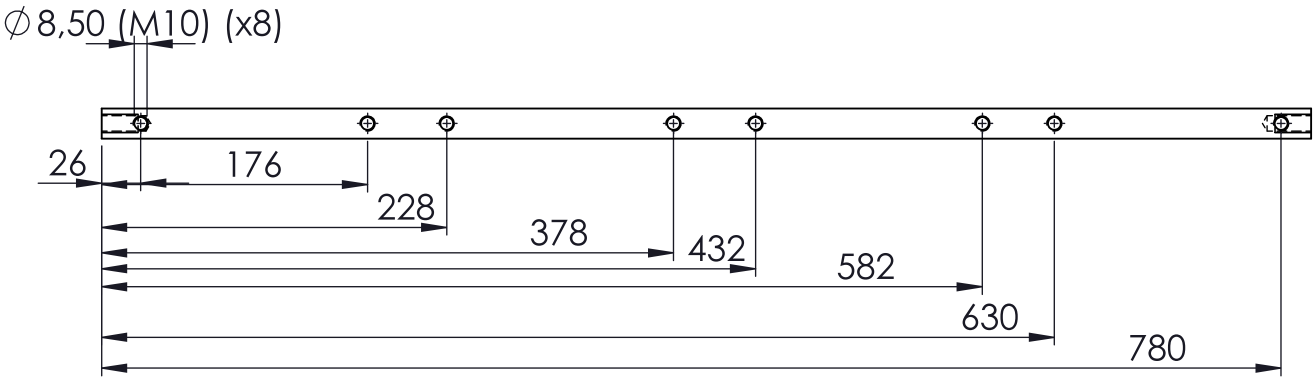


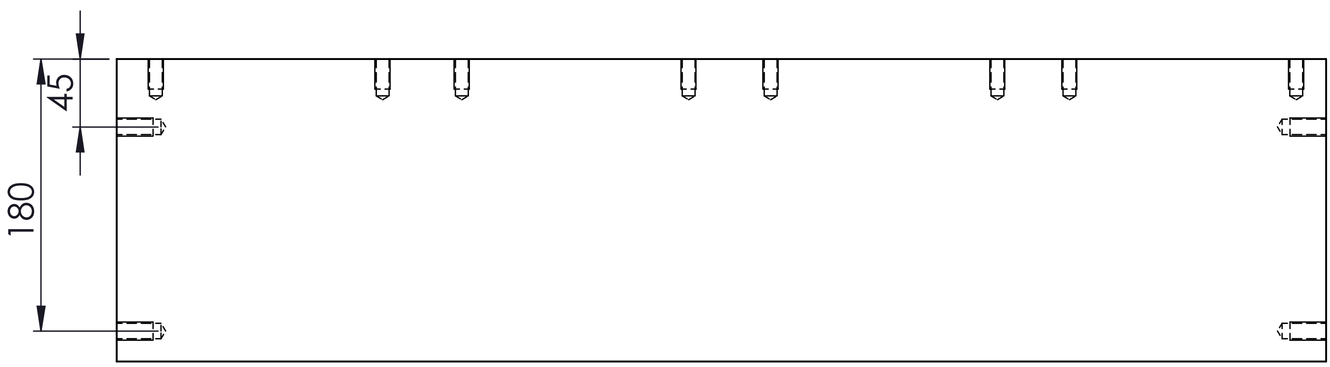
Opp. ruwheid (zie NEN 3634)	Maattoleranties NEN-ISO 2768-	MATERIAAL: staal	Vorm- en plaatstol. (zie NEN-ISO11010)
	SCHAAL: 1:2	GETEKEND: Michiel Vrijsen	OPMERKING:
	MAATEENHEID: mm	KLAS: MTM4B4	
	DATUM: 6-9-2017	GEZIEN:	
SUMMA Engineering		BENAMING:	NUMMER: A4



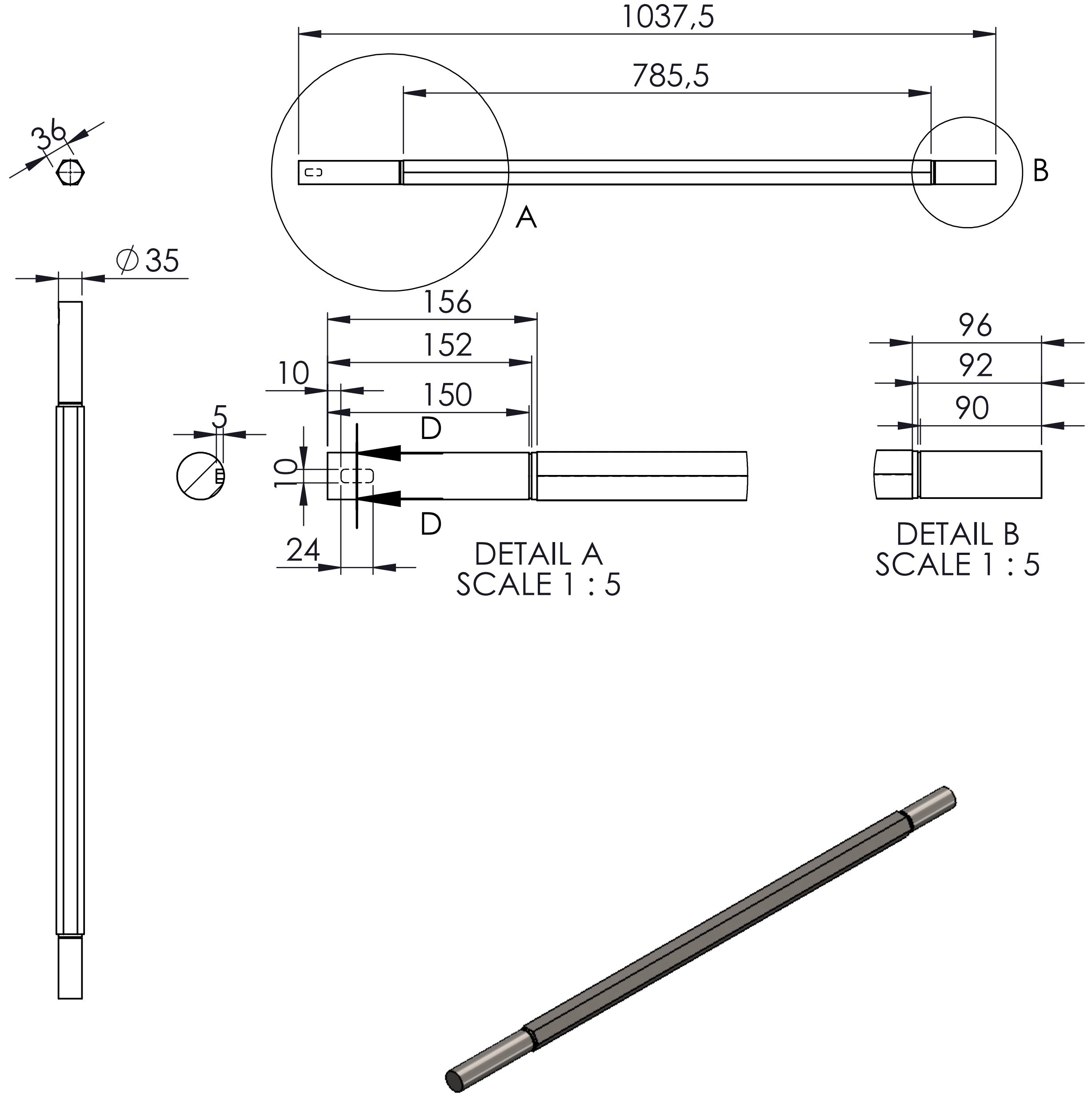


schaal 1:10
diepte gaten:
M10 (8x): 20mm
M12 (4x): 30mm





Opp. ruwheid (zie NEN 3634)	Maattoleranties NEN-ISO 2768-	MATERIAAL: staal	Vorm- en plaatstol. (zie NEN-ISO11010)
	SCHAAL: 1:10	GETEKEND: Michiel Vrijsen	OPMERKING: diepte gaten 8x: 20 mm diepte gaten 4x: 30
	MAATEENHEID: mm	KLAS: MTM4B4	
	DATUM: 6-9-2017	GEZIEN:	
SUMMA Engineering		BENAMING:	NUMMER: A4



Opp. ruwheid (zie NEN 3634)	Maattoleranties NEN-ISO 2768-	MATERIAAL:	Vorm- en plaatstol. (zie NEN-ISO11010)
	SCHAAL: 1:10	GETEKEND:	OPMERKING:
	MAATEENHEID: mm	KLAS:	
	DATUM: 6-9-2017	GEZIEN:	
SUMMA Engineering		BENAMING:	NUMMER: A4

Bill of material: Overview

Part	Price total	Sponsoring	Price after sponsoring
Structure	€ 8.303,35	€ 2.396,40	€ 5.906,95
Electronics	€ 9.382,02	€ 7.135,43	€ 2.246,59
Air	€ 1.195,00	€ 700,00	€ 495,00
Water	€ 3.996,85	€ 3.376,75	€ 620,10
Furniture	€ 2.522,06	€ 1.903,27	€ 618,79
Tools for container	€ 3.755,52	€ 3.755,52	€ 0,00
Tools in container	€ 398,00	€ 398,00	€ 0,00
Control	€ 1.125,00	€ 1.125,00	€ 0,00
Total	**€ 30.677,80**	**€ 20.790,37**	**€ 9.887,43**

Bill of Material: Constructie

Product
~~Houten balken~~
isolatie plaat wanden, vloer en plafond
underlayment plaaten (zijwanden, plafond, achterzijde)
underlayment plaaten (voorzijde
Betonplex (vloer)
Hi-tackkit
acrylaatkit
zelf borende schroeven
hoekijzer
lxbxh: 12,20 x 2,44 x 2,59 buitenmaat
lxbxh: 12,20 x 2,33 x 2,37 binnenmaat

Omschrijving	Leverancier
~~60x60x3000 mm~~	~~Hout leverancier~~
PIR 120x60x5 cm	bouw groothandel
2440 x 1220 x 10 mm	bouw groothandel
2440 x 1220 x 18 mm	bouw groothandel
2440 x 1220 x 18 mm	bouw groothandel
tussen de houtplaaten/betonplex platen voor vastzetten	bouw groothandel
tussen de houtplaaten, ramen, doorvoerpaneel, deuren voor afdichting	bouw groothandel
Tex BK DIN 7504-N 5.5x32	
20x20 3mm dik	staalboer

Omschrijving Leverancier	Aantal
	~~120~~
	274
	35
	2
	10
	50
	100
	1500
	40

Opmerking	Evt. code
~~120 lengtjes van 3 m~~	
400 platen	
35 platen	
2 platen	
10 platen	
50 bussen	
100 bussen	
1500 schroeven voor het vastzetten van underlayment/betonplex plaaten	
40 hoekijzers vastzetten plaaten	
	Na sponsoring
	Zonder sponsoring

Prijs p/s	Totaal Prijs	Op Voorraad Ja/Nee	Sponsor	Link
~~€ 19,97~~	~~€ 2.396,40~~		~~SUMMA~~	
€ 13,15	€ 3.603,10			
€ 17,75	€ 621,25			
€ 29,00	€ 58,00			
€ 88,59	€ 885,90			
€ 5,93	€ 296,50			
€ 1,82	€ 182,00			
€ 0,15	€ 231,00			
€ 0,73	€ 29,20			
	€ 0,00			
	€ 0,00			
TOTAAL	€ 5.906,95			
	€ 8.303,35			

#NAME?

Bill of Material: Electra

Product
~~Stago Ladderbaan KHZP 300MM~~
~~Stago Eindkap Rood~~
~~Stago Wandbevestiging 11/25~~
~~Stago Koppelplaat 21 TV~~
Clickfit Spaanplaatschroeven 5x40mm
~~Fischer ASF Carrosseriering M6~~
~~Thomas & Betts TY 527MR~~
~~Draka VULT Installatiekabel 5G10mm² Grijs~~
~~Draka VULT Installatiekabel 5G6mm² Grijs~~
~~Draka VULT Installatiekabel 5G2.5mm² Grijs~~
~~Draka VULT Installatiekabel 3G2.5mm² Grijs~~
OBO Rijg-Druk-Zadel 27-43mm, PA, Lichtgrijs, RAL 7035
OBO Rijg-Druk-Zadel 18-30mm, PA, Lichtgrijs, RAL 7035
Wago Verbindingsklem 5x2,5mm² Grijs
Wavin PVC Elektrobuis VSV GR 3/4"
~~Attema AK1-IP65 Kabeldoos met Nylon Wartels~~
~~ABB Busch-Jaeger Opbouw 2x Wandcontactdoos~~
~~ABB Busch-Jaeger Opbouw Wandcontactdoos + Lichtschakelaar~~
~~Mennekes CEE Form Stekker 63A 5polig 400V~~
~~Mennekes CEE Form Stekker 32A 5polig 400V~~
~~Mennekes CEE Form Stekker 16A 5polig 400V~~
~~Mennekes CEE Form WCD Opbouw 63A 5polig 400V~~
~~Mennekes CEE Form WCD Opbouw 32A 5polig 400V~~
~~Mennekes CEE Form WCD Opbouw 16A 5 polig 400V~~
ABB Verdeler Opbouw 72 Modulen
JMV Bevestigingsrail DIN-rail
Legrand Bedradingskoker Segma L2000 40 x 40
Van der Valk Popnagels Aluminium 6,3x23,4
~~Schneider Electric Installatieautomaat C63~~
~~Schneider Electric Aardlekschakelaar 40A~~
~~Schneider Electric Installatieautomaat C16~~
~~Schneider Electric Installatieautomaat C16~~
~~Schneider Electric Installatieautomaat C32~~
~~Schneider Electric Aardlekschakelaar 25A~~
Schneider Electric THERM-MAGN 1,6-2,5A
Schneider Electric THERM-MAGN 2,5-4A
Schneider Electric THERM-MAGN 6-10A
Verdeelkast Opbouw 24 Modules
Klemko Adereindhuls 4mm² Grijs
~~Donne VDS Installatiedraad 4mm² Groen/Geel~~
~~Donne VDS Installatiedraad 4mm² Blauw~~
~~Donne VDS Installatiedraad 4mm² Bruin~~
~~Donne VDS Installatiedraad 4mm² Zwart~~
~~Donne VDS Installatiedraad 4mm² Grijs~~
Klemko Adereindhuls 2.5mm² Blauw
~~Donne VDS Installatiedraad 2.5mm² Groen/Geel~~
~~Donne VDS Installatiedraad 2.5mm² Blauw~~

~~Donne VDS Installatiedraad 2.5mm² Bruin~~
~~Donne VDS Installatiedraad 2.5mm² Zwart~~
~~Donne VDS Installatiedraad 2.5mm² Grijs~~

Omschrijving	Leverancier	Omschrijving Le	Aantal
STAGO ladderbaan	Electraleveranciers	REXEL	12
Eindkap tbv ladderbaan	Electraleveranciers	REXEL	12
Beugels wandbevestiging	Electraleveranciers	REXEL	18
Koppelplaat tbv ladderbaan	Electraleveranciers	REXEL	8
Schroeven tbv beugels	Electraleveranciers	REXEL	1
Carrosseriering tbv schroeven	Electraleveranciers	REXEL	1
Tyraps tbv kabel	Electraleveranciers	REXEL	2
Installatiekabel 3 fase + N + PE	Electraleveranciers	REXEL	25
Installatiekabel 3 fase + N + PE	Electraleveranciers	REXEL	50
Installatiekabel 3 fase + N + PE	Electraleveranciers	REXEL	50
Installatiekabel fase + N + PE	Electraleveranciers	REXEL	50
Drukzadels voor kabel	Electraleveranciers	REXEL	100
Drukzadels voor kabel	Electraleveranciers	REXEL	50
Wago Lasklemmen	Electraleveranciers	REXEL	1
Kabelbuis tbv Lasklemmen	Electraleveranciers	REXEL	100
Kabeldoos tbv Lasklemmen	Electraleveranciers	REXEL	5
2x Wandcontactdoos	Electraleveranciers	REXEL	10
Wandcontactdoos + Schakelaar	Electraleveranciers	REXEL	5
Adapter Male IP67	Electraleveranciers	REXEL	1
Adapter Male IP44	Electraleveranciers	REXEL	2
Adapter Male IP44	Electraleveranciers	REXEL	10
Socket Female IP67	Electraleveranciers	REXEL	1
Socket Female IP44	Electraleveranciers	REXEL	2
Socket Female IP44	Electraleveranciers	REXEL	10
Verdeelkast dubbel geisoleerd	Electraleveranciers	REXEL	1
DIN-rail tbv installatiekast	Electraleveranciers	REXEL	25
Bedradingskoker voor de kast	Electraleveranciers	REXEL	10
Popnagels voor rail/goot	Electraleveranciers	REXEL	1
3P + N 10kA installatieautomaat	Electraleveranciers	REXEL	1
3P + N aardlekschakelaar	Electraleveranciers	REXEL	2
3P + N 10kA installatieautomaat	Electraleveranciers	REXEL	3
1P + N 10kA installatieautomaat	Electraleveranciers	REXEL	3
3P + N 10kA installatieautomaat	Electraleveranciers	REXEL	2
3P + N aardlekschakelaar	Electraleveranciers	REXEL	2
Motorbeveiligingschakelaar	Electraleveranciers	REXEL	2
Motorbeveiligingschakelaar	Electraleveranciers	REXEL	3
Motorbeveiligingschakelaar	Electraleveranciers	REXEL	3
Verdeelkast per pomp	Electraleveranciers	REXEL	5
Adereindhuls tbv draad	Electraleveranciers	REXEL	5
Aardedraad voor bedrading	Electraleveranciers	REXEL	1
Nuldraad voor bedrading	Electraleveranciers	REXEL	1
Fasedraad voor bedrading	Electraleveranciers	REXEL	1
Fasedraad voor bedrading	Electraleveranciers	REXEL	1
Fasedraad voor bedrading	Electraleveranciers	REXEL	1
Adereindhuls tbv draad	Electraleveranciers	REXEL	5
Aardedraad voor bedrading	Electraleveranciers	REXEL	1
Nuldraad voor bedrading	Electraleveranciers	REXEL	1

~~Fasedraad voor bedrading~~	~~Electraleveranciers~~	~~REXEL~~	~~1~~
~~Fasedraad voor bedrading~~	~~Electraleveranciers~~	~~REXEL~~	~~1~~
~~Fasedraad voor bedrading~~	~~Electraleveranciers~~	~~REXEL~~	~~1~~

Opmerking	Evt. Code	Prijs p/s	Totaal Prijs
~~1 Meter Lang~~	~~7321677185641~~	~~€ 69,20~~	~~€ 830,40~~
~~Bescherming~~	~~7321677090198~~	~~€ 1,93~~	~~€ 23,16~~
~~Bevestiging~~	~~7321677132041~~	~~€ 19,58~~	~~€ 352,44~~
~~Koppelen~~	~~7321677911998~~	~~€ 27,63~~	~~€ 221,04~~
100 Stuks		€ 25,00	€ 25,00
~~100 Stuks~~	~~8712061022229~~	~~€ 9,06~~	~~€ 9,06~~
~~100 Stuks~~	~~5414363065852~~	~~€ 56,74~~	~~€ 113,48~~
~~1 Meter~~	~~8711401177049~~	~~€ 22,17~~	~~€ 554,25~~
~~1 Meter~~	~~8711401033055~~	~~€ 11,70~~	~~€ 585,00~~
~~1 Meter~~	~~8711401213723~~	~~€ 5,01~~	~~€ 250,50~~
~~1 Meter~~	~~8711401192400~~	~~€ 3,08~~	~~€ 154,00~~
Per Stuk	4012195221531	€ 1,17	€ 117,00
Per Stuk	4012195221531	€ 1,17	€ 58,50
100 Stuks	4044918464956	€ 57,48	€ 57,48
1 meter	8712148068034	€ 2,23	€ 223,00
~~Lasklemmen~~	~~8712259272726~~	~~€ 8,01~~	~~€ 40,05~~
~~Ocean~~	~~4011395026069~~	~~€ 28,34~~	~~€ 283,40~~
~~Ocean~~	~~4011395026014~~	~~€ 30,49~~	~~€ 152,45~~
~~Male 63A~~	~~4015394239567~~	~~€ 76,35~~	~~€ 76,35~~
~~Male 32A~~	~~4015394000181~~	~~€ 13,50~~	~~€ 27,00~~
~~Male 16A~~	~~4015394000150~~	~~€ 10,15~~	~~€ 101,50~~
~~Female 63A~~	~~4015394000631~~	~~€ 86,35~~	~~€ 86,35~~
~~Female 32A~~	~~4015394012184~~	~~€ 73,25~~	~~€ 146,50~~
~~Female 16A~~	~~4015394000105~~	~~€ 13,50~~	~~€ 135,00~~
IP31, RAL9016	4011617301202	€ 410,00	€ 410,00
1 Meter	8712978998051	€ 3,59	€ 89,75
1 Meter	3271780211550	€ 7,99	€ 79,90
100 Stuks	8719632521211	€ 92,06	€ 92,06
~~Voeding 1x63~~	~~3606480095276~~	~~€ 202,80~~	~~€ 202,80~~
~~Veiligheid~~	~~3606480091629~~	~~€ 157,40~~	~~€ 314,80~~
~~3 Groepen~~	~~3606480095214~~	~~€ 130,00~~	~~€ 390,00~~
~~3 Groepen~~	~~3606480095306~~	~~€ 44,30~~	~~€ 132,90~~
~~Voeding 2x32~~	~~3606480095245~~	~~€ 152,00~~	~~€ 304,00~~
~~Veiligheid~~	~~3606480091599~~	~~€ 167,00~~	~~€ 334,00~~
1,6A - 2,5A	3389110343076	€ 70,50	€ 141,00
2,5A - 4A	3389110343090	€ 70,50	€ 211,50
6A - 10A	3389110343137	€ 81,95	€ 245,85
IP65, RAL7035	8000126098976	€ 90,30	€ 451,50
100 Stuks	8716643014947	€ 5,49	€ 27,45
~~100 Meter~~	~~8712943007221~~	~~€ 164,00~~	~~€ 164,00~~
~~100 Meter~~	~~8712943007146~~	~~€ 164,00~~	~~€ 164,00~~
~~100 Meter~~	~~8712943007429~~	~~€ 164,00~~	~~€ 164,00~~
~~100 Meter~~	~~8712943007306~~	~~€ 164,00~~	~~€ 164,00~~
~~100 Meter~~	~~8712943007382~~	~~€ 164,00~~	~~€ 164,00~~
100 Stuks	8716643014909	€ 3,32	€ 16,60
~~100 Meter~~	~~8712943007214~~	~~€ 99,00~~	~~€ 99,00~~
~~100 Meter~~	~~8712943014663~~	~~€ 99,00~~	~~€ 99,00~~

~~100 Meter~~	~~8712943007412~~	~~€ 99,00~~	~~€ 99,00~~
~~100 Meter~~	~~8712943007290~~	~~€ 99,00~~	~~€ 99,00~~
~~100 Meter~~	~~8712943007375~~	~~€ 99,00~~	~~€ 99,00~~
	Na sponsoring	**Totaal**	**€ 2.246,59**
	Zonder sponsoring	Totaal	€ 9.382,02

Sponsor	Op Voorraad Ja/Nee
~~Peeters techncial solutions~~	~~Ja~~
~~Peeters techncial solutions~~	~~Ja~~
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~~Peeters techncial solutions~~	~~Ja~~
~~Peeters techncial solutions~~	~~Ja~~
~~Peeters techncial solutions~~	~~Ja~~

Bill of material: Water

Product	Omschrijving
~~Full compact production line~~	~~Cellcrete production line~~
~~Shredder~~	~~Cellulose shredder~~
~~Storz Slangpilaar NA 66 X Tule 52 mm 2"~~	~~Koppeling Slang~~
STORZ NA 66 X BUITENDRAAD 2"	Koppeling Flens DN50
Draadflens DN50 zwart 2" 4 gaten	Flens DN50 t.b.v. Pomp
~~Brandweerslang 52mm 2"~~	~~Leidingwerk Buiten~~
Mikalor RVS Slangklem 16 - 27	Slangklem Koppeling
Mikalor RVS Slangklem 20 - 32	Slangklem Koppeling
Mikalor RVS Slangklem 25 - 40	Slangklem Koppeling
Mikalor RVS Slangklem 30 - 45	Slangklem Koppeling
Mikalor RVS Slangklem 32 - 50	Slangklem Koppeling
Mikalor RVS Slangklem 40 - 60	Slangklem Koppeling
Teflon Tape Rol 12 MTR.	Teflontape Koppeling
~~Camlock Female Met Slangtule 25MM X 1"~~	~~Tule voor slang~~
~~Camlock Female Met Slangtule 32MM X 1¼"~~	~~Tule voor slang~~
~~Camlock Female Met Slangtule 38MM X 1½"~~	~~Tule voor slang~~
~~Camlock Female Met Slangtule 50MM X 2"~~	~~Tule voor slang~~
~~Camlock Male Met Slangtule 25MM X 1"~~	~~Tule voor slang~~
~~Camlock Male Met Slangtule 32MM X 1¼"~~	~~Tule voor slang~~
~~Camlock Male Met Slangtule 38MM X 1½"~~	~~Tule voor slang~~
~~Camlock Male Met Slangtule 51MM X 2"~~	~~Tule voor slang~~
~~Tyleenslang HDPE KIWA PN16 25mm x 2,3mm~~	~~Wateraanvoer~~
~~Tyleenslang HDPE KIWA PN16 32mm x 3mm~~	~~Wateraanvoer~~
~~Tyleenslang HDPE KIWA PN16 40mm x 2,4mm~~	~~Wateraanvoer~~
~~Tyleenslang HDPE KIWA PN16 50mm x 3mm~~	~~Wateraanvoer~~

Leverancier	Omschrijving Leverancier	Aantal	Opmerking	Evt. Code	Prijs p/s
~~TU/e~~		~~1~~	~~Per Stuk~~	~~4385~~	~~€ -~~
~~SUMMA~~		~~1~~			~~€ 300,00~~
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~4385~~	~~€ 11,26~~
Groothandel water	PVC voordeel	5	Per Stuk	4408	€ 11,80
Groothandel water	Van Walraven	5	Flensstaal	331555	€ 24,64
~~Groothandel water~~	~~PVC voordeel~~	~~150~~	~~Per Meter~~	~~996791~~	~~€ 9,25~~
Groothandel water	PVC voordeel	50	RVS 304	3458	€ 1,29
Groothandel water	PVC voordeel	50	RVS 304	3459	€ 1,32
Groothandel water	PVC voordeel	50	RVS 304	3460	€ 1,43
Groothandel water	PVC voordeel	50	RVS 304	3461	€ 1,50
Groothandel water	PVC voordeel	50	RVS 304	3462	€ 1,56
Groothandel water	PVC voordeel	50	RVS 304	3463	€ 1,57
Groothandel water	PVC voordeel	5	12 Meter	2295	€ 0,88
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~1003106~~	~~€ 7,50~~
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~1003107~~	~~€ 9,75~~
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~1003108~~	~~€ 8,50~~
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~1003109~~	~~€ 10,95~~
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~1003154~~	~~€ 10,50~~
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~1003155~~	~~€ 14,50~~
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~1003156~~	~~€ 16,50~~
~~Groothandel water~~	~~PVC voordeel~~	~~10~~	~~Per Stuk~~	~~1003157~~	~~€ 17,95~~
~~Groothandel water~~	~~PVC voordeel~~	~~1~~	~~Rol 100m~~	~~5264~~	~~€ 94,65~~
~~Groothandel water~~	~~PVC voordeel~~	~~1~~	~~Rol 100m~~	~~1000965~~	~~€ 131,50~~
~~Groothandel water~~	~~PVC voordeel~~	~~1~~	~~Rol 100m~~	~~2200~~	~~€ 157,00~~
~~Groothandel water~~	~~PVC voordeel~~	~~1~~	~~Rol 100m~~	~~2202~~	~~€ 232,00~~
				Na sponsoring	**Totaal**
				Zonder sponsoring	

Totaal Prijs	Op Voorraad Ja/Nee	Sponsor
~~€ -~~	~~Nee~~	~~Easycool~~
~~€ 300,00~~		~~SUMMA~~
~~€ 112,60~~	~~Nee~~	~~Easycool~~
€ 59,00	Nee	
€ 123,20	Nee	
~~€ 1.387,50~~	~~Nee~~	~~MLV~~
€ 64,50	Nee	
€ 66,00	Nee	
€ 71,50	Nee	
€ 75,00	Nee	
€ 78,00	Nee	
€ 78,50	Nee	
€ 4,40	Nee	
~~€ 75,00~~	~~Nee~~	~~Easycool~~
~~€ 97,50~~	~~Nee~~	~~Easycool~~
~~€ 85,00~~	~~Nee~~	~~Easycool~~
~~€ 109,50~~	~~Nee~~	~~Easycool~~
~~€ 105,00~~	~~Nee~~	~~Easycool~~
~~€ 145,00~~	~~Nee~~	~~Easycool~~
~~€ 165,00~~	~~Nee~~	~~Easycool~~
~~€ 179,50~~	~~Nee~~	~~Easycool~~
~~€ 94,65~~	~~Nee~~	~~Easycool~~
~~€ 131,50~~	~~Nee~~	~~Easycool~~
~~€ 157,00~~	~~Nee~~	~~Easycool~~
~~€ 232,00~~	~~Nee~~	~~Easycool~~
€ 620,10		
€ 3.996,85		

Link
~~https://pvcvoordeel.nl/storz-slangpilaar-na-66-x-tule-52-2-prod/~~
~~https://pvcvoordeel.nl/storz-slangpilaar-na-66-x-tule-52-2-prod/~~
https://pvcvoordeel.nl/storz-na-66-x-buitendraad-2-prod/
https://www.vanwalraven.com/nl/catalog/leidingsystemen-toevoer/flenzen/flenzen-staal/draadflens-geboor
~~https://pvcvoordeel.nl/brandweerslang-52mm-2-per-meter-prod/~~
https://pvcvoordeel.nl/mikalor-rvs-slangklem-16-27-prod/
https://pvcvoordeel.nl/mikalor-rvs-slangklem-20-32-prod/
https://pvcvoordeel.nl/mikalor-rvs-slangklem-25-40-prod/
https://pvcvoordeel.nl/rvs-slangklem-30-40/
https://pvcvoordeel.nl/mikalor-rvs-slangklem-32-50-prod/
https://pvcvoordeel.nl/mikalor-rvs-slangklem-40-60-prod/
https://pvcvoordeel.nl/teflon-tape-12mtr/
~~https://pvcvoordeel.nl/camlock-alu-v-deel-met-slangtule-type-e-25mm-x-1-prod/~~
~~https://pvcvoordeel.nl/camlock-alu-v-deel-met-slangtule-type-e-32mm-x-1-prod/~~
~~https://pvcvoordeel.nl/camlock-alu-v-deel-met-slangtule-type-e-38mm-x-1-prod/~~
~~https://pvcvoordeel.nl/camlock-alu-v-deel-met-slangtule-type-e-50mm-x-2-prod/~~
~~https://pvcvoordeel.nl/camlock-alu-m-deel-met-slangtule-type-c-25mm-x-1-prod/~~
~~https://pvcvoordeel.nl/camlock-alu-m-deel-met-slangtule-type-c-32mm-x-1-prod/~~
~~https://pvcvoordeel.nl/camlock-alu-m-deel-met-slangtule-type-c-38mm-x-1-prod/~~
~~https://pvcvoordeel.nl/camlock-alu-m-deel-met-slangtule-type-c-50mm-x-2-prod/~~
~~https://pvcvoordeel.nl/hdpe-buis-kiwa-25-x-2-3-pn16-sdr11-6-100-meter/~~
~~https://pvcvoordeel.nl/hdpe-buis-kiwa-32-x-3-pn16-sdr11-100-meter/~~
~~https://pvcvoordeel.nl/hdpe-buis-kiwa-40-x-2-4-pn10-sdr17-100-meter/~~
~~https://pvcvoordeel.nl/hdpe-buis-kiwa-50-x-3-pn10-sdr17-100-meter/~~

d/331555/g+c+p+a+nr	

Bill of Material: Lucht

Product
Afzuiging
~~electrische naverwarmer~~
~~electrische voorverwarmer~~
afschermings kappen buiten
afschermings kappen buiten
ventilatie kappen op uiteinde 180Ø
inbouw afvoer ventilatie kappen
spiro buis
verbindings stuk tussen de spiro buizen
ophangbeugel

Omschrijving	Leverancier
Ventialion-unit 300m³/h 180Ømm	
~~enkel fase > 3,5Kw (~~	
~~enkel fase > 2,5Kw~~	
afblaaskappen inbouw	
aanzuigkap inbouw	
aan het einde een ventilatie verdeling	
inbouw in 180Ø spiro buis	
180Ømm	
180Ømm	
ophangbeugel 180Ø	

Omschrijving Leverancier	Aantal	Evt. Code	Prijs p/s	Totaal Prijs
	1		€ 150,00	€ 150,00
	~~2~~		~~€ 300,00~~	~~€ 600,00~~
	~~1~~		~~€ 100,00~~	~~€ 100,00~~
	1		€ 25,00	€ 25,00
	1		€ 20,00	€ 20,00
DKS deksel voor buis safe	4	2002000999	€ -	€ 0,00
	2		€ 10,00	€ 20,00
per 3 meter	4	2001000013	€ 10,00	€ 40,00
	6	2002000581	€ 8,00	€ 48,00
	16	2010000007	€ 12,00	€ 192,00
		Na sponsoring	TOTAAL	€ 495,00
		Zonder sponsoring		€ 1.195,00

Op Voorraad Ja/Nee	Sponsor	Link
	~~Summa~~	
	~~Summa~~	
		https://www.wasco.nl/artikel/alu-schoepenroost-200x20
		https://www.rvsland.nl/buitenrooster-180mm-rvs?gclid=

)0-wit/4105490
:EAIaIQobChMIwLLdnqbX1gIVAxbTCh04AwgDEAQYASABEgKh1fD_BwE

Bill of Material: Inboedel

product	omschrijving	leverancier
Koffie zetapparaat		
Tosti ijzer		
klapstoelen		ikea
~~Bureaustoel~~		~~ikea~~
~~tafel~~		~~ikea~~
~~monitoren~~		
~~wasbak~~		
~~wand kast~~		
koelkast	KAN GAVIN REGELEN	
~~rookmelders~~		
~~brandblussers~~	~~Deficare CO2 brandblusser 2 KG~~	
werkbank		
bankschroef		
gereedschapkist	Gereedschapskist Agecom 93 stuks	
~~Spots~~		
~~LED tl stukken~~		
~~Olie kachel~~	~~2 van Remon (2000W)~~	
~~waterkoker~~	~~Severin WK 3482 Waterkoker Snoerloos Wit~~	
~~laptop~~	~~Krachtig genoeg voor 2 schermen~~	
Bekers	Pokal 6 stuks	ikea
bestekset (vork, lepel, mes)	FÖRNUFT Bestek 24-delig, roestvrij staal (	ikea
~~wastafelmeubel~~		
Antenne		
~~Router~~	~~TP-LINK TL-WR841N WiFi router 2.4 GHz 3~~	~~conrad~~
~~**NOODARREGRAAT**~~		

omschrijving leverancier	aantal	evt. code	prijs p/s	Tot prijs
	1		€ 30,00	€ 30,00
	1		€ 30,00	€ 30,00
	5		€ 25,00	€ 125,00
	~~1~~		~~€ 35,00~~	~~€ 35,00~~
	~~2~~		~~€ 40,00~~	~~€ 80,00~~
	~~2~~		~~€ 100,00~~	~~€ 200,00~~
	~~2~~		~~€ 50,00~~	~~€ 100,00~~
	~~14~~		~~€ 29,00~~	~~€ 406,00~~
	1		€ 10,00	€ 10,00
	~~2~~		~~€ 30,00~~	~~€ 60,00~~
	~~2~~		~~€ 70,00~~	~~€ 140,00~~
	1		€ 80,00	€ 80,00
	1		€ 70,00	€ 70,00
	1		€ 240,00	€ 240,00
	~~3~~		~~€ 27,99~~	~~€ 83,97~~
	~~20~~		~~€ 3,57~~	~~€ 71,40~~
	~~2~~		~~€ 54,95~~	~~€ 109,90~~
	~~1~~		~~€ 18,00~~	~~€ 18,00~~
	~~1~~		~~€ 250,00~~	~~€ 250,00~~
	1		€ 0,89	€ 0,89
	2		€ 10,00	€ 20,00
	~~1~~		~~€ 170,00~~	~~€ 170,00~~
	1		€ 12,90	€ 12,90
	~~1~~		~~€ 20,00~~	~~€ 20,00~~
			~~€ 159,00~~	~~€ 159,00~~
		Na sponsoring	**TOTAAL**	€ 618,79
		Zonder sponsoring		€ 2.522,06

Op voorraad ja/nee	contactnaam/E-mail
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link
https://www.bol.com/nl/p/plieger-basic-uitstortgootsteenpack-uitstortgootsteen-tapkraan-sifon-plaatstaal-w
http://www.kickoffice.nl/kick-50
https://www.allesveilig.nl/ei-146-rookmelder-230v
http://www.manutan.nl/nl/mnl/gereedschapskist-agecom-93-stuks-92032468?gclid=EAIaIQobChMIi-PxgrfF1g
https://www.conrad.nl/nl/severin-wk-3482-waterkoker-snoerloos-wit-396080.html
http://www.ikea.com/nl/nl/catalog/products/30288241/
http://www.ikea.com/nl/nl/catalog/products/70014999/
https://www.conrad.nl/nl/tp-link-tl-wr841n-wifi-router-24-ghz-300-mbits-399734.html?sc.ref=Search%20Resu

:it/9200000010576439/?Referrer=ADVNLGOO002042-G-35679826486-S-273977865732-920000001057

:lVir3tCh30-AbCEAQYASABEgL_IPD_BwE

ults

76439&gclid=EAIaIQobChMI7LT7jLTF1gIVqLztCh239wuHEAQYAyABEgKe7vD_BwE

tools for: Project bridge in ice

product	omschrijving
~~doppen set~~	~~94-delig~~
~~las apparaat~~	~~FERM WEM1035~~
~~slijp tol~~	~~MAKITA 9558HNRGK2~~
~~accuboor~~	~~BLACK & DECKER BDCHD18BAFC-QW~~
~~boren set~~	~~Zit bij accuboor~~
~~cirkelzaag~~	~~HITACHI C7SS~~
~~bit set~~	~~Zit bij accuboor~~
~~stempels~~	~~SCHROEFSTEMPEL GB 300~~
~~ladder/keukentrap~~	~~ALTREX Huishoudtrap Lima, 4 treden~~
~~kit pistool~~	~~AKKIT Kitpistool kunststof JM 138P~~
~~hamer~~	~~STANLEY Klauwhamer Blue Strike 450 gr~~
~~schroevendraaier set~~	~~Wera 17 delige Kraftform Kompakt VDE~~
~~gaten zaag set~~	~~Makita D-47298 14 delige Gatzagenset~~
~~decoupeer zaag~~	~~Makita 4329 Decoupeerzaag - 450W~~
~~pallet wagen~~	
~~strip tang~~	~~Sencys striptang 1000V 16cm~~
~~amp tang~~	~~TOOLCRAFT Krimptangset 439-delig 0.5 tot 16 mm²~~
~~multimeter~~	~~DUSPOL expert Benning~~
~~kniptangset~~	~~KNIPEX Montage-set 00 20 11~~
~~afkortzaag~~	
~~kruiwagen~~	~~ALTRADFORT Kruiwagen SMB-100~~

leverancier	omschrijving leverancier	aantal	evt. code	prijs p/s
		~~2~~		~~€ 50,00~~
		~~2~~		~~€ 700,00~~
		~~2~~		~~€ 105,00~~
		~~2~~		~~€ 123,00~~
		~~2~~		~~€ 39,95~~
		~~1~~		~~€ 100,00~~
		~~2~~		~~€ 12,63~~
		~~2~~		~~€ 32,50~~
		~~2~~		~~€ 60,00~~
		~~4~~		~~€ 7,95~~
		~~4~~		~~€ 15,00~~
		~~1~~		~~€ 70,00~~
		~~1~~		~~€ 128,00~~
		~~1~~		~~€ 81,19~~
		~~1~~		~~€ 284,35~~
		~~2~~		~~€ 21,50~~
		~~2~~		~~€ 105,00~~
		~~2~~		~~€ 67,75~~
		~~2~~		~~€ 35,31~~
		~~1~~		~~€ 119,90~~
		~~1~~		~~€ 175,00~~
			Na sponsoring	**TOTAAL**
			Zonder sponsoring	

Tot prijs	Op voorraad ja/nee	Sponsor	link
~~€ 100,00~~	~~ja~~	~~Summa~~	
~~€ 1.400,00~~	~~ja~~	~~Summa~~	
~~€ 210,00~~	~~ja~~	~~Summa~~	
~~€ 246,00~~	~~ja~~	~~Summa~~	
~~€ 79,90~~	~~ja~~	~~Summa~~	
~~€ 100,00~~	~~ja~~	~~Summa~~	
~~€ 25,26~~	~~ja~~	~~Summa~~	
~~€ 65,00~~		~~Summa~~	
~~€ 120,00~~	~~ja~~	~~Summa~~	
~~€ 31,80~~	~~ja~~	~~Summa~~	
~~€ 60,00~~	~~ja~~	~~Summa~~	
~~€ 70,00~~	~~ja~~	~~Summa~~	
~~€ 128,00~~	~~ja~~	~~Summa~~	
~~€ 81,19~~	~~ja~~	~~Summa~~	
~~€ 284,35~~		~~Summa~~	
~~€ 43,00~~	~~ja~~	~~Summa~~	
~~€ 210,00~~	~~ja~~	~~Summa~~	
~~€ 135,50~~	~~ja~~	~~Summa~~	
~~€ 70,62~~	~~ja~~	~~Summa~~	
~~€ 119,90~~	~~ja~~	~~Summa~~	
~~€ 175,00~~		~~Summa~~	
€ 0,00			
€ 3.755,52			

tools for: Project bridge in ice

product	omschrijving	leverancier
doppen set		
~~las apparaat~~	~~voor de inflatable te lassen~~	
~~slijp tol~~		
~~accuboor~~		
boren set		
cirkelzaag		
bit set		
~~stempels~~		
~~ladder/keukentrap~~	~~Maximaal 2,20meter hoog~~	
~~kit pistool~~		
hamer		
schroevendraaier set		
~~gaten zaag set~~		
strip tang		
amp tang		
multimeter		
kniptang		

omschrijving leverancier	aantal	evt. code	prijs p/s	Tot prijs
vanuit "Tools voor de container"	2		€ 30,00	€ 60,00
~~*vanuit "Tools voor de container"*~~	~~1~~		~~€ -~~	~~€ 0,00~~
~~*vanuit "Tools voor de container"*~~	~~2~~		~~€ -~~	~~€ 0,00~~
~~*vanuit "Tools voor de container"*~~	~~2~~		~~€ -~~	~~€ 0,00~~
vanuit "Tools voor de container"	2		€ 40,00	€ 80,00
vanuit "Tools voor de container"	1		€ 80,00	€ 80,00
vanuit "Tools voor de container"	2		€ 30,00	€ 60,00
~~*vanuit "Tools voor de container"*~~	~~2~~		~~€ -~~	~~€ 0,00~~
~~*vanuit "Tools voor de container"*~~	~~1~~		~~€ -~~	~~€ 0,00~~
~~*vanuit "Tools voor de container"*~~	~~1~~		~~€ -~~	~~€ 0,00~~
vanuit "Tools voor de container"	2		€ 12,00	€ 24,00
vanuit "Tools voor de container"	2		€ 30,00	€ 60,00
~~*vanuit "Tools voor de container"*~~	~~1~~		~~€ -~~	~~€ 0,00~~
			€ -	€ 0,00
vanuit "Tools voor de container"	1		€ 7,00	€ 7,00
vanuit "Tools voor de container"	1		€ 12,00	€ 12,00
vanuit "Tools voor de container"	1		€ 8,00	€ 8,00
vanuit "Tools voor de container"	1		€ 7,00	€ 7,00
			€ -	€ 0,00
	1		€ -	€ 0,00
	1		€ -	€ 0,00
	1		€ -	€ 0,00
	1		€ -	€ 0,00
	3		€ -	€ 0,00
			€ -	€ 0,00
		Na sponsoring	**TOTAAL**	€ 0,00
		Zonder sponsoring		€ 398,00

Op voorraad ja/nee	Sponsor	link
	Summa	
	~~MLV~~	
	~~MLV~~	
	~~MLV~~	
	~~MLV~~	
	~~MLV~~	
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	~~MLV~~	
	~~MLV~~	
	~~Van Doorn~~	
	~~Van Doorn~~	
	~~Van Doorn~~	
	~~MLV~~	

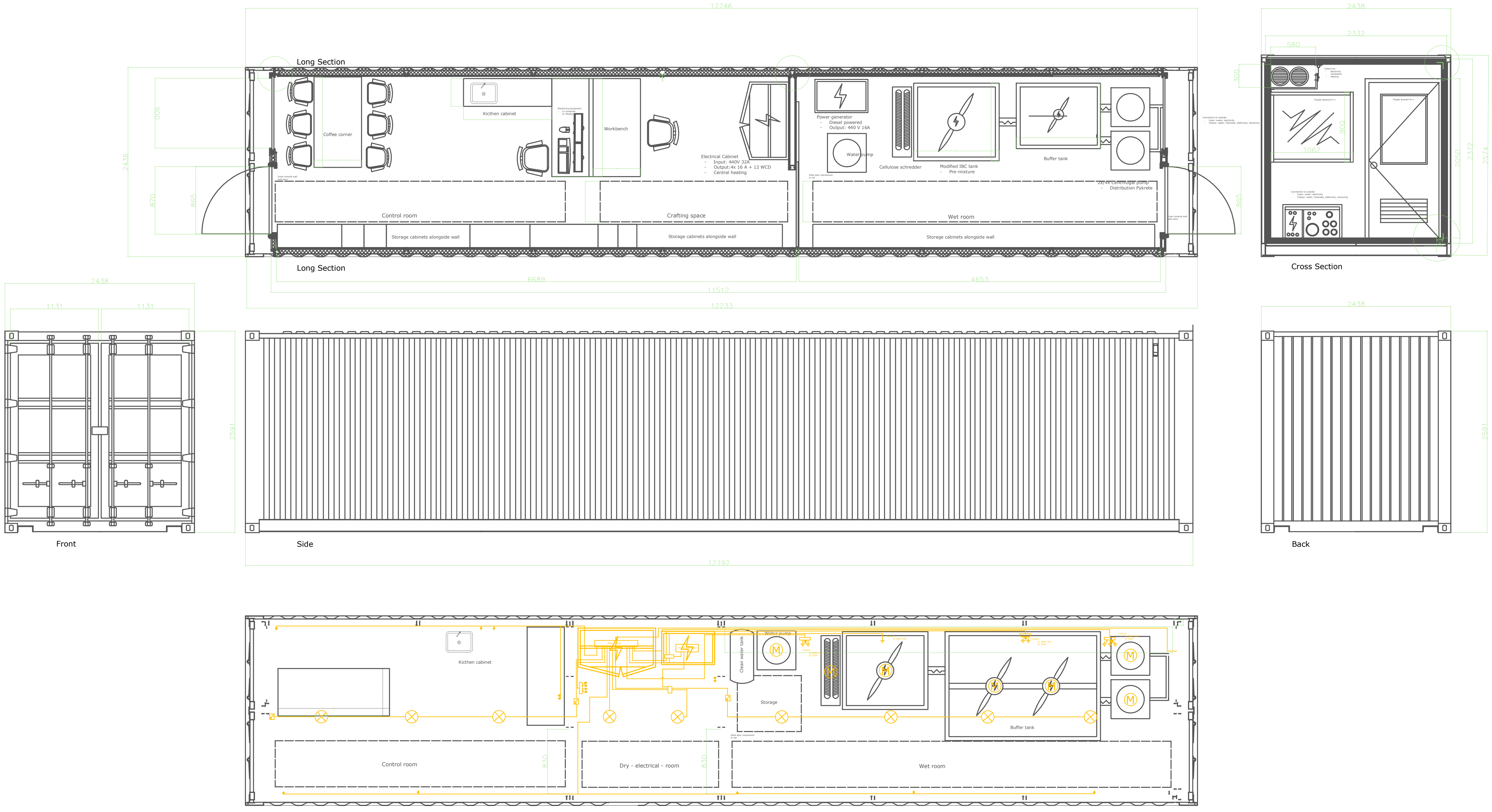
Bill of material: Container

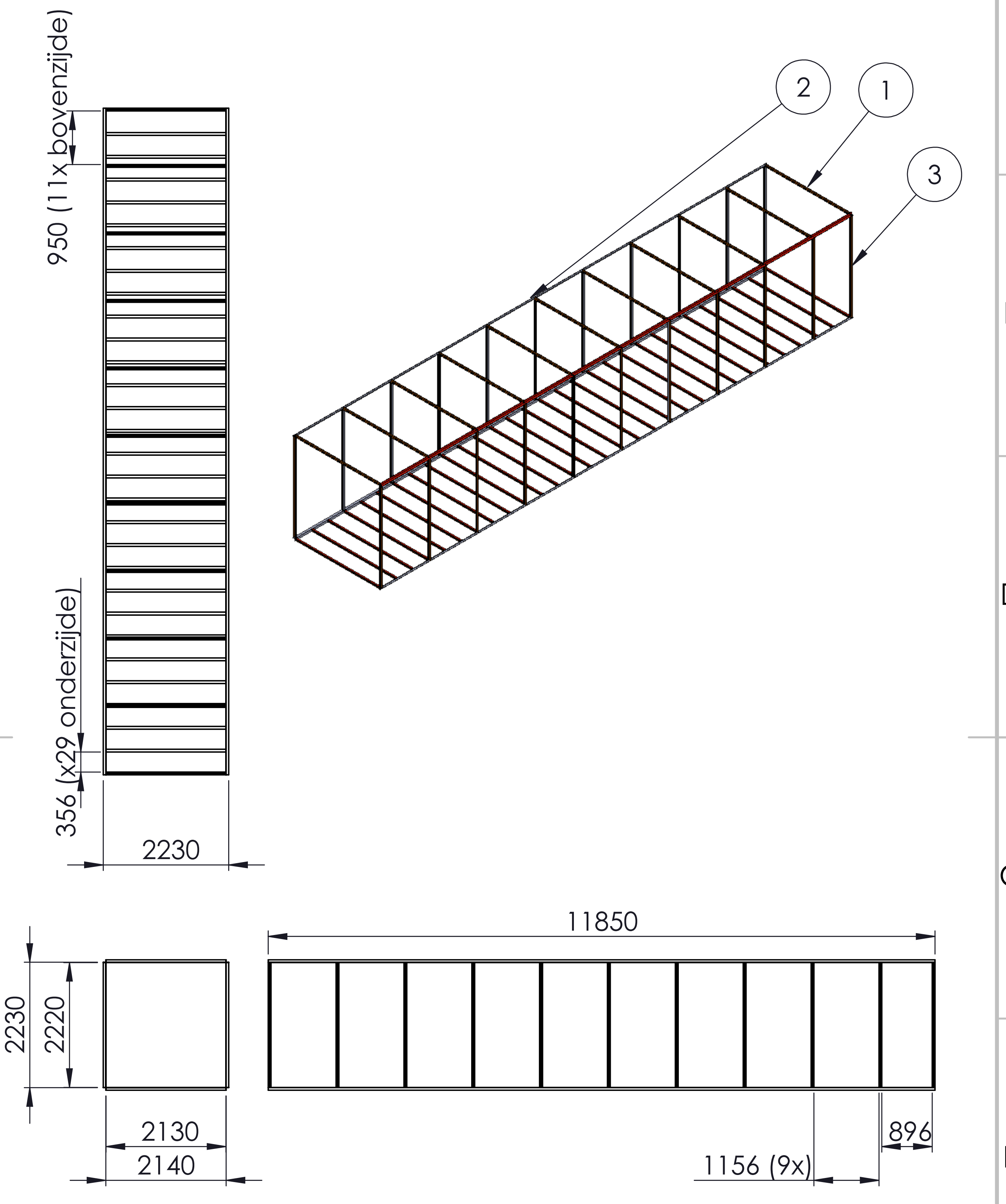
Product	Omschrijving	Leverancier	Omschrijving Leverancier
~~Blowers~~	~~3600 m3/uur~~		
Air monitoring system	Air system	TU/e	

Aantal	Opmerking	Evt. Code	Prijs p/s	Totaal Prijs
~~3~~			~~€ 375,00~~	~~€ 1.125,00~~
1			€ -	€ 0,00
			€ -	€ 0,00
		Na sponsoring	**TOTAAL**	€ 0,00
		Zonder sponsoring		€ 1.125,00

Op Voorraad ja/nee	Sponsor	Link
~~ja~~	~~SUMMA~~	
	Van Doorn	

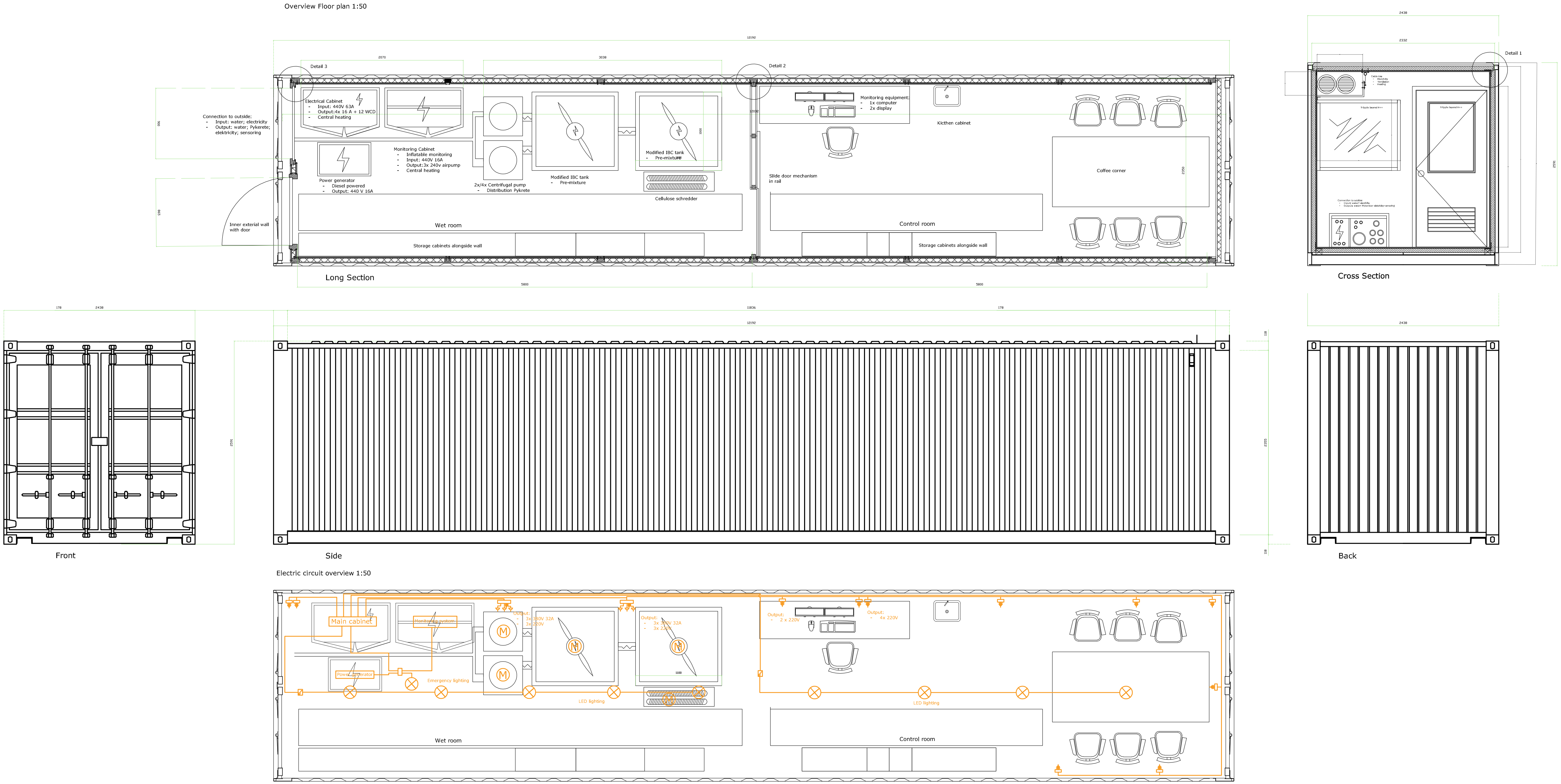
Standard ISO 20'





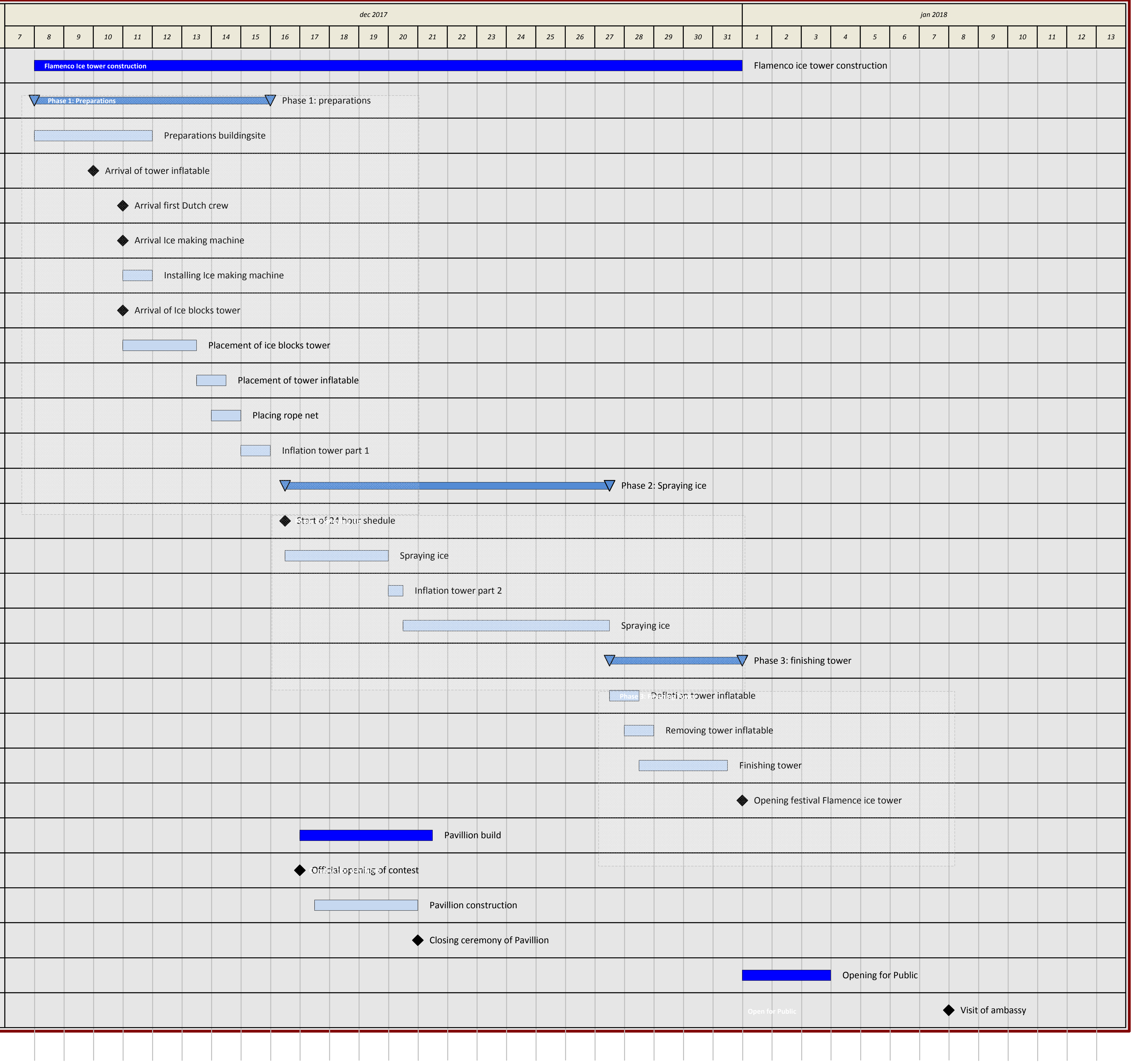
ITEM NO.	PART NUMBER	QTY.
1	T profiel 50x50x6 213cm lang tbv vloer plafond	41
2	hoekprofiel 50x50x5	4
3	T profiel 50x50x6 222cm lang tbv wanden	22

Schaal: 1:100	Afdeling: ICE container	MATERIAL: Gegalvaniseerd staal SJ235	Titel: Frame container	A4
Maateenheid: mm				
Datum: 27-09-17				
	Getekend: Gavin van Turnhout		SCALE:1:100	SHEET 1 OF 1

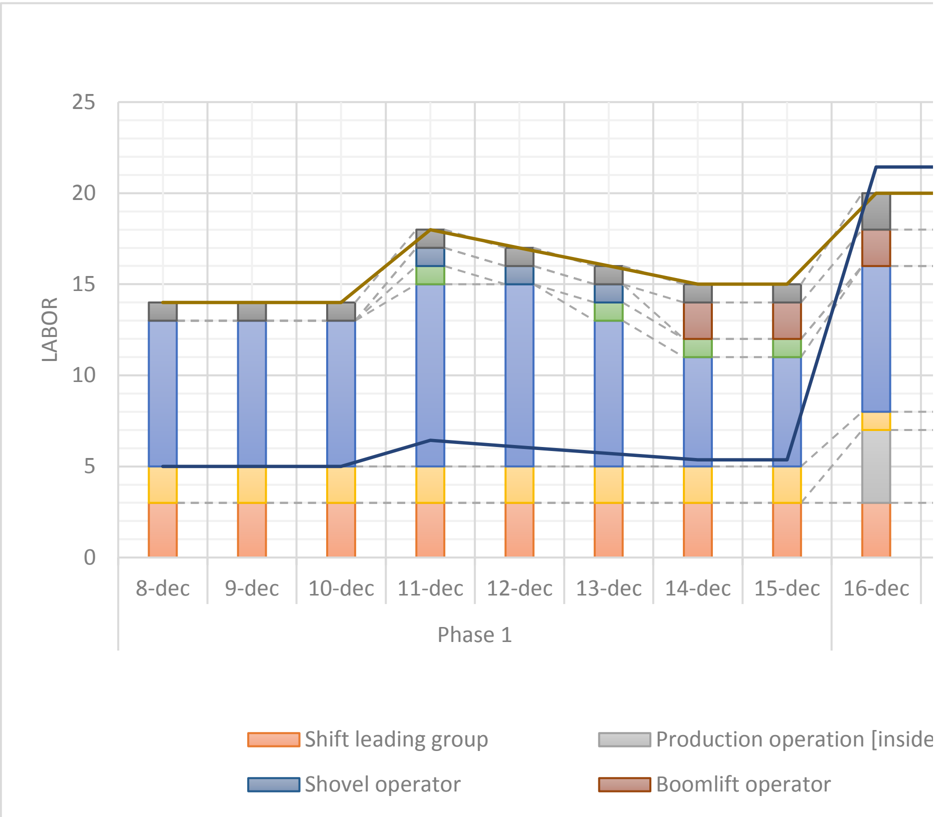


Project:	Flamenco tower in Ice	Date:	10-09-2017
Content:	Mobile factory -Overview -Electric circuit overview	Scale:	1:50
Engineering:	University of Technology Eindhoven SUMMA College Eindhoven Harbin Institute of Technology	Dimension:	mm

Id	Activity	Discription	Heavy Equipment	Start date [dd-mm-yyyy]	End date [dd-mm-yyyy]	Duration [days]
1	Flamenco ice tower construction	Total construction of ice tower		8-12-2017	31-12-2017	24d
2	**Phase 1: preparations**	**Overall preparations for the spray phase**	**- Platform lift - Telehandler - Crane**	**8-12-2017**	**15-12-2017**	**8d**
3	Preparations buildingsite	Peparing building site: - Electricity - Lightning - Water connections	- Platform lift	8-12-2017	11-12-2017	4d
4	Arrival of tower inflatable	Arrival from factory; will be temporarily stored on site	- Telehandler	10-12-2017	10-12-2017	0d
5	Arrival first Dutch crew	Yaron Moonen + 5 students		11-12-2017	11-12-2017	0d
6	Arrival Ice making machine	Arrival by truck; telehandler is needed to pick up and unload container; extra long fork is needed.	- Telehandler	11-12-2017	11-12-2017	0d
7	Installing Ice making machine	Unloading and installing container; Accu drill is needed + telehandler with extra long fork.	- Telehandler	11-12-2017	11-12-2017	1d
8	Arrival of Ice blocks tower	Will be stored temperarily on site; moved by telehandler with grip-claw	- Telehandler	11-12-2017	11-12-2017	0d
9	Placement of ice blocks tower	Construction of ice stairs using ice blocks with telehandler with grip-claw.	- Telehandler	11-12-2017	13-12-2017	2,5d
10	Placement of tower inflatable	Inflatable will be set on position with crane.	- Crane - Telehandler	13-12-2017	14-12-2017	1d
11	Placing rope net	Securing inflatable to foundation and ropes	- Platform lift	14-12-2017	14-12-2017	1d
12	Inflation tower part 1	First inflation of middle part+legs; crane hold top part; testing of air systems	- Crane - Platform lift	15-12-2017	15-12-2017	1d
13	**Phase 2: Spraying ice**	**Start of operation of mobile ice factory**	**- Platform lift - Telehandler**	**16-12-2017**	**27-12-2017**	**11d**
14	Start of 24 hour shedule	Start of working day and night in 4 shifts		16-12-2017	16-12-2017	0d
15	Spraying ice	Spraying of ice from ice making machines.	- Telehandler - Platform lift	16-12-2017	19-12-2017	3,5d
16	Inflation tower part 2	Total inflation	- Crane - Platform lift	20-12-2017	20-12-2017	,5d
17	Spraying ice	Spraying of ice from ice making machines.	- Telehandler - Platform lift	20-12-2017	27-12-2017	7d
18	**Phase 3: finishing tower**	**Completion of ice tower**	**- Platform lift - Telehandler - Crane**	**27-12-2017**	**1-1-2018**	**4,5d**
19	Deflation tower inflatable	Deflation by redirecting air pumps.		27-12-2017	28-12-2017	1d
20	Removing tower inflatable	Inflatable will be removed using the telehandler	- Telehandler	28-12-2017	28-12-2017	1d
21	Finishing tower	The finishing of the inside and the opening of the top; using chainsaws	- Platform lift	28-12-2017	31-12-2017	3d
22	Opening festival Flamence ice tower	Opening of festival		1-1-2018	1-1-2018	0d
23	Pavillion build	Preparation and construction of pavillions for contest	- Platform lift - Telehandler	17-12-2017	21-12-2017	4,5d
24	Official opening of contest	Opening ceremony of contest		17-12-2017	17-12-2017	0d
25	Pavillion construction	construction of pavillions	- Platform lift - Telehandler	17-12-2017	20-12-2017	3,5d
26	Closing ceremony of Pavillion	Closing ceremony of contest + winner		21-12-2017	21-12-2017	0d
27	Opening for Public			1-1-2018	3-1-2018	3d
28	Visit of ambassy	Ceremony of Chinese Dutch ambassy for coorporation		8-1-2018	8-1-2018	0d

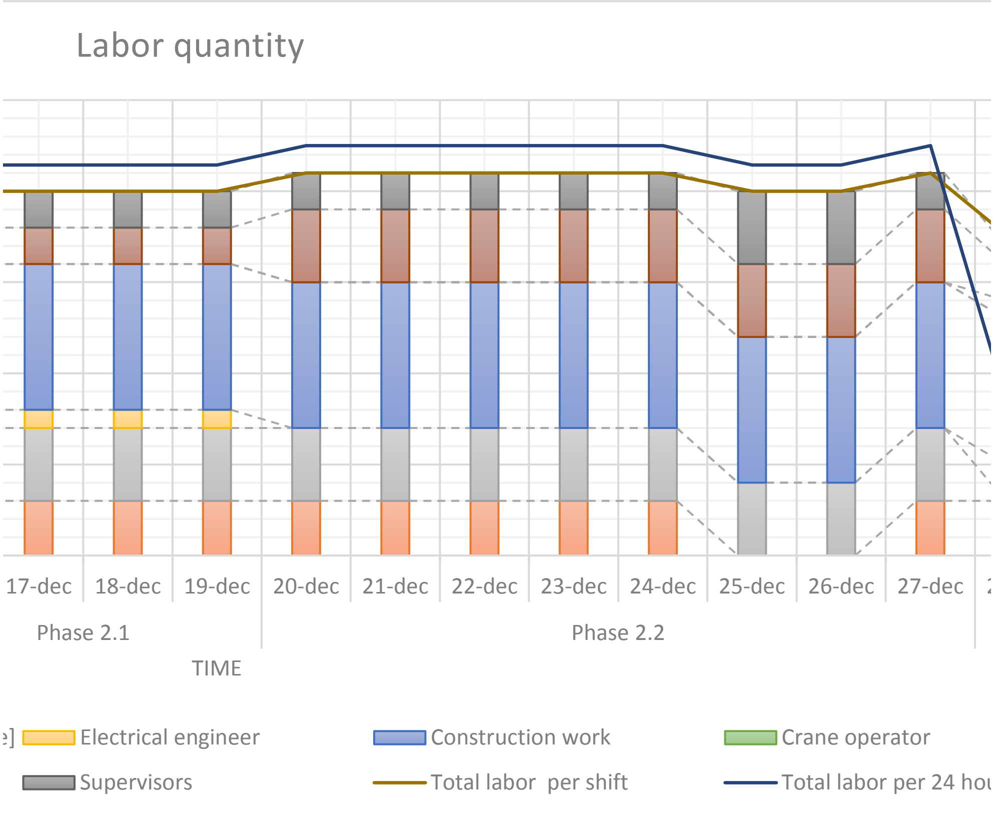


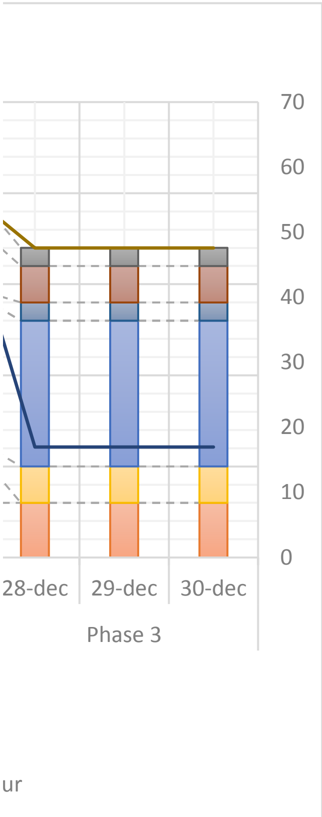
Team	Leader	Working hours	Member (CH)
Shift 1	Arno	22:00-0:60	Fang Fang/Xiuming
Shift 2	Yaron	0:60-14:00	Boxuan
Shift3	Gilles	14:0-22:00	Yilling



Inside team and hose carrying team will switch every 2 hours
This shedule is only for work on the tower out of the red container.

Member (NL)
Qingpeng
Gavin
Bart





Date:
activity:
Shift leading group
Production operation [inside]
Electrical engineer
Construction work
Crane operator
Shovel operator
Boomlift operator
Supervisors

Total labor **per shift**
Total labor **per 24 hours**

Phase 1								Phase 2.1
8-dec	9-dec	10-dec	11-dec	12-dec	13-dec	14-dec	15-dec	16-dec
3	3	3	3	3	3	3	3	3
0	0	0	0	0	0	0	0	4
2	2	2	2	2	2	2	2	1
8	8	8	10	10	8	6	6	8
0	0	0	1	0	1	1	1	0
0	0	0	1	1	1	0	0	0
0	0	0	0	0	0	2	2	2
1	1	1	1	1	1	1	1	2
14	14	14	18	17	16	15	15	20
14	14	14	18	17	16	15	15	60

			Phase 2.2					
17-dec	18-dec	19-dec	20-dec	21-dec	22-dec	23-dec	24-dec	25-dec
3	3	3	3	3	3	3	3	0
4	4	4	4	4	4	4	4	4
1	1	1	0	0	0	0	0	0
8	8	8	8	8	8	8	8	8
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
2	2	2	4	4	4	4	4	4
2	2	2	2	2	2	2	2	4
20	20	20	21	21	21	21	21	20
60	60	60	63	63	63	63	63	60

		Phase 3		
26-dec	27-dec	28-dec	29-dec	30-dec
0	3	3	3	3
4	4	0	0	0
0	0	2	2	2
8	8	8	8	8
0	0	0	0	0
0	0	1	1	1
4	4	2	2	2
4	2	1	1	1
20	21	17	17	17
60	63	17	17	17

Gainings

Catogory	Item	Description
Subsiduations	Research subsidy	Subsidy for ice project
Accomodation	Team members	Contribution for travel and accomodation
other	Sponsors	Overall financial sponsor contributions

T

Total costs
Total Sponsoring in goods
Total Remaining costs

Total gainings

Overall project balance

Quantity	Unit	Price/unit [€]	Total Gainings[€]
1	Amount	€ 10.000,00	€ 10.000,00
10	People	€ 500,00	€ 5.000,00
1	Amount	€ 7.500,00	€ 7.500,00

Total Gainings

€ 176.971,40
€ 154.983,97
€ 21.987,43

€ 22.500,00

€ 512,57

Total catogory [€]
€ 10.000,00
€ 5.000,00
€ 7.500,00
€ 22.500,00

Expenses Catogory
Accomodate team members
Building site
Building material
Consumption
Heavy equipment
Mobile factory
Labor

Item	Description
Flight and transit	from the netherlands to Harbin
Accomodation	Accomodation near building site
Consumption	Breakfast, lunch and diner
Transport	Between accomodation and building site
Fenching	For enclosing building site
Water supply + plumping	Two water lines provided with heating cord
Eelctricity supply+ cabels	Electricity lines from inside with cabinets
Lightning	Lightning for construction
Guarding	24/7 guarding of buiding site by 2 guards
Maintaince	Maintaince of building site during construction
Carbage disposal	Disposal of garbarge 4m3
Ground anchors	Anchoring for inflatable
Membrame	PVC-foil of 950 gr/m2
Cellulose	Linquin cellulose delivered in sheets
Ropes	Ropes for ropenet+spare rops
Cable connectors	Steel U-connectors M12
Ice blocks	Ice blocks for building of ice ring
Water	Water consumpumption of production line
Electricity	Electricity usage
Fuel	Fuel consumed by heavy equipment
Boomlift	2 Boomlifts will be operational at max
Crane	Crane for unloading factorry and inflatable
Shovel	For different ground works + ice ring
Total costs by individual overview	Specified by cost overview of mobile factory
Transport	From Eindhoven to Harbin by train
Construction inflatable	Hours for the construcion of the inflatable
Labor at construction	Construction workers on site

Quantity	Unit	Price/unit [€]	Total costst [€]
10	Persons	€ 900,00	€ 9.000,00
10	Persons for the full time	€ 700,00	€ 7.000,00
26	Days	€ 200,00	€ 5.200,00
26	Days	€ 100,00	€ 2.600,00
500	m	€ 13,50	€ 6.750,00
2	Lines	€ 500,00	€ 1.000,00
500	m	€ 1,50	€ 750,00
5	Pieces	€ 500,00	€ 2.500,00
1200	hours	€ 4,30	€ 5.160,00
1	Pieces	€ 1.000,00	€ 1.000,00
4	Times	€ 200,00	€ 800,00
108	Pieces	€ 30,00	€ 3.240,00
6500	m2	€ 3,00	€ 19.500,00
30	m3	€ 300,00	€ 9.000,00
1100	m	€ 1,00	€ 1.100,00
100	Pieces	€ 1,20	€ 120,00
300	m3	€ 50,00	€ 15.000,00
30000	L	€ -	€ -
10720	KWh	€ 0,14	€ 1.500,80
1500	L	€ 1,50	€ 2.250,00
25	Days	€ 70,00	€ 1.750,00
5	Days	€ 2.000,00	€ 10.000,00
9	Days	€ 100,00	€ 900,00
1	Piece	€ 30.677,80	€ 30.677,80
1	Piece	€ 4.500,00	€ 4.500,00
1000	Hours	€ 4,30	€ 4.300,00
7296	Hours	€ 4,30	€ 31.372,80

Costs by sponsor [€]	Sponsor/resonsible	Total catogory [€]
€ 4.000,00	Summa and students	
€ 7.000,00	H.I.T.	
€ 5.200,00	MLV	
		€ 23.800,00
€ 6.750,00	MLV	
€ 1.000,00	MLV	
€ 750,00	MLV	
€ 2.500,00	MLV	
€ 5.160,00	MLV	
€ 1.000,00	MLV	
€ 800,00	MLV	
		€ 17.960,00
€ 3.240,00	MLV	
€ 19.500,00	H.I.T.	
€ 9.000,00	MLV	
€ 1.100,00	MLV	
€ 120,00	MLV	
€ 15.000,00	MLV	
		€ 47.960,00
€ -	MLV	
€ 1.500,80	MLV	
€ 2.250,00	MLV	
		€ 3.750,80
€ 1.750,00	MLV	
€ 10.000,00	MLV	
€ 900,00	MLV	
		€ 12.650,00
€ 20.790,37	TU/e	
€ -	TU/e	
		€ 35.177,80
€ 4.300,00	H.I.T.	
€ 31.372,80	MLV	
		€ 35.672,80

Total costs (excluded taxes)	€ 176.971,40
Total Sponsoring	€ 154.983,97
Remaining costs	€ 21.987,43

Refference

https://www.google.fr/flights/#flt=/m/0k3p.HRB.2018-12-10*HRB./m/0k3p.2019-01-03;c:EUR;e:1;sd:1;t:
https://www.booking.com/searchresults.en-gb.html?aid=316389&label=zininfrankrijk_meren&lang=en-g
https://www.numbeo.com/taxi-fare/country_result.jsp?country=China
https://www.numbeo.com/taxi-fare/country_result.jsp?country=China

(Hijl, et al., 2014); Boels
(Koekkoek, et al., 2016); Boels
(Hijl, et al., 2014); Boels
(Hijl, et al., 2014); Boels
https://www.numbeo.com/cost-of-living/in/Chengdu
(Koekkoek, et al., 2016);
Renewy

Anchor plan
Area of inflatble model; Rhino model
Volume of shell model; Rhino model with 2% cellulose Cellcrete
Stated by the ropenet drawing
Stated by the ropenet drawing
Stated by the initial design

Estimation of volume of tower; Rhino model
Estimation of electrical consumption Mobile factory+ additinoal lighting
Estimation of fuel use of heavy equipment (Koekkoek, et al., 2016)

(Koekkoek, et al., 2016)
(Koekkoek, et al., 2016)
(Koekkoek, et al., 2016)

BOM
Appex shipping

https://www.numbeo.com/cost-of-living/in/Chengdu

:f
;b&sid=c7d4563e9ef8e032dff22872637406e0&sb=1&src=profile%2Fprofile_dashboard&src_elem=dash

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ı_sf=1&ss_raw=harbin&ac_position=0&ac_langcode=en&dest_id=-1908524&dest_type=city&iata=HRB

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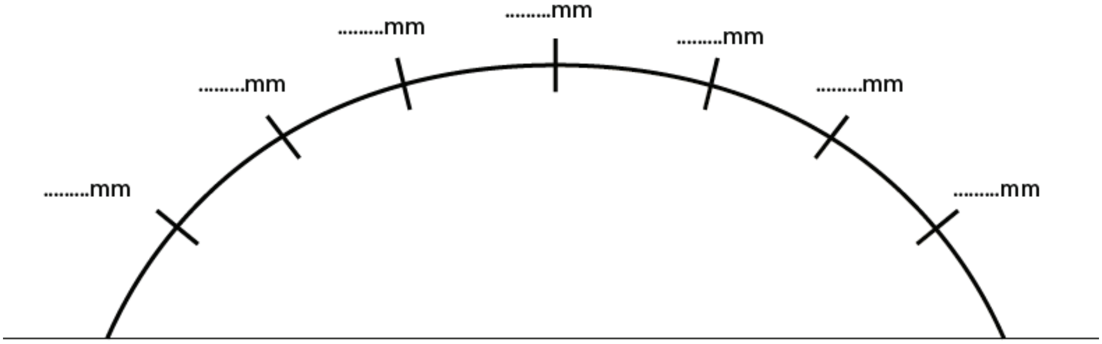
Report log

Monitoring Thickness (once per 6 hours):



Checklist Shift switch:

- ☐ Building site is clean and accessible (not slippery)
- ☐ Equipment has been returned to its original place.
- ☐ Heavy equipment is parked on the right spot and plugged in the electricity.
- ☐ The headlights and radios are being charged.
- ☐ Helmets and spikes are transferred to the next shift.
- ☐ The Report has been filled in complete and correctly.
- ☐ **End of shift**

Use and replenishment:

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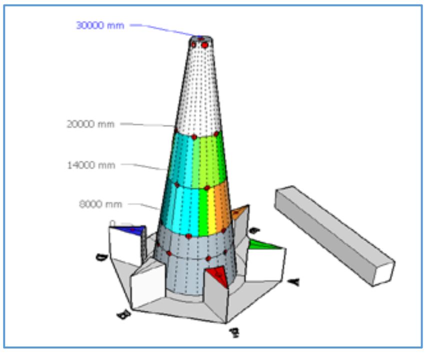
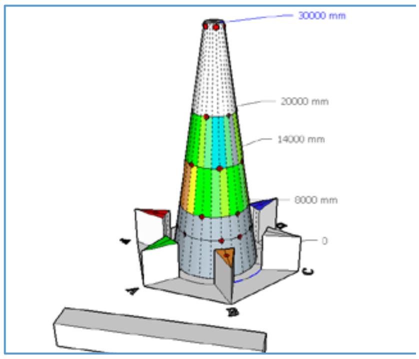
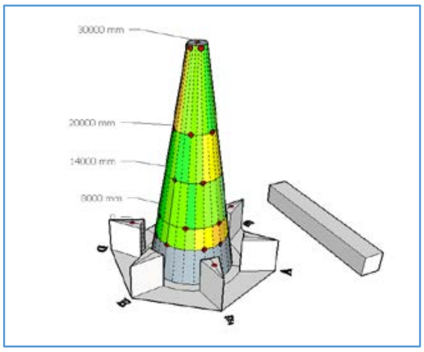
	(Optional) extra comments:
1.	
2.	
3.	
4.	
5.	
6.	

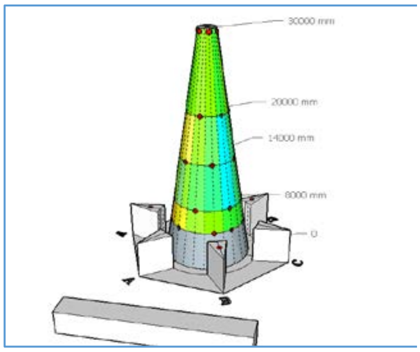
Meusurement 1



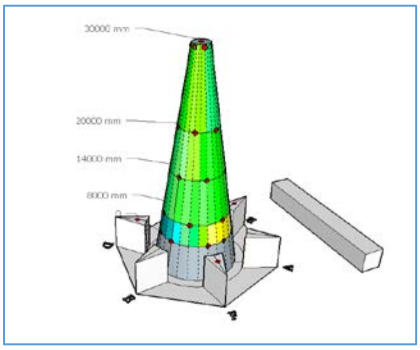


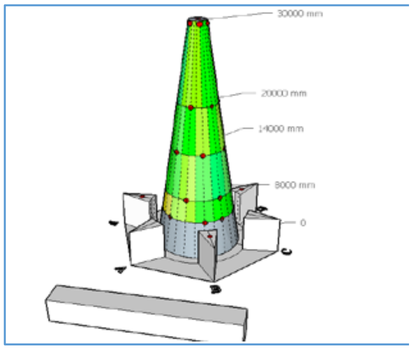
Meusurement 2





Meusurement 3





Color code overview				
	RGB			
Difference[mm]	R	G	B	Difference[mm]
-20	225	225	0	-100
-18	225	213	0	-90
-16	225	201	0	-80
-14	225	190	0	-70
-12	225	178	0	-60
-10	225	166	0	-50
-8	225	154	0	-40
-6	225	142	0	-30
-4	225	131	0	-20
-2	225	119	0	-10
0	225	107	0	0
2	225	95	0	10

4	225	83	0	20
6	225	72	0	30
8	225	60	0	40
10	225	48	0	50
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14	225	24	0	70
16	225	13	0	80
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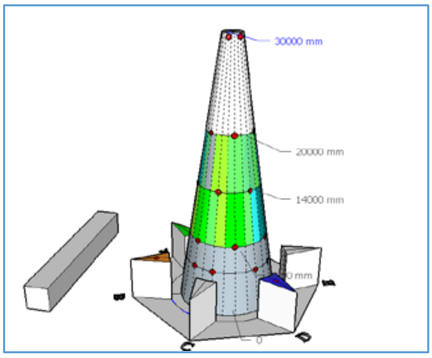
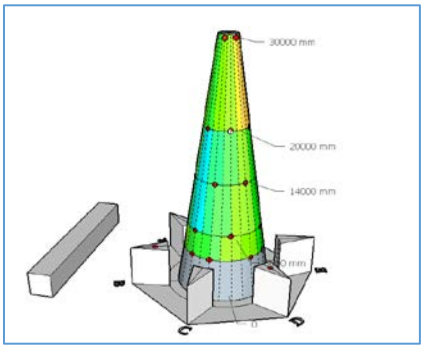
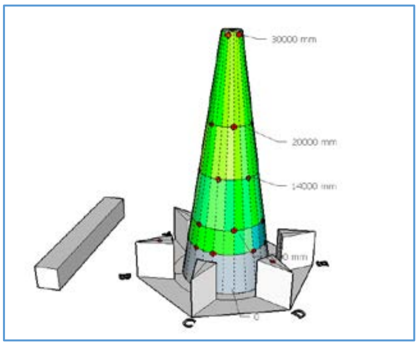






Descriptioin
Ring 1

Ring 2

Ring 3

Top

Ring legs
between

Ring legs
connection to tower

Ring legs
Top of legs

HSL		
Hue	Sat	Lum
175	225	150
166	225	150
158	225	150
149	225	150
140	225	150
131	225	150
123	225	150
114	225	150
105	225	150
96	225	150
88	225	150
79	225	150

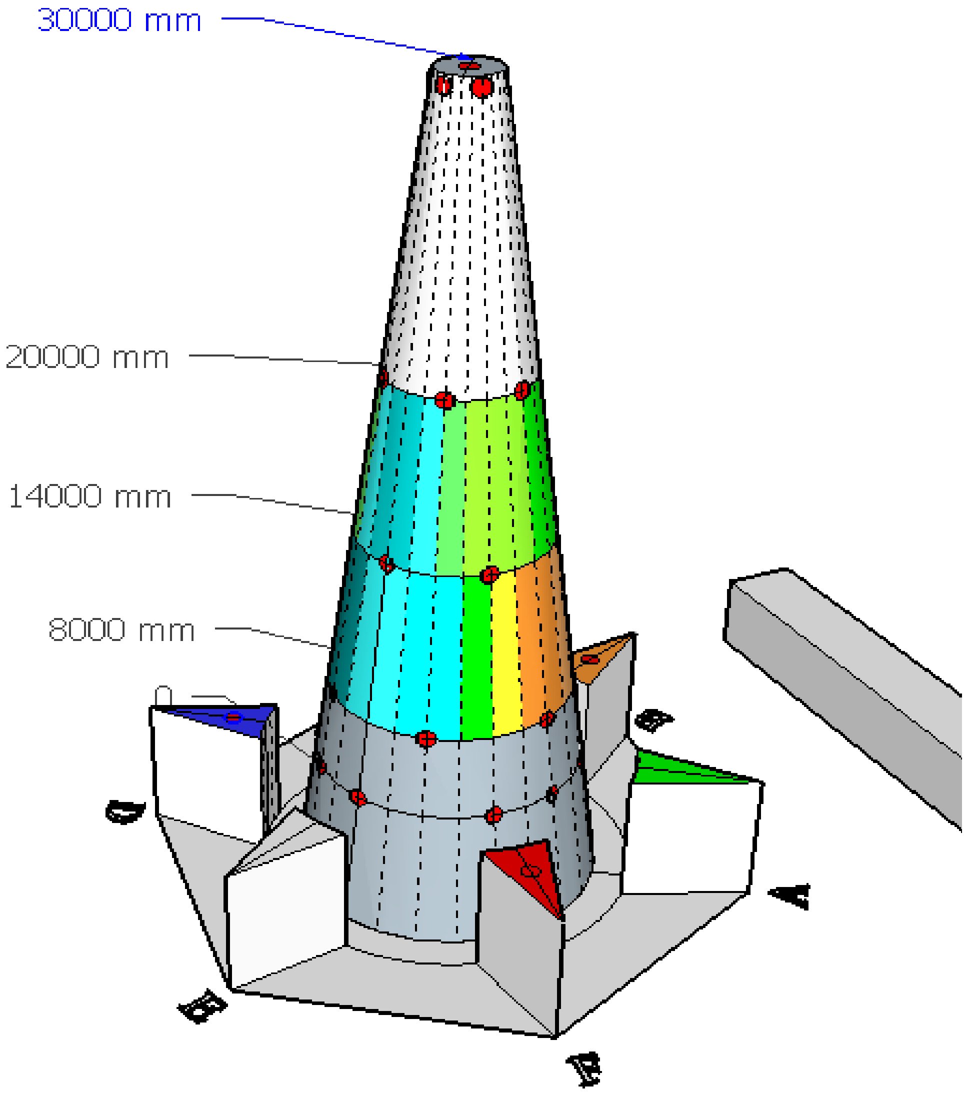
70	225	150
61	225	150
53	225	150
44	225	150
35	225	150
26	225	150
18	225	150
9	225	150
0	225	150

		Date:	30-dec-17		
		Measurement 1			M
Ring heigt [mm]	Point	Thickness [mm]	Diffrence [mm]	Color code	Thickness [mm]
8000	1	225	61		340
	2	180	16		-
	3	180	16		250
	4	180	16		-
	5	100	-64		300
	6	120	-44		-
Average		164	mm		297
14000	7	110	4		-
	8	140	34		-
	9	90	-16		-
	10	110	4		-
	11	100	-6		-
	12	85	-21		-
Average		106	mm		#DIV/0!
20000	13	10	-20		-
	14	75	45		190
	15	45	15		-
	16	20	-10		90
	17	20	-10		-
	18	10	-20		140
Average		30	mm		140
30000	19	-	#VALUE!		-
	20	-	#VALUE!		55
	21	-	#VALUE!		-
	22	-	#VALUE!		50
	23	-	#VALUE!		-
	24	-	#VALUE!		70
	25	-	#VALUE!		-
Average		#DIV/0!	mm		58
4000	26	-	#VALUE!		41
	27	-	#VALUE!		16
	28	-	#VALUE!		33
Average		#DIV/0!	mm		30
4000	29	-	#VALUE!		-
	30	-	#VALUE!		-
	31	-	#VALUE!		-
	32	-	#VALUE!		-
	33	-	#VALUE!		-
	34	-	#VALUE!		-
Average		#DIV/0!	mm		#DIV/0!
4000	35	210	20		-
	36	250	60		-
	37	110	-80		-

Average	190 mm	#DIV/0!

3-jan-18			7-jan-18	
/leasurement 2		Measurement 3		
Diffrence [mm]	Color code	Thickness [mm]	Diffrence [mm]	Color code
43		370	32	
#VALUE!		-	#VALUE!	
-47		320	-18	
#VALUE!		-	#VALUE!	
3		325	-13	
#VALUE!		-	#VALUE!	
mm		338	mm	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
mm		#DIV/0!	mm	
#VALUE!		-	#VALUE!	
50		320	13	
#VALUE!		-	#VALUE!	
-50		310	3	
#VALUE!		-	#VALUE!	
0		290	-17	
mm		307	mm	
#VALUE!		70	-8	
-3		-	#VALUE!	
#VALUE!		80	3	
-8		-	#VALUE!	
#VALUE!		75	-3	
12		-	#VALUE!	
#VALUE!		-	#VALUE!	
mm		78	mm	
11		510	53	
-14		410	-47	
3		450	-7	
mm		457	mm	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
mm		#DIV/0!	mm	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	
#VALUE!		-	#VALUE!	

mm		#DIV/0!	mm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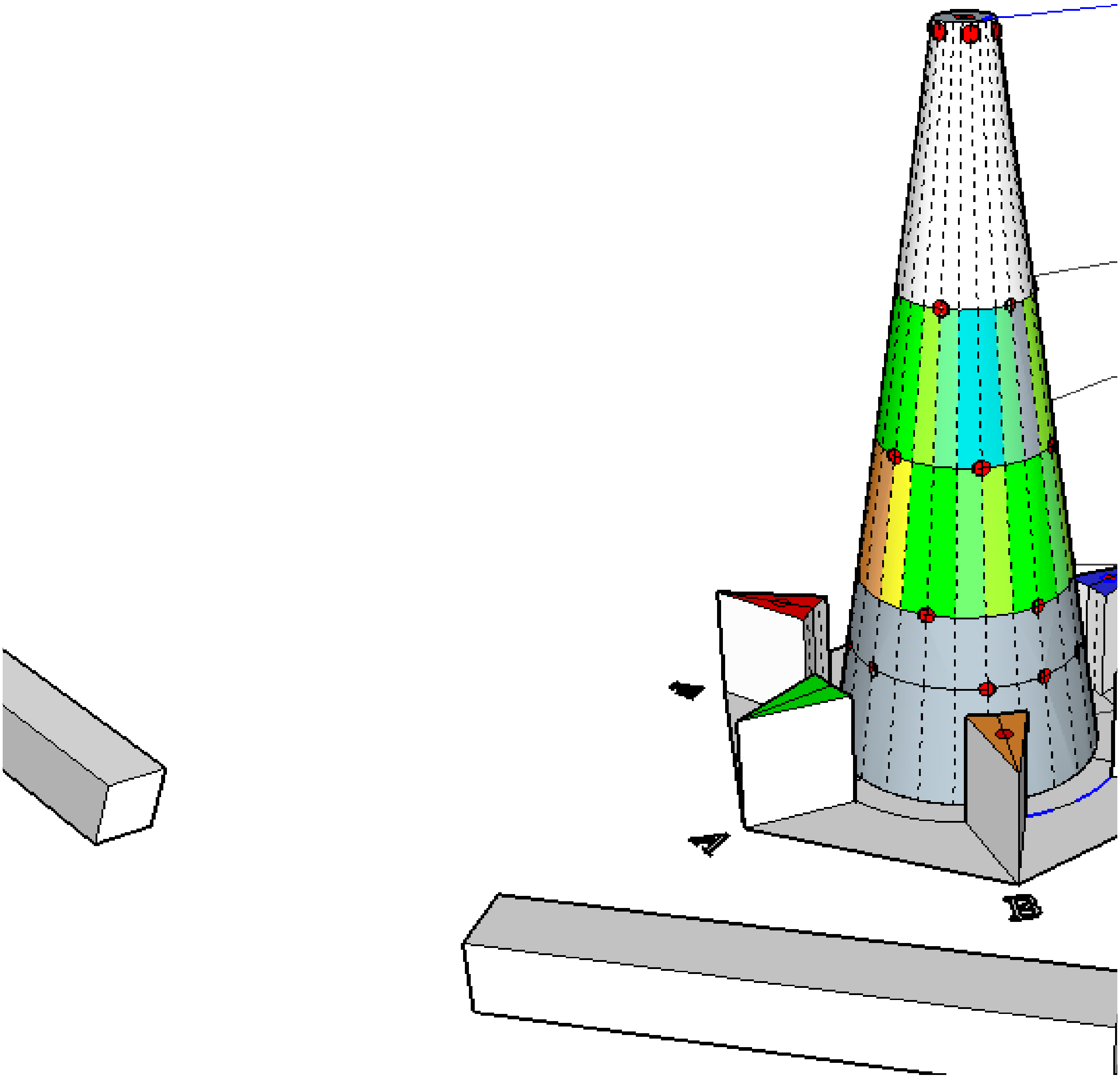
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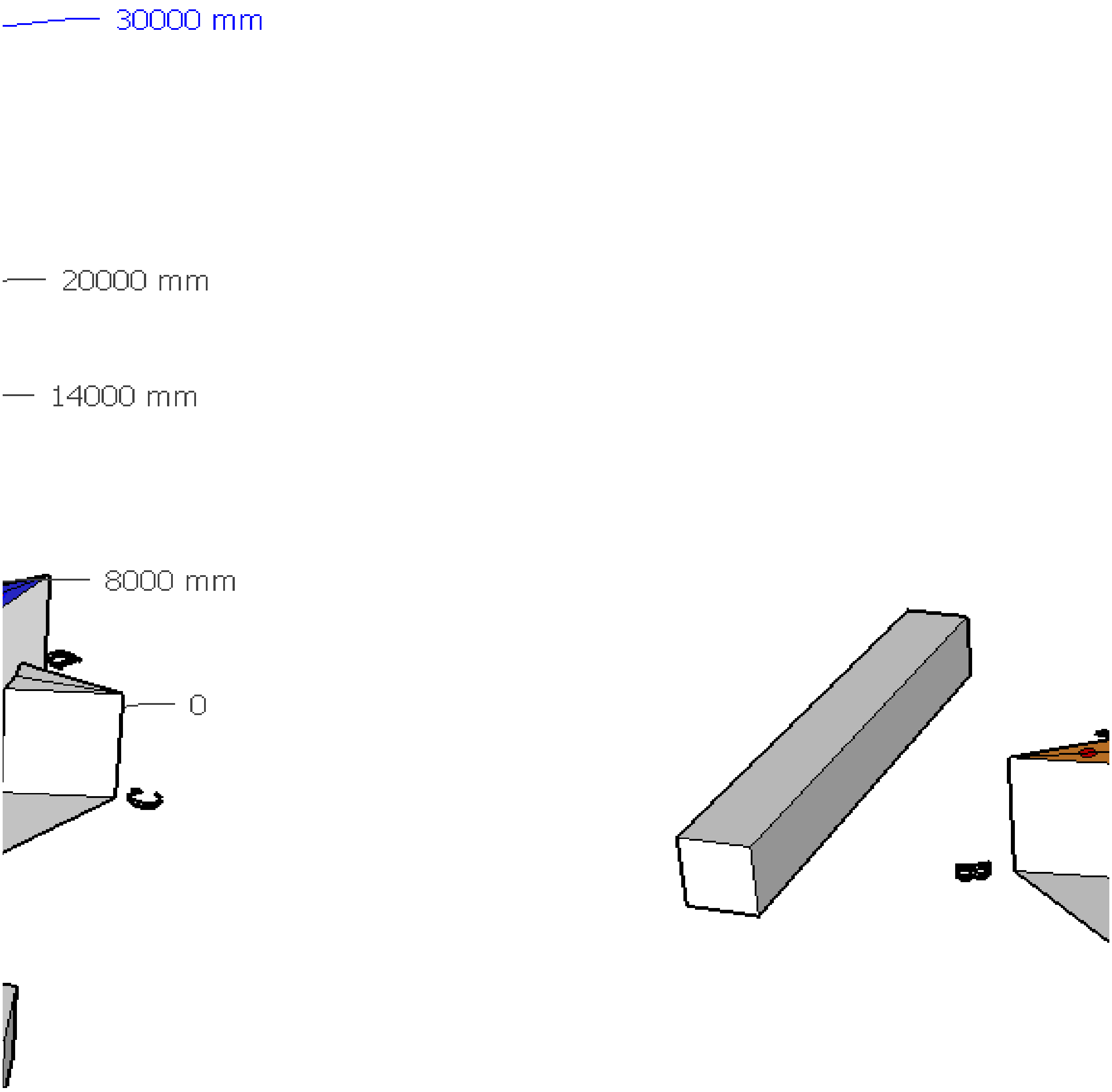
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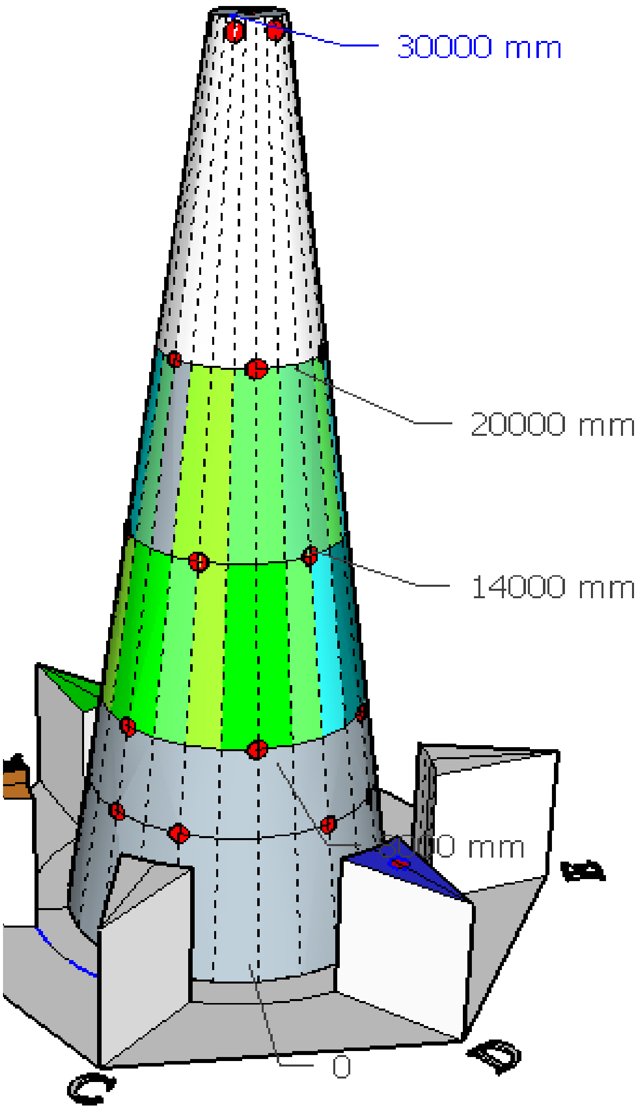
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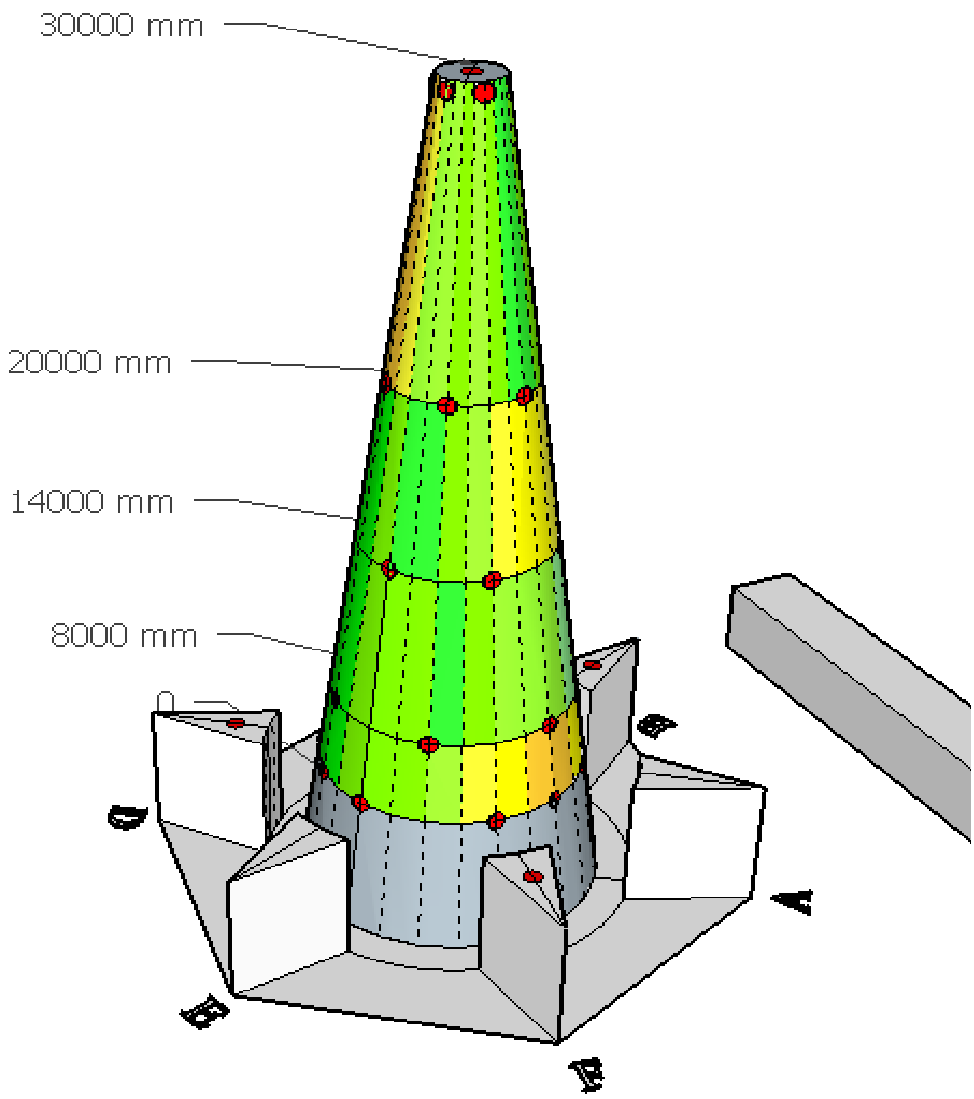
C
D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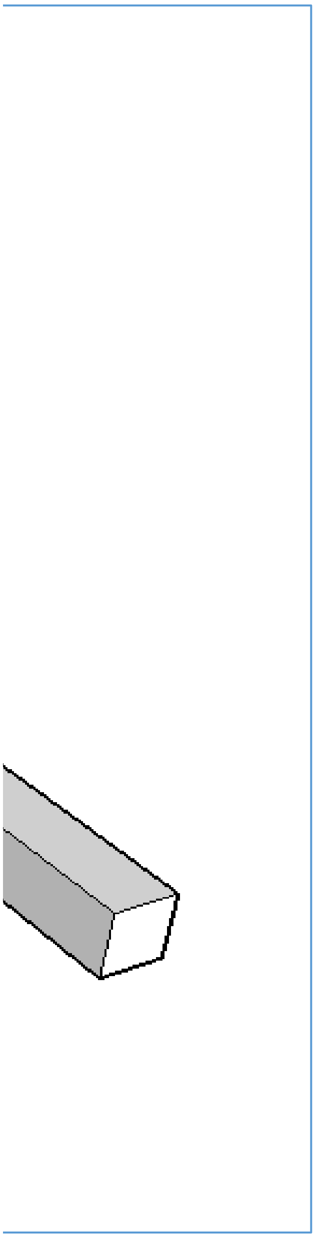

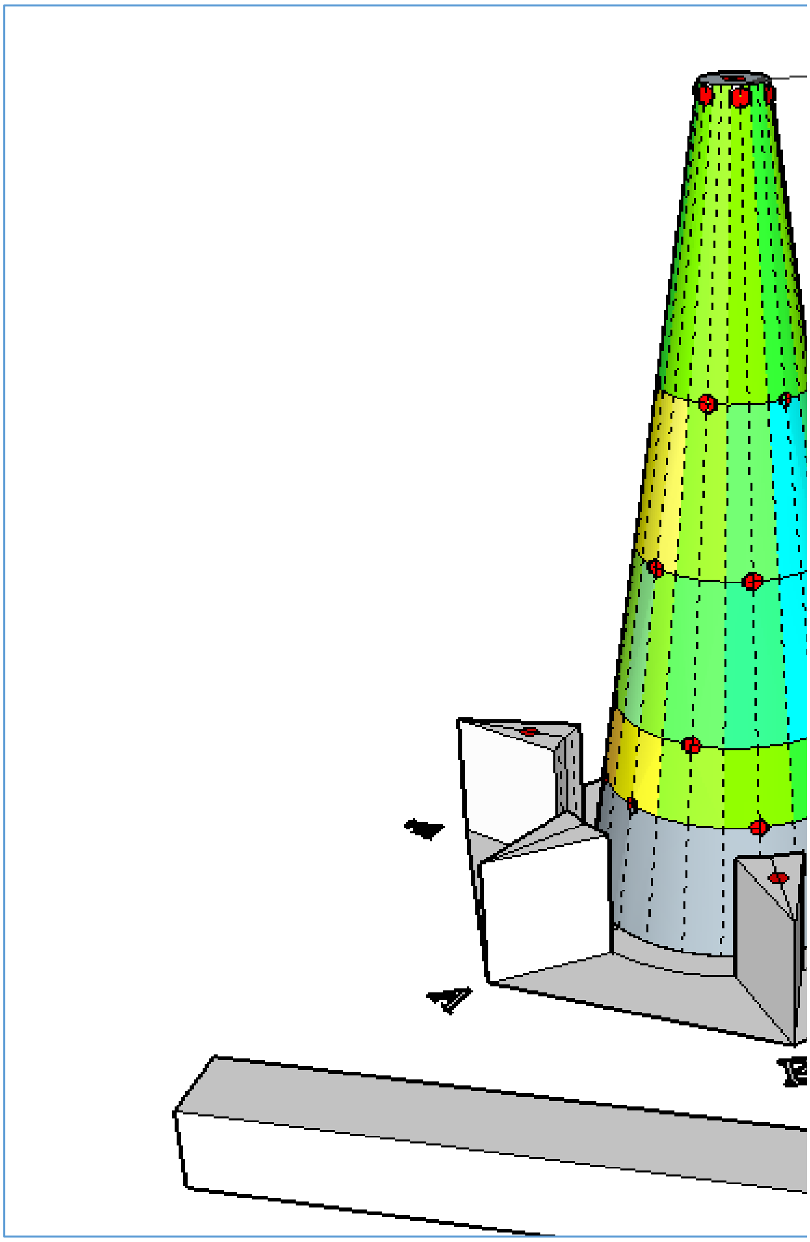

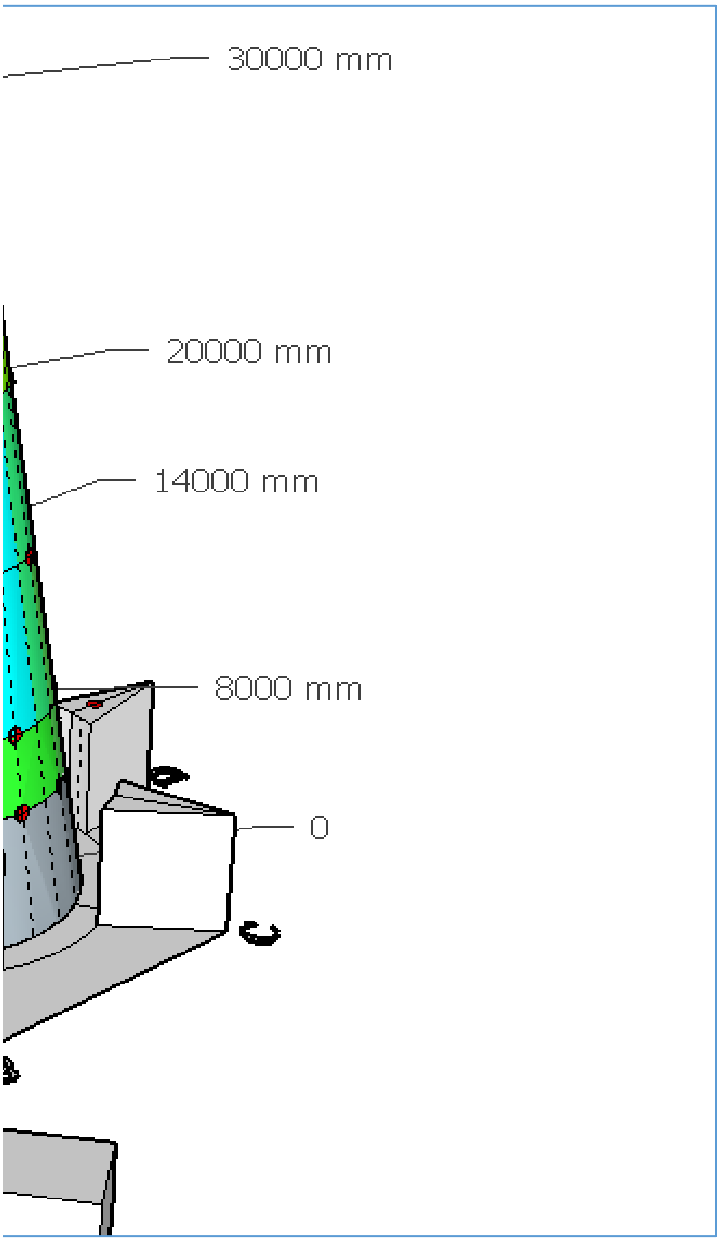
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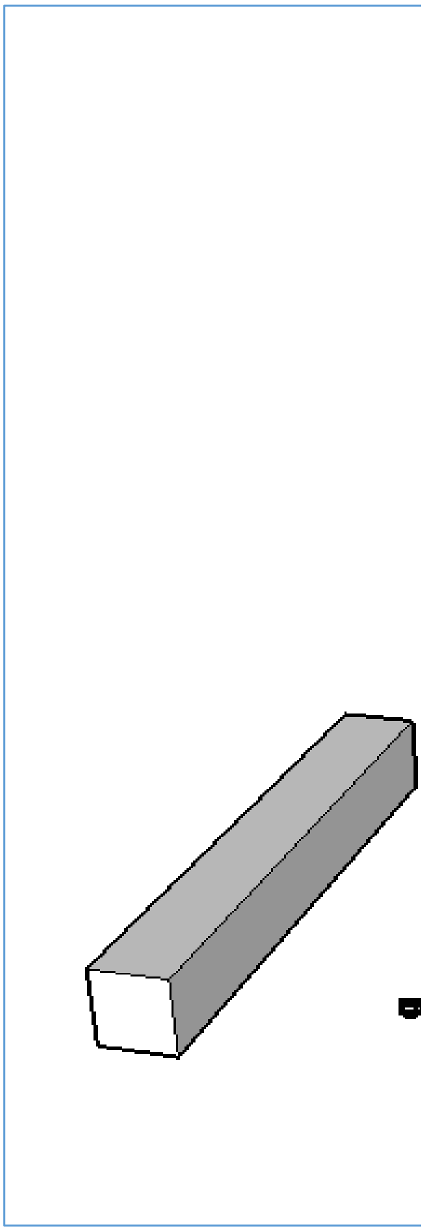

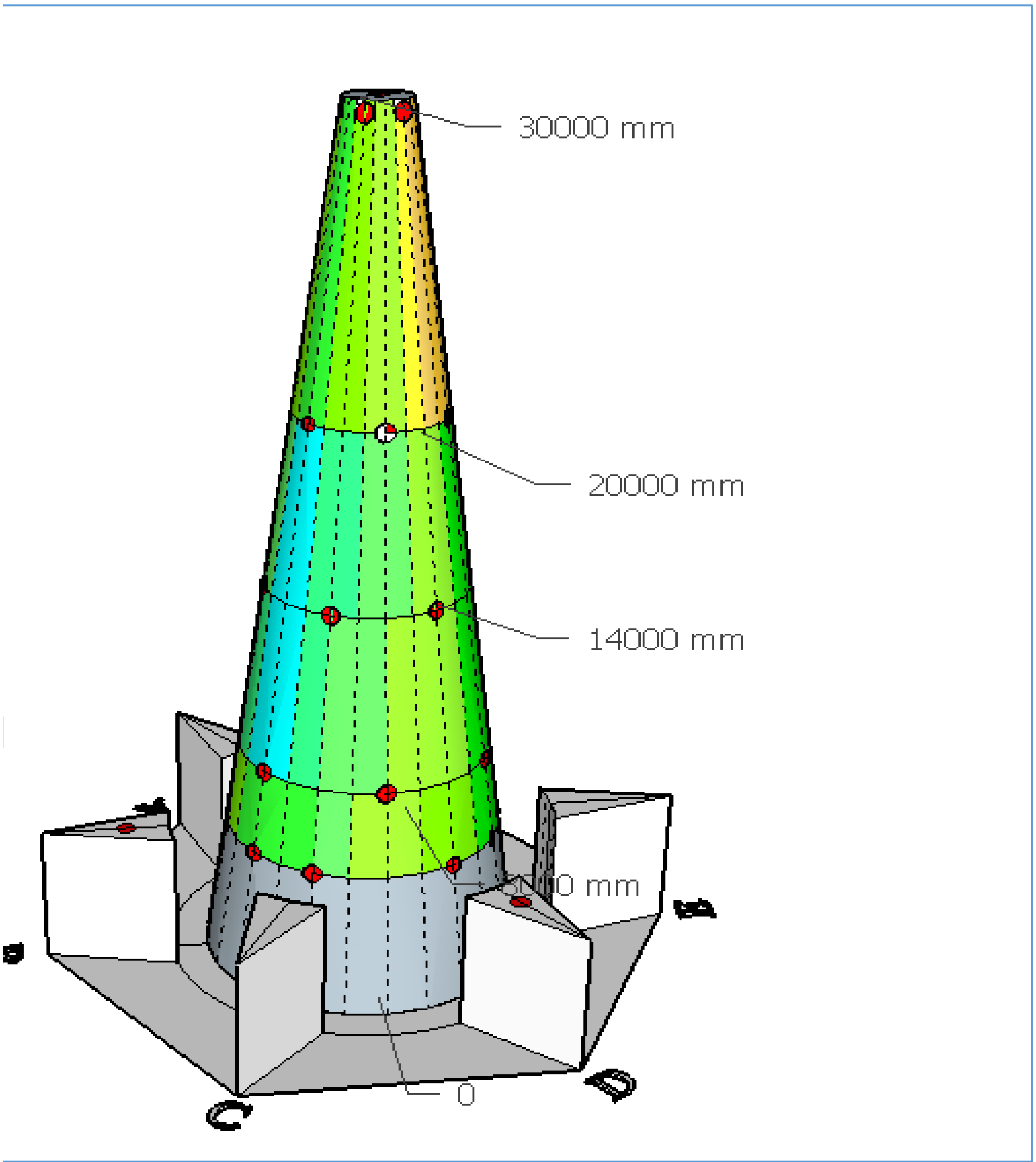
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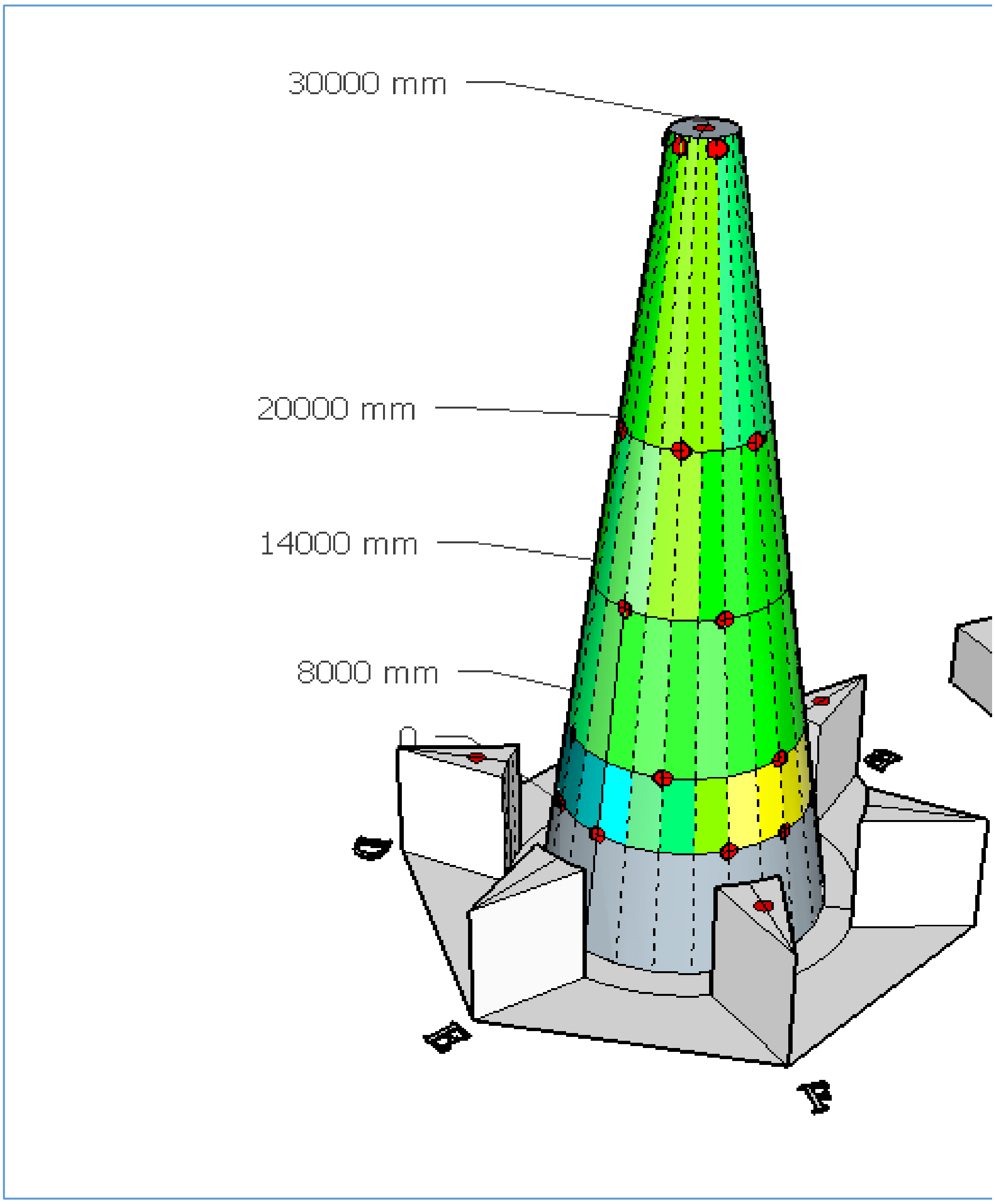
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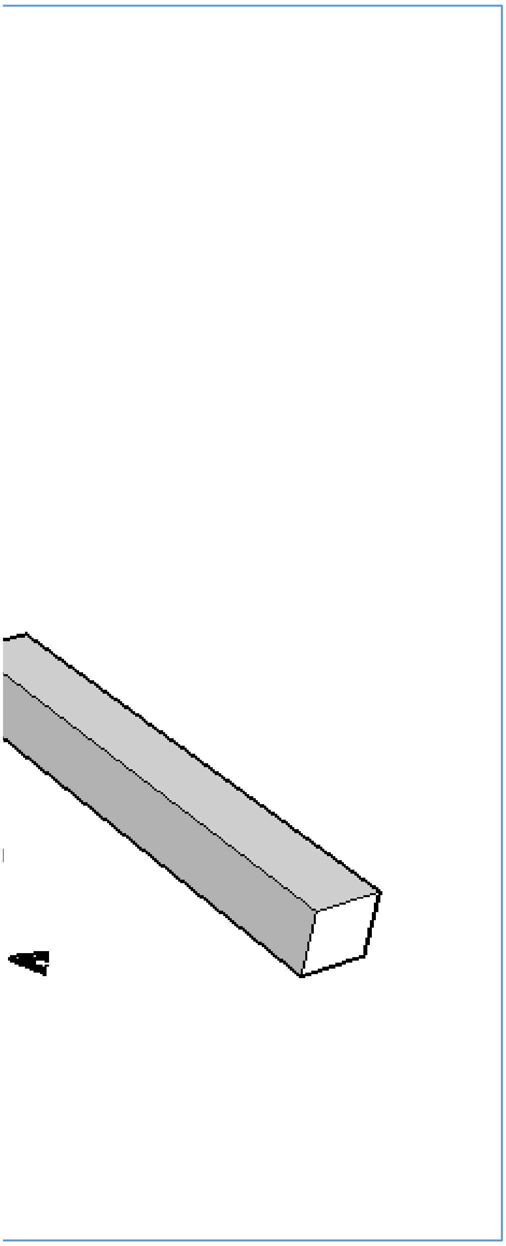

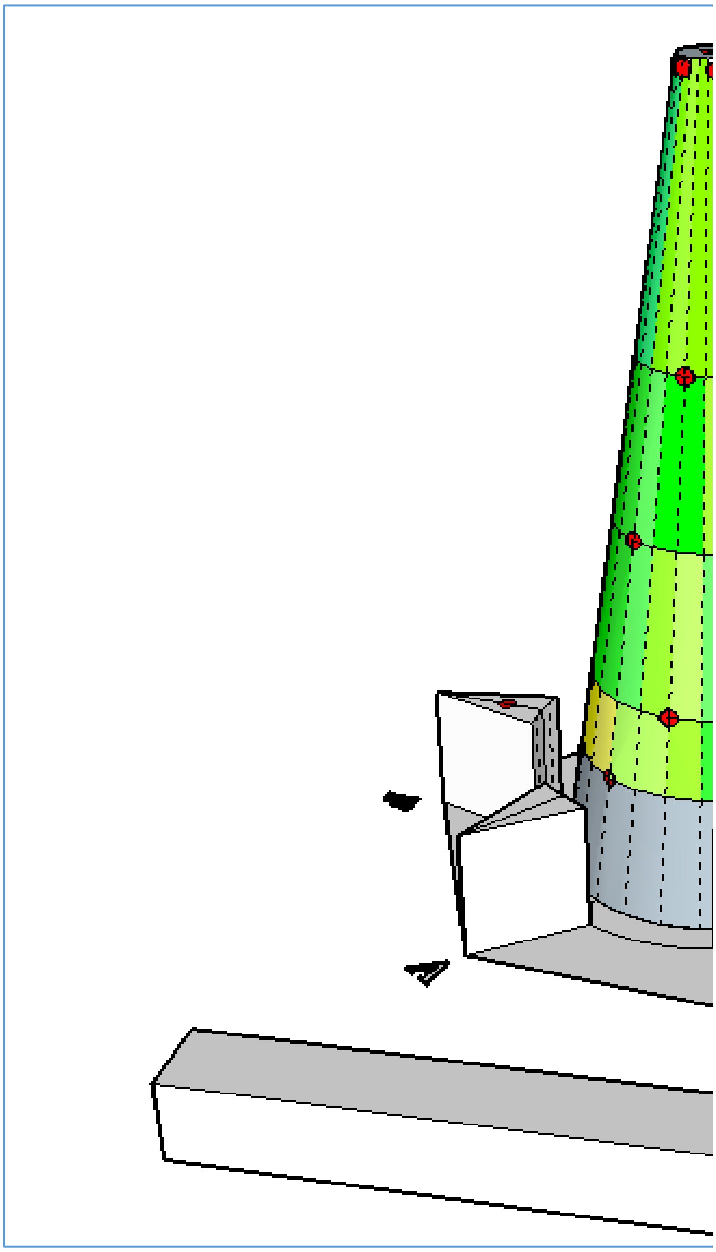

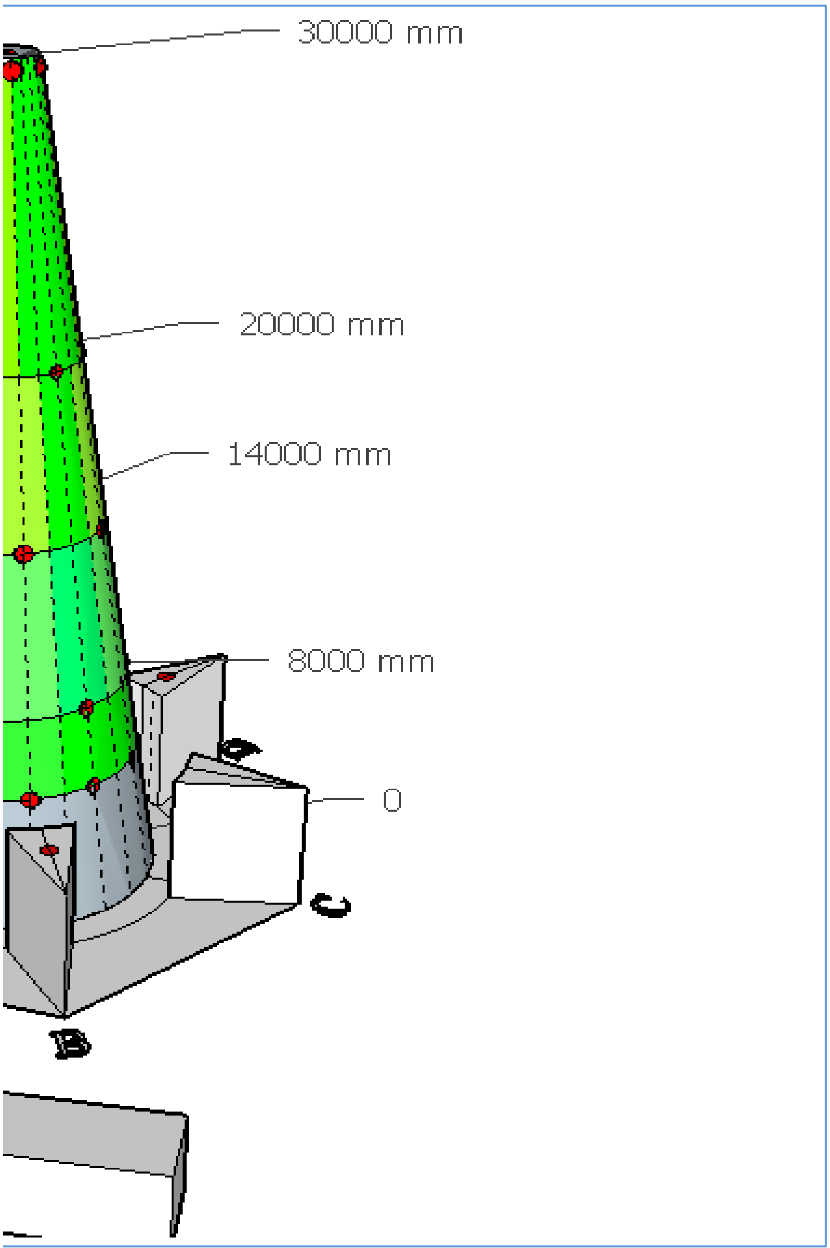
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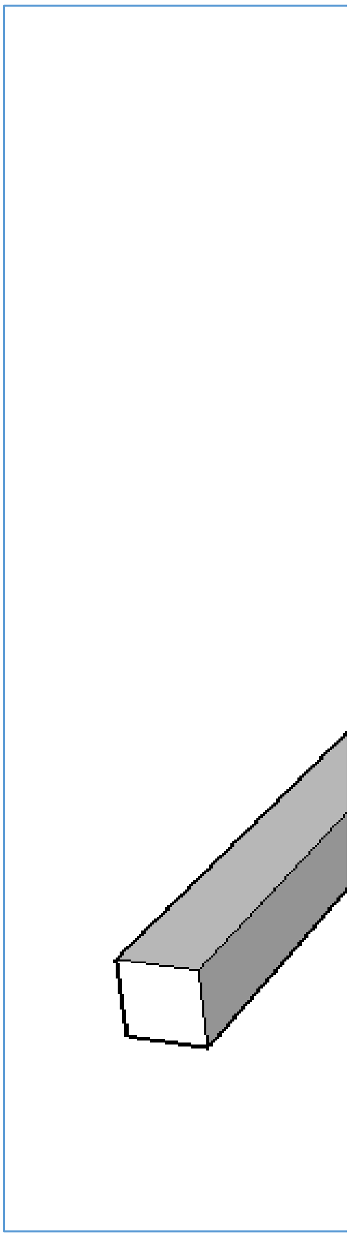

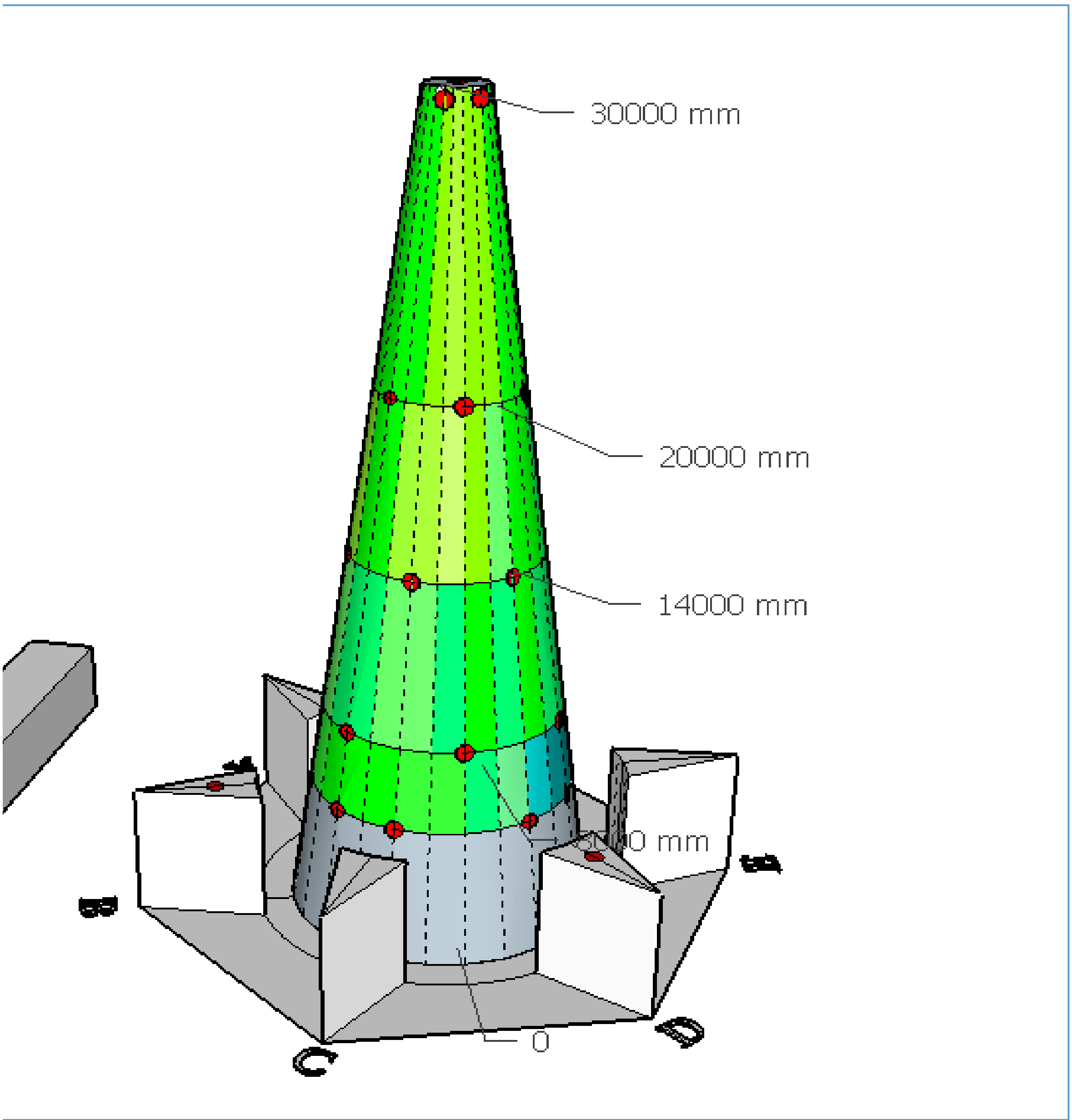
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