LUT UNIVERSITY
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DEVELOPMENT OF SHELL AND SUPPORTIVE STRUCTURE FOR A HORSEBACK RIDING SIMULATOR

Examiner(s): Professor Heikki Handroos
D. Sc. (Tech.) Ming Li

ABSTRACT

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Development of shell and supportive structure for a horseback riding simulator

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This thesis presents a part of a project of Laboratory of Intelligent Machines, LUT University, and perform the development method of how shell and supportive structure for a horseback riding simulator can be produced. It consists of a scanning method of a moving object, processing the giving model after, and preparing a supportive structure for the manufactory. In this thesis, scanning was done by implementing two units: Leica RTC360 and Leica BLK360. The next following model processing was done in Geomagic Design X and Autodesk Meshmixer. The supportive structure was modeled, and strength calculation was introduced in SolidWorks, the structure was produced and assembled as an outcome.

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Vadim Federa

Vadim Federa

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	2-Dimensional
3D	3-Dimensional
6-DOF	6 Degrees of Freedom
3DS	3-Dimensional Scene
ABS	Acrylonitrile Butadiene Styrene
AM	Additive Manufacturing
CAD	Computer-Aided Design
CO_2	Carbon dioxide
COLLADA	Collaborative Design Activity
DIN	Director Identification Number
E57	LIDAR Point Cloud Data Format
HZ01	Horseback riding simulator
FBX	Filmbox
FEM	Finite Element Method
FOS	Factor of Safety
IGES	The Initial Graphics Exchange Specification
ISO	International Organization for Standardization
LIDAR	Light Detection and Ranging
MIX	Microsoft Image Extension
MP	Megapixel
MTL	Material Template Libraries
OBJ	Wavefront Object
PLA	Polylactic acid
PP	Polypropylene
PTS/SEC	Points per Second
RAL	Color system
STEP	Standard for the Exchange of Product Data
STL	Stereolithography

LIST OF FIGURES

1. INTRODUCTION

The main task of the horse-riding simulator is to help people to practice with a real-life horse model. With this machine, a person can practice riding the whole day, instead of just an hour with a real animal. One of the main group of people who would like to purchase this horse-riding simulator are organizations which are targeted on horse-riding championships since for them it is important to be in fit as long as they could. Additionally, it can be used as a replacement for hippotherapy.

The aim of the thesis is to create a 3D (3-dimensional) model of a horse, and then, based on the file build a supportive structure that will be able to resist all possible loads. A literature review was done to concern the main theory principles of the research. Not only existing examples of the given task but also of related research are illustrated and reviewed as well.

1.1. Horseback riding simulator examples and its effect on the health and benefits for the professional riders

Undoubtedly, any simulator cannot change the real animal. However, it is possible to reach the imitation level when the difference will be insignificant. Researchers who published an article, related to the simulator, in the European Journal of Integrative Medicine found out that depends on riding type there are a lot of remarkable factors affecting a person in the saddle no matter real horse is used or not. (Kim, et al., 2016, p. 8)

Not only benefit but in some cases even harm can bring the use of the simulator. By researching group of Laboratory of Intelligent Machines in LUT it was revealed that sometimes inexperienced people riding on the simulator making mistakes which leads to back asymmetry. (Byzova, et al., 2020, p. 162169)

According to the research which was conducted by Monika Zadnikar and Andrej Kastrin from Slovenia it has been proved that hippotherapy helps people with cerebral palsy to improve not only their postural control but also balance since during the riding people have to keep the coordination, trunk control and many other significant parameters for the rider. (Zadnikar & Kastrin, 2011, p. 690)

Researchers from India have concluded that sitting motor functions will be improved after conducting hippotherapy on a horse-riding simulator (Chinniah, et al., 2020, p. 6). There were two groups of children, where the first one was receiving physiotherapy only, and the second one could use horse riding simulator for 15 minutes extra (in figure 1.1). After 12 weeks children from both groups have shown improvement in sitting, but the second one introduced better results. Unfortunately, some important aspects as muscle strength, participation level were not included, but even though, the results are decent to be mentioned.

Figure 1.1. Horseback riding simulator used in the research (Chinniah, et al., 2020, p. 3).

Research group from Korea created a 6-DOF (6 Degrees of Freedom) platform (which is called Stewart platform) to make a robotic horse in order to use it for therapy or riding aspects further in projects. The concept of it is shown in the figure 1.2. Most of the members participated in survey mentioned that they were satisfied with the simulator and got an exercise effect. It is proved one more time that such simulators are sufficient and should have been developing. (Lee, et al., 2018, p. 10)

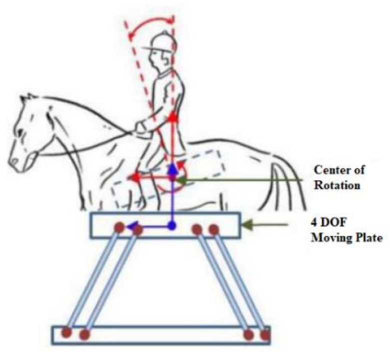

Figure 1.2. Proposed structure of the simulator (Lee & Kwak, 2013, p. 2).

Researching group from United Kingdom published an article, where compared how different real horses from the simulator in riding on them (Walker, et al., 2016, p. 6). They revealed that by training on the simulator it is possible to improve the stability of the jockey. This example is one from the many other ones who proves the realness how normal training on a horse can be similar to the training applying various technologies.

Another example, and even, nowadays the leader in this field can be called Racewood from England (in figure 1.3) (Racewood, 2017). Without a doubt, they can be considered the pioneers of the industry, since the first simulator was developed more than 30 years ago. A huge number of projects can be created by relying on their success. Due to several possible options for simulator operations, they can be used not only in sports but also for postural recoveries after some incidents.

Figure 1.3. Racehorse simulator from Racewood (Racewood, 2017).

1.2. Measurements

For any research, initially, it is required with which dimensions the further work is going to be. Not only for horses but also other animals such body measurements are important. For example, by collaboration of two research groups in China it was conducted the way of how to measure pigs in order to control the production (in figure 1.4) (Wang, et al., 2018, p. 297). By installing two depth cameras, the cloud of points was obtained. As a result, this method shows relative errors are around 7% which is acceptable for this area.

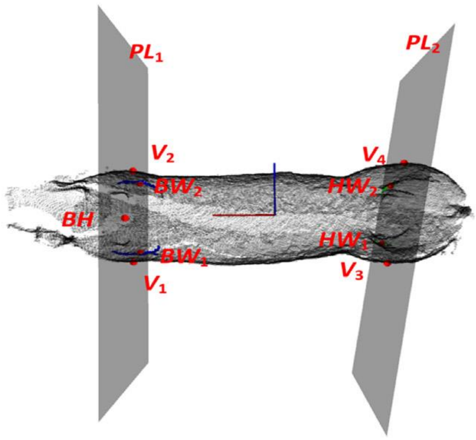

Figure 1.4. Top view of the obtained result (Wang, et al., 2018, p. 294).

Another example, illustrated in figure 1.5., is from France where researchers revealed the way how to scan a cow body with high precision. A distinctive feature in the article, the authors note the scanning process which leads to zero risk of human injuries. The data provided from the research could help for the farms estimate profit more accurately. (Le Cozler, et al., 2019, p. 452)

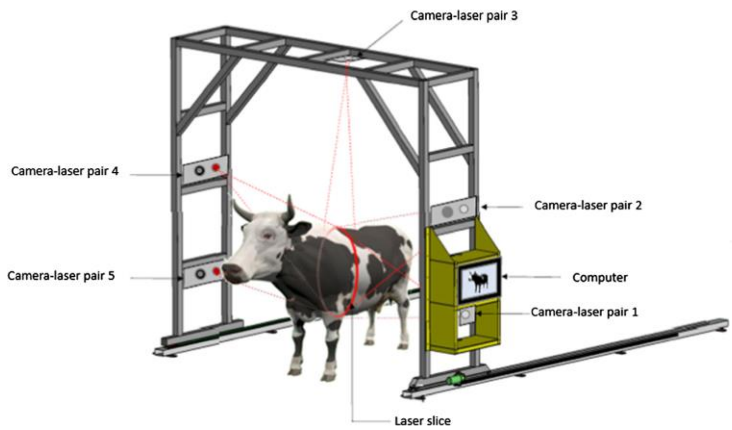

Figure 1.5. Design of how data was acquired (Le Cozler, et al., 2019, p. 449).

The idea of horse simulator is floating around the world for a long time. Some companies have been developed their own concepts to be in the forefront of this technology field. For instance, researchers from Korea have been conducted a three-dimensional motion analysis and revealed that it is possible for a simulator to be close to a real horse to imitate all the movements for the rider. (Lee & Kwak, 2013)

To help riders challenge with a power of a horse, a group of scientists conducted a research. As the main aim of the horseback riding simulator was to train people with a dynamic model which was supposed to test the riders in different modes of moving (in figure 1.6). As a result, the model was done successfully. The obtained data will help future riders to overcome their limits. (Lim, et al., 2015, p. 69)

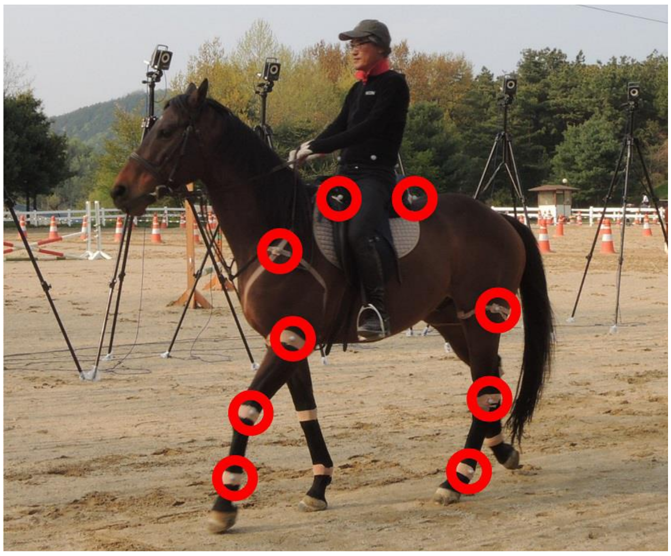

Figure 1.6. The horse which was used for the experiment. All markers are circled (Lim, et al., 2015, p. 66).

1.3. 3D scanners

Before 3D scanners were invented, there had to create a model manually, by using professional software. Results could be far from desired sometimes due to miscalculations. To neutralize this problem and other possible errors, 3D scanners were invented.

3D scanners are devices that are serving to create a digital 3D model from the real world with high resolution. Scanners create a cloud of points connected by lines, thereby obtaining the geometry of the body. It can be used in any CAD (Computer-Aided Design) application further to process or to improve the obtained model if some details are broken or missing.

Generally, according to the review by the department of mechanical engineering at S P Pune University, there are two types of scanners (Chougule, et al., 2018, p. 41):

1. Contact scanners. In this case, the ones work in direct contact with an analyzing object. Since it is contact this group is extremely precise. The drawback of it that during the survey the observing object can be not only changed in shape but also damaged or even broken. One of the possible examples, where contact scanners can be applied was introduced in 2020 by a research group of European countries (Van Damme, et al., 2020, p. 4). Due to 2D (2-dimensional) drawings can be done with inaccuracy, because of the human factor, contact

digitizing way of making a model was discovered. Unfortunately, according to the article, all other 3D scanning methods have the benefit that they are faster and do not require specific skills for the process.

2. Contactless scanners (or Non-contact). This type of scanners is surveying by using ultrasonic waves, light beams et cetera. Such scanners can be applied in the medical field. For instance, it is possible to make a scan of a hand and use the obtained file further to print a unique cast for it (Geierlehner, et al., 2019, p. 75). The way how the process was performed is depicted in figure 1.7. below.

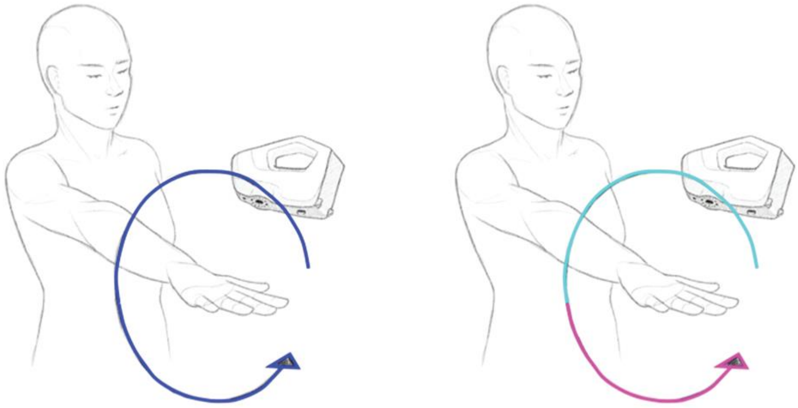

Figure 1.7. Scanning process of a hand (Geierlehner, et al., 2019, p. 73).

As it is shown, it is possible to produce a model in 2 ways. The first one can be done by continuous scanning around the hand (on the left side of the figure) or by operating the second way the process can be separated into two steps to make a model both from back side of the hand and from the palm (on the right side of the figure).

Additionally, to save heritage, it is popular to use this technique. Researchers from Kuala Lumpur, Malaysia performed a way how to digitalize it and thus save it, preventing possible loss due to the age (Sharif, et al., 2018, p. 7). The process is depicted in figure 1.8.

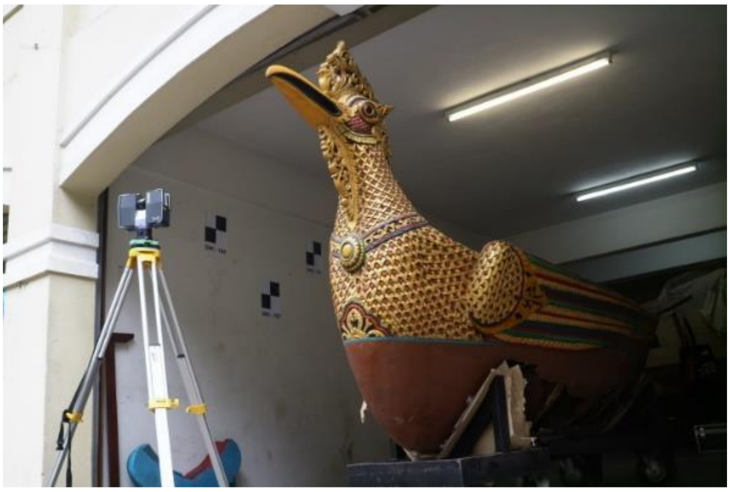

Figure 1.8. Scanning process of a boat (Sharif, et al., 2018, p. 3).

Paleontologists use this technology to obtain a good replica. A group of people from the United States described how paleontological specimens could be scanned. Applying the described method and using Microsoft Kinect v2 module the model of a Tyrannosaurus rex was received (Das, et al., 2017, pp. 2-9). The scanned model is shown in figure 1.9.

Figure 1.9. Obtained model of a skull (Das, et al., 2017, p. 9)

Nowadays, even police use 3D scanning technology to investigate accidents by reconstructing them. For example, by using the given technologies, a driver was convicted to exceed the speed limit and sentenced to 7 years in jail (Baier, et al., 2020, p. 4). Figure 1.10. depicts a match between an injured dummy model and a car that has received damage of suitable shape.

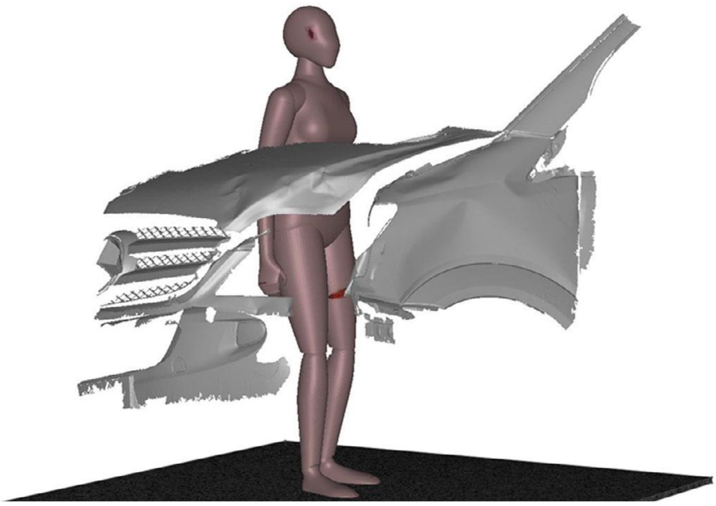

Figure 1.10. Crime model simulation (Baier, et al., 2020, p. 4)

1.4. Format types for the model

One of the widespread file formats using in AM (Additive Manufacturing) is STL (stereolithography is one of the acronyms for STL since initially was applying in that field). The data of a model stores in STL by lots of triangles, where numbers of them can be controlled by how the structure is detailed. It was created by Chuck Hull (in figure 1.11), who withal invented the first 3D printer (in figure 1.12.). (3D Systems, 2020)

Figure 1.11. Chuck Hull (3D Systems, 2020)

Figure 1.12. The first 3D printer (3D Systems, 2020)

It is clear to see that STL is today's the most usable format in the world. According to the article, from ALL3DP which is describing which file format is the most popular and why everyone uses it, it is said that people prefer this format for its simplicity and widespread. The biggest drawback is the accuracy of obtained models, but for some cases, this can be ignored by the accuracy of the printer's printing. (All3DP, 2020)

The OBJ file format (Wavefront object), by comparison with STL, is able to keep information about texture and even colors. For this additional information MTL (Material Template Libraries are used. A distinctive feature of this file format is that it can use not only tessellation but also surfaces and curves which have free form. By using it benefit more precise model could be obtained. That is why this format is widely using in industries where engineering accuracy is important. Since the field of 3D printing has been developing constantly, it is already available to print details not just in one color only. Color benefit, the accuracy of result models, and open license for the format are proving that OBJ is a decent competitor to STL. (All3DP, 2020)

Summing up the conclusion of this short review of file format types it is obvious to say that the world of 3D models and 3D printing consist of a big number of various formats. Another article is giving an explanation of other types as 3DS (Three Dimensional Scene), COLLADA (Collaborative Design Activity), STEP (Standard for the Exchange of Product Data), FBX (Filmbox) et cetera (Chakravorty, 2019). Some of them are widely using in movies or gaming industries since they are popular choices for animation. Such types as IGES (The Initial Graphics

Exchange Specification) or STEP are almost an integral part of technical drawing or for engineering tasks due to its way to keep other files together and their way to work with geometry. But that is why it is important to use only one preferable format and preparing a model by using its benefits and avoiding possible drawbacks.

1.5. Additive Manufacturing

3D printing is a technology of the future that is already available for us. AM has already become an integral part of the production for many companies. Indeed, the way of producing details can skip expensive and time-consuming part of using numerous machines to produce units. Moreover, workers' labor can be significantly reduced. It should be mentioned that it additionally helps with reducing the amount of CO_2 (Carbon dioxide), which became one of the main problems of today's globalized world. The point of AM is that the aim of the technology is to print a detail by literally adding plastic component layer-by-layer. Thus, it also can be called a "green technology", since it is not necessary to cut out the desired product from a cube which could lead to a lot of waste. Another prove which justifies that it is indeed a "green technology" are raw materials used in printing. PLA (Polylactic acid) is a biodegradable plastic usually made of sugarcane or corn.

The value of 3D printing can be checked on the hype curve created by Gartner. This curve describes the dependence of expectations on time. According to the obtained data as of July 2018 introduced in figure 1.13., the chosen technology is located on the so-called "plateau of productivity" of the graph. (V., 2019)

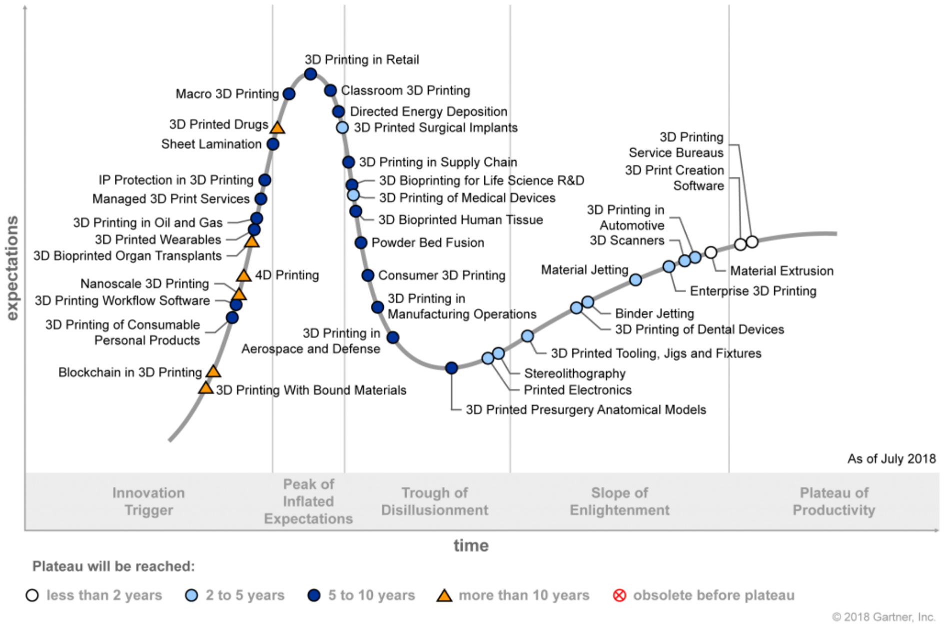

Figure 1.13. Gartner's hype curve (V., 2019)

Another thing which can impress in this technology is availability of printers. Nowadays, anyone who wants can acquire a 3D printer at an affordable price. Even these models are able to print not only primitive toys for exploring technology, but additionally, be used in real-life situations. The clearest and most simple example of it has been happened not a while ago. During the pandemic situation, a big amount of people faced the problem of chafing of the ears due to wearing a mask. The problem was solved by a student with a simple 3D printer who invented a device that allowed the rope of the mask to hold onto it and be behind the head. Simple in design and even more simple in producing, helped thousands of people avoid the problem in the future. (The Washington Post, 2020)

1.6. Material

Depending on needs, it is necessary to take a responsible approach to the material selection. There are several groups of material which are widely used in 3D printing technology. One of the most popular are polymers, ceramics, metals, and concretes.

The latter has been becoming more popular in building manufacturing. Unfortunately, according to the life-cycle performance of it nor the durability of the printed models have not been yet investigated properly. (Ngo, et al., 2018, p. 181)

Another material is ceramic which also has good properties such as lack of large pores or cracks. In medicine, it can be used due to individualization properties (Shahrubudin, et al., 2019, p. 1290). Authors of an article about scaffold 3D printing for a bone reviewed ceramic as a scaffold for bones and revealed that it is a good replacement for familiar tools, due to the porosity of the material and its high mechanical strength. (Wen, et al., 2017, p. 22)

Another popular group is polymers. For this material, various composites should also be mentioned. Such polymers as ABS (Acrylonitrile Butadiene Styrene) along with PLA or PP (Polypropylene) are commonly used when it comes to not only nonprofessional 3D printing but also for some professional fields. Usually, by choosing a specific polymer the desired requirements can be achieved. For instance, ABS has better mechanical properties, when PLA is better for the environment since it is biodegradable (Ngo, et al., 2018, p. 178). Unfortunately, according to research which was conducted by a group of scientists from Germany and Norway it is proved that biodegradable or bio-based materials are as toxic as ABS, for example, due to the chemicals they have in their composition (Zimmermann, et al., 2020, p. 10). As for composites, for instance, polymers can be glass fiber reinforced, which will lead to increase better impact performance. (Caminero, et al., 2018, p. 102)

The last but not least group of material which should be mentioned is metal. Fields, when it has already become popular, are aerospace, automotive industry, and so on since it has decreased prices for the required components, tooling costs et cetera, according to a group of researchers review from Australia and USA. (Ngo, et al., 2018, pp. 175-177)

1.7. Finite Element Method

It is a huge benefit that in today's world we are able to predict possible conditions and load applied to various bodies. For instance, FEM (Finite Element Method) can conduct a simulation where it is possible to calculate stresses or other behavior applied to mechanical bodies or examine fluids flow. Briefly speaking, the concept idea of FEM is to divide an object into many parts, which are called finite elements. The places where they are connecting are calling nodes. The object can be not only supposed to be a solid or a liquid body but also consists of any value, such as temperature, pressure et cetera. This method is significantly useful when geometrical calculations of complicated bodies are required.

SolidWorks is one of the software where FEM is implemented. With the given application user can not only design a model but also conducted a study to detect and eliminate the deficiency it causes. One of the examples is provided by a research group from Malaysia. Comparing three materials (steel alloy, aluminum alloy, and carbon fiber composite) and applying them for the car door they revealed that aluminum alloy is more appropriate to use to save the passengers in the car (Mohamed, et al., 2018, p. 951). It was possible to simulate thanks to FEM in SolidWorks.

Another example related to automotive industry was performed in China. Because of FEM analysis scientists could decrease the weight of the wheel, since the maximum stress of the material is more than it was modeled. (Guiju & Caiyuan, 2019, p. 35)

This method can be applied likewise in the military field. Researchers designed a pilot helmet (in figure 1.14.), where FEM helped them to find the optimum thickness for it and appropriate weight to keep comfort level on normal condition. (Singh, et al., 2016, p. 39)

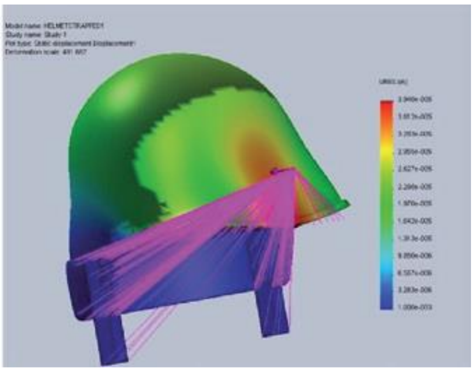

Figure 1.14. Bullet modelling for the helmet (Singh, et al., 2016, p. 37)

2. METHODS

In this chapter, a methodology of shell and supportive structure development for a horseback simulator is performed.

2.1. 3D Scanning survey

The first thing which should be done is to check parameters of both two scanners since because of them survey will be created. According to the information taken from data sheets table 1 was created (Leica Geosystems, 2020), (Leica Geosystems, 2020). Two given scanners are shown in figure 2.1.

Table 1. Table of comparison of the two scanners

Parameter	**Leica RTC360**	**Leica BLK360**
Number of points during the survey (scanning speed)	2,000,000 pts / sec	360,000 pts / sec
Maximum range	130 m	60 m
Minimum range	0.5 m	0.6 m
Accuracy	1.9mm (10m) 2.9mm (20m) 5.3mm (40m)	4mm (10m) 7mm(20m)
Field of view (Horizontal / Vertical)	360°/300°	360°/300°
Cameras	36 MP 3 cameras	15 MP 3 cameras
Full panorama	432 MP	150 MP
HDR	Enable	Enable
Working temperature	From -5 to + 40 °C	From +5 to + 40 °C
IP	IP54	IP54
Scanner dimensions	120mm x 240mm x 230 mm	165mm x 100mm x 100 mm
Scanner weight without battery	5.8 kg	1 kg

Figure 2.1. Leica RTC360 (the big one) and Leica BLK360 (the small one)

Based on the given table 1, it is possible to make a conclusion with some important aspects, which are mentioned below:

- The temperature at the arena should be at least -5 degrees Celsius. Otherwise, scanners can go runs out of battery fast or can be turned off.
- Due to possible deviations in the survey, it is suggested to make a scan with a person who holds the horse and without him or her to compare the results after.
- The height of the scanners is around 150-160cm, hence it can be problematic to scan a horse as its normal height 150-180 cm. That is why it is needed to take care of the platforms for the scanner to be able to scan the whole horse. These platforms can be made of pallets. But the top surface of it must be solid and stable.
- Due to the given 3D laser scanners are not widely used in moving objects scanning, it should be better to scan as much as possible in order to get a lot of data which will be processed later. That is why a horse should be scanned with all resolutions: 1.9, 2.9, and 5.3 for Leica RTC360, 4mm, and 7mm for Leica BLK360. The first one has the highest priority. An approximate distance from a scanner to an object is 5 meters to provide a comfortable working area for the scanners (Sharif, et al., 2018). This buffer distance will obtain the highest resolution.

The next step is to create visual targets, which are also can be called checkerboards (Sharif, et al., 2018). The more targets the scanner sees (but at least three on each side), the more accurately it is able to recognize the environment around itself.

After the visual targets are drawn and printed, 3D laser scanners compared, and conclusion conducted it is possible to group data and create a scan plan:

1. Print 12-15 visual targets in order to help a scanner find the location.
2. Place a scanner on the platform 5 meters away from the horse.
3. Someone should hold the horse during the scan. It can be necessary since the scanners produce noise during work.
4. To make the resulting model as accurate as possible it is required to take at least 4 setups during one survey (two sides, bottom, and profile).

2.2. Horse 3D model creating

After the survey, the first step which should be done is to check the files for compliance with the real sizes. That is why it is necessary to export raw files into an appropriate format. Cyclone application from Leica geosystems works with file types which are obtained by Leica scanners. Withal, it is a useful app since it is possible to export files to the format you need at the moment.

Dimensions in the files should be checked to compare obtained data with real life. When measurements check is done, the next step is to import all the raw exported files into Geomagic Design X. This is an application that allows the user to modify the data obtained when scanning bulk objects. Since scanners create files with a huge number of points, this cloud must be converted into surfaces in order to work with them later. For this, the command "Mesh" should be used.

The scanners provide too much information which is unnecessary for the project. Therefore, the next step is eliminating all the surfaces which are not needed and to prepare the model for the next process part. One detail to mention is that all the given data are helpful, so all of them should be prepared for further work in other applications.

After Geomagic Design X next program to use is Autodesk Meshmixer instead of SolidWorks to polish the details, remove all unnecessary details (such as people, building arena, ground et cetera) and make the virtual horse more real. The main benefit of this program is to change the shape of the model by using different brushes, bridge, fill functions et cetera. In this program, parts were “glued” together, polished angular surfaces, and filled empty spaces. The main file type which lets you process the objects in the program is MIX (Microsoft Image Extension). After that it can be exported into STL format type.

SolidWorks opens these files so it could be also used for this task. However, it is still complicating to use the mirror function that is why Meshmixer by Autodesk has more benefits. It is a software which helps to work with triangle meshes and what is more important for the project. After that, to print the model, BigFDM 3D printer (Ingrassia, 2019), which is available at the university can be used. As a raw, ABS reinforced with fiberglass should be chosen to increase mechanical properties of the shell

2.3. Design of supporting structure and model verification for strength

After scan files were processed into one final model, the step after was to implement support constructions for the horse which will be printed later. It is one of the most crucial parts of this project since it is important to make constructions inside the shell as durable as possible, but avoid a lot of details due to the weight restrictions because of the weight limit due to the power of the electric drives, which will be connected under the model. Also, it was necessary to understand that everything has a price, and the job has been done by avoiding too expensive material. In order to make supportive constructions easier to construct and weld it was decided to create universal components which can be implemented in many parts and make the construct process easier and faster, The design must be simple and quick to assemble and disassemble. Thus, a lot of parts have bolts connection instead of welding. That is why it is also important to use the same bolt holes everywhere. Universal details are the main cause to make the project cheaper. By building a prototype it is possible to notice flaws. The fewer flaws there are at the stage of creating and assembling a prototype, the better, faster, and cheaper the final products will be after testing.

It is important to make a design realistic to assembly and, which is more important, be sure that supportive constructions will be able to resist all the possible stresses and forces during the ride. Thus, for finite element analysis next parameters should be considered:

- The maximum weight of the rider is 170 kg. The average weight is way less, but to test the system it is important to check how the system will behave in extreme conditions.
- The maximum overload should reach 3g. The system should behave well due in all simulator options.
- Information should be checked from the results of horizontal load applying. Since it is horseback riding, the model will experience most of the load while moving in the horizontal plane.

- The von Mises stresses must be significantly less than the yield point of the steel, otherwise, the material will lose its shape and deform.
- In accordance with the previous requirement, the minimal factor of safety must be greater than the minimum equal to one.
- Based on extreme parameters conditions life cycle of the model can be calculated by SolidWorks. It shows how many times the movement can be repeated. Thus, a maximum number of cycles must be enough to introduce how final project works.

Steps of FEM are:

1) Create a model of the body. On this first step CAD, is needed. It was decided to use SolidWorks.
2) Create a finite element mesh of all elements connected together, in order to divide a model into numerous numbers of bodies.
3) Make calculations by using Solver implied in SolidWorks
4) Analysis of obtained results. In this step “Postprocessor” is using.

2.4. Drawings preparing

When all preparations and improvements in FEM are done, the next step is to prepare all drawings for the manufacture. For that, it was required to separate all the details on several parts to make assemble understandable not only for developers but also for the welder who will weld beams to flanges together. It is supposed to call all the names according to the unified principles. So, because the project name is a horse-riding simulator the first symbols should be HZ01 (Horseback riding simulator). Three digits which come after are specifying that it is the main body of the horse. At the end number 100 explains that it is a welding part. All of them must start with a digit. Thus, all details in welding HZ01.001.100 have names HZ01.001.101, HZ01.001.102. The policy of naming other details was created accordingly.

Drawings must be done according to ISO (International Organization for Standardization). The more understandable the drawing and clearer the instructions, applied to it, the easier to produce. All dimensions should be in millimeters. Possible tolerances are 1mm for linear and 1° for angular one unless otherwise specified. Welding should be done according to requirements shown in the drawings. Ribs should be welded as well to increase the mechanical properties of the structure. If specific explanations are needed, they should be located on extra views. After FEM is done details ordering can be started. Afterward, it is needed to calculate the number of bolted connections to buy.

After the parts are produced, the final step should be their assembly, which must be carried out in accordance with safety regulations and carried out with the tools intended for it.

3. RESULTS

In this chapter, results are described and explained.

The scanning process was done on the arena which is shown in figure 3.1. in November 2019 in Lappeenranta, Finland. The chosen location allowed to keep the devices warm and to prevent moisture from entering them. The figure below introduces the given place. Since there was plenty of free space, it was decided not to use the whole space, but a small part to increase the accuracy of the scanner. Although the arena had been fully scanned, this was not a problem as all unnecessary details were removed later. The horse was introduced to both scanners from the very beginning, otherwise, it could be fully distracted by the noise during the process.

Figure 3.1. The arena where all the scans were obtained. Lappeenranta, Finland

To prepare for the survey several visual targets were created. As it was briefly explained in methods, these checkerboards are important since scanners need to locate themselves during carrying out the survey. By using SolidWorks, the visual targets have been drawn and introduced in figure 3.2 below.

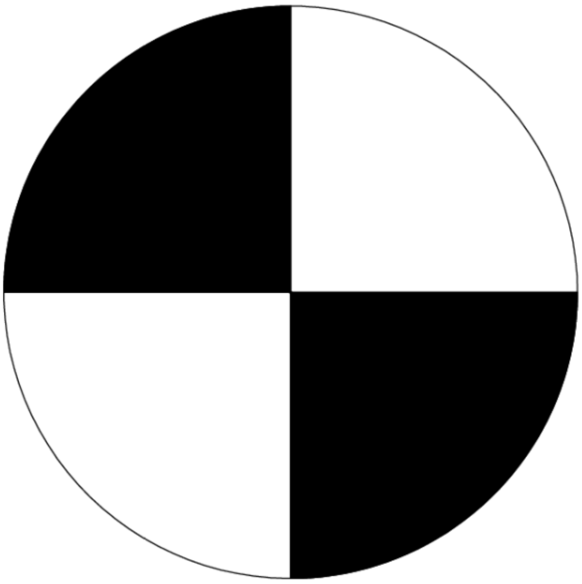

Figure 3.2. Visual target

The next step which was performed after was to pin checkboards as much as possible. It is necessary for 3D scanners to see at least 3 visual targets from each side. All visual targets must be at a different non-repeating height. The way how they were added is shown in figure 3.3.

Figure 3.3. Checkboards pinning

The step after was to set the scanner on the right place and on the required height, since another problem which was described in methods was that horse height at withers was slightly more than the maximum scanner's tripod. To prevent possible resonance due to the rapid mechanical rotation of the camera, two wooden boxes were added below the logs which also added stability for such primitive, but extraordinary robust construction. From figure 3.4. Leica BLK360 is used on this construction.

Figure 3.4. Leica BLK360 on an impromptu stand

After it, a scanning process was started. At this stage, it was obligatory to keep the horse calm during the survey. Otherwise, if it starts moving the result will be unclear and impracticable to work with. It is clear from the figure that the horse started moving and increased its body length twice. Fortunately, results are possible to check in the official app (in figure 3.5), so the unsuccessful attempt was revealed instantly after the survey. It was decided not to delete the unsuccessful attempt for its possible further correction.

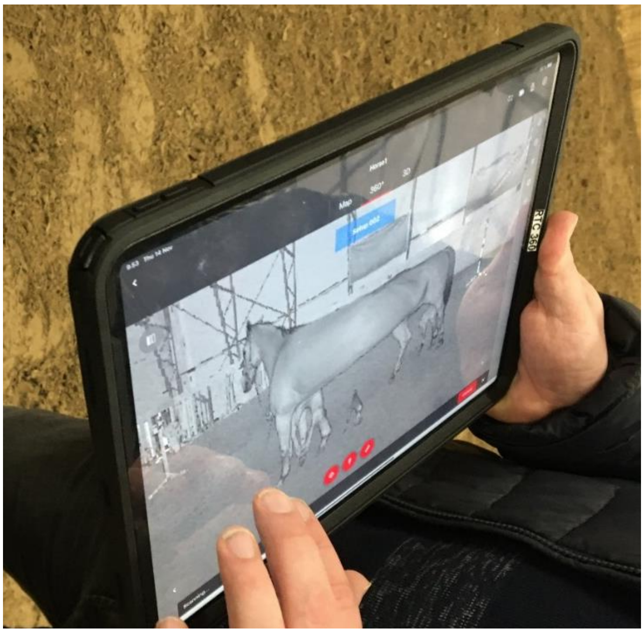

Figure 3.5. Unsuccessful surveying attempt.

To make the survey most efficiently the horse was scanned several times from side, front, and back. In further work with the model, a large number of files became convenient for “stitching” the horse model together. The profile image carries the greatest amount of valuable information. Therefore, the number of isometric view materials are the largest. Also, images of the horse's head and croup were obtained.

There is a big difference between the two chosen scanners. The former is more precise since a huge cloud of dots (over 2 million points per second, according to table 1), but the latter one has less scanning required time, which for the given task was also taken into account.

In figure 3.6. one of the successful scans is shown. It could be seen that the whole side of the horse is made correctly. There is possible accuracy with a belly which can be improved in the next steps.

Figure 3.6. Successful scan when the owner was keeping the horse

According to the results of scanning it could be said that there is no other way, but hold a moving object during the process, otherwise, there will be no progress. After the scanning survey was conducted and all the files were exported into type format E57 (LIDAR Point Cloud Data Format, where LIDAR is an acronym for Light Detection and Ranging) to start processing the obtained files. But the next step which was done after was to check how dimensions were close to real. It was mentioned that the height of the horse at the withers is about 170 cm. By using Global Mapper, it was revealed that the needed height is 1.705 m according to the scanner’s data (in figure 3.7.). The result showed that dimensions are close and could be used further in the project.

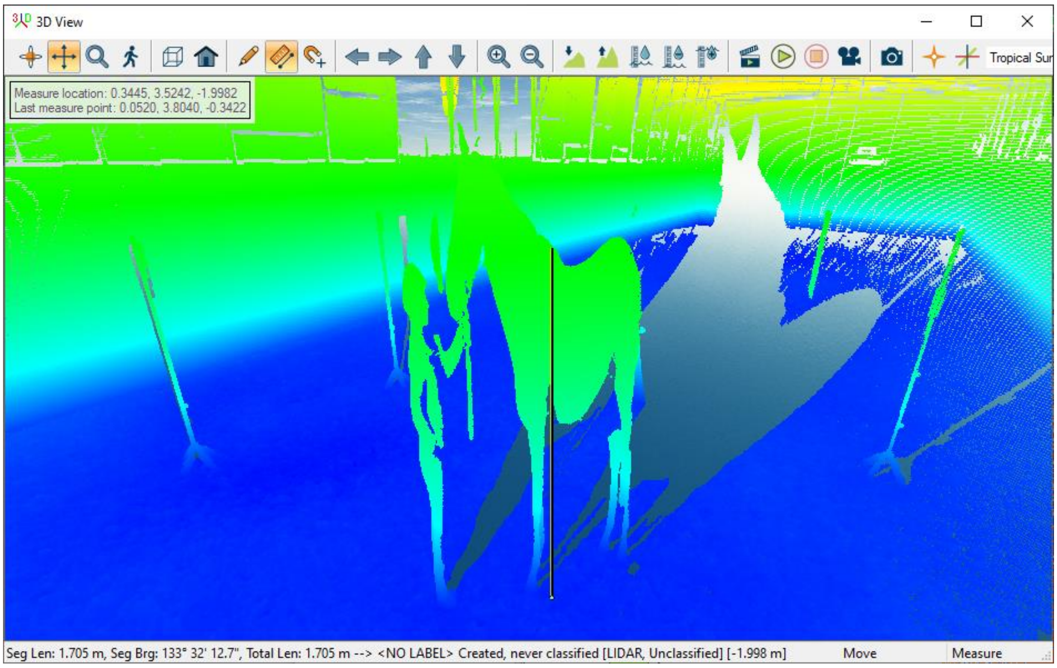

Figure 3.7. Height measurement

Here and after the difference between the two scanners is quite remarkable. Since Leica BLK360 is cheaper and does not have so powerful components, a lack of points which effects accuracy could be seen. By contrast, Leica RTC360 is obtaining 2 million pts/sec during the survey. That is why its model from the figure 3.8. looks more solid. The former has noticeable empty spaces; therefore, the created surface will not be realistic enough for the curves as it could be.

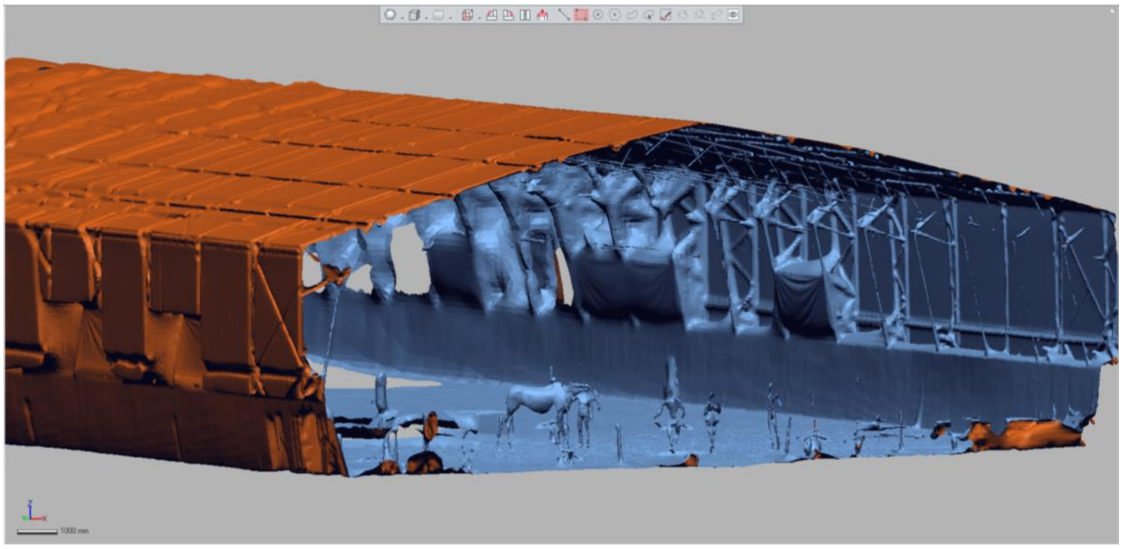

Figure 3.8. Triangulation result

From this step, it is also possible to compare the results of the survey. In the figure there is not only the arena where the survey was conducted but also a profile view of the horse which was taken and almost the whole team of the project (in figure 3.9.). People were moving during the scanning process since they were not the aim of the project. Therefore, there are also a lot of people from scanning which should be deleted from the scanners' memory.

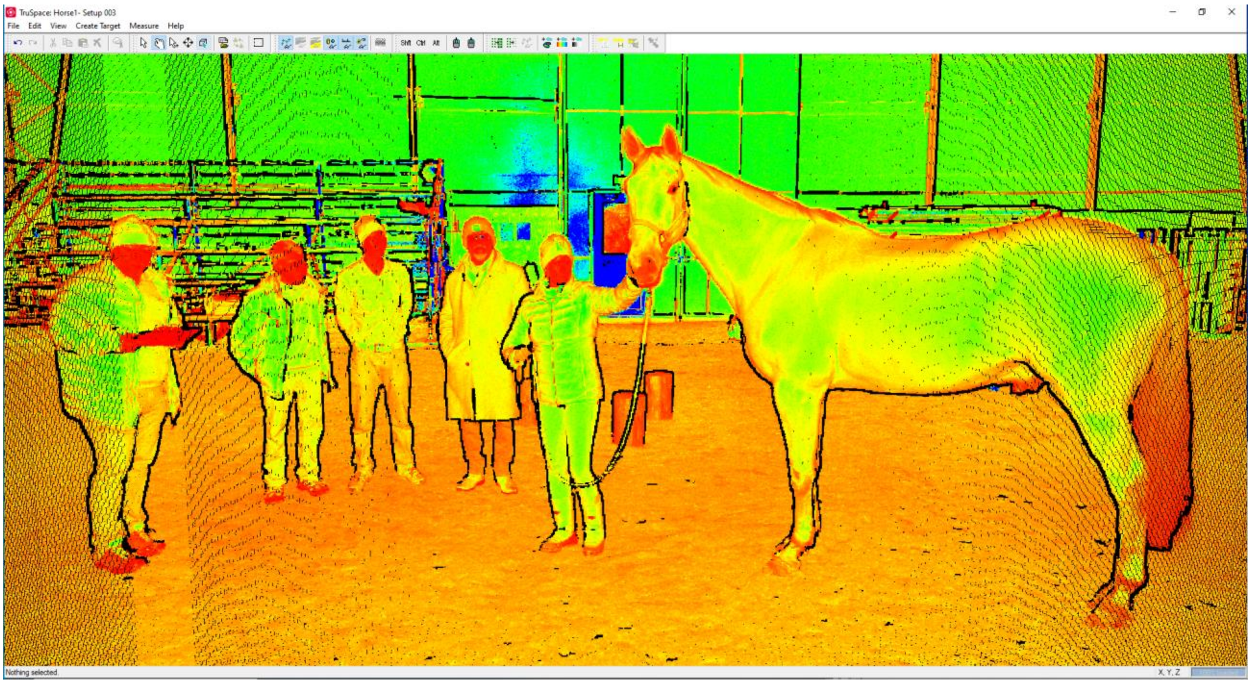

Figure 3.9. Scan of the team

All the files were processed in order to save time for the next steps, where all the files were combined together. One important detail to be mentioned: as for the project horse legs are not required because of the construction of the horseback riding simulator, they are also were erased.

All the results of Leica RTC 360 are performed in blue color. Figure 3.10. below can be used not only to get data to make a head properly but also neck a profile side, except belly. Here it is shown that ears were not scanned properly, therefore the rational way to solve the problem was to change them to leather copies. In this way, there is no need to have an exact scan copy of it. The scan is introduced in figure 3.11. keeps the information about the head and the profile view. As for legs, a tail, and a neck they will not be used, since legs and the tail will be removed, and the neck is not straight. The third file, which is shown in figure 3.12., contains some useful information about another side of the horse. Unfortunately, due to the moving, it will not be used further, since all the surfaces are not made on an appropriate level to improve it after.

Figure 3.10. Leica RTC360, Scan 1

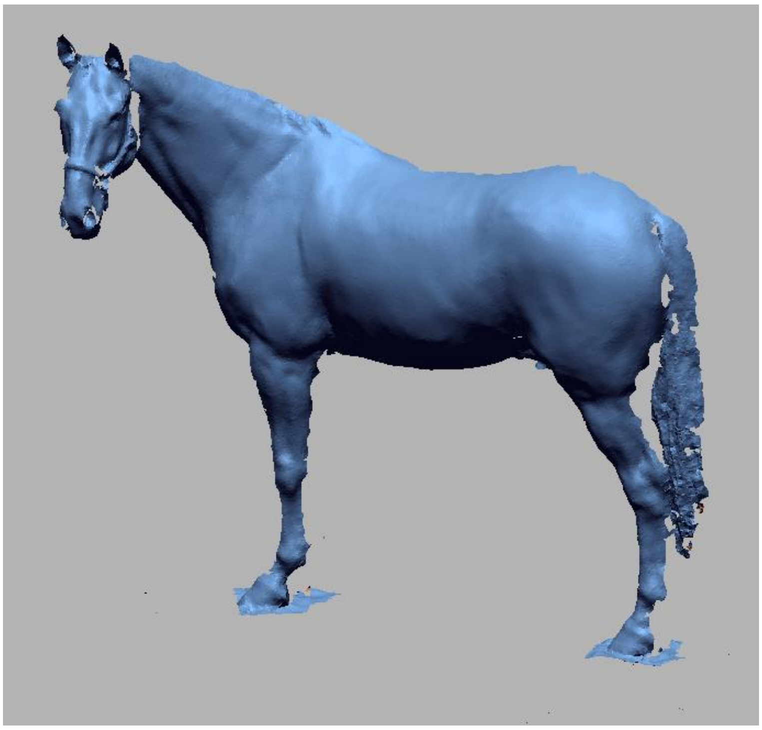

Figure 3.11. Leica RTC360, Scan 2

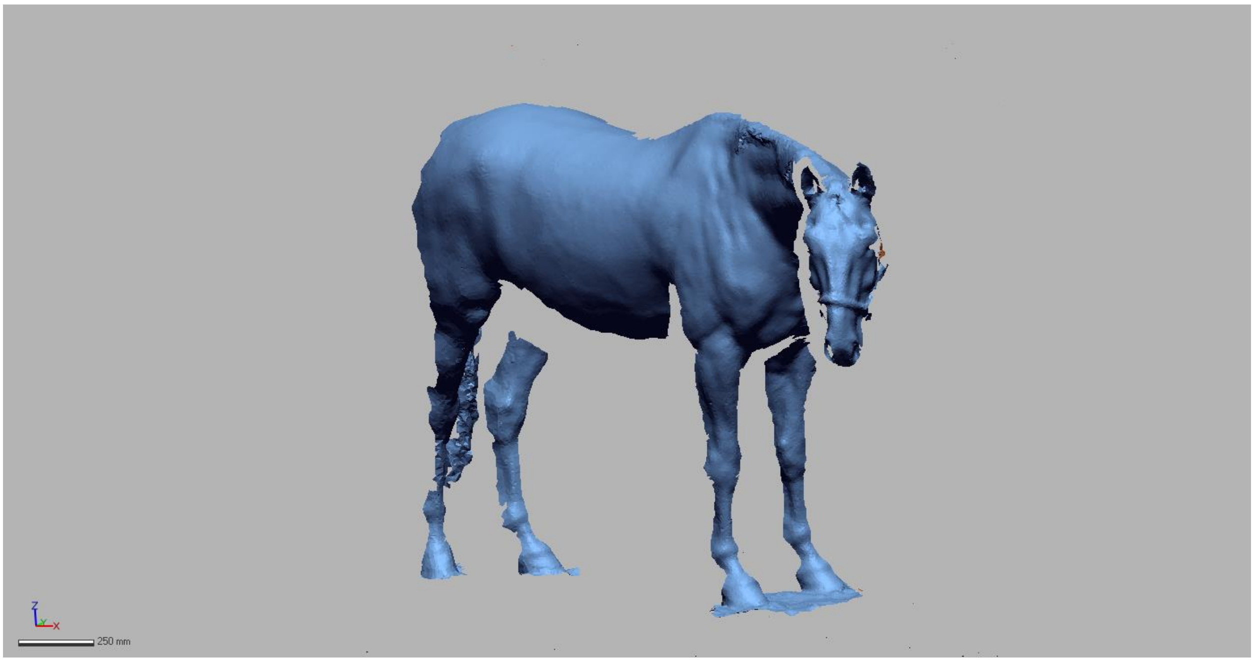

Figure 3.12. Leica RTC360, Scan 3

Files which are done by Leica BLK360 are marked in orange. After the first one (in figure 3.13) was processed it was decided not to use it, due to the roughness of sizes. Another scan, illustrated in figure 3.14, obtained by Leica BLK360 introduced with a profile side, but the problem is the same, and it could be hard to make improvements. As for the third file, showed in figure 3.15, it became useful since it was possible to take a croup from there. Figure 3.16 depicts a scan from the survey which was decided not to use as well since even after improving the files and removing parts, they were not possible to implement in the further work. Because of the moving during the process, the whole file became useless even after several improvements.

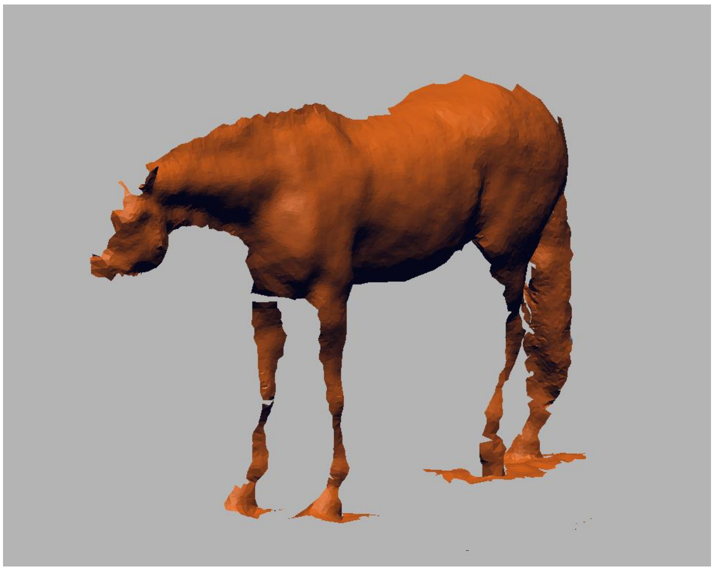

Figure 3.13. Leica BLK360, Scan 1

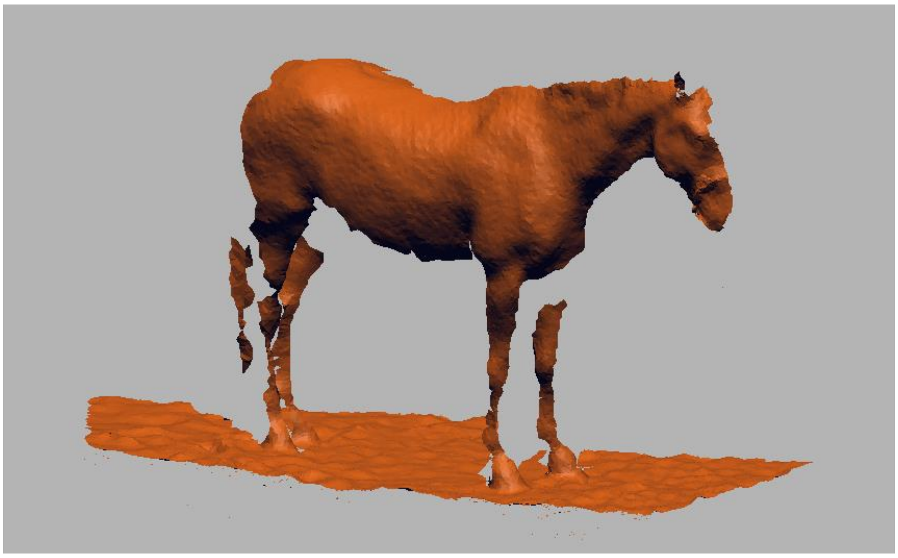

Figure 3.14. Leica BLK360, Scan 2

Figure 3.15. Leica BLK360, Scan 3

Figure 3.16. Leica BLK360, Scan 4

Using such figures as one from figure 3.17 could cause troubles with measurements, which are required not only for the supportive structure but also for other details from the project since all of them are connected.

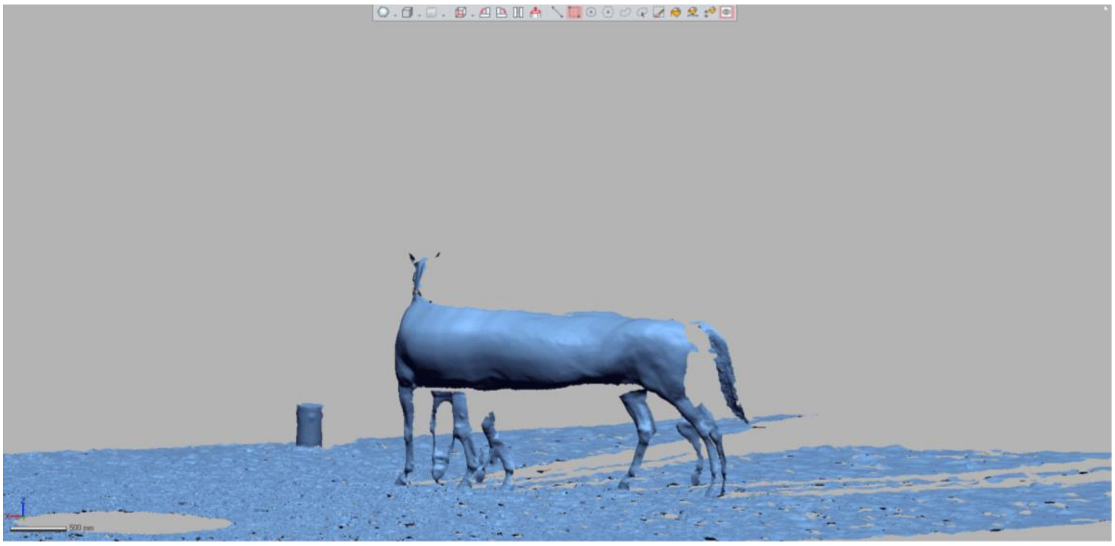

Figure 3.17. Leica RTC360, Scan 4

After all unnecessary details were removed the final model was ready to export. The next application which was used to combine and prepare the model for printing is Autodesk Meshmixer. It was decided to separate the body from the neck and the head, and the body was updated firstly. It was important to use the mirror function on it to get a solid body. Also, it was supposed to make it not too symmetric since it will look unrealistic. In the next following figure 3.18, the process of editing is obtained.

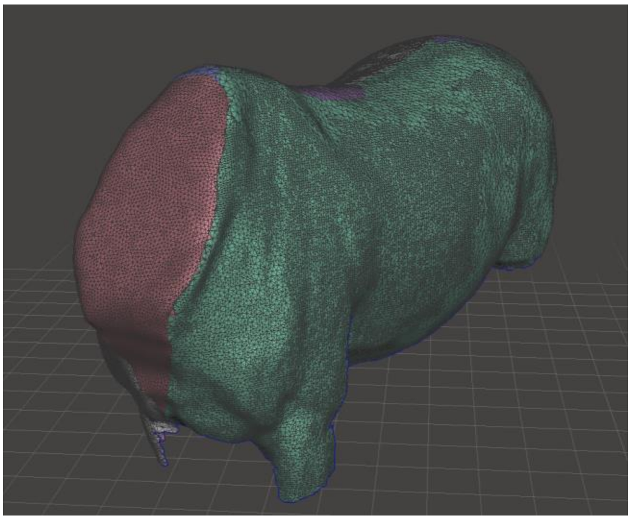

Figure 3.18. Model with triangle mesh

As it was mentioned above, the horse was moving during the scan and hence, the scanners could not get perfect result. A croup was updated as much as possible. All the unrealistic details can be hidden by the tail which will be added later (in figure 3.19 and figure 3.20).

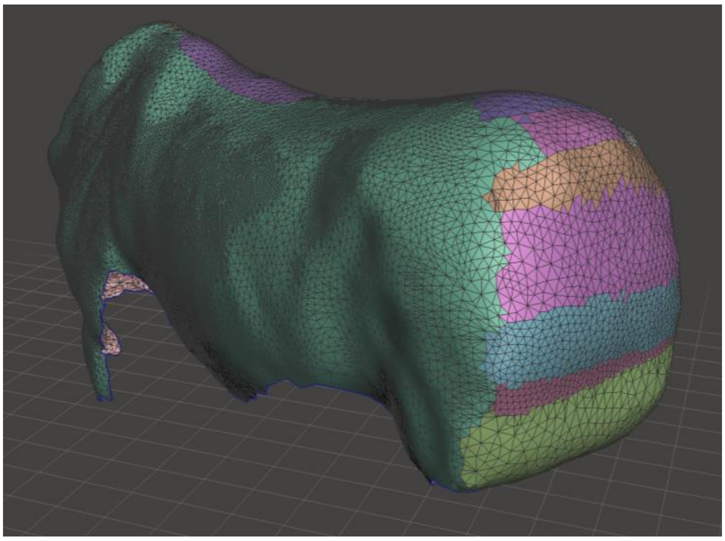

Figure 3.19. A croup of the horse, which was created

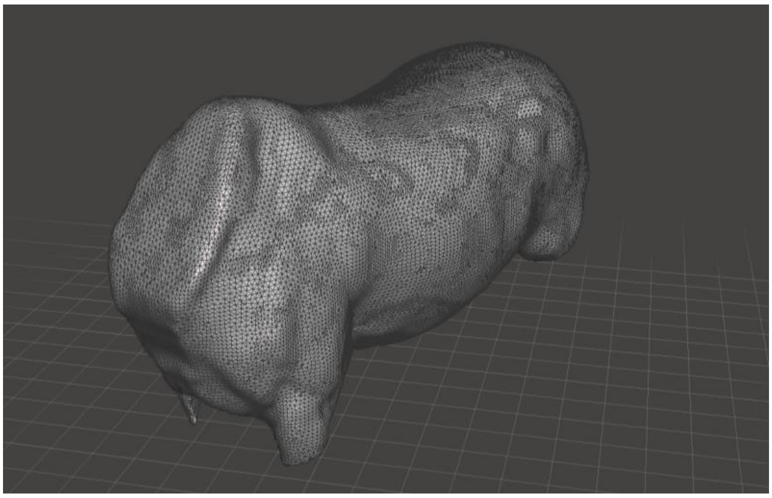

Figure 3.20. Result in mesh view mode

During the model processing, there were several attempts to get the best result, by combining all the files together. In picture 3.21 below the attempt of combining results of the survey of both two scanners is shown. The croup was taken from Leica BLK360 survey and the main part came from Leica RTC360. Here it is clear to see the difference, since the former file has quite a rough shape, as there was a lack of points to make the mesh properly.

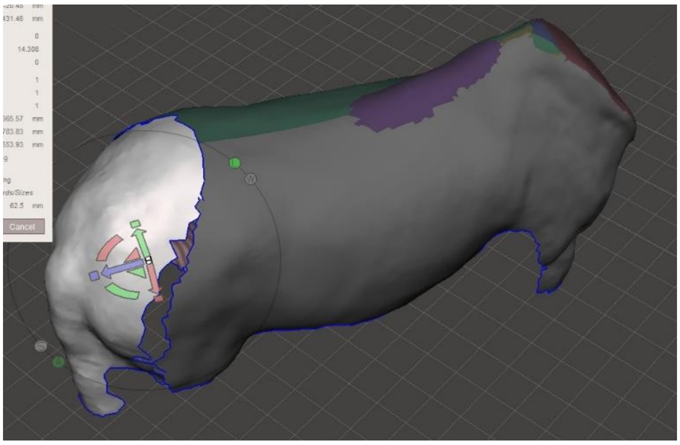

Figure 3.21. Connection of two models

The result of this attempt is depicted in figure 3.22 below. In order to combine two parts together it was necessary to "sew" them together, by applying new surfaces layer by layer. A view with a triangle mesh was used during the processing of the file to control the sharp surfaces and to simplify filling the entities.

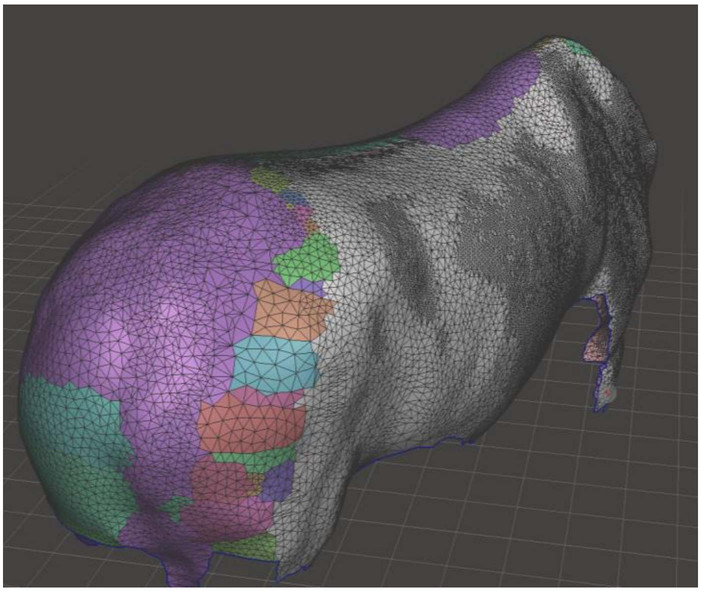

Figure 3.22. Connection result

The next step was to make a head for the horse by using files from both scanners and mirror function (figure 3.23) to obtain it more realistic. A step after was to fill all the spaces in the head part, which is shown in figure 3.24. The head was “sewn” as shown in figure 3.25 to the main body together by laying several numbers of layers.

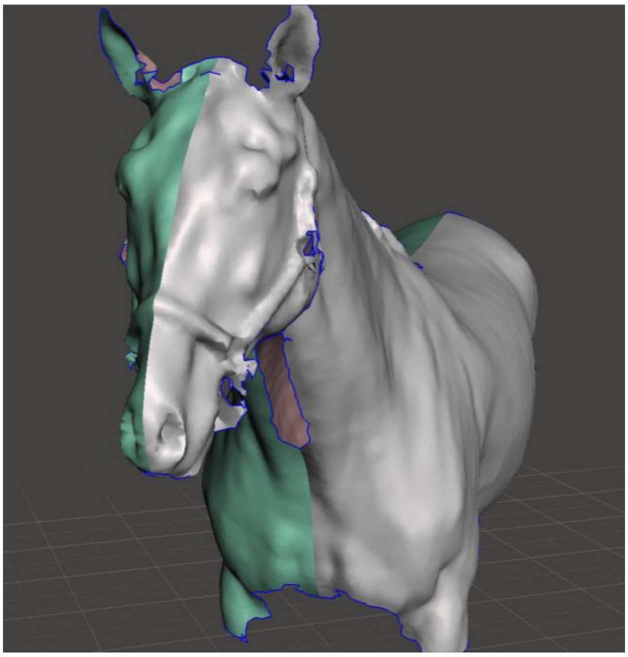

Figure 3.23. Head view

Figure 3.24. Filling cavities

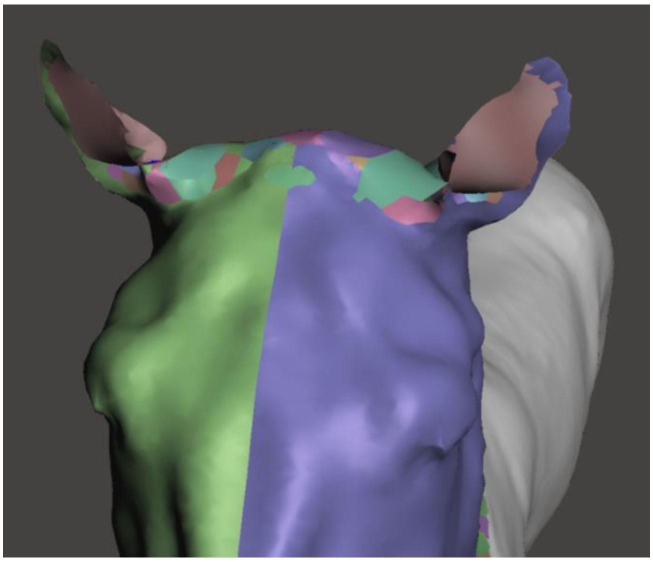

Figure 3.25. Head surface improving

Ears have not been improved since it was decided to make them out of leather instead of printing. The resulting file is shown in figure 3.26 below.

Figure 3.26. Resulted shell

Initially, to design a supportive structure it was crucial to do measurements from the expected location of the platform to the saddle, croup et cetera (in figure 3.27).

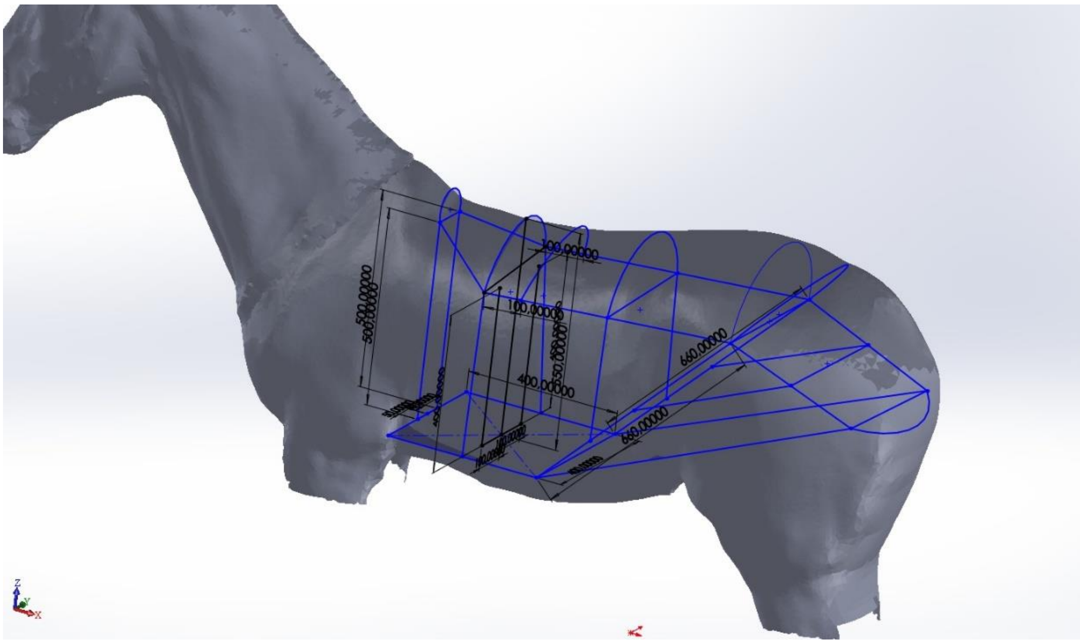

Figure 3.27. Body measurements

During the supportive structure creating, there were designed several various models to make the best version of it (figure 3.28).

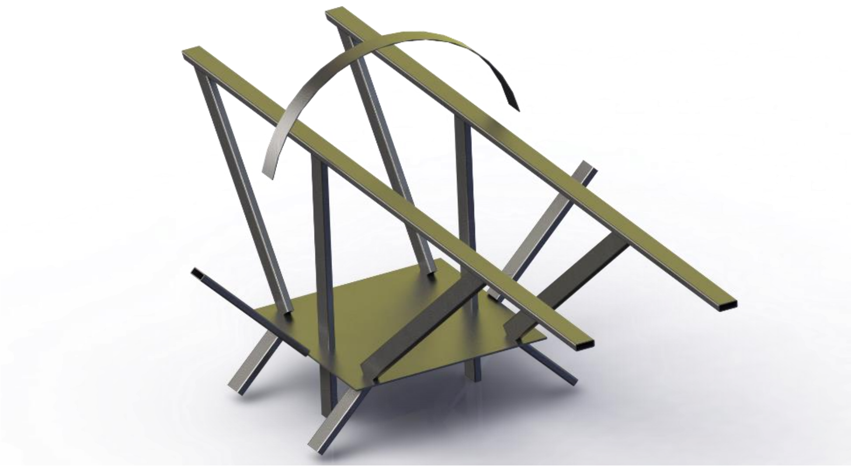

Figure 3.28. First version of the supportive structure

After the example has been done, it was implemented into the processed shell to check how will it be fitted, does it have any dimension errors and so on (in figure 3.29). It is clear to see that side beams are out of the shell, thus, they must be redone, since they will hurt a rider and destruct the shell during riding simulation.

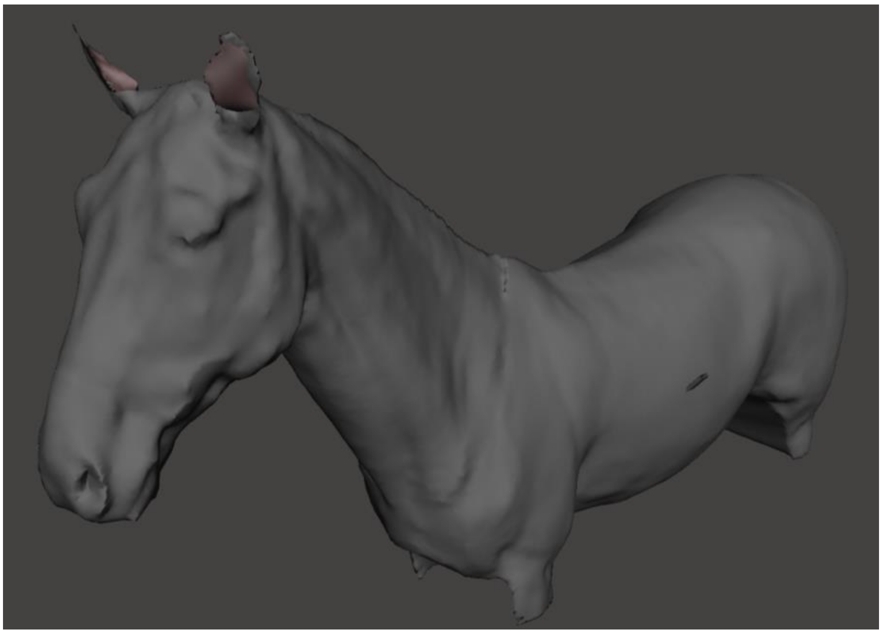

Figure 3.29. Implemented structure into the shell

Additionally, the curved beam is not connected nether to the main structure nor the shell, but the idea is good, since, by varying the thickness of the curve during the design, the most appropriate parameter can be reached. This curved sheet is necessary, as this part of the supportive structure is impossible to make ideal, due to the specific shape of the body. That is why labor work will help to modify the curve by using tools. Thus, this sheet should be modified, and there is no option to remove it. It is required to add at least two more of them along the main body. It should not be right under the rider, as the saddle, which will be applied after, will take the load. The drawbacks investigation process is shown in figure 3.30.

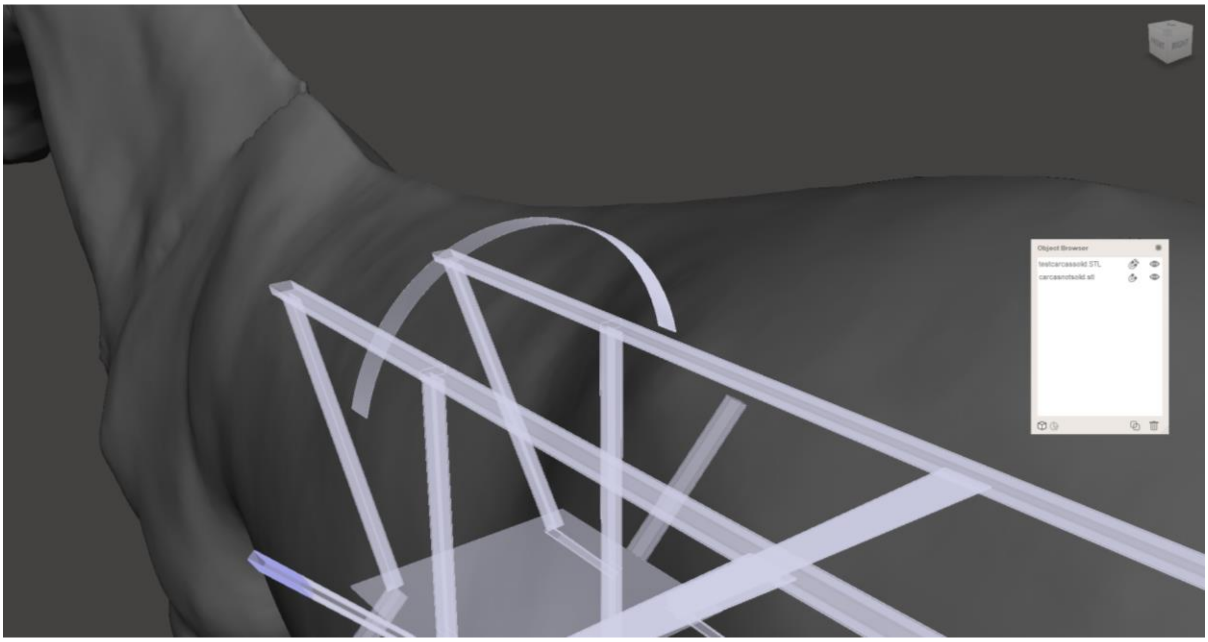

Figure 3.30. Visual examining to find drawbacks

During to approach the most appropriate result there were several attempts to understand the concept of the supportive structure. As it was decided earlier, more curve sheets were added, and side beams were erased. In figure 3.31 below construction became lighter but tension would destroy it immediately right after start testing, hence, it was decided to add side vertical beams to increase durability for the model. Also, there were several attempts to combine beam structure and sheet curves together, without complex design creating. Figure 3.32 illustrates one of them. Due to the curve should reach the shell, there was an attempt to extend the length of the crossbeam by making a hole in the longitudinal one.

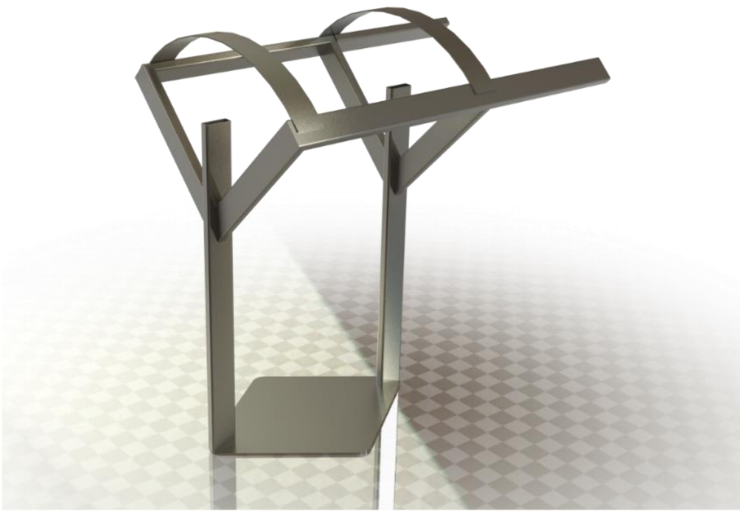

Figure 3.31. Second version where all drawbacks were eliminated

Figure 3.32. Second version with extended beams

Also, in this model, some supports were added later to achieve structural stability (in figure 3.33). Unfortunately, the model will be hard or even impossible to produce in this way, since there are a lot of locations which will be complex to weld or to connect.

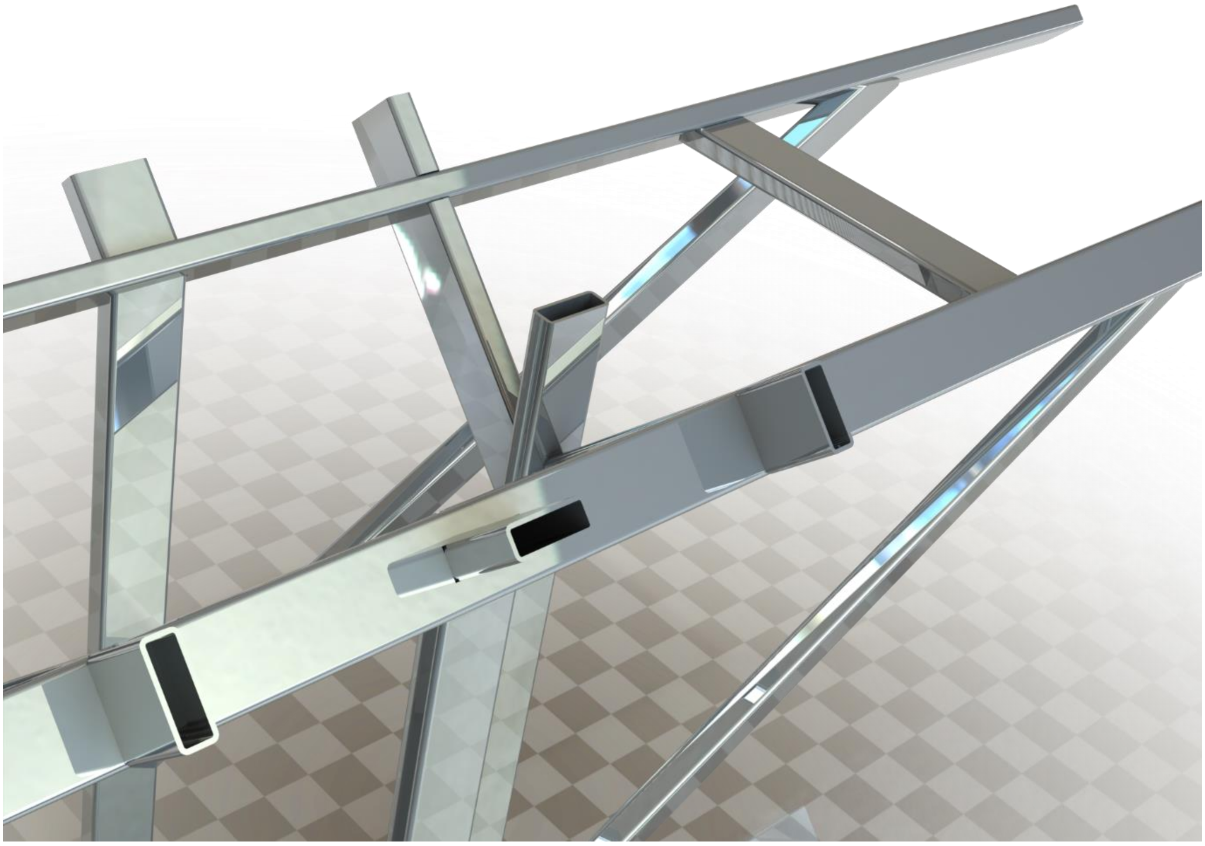

Figure 3.33. Added support beam to increase stability of the structure

But due to the complexity of assemble and time consumption for transportation, the whole idea was rethought, and all probable welded connections were changed to bolted ones. The main body connects at the same time with two other parts: a neck mechanism and a saddle, hence, it was important not only to make it durable but also make it real to interconnect all the parts together for assembling after. All the beams were connected to the base plate, which was installed at electrical actuators.

In figure 3.34 below one of the final model is shown. One of the biggest mass loads is located above red beams, as they are set right under the rider. Curve sheets were replaced by other details with complex shapes with plenty of holes to make a tight connection with the horse shell. All the bright green details are flanges which are welded to the beams. They connect all parts together by having bolted connections.

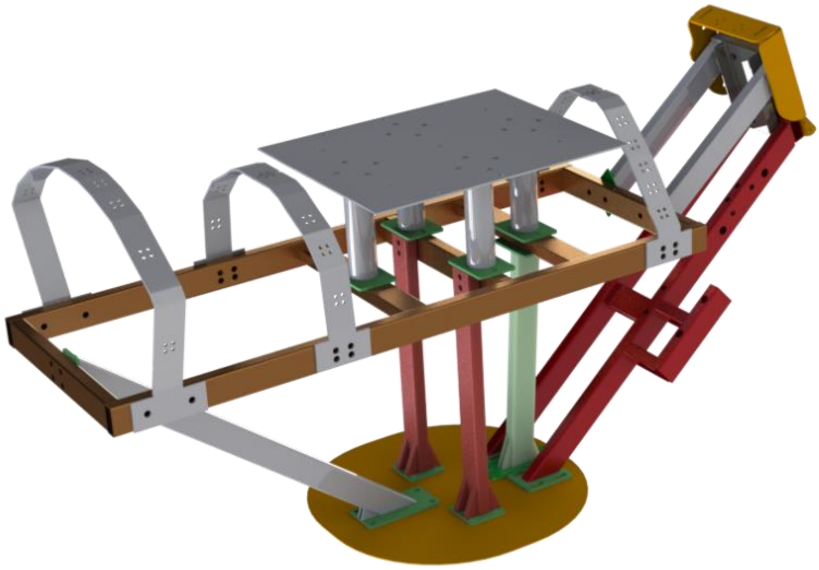

Figure 3.34. Updated supportive structure

After the right idea was designed, the next step was to check whether the model is able to manage with all the loads. In order to this FEM was implemented. In figure 3.35 there is a von Mises simulation result. Horizontal load for this was 3000N (this force was chosen because there was an assumption that probable overload could be around 3g and a maximum weight of the rider is 100kg), gravity was used as well (direction arrow has been added on the screen). For this steel yield limit is 4,800e+08N/m^2. From the bar on the right side it is depicted that the maximum yield here is 4,590e+08N/m^2. For the model it is unacceptable since it will cause deformation. By checking FOS (Factor of Safety), it was said the coefficient is 1 which is quite low for the project (figure 3.36). By checking the number of cycles option in fatigue analysis, it was revealed that there was a problem with forward beam which had light green color on the figure. The number of cycles for this was 1757,311 times which was not enough even for the prototype. This problem is marked in red in figure 3.37.

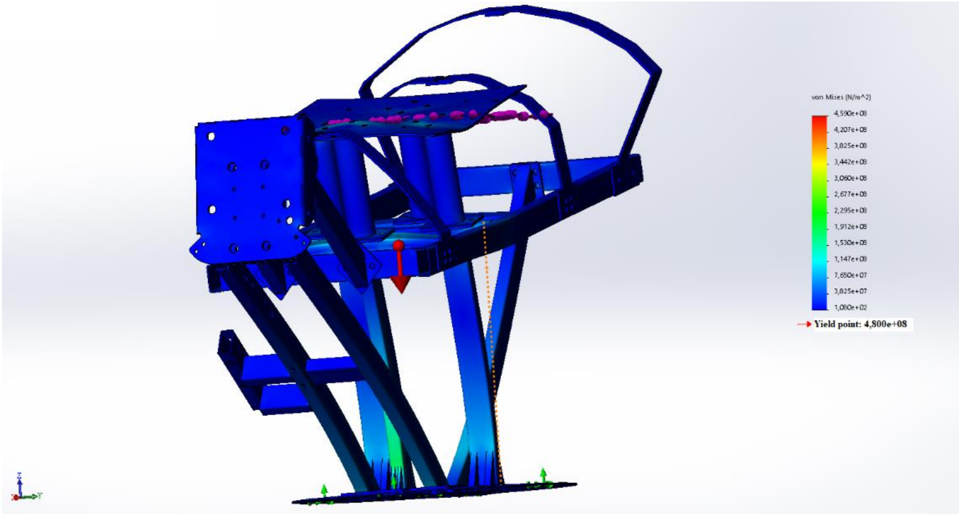

Figure 3.35. Updated supportive structure, von Mises simulation result

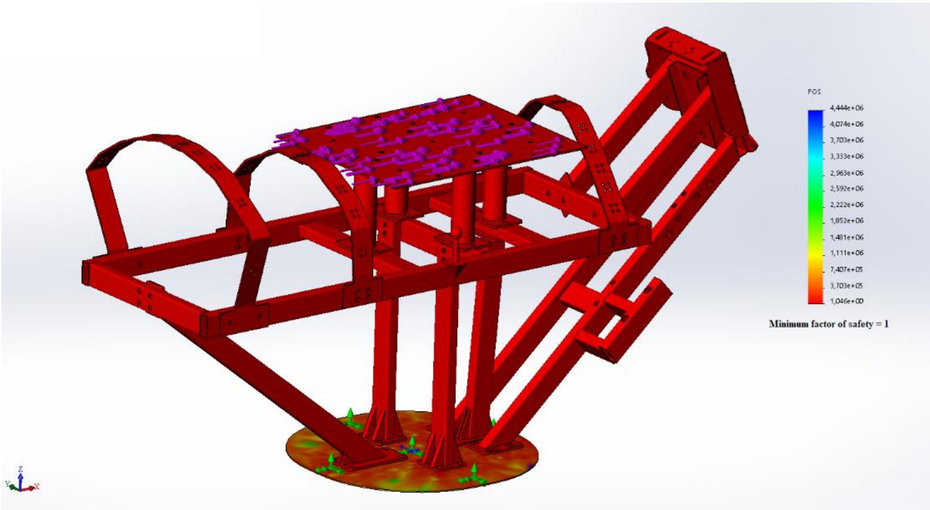

Figure 3.36. Updated supportive structure, FOS result

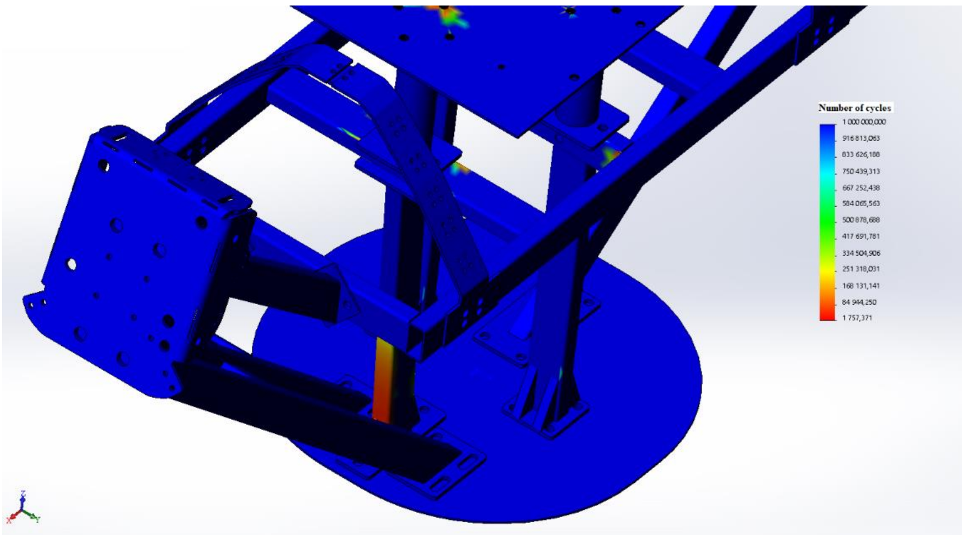

Figure 3.37. Updated supportive structure, number of cycles result

After all results were obtained and processed it was decided to update the model. There was necessary to add supporting ribs for the beams and move forward light-green beam a little bit closer to the forward edge of the base plate to reduce stresses. All the beams were required in a tight connection to decrease the stresses by holding each other. Also, some updates were applied to the saddle part during the improving supportive constructions for the main body. The base plate was modified as well, since of changing in other parts of the project. On this step it was decided to bring curve sheets back due to its physical properties and cheaper manufacturing.

As for FEM, input parameters were updated as well. It was supposed that the maximum weight of the rider could be around 170kg (horizontal force is 5000N and 3g is the overload). Another load (500N) to the forward part was added to simulate real weight of the neck mechanism of the horseback riding simulator. The model for FEM is depicted in figure 3.38 below. According to the results, the largest indicator of stresses has been decreased down to 1,744e+08N/m^2. The forward beam which was painted in red changed color to light green which is located on the top of the von Mises color bar meter (figure 3.39).

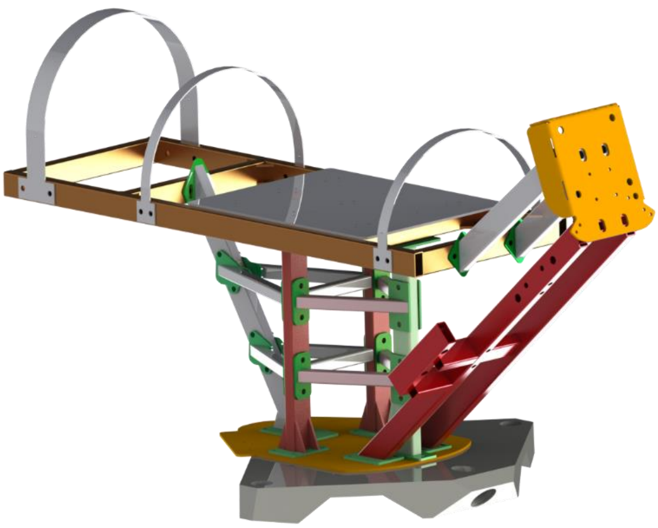

Figure 3.38. Improved model of supportive structure

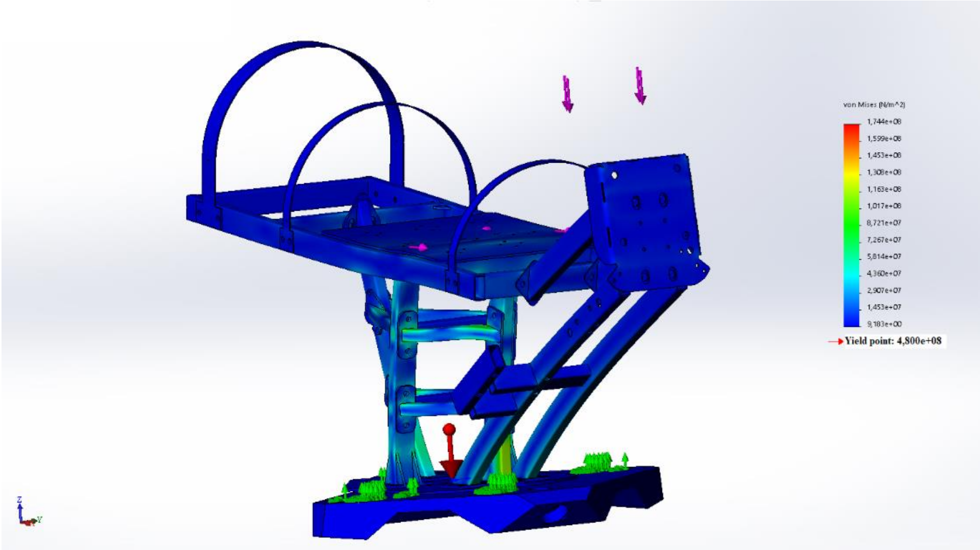

Figure 3.39. Improved model, von Mises result

From figure 3.40, it is obviously simple to compare the difference with the previous analysis. Now, stresses have become distributed evenly over all support beams. The maximum value of the maximum stress is located between support ribs and the middle beam of the top frame. This is due to the application of force in the horizontal plane. As for FOS, which is described in figure 3.41, the value has been increased up to 2.6, which is remarkably better rather than the first try (coefficient used to be equal 1).

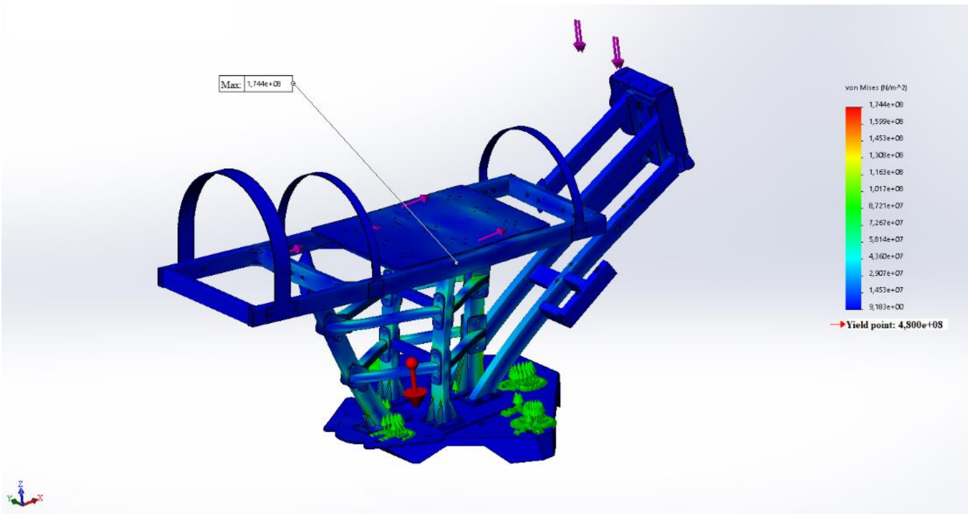

Figure 3.40. Maximum value of von Mises result

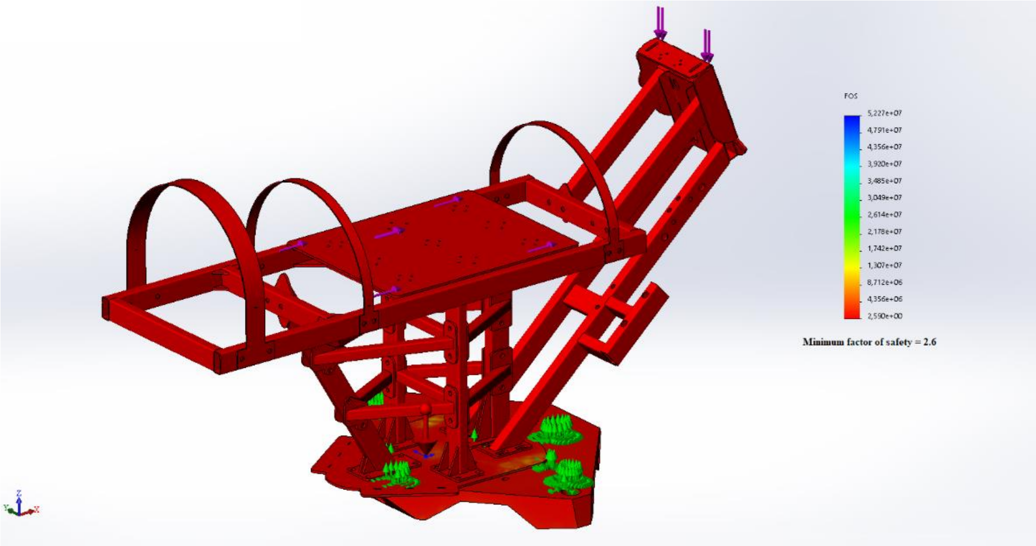

Figure 3.41. Improved model, FOS result

The number of cycles has been improved and now there are minimum of 29020 times of repeating with 5000N horizontal load, which for the model is acceptable (figure 3.42). The minimal value is in the same place where the stress is the highest. It is understandable since the rider is located right under it. Figure 3.43 depicts the minimal value of it.

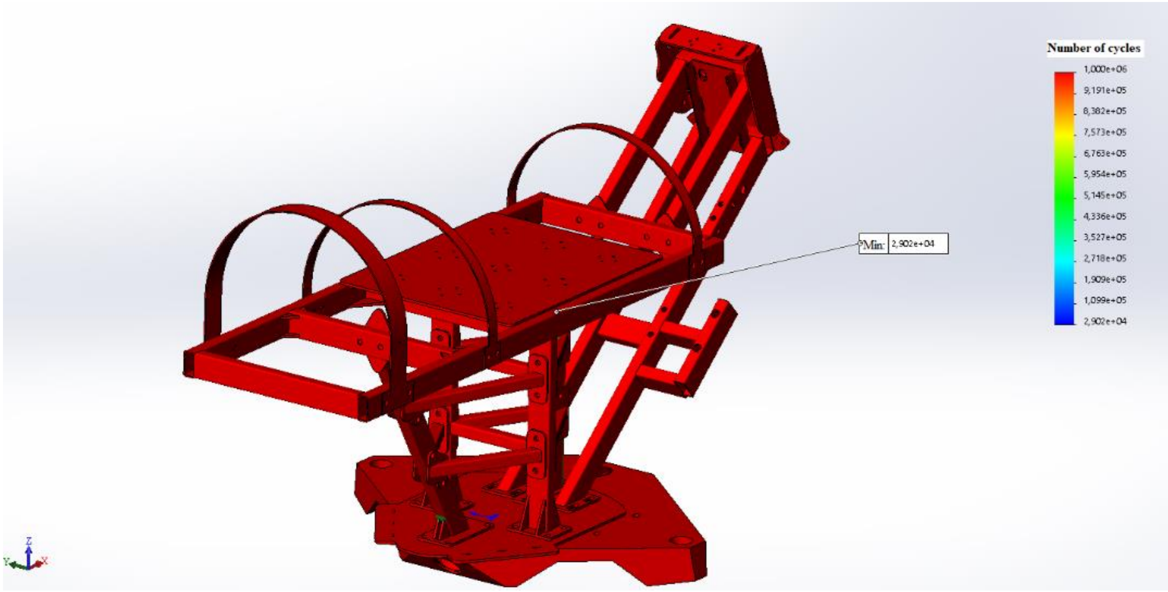

Figure 3.42. Minimum value of number of cycles

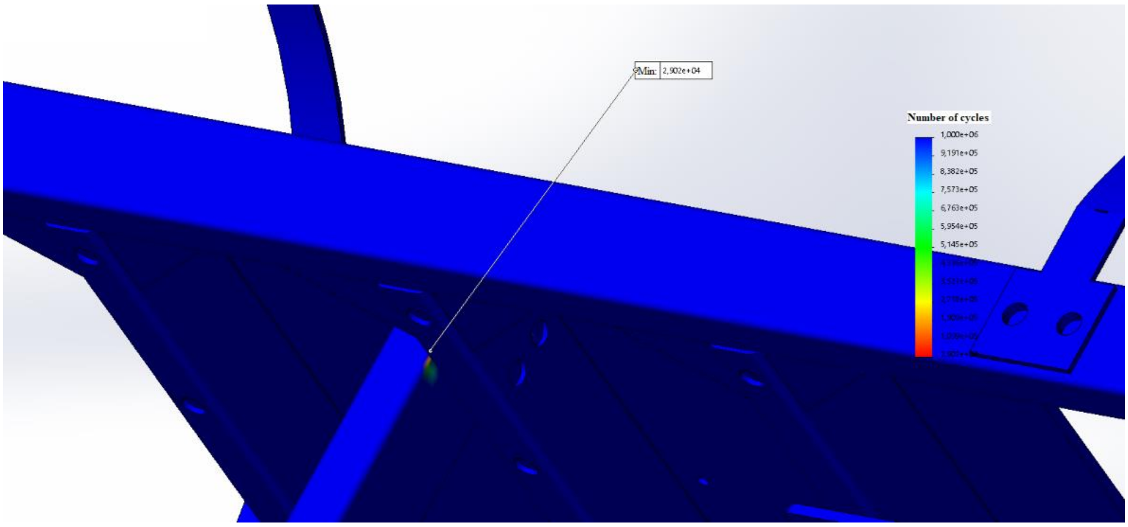

Figure 3.43. Minimum number of cycles, close look

As it was designed most of the beams have a universal size, but the length depends on the location. After a detailed examination, the next following table with all required bolted connections was made. The process of filling the holes is shown in figure 3.44 below.

Table 2. Calculation of the required number of bolted connections

Name	Standard	Quantity
Bolts		
M8x40	ISO 7380	58
M8x55	ISO 7380	10
M8x60	ISO 7380	16
Nuts		
M8 Self-locking	DIN (Director Identification Number) 985-8 Zn	84
Washers		
M8/8.4 Washer	DIN 125	168

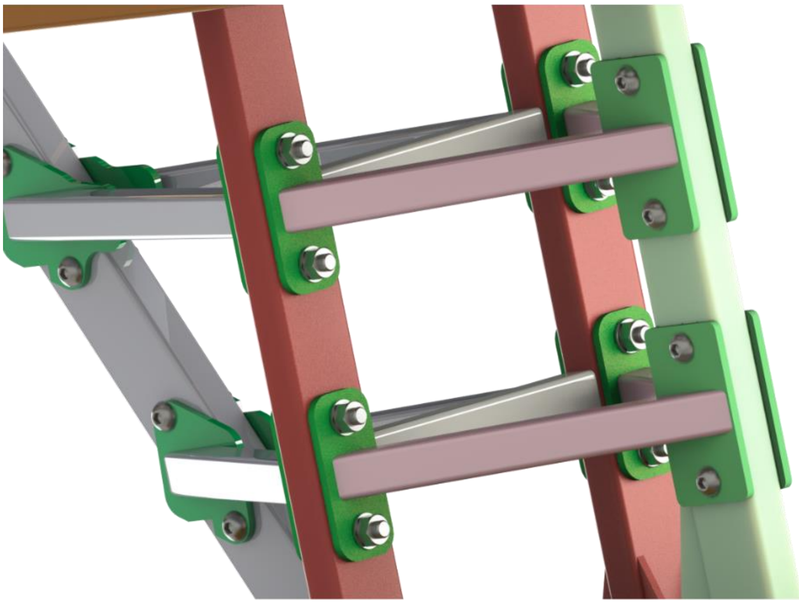

Figure 3.44. Bolted connections

Details specification table located in Appendix I introduces all necessary information and instructions for the details.

All the parts were divided on to 10 different groups, where 9 of them are welding connections. Overall, all the flanges were modified for real usage, and sharp edges became smoother to avoid probable cuts during assemble.

The first welding was HZ01.001.100. It consists of three beams and two flanges welded together. In order to simplify the manufacturing process flanges, have cutouts that let the welder makes welding accurately. This part is connected to the horse-neck mechanism. In figure 3.45, the part of the drawing with dimension and welding information is depicted. The whole HZ01.001.100 drawing is applied as Appendix II to the work.

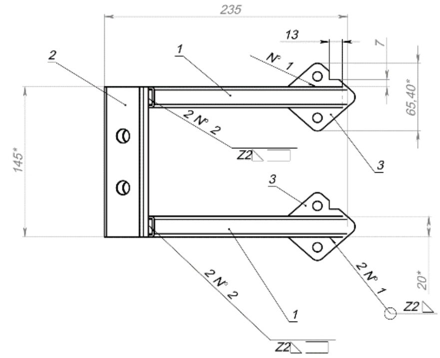

Figure 3.45. Part of HZ01.001.100 drawing

The next welding drawing was HZ01.001.200. It is a frame made of beams, located on the top of the supportive constructions (figure 3.46). The welding consists of eight beams and thirty-two ribs which are welded to the beams. To make welding process easier all the ribs here and on other figures have small cuts to make welding possible and not labor-intensive. Views “K” and “L” are described how welding should be implemented. Appendix III contains the full drawing of HZ01.001.200.

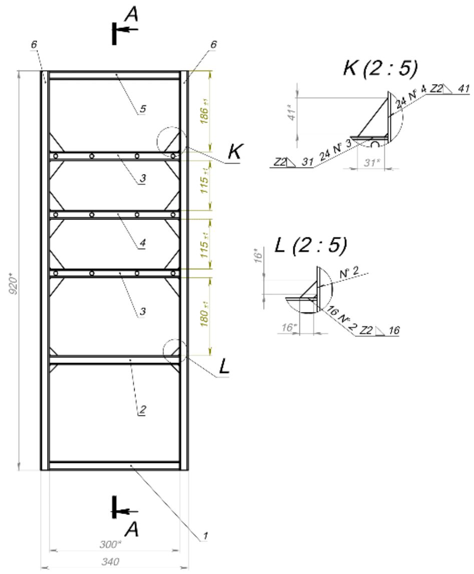

Figure 3.46. Part of HZ01.001.200 drawing

Welding HZ01.001.300 is welding of the forward beam. It connects the base plate, the top frame, and the saddle by bolted flanges. “B” view described how it was supposed to be welded (figure 3.47). The full drawing is mentioned in Appendix IV of the work.

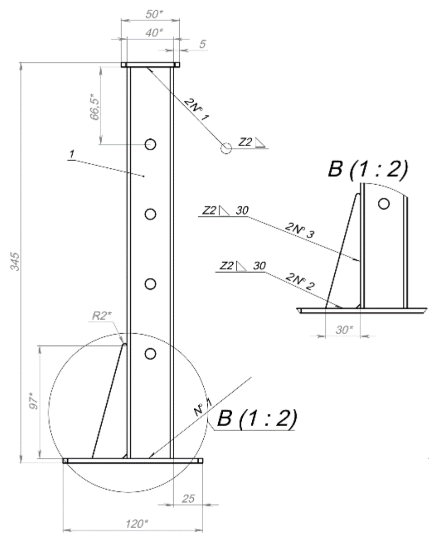

Figure 3.47. Part of HZ01.001.300 drawing

Welding HZ01.001.400 consists of four beams, two flanges, and eight ribs and locates in the middle right under the saddle (figure 3.48). Thus, it is protected by two welded support beams which are holding the part together. Appendix V contains the full drawing.

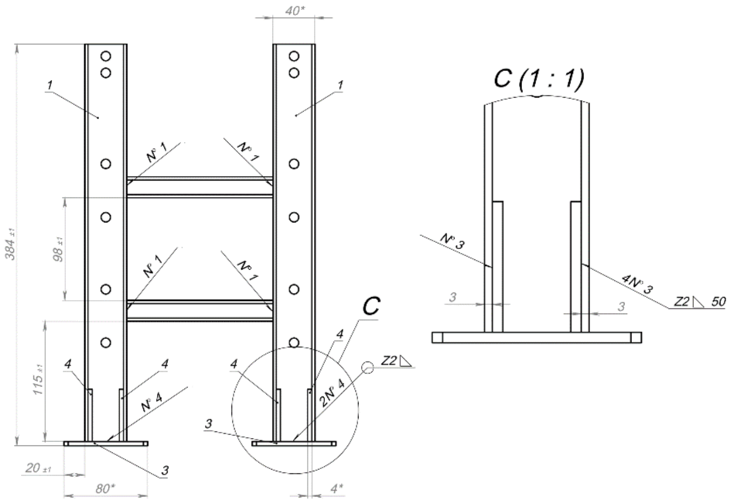

Figure 3.48. Part of HZ01.001.400 drawing

HZ01.001.500 units are serving as support beams for the forward part of the structure (figure 3.49). There are 4 copies of it which were increased the performance of the model. Flanges on both sides are the same which makes this part universal. Not clipped design is introduced in Appendix VI.

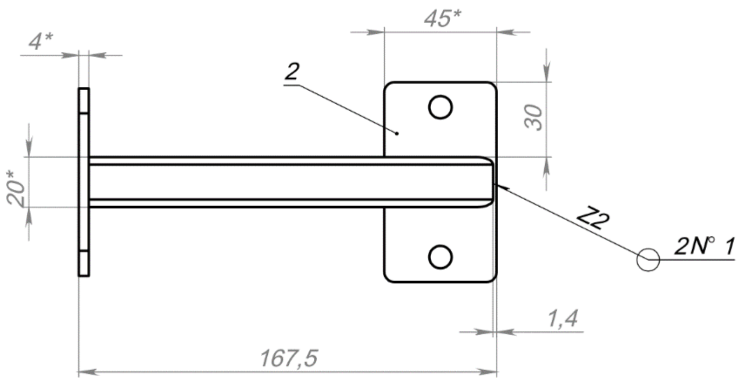

Figure 3.49. Part of HZ01.001.500 drawing

HZ01.001.600 consists of 3 parts where all of them are different (figure 3.50). The section is designed to support the structure in a vertical plane. Due to it connects to the supporting flanges, there are 4 holes which make the bolted connections possible. Appendix VII is serving to provide full information about this drawing.

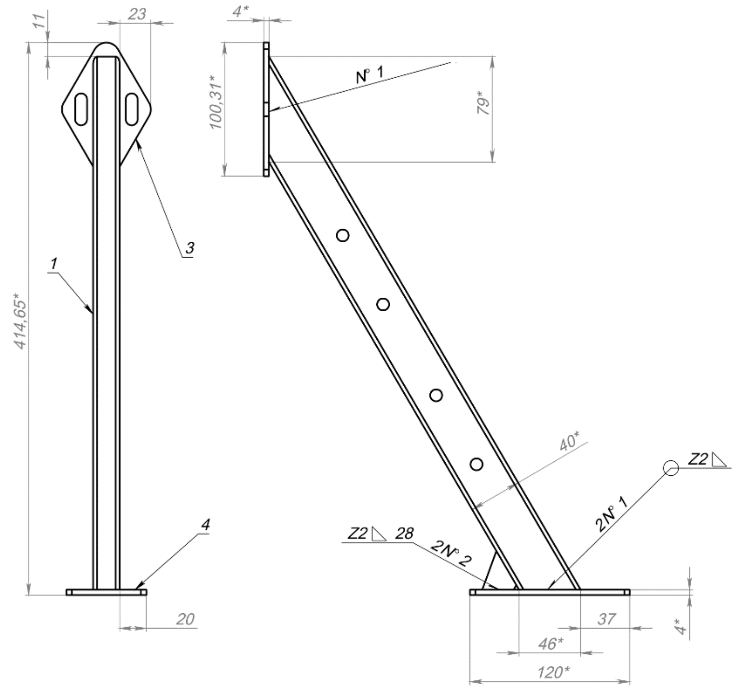

Figure 3.50. Part of HZ01.001.600 drawing

Both support welding parts HZ01.001.700 (figure 3.51) and HZ01.001.700-01 are serving to decrease the big stresses by distributing them along its structure and other connected parts. HZ01.001.800 and HZ01.001.800-01 were made for the same goal, so there is no need to introduce them in the work, but they are applied to the thesis as appendices as well. Appendix VIII contains information about HZ01.001.700 and Appendix IX introduces HZ01.01.800 drawing.

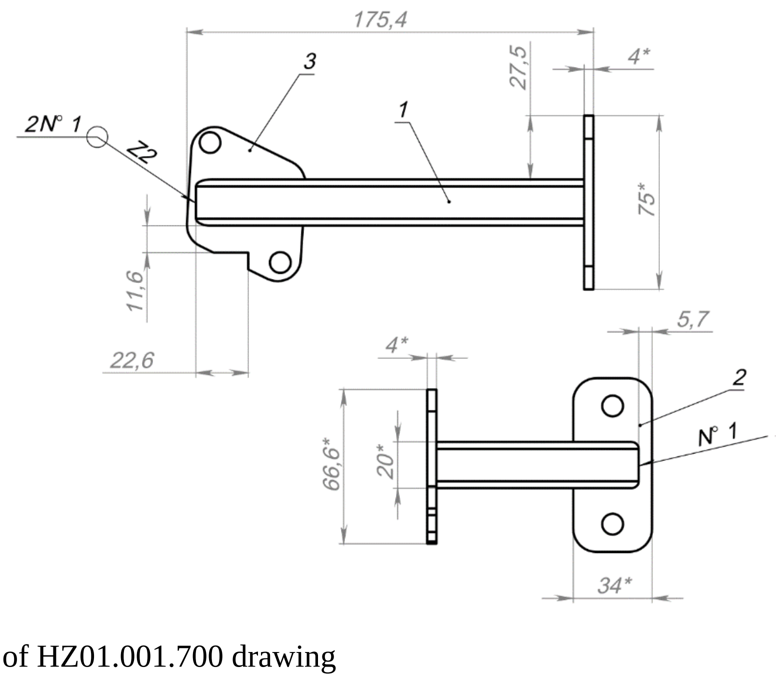

Figure 3.51. Part of HZ01.001.700 drawing

All details were manufactured according to the requirements. In figure 3.52 all of them are attached. As they were designed and produced on manufacture curve sheets are shown in figure 3.53.

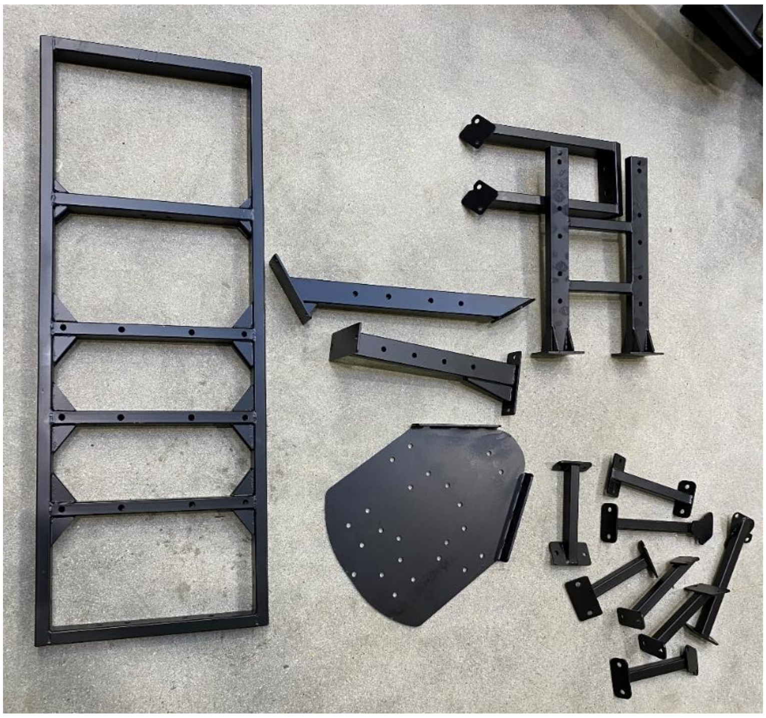

Figure 3.52. Produced and welded parts of the structure

Figure 3.53. Produced curve sheets

In order to assemble it, hexagons, screwdrivers, and ratchet wrench were used. The final result of assembly is shown in figure 3.54 below.

Figure 3.54. Assembled final result

4. DISCUSSION

In this part, there is a discussion according to the obtained results.

The given results convince us that this technology can be applied in the fields of industry, which are close to the target one. 3D scanning of active objects is a hard task, due to the constant movement of the body. Nevertheless, this technology is already able to get enough data to processing it successfully in the future, and the given scanners Leica BLK360 and Leica RTC360 both proved it. The problem which could affect on the experiment was not enough the height of the scanner's stand. It was eliminated by adding extra height with the help of improvised means. A possible consequence of which the boxes and logs, on which the scanner was installed, could lead, is the loosening of the entire structure, due to mechanical torsion of the scanners lens. In further research such a problem should be considered in advance. The height stand of a scanner should be enough to obtain the whole surface of a surveying object.

The problem which was occurred after was a special type format of Leica scanners. The problem was solved by changing the format into another one in order to be able to use the files in other applications. Both two scanners provided much more information that was needed. Fortunately, all unnecessary information was easy to remove.

Due to all scan files were separated from each other and were not a single project, there was complex to prepare the processed model to print. By using Autodesk Meshmixer all the irregularities and inaccuracies in the mesh have been eliminated. Since only one half of the horse's neck and the head were successfully obtained due to difficulties encountered during surveying, the problem arose of creating a realistic model. By using the mirroring function, it was visually revealed that even after making an exact copy of the first half of the neck and head model and adding them as a second part to the first one, the horse still looked realistic.

3D printing is a technology of the future which is already available. Applied this, a shell of the body was made, without spending a big amount of money for various technology on plastic details producing. It was decided to print the whole model by pieces using BigFDM 3D printer with 800mm x 800mm x 900mm printing area. The material should be ABS, reinforced with fiberglass, due to good material properties.

Supportive structure created by using 3D design of products option in SolidWorks helped not only to create the structure but also to be sure that it will be able to resist all the possible applied stresses, by using FEM. The initial values for the analysis are quite large that are expected from the rider, because of him or her safety.

Drawings are the last but not least step which was performed in this project. Welders should be notified properly about all the aspects and bottlenecks of the model to manufacture the details with precisely closed to how it was modeled.

5. CONCLUSION

The aim of the thesis was to develop a shell and supportive structure for a horseback riding simulator to implement it in a sports activity or as one of the forms of therapy as it was discussed in the introduction. The outcome of the work was produced and assembled structure, introduced in the results chapter.

In addition, there was conducted a comparison between two scanners Leica BLK360 and Leica RTC360 after which it could be decided in advance from which obtaining files, the result would be more desired.

After the survey was done, all the files were processed in Geomagic Design X to prepare the model for more accurate processing in Autodesk Meshmixer. The former application let the project to erase all unnecessary details and provided meshes of a model to other projects related to the conducted study. The latter was used to connect all the parts together and gave the model a natural look.

SolidWorks was used to create a model of the supportive structure and to test the possible stresses implementing FEM after. It was decided to apply the vertical load with the force of 5000N to the place where the saddle is supposed to be and 500N instead of the horse neck mechanism due to possible difficulties of FEM conducting. This method revealed that FOS is 2.6 and will keep the model not damaged at least for 29020 repeats in a horizontal plane.

Considering all the possible problems causing unrealistic structure, drawings were created. All the drawings have been done in accordance with ISO standards. After all the beams and other details were produced the model was assembled and depicted in the results. Welding and bolted connection were done by following not only standards but also understanding of how it could be produced in real life.

Further investigations for this project could be done to improve the minimum number of cycles for the supporting structure. Also, by implementing new features better grip with the horse shell can be achieved.

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Table. Details specification

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HZ01.001.302	4	1,0038	2	
HZ01.001.303	4	1,0038	1	
HZ01.001.304	4	1,0038	1	
HZ01.001.403	4	1,0038	2	
HZ01.001.404	4	1,0038	8	
HZ01.001.502	4	1,0038	4	
HZ01.001.503	4	1,0038	8	
HZ01.001.602	4	1,0038	2	
HZ01.001.603	4	1,0038	1	
HZ01.001.604	4	1,0038	1	
HZ01.001.702	4	1,0038	1	
HZ01.001.703	4	1,0038	1	
HZ01.001.802	4	1,0038	1	
HZ01.001.803	4	1,0038	1	
HZ01.001.901	4	1,0038	1	+painting RAL (color system) 9005 or any closest
HZ01.001.902	2	1.0038 + Zinked	1	
HZ01.001.903	2	1.0038 + Zinked	1	
HZ01.001.904	2	1.0038 + Zinked	1	
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HZ01.001.201	Rectangular tube 40x20x2		1	
HZ01.001.202	Rectangular tube 40x20x2		1	
HZ01.001.203	Rectangular tube 40x20x2		2	
HZ01.001.204	Rectangular tube 40x20x2		1	
HZ01.001.205	Rectangular tube 40x20x2		1	
HZ01.001.206	Rectangular tube 40x20x2		2	

Table continues. Details specification

Part	Other details	Material	Quantity	Comments
Beams	**Type**			
HZ01.001.301	Rectangular tube 40x20x2		1	
HZ01.001.401	Rectangular tube 40x20x2		2	
HZ01.001.402	Rectangular tube 20x20x2		2	
HZ01.001.501	Rectangular tube 20x20x2		4	
HZ01.001.601	Rectangular tube 40x20x2		1	
HZ01.001.701	Rectangular tube 20x20x2		2	
HZ01.001.801	Rectangular tube 20x20x2		2	
Welding				
HZ01.001.100			1	+painting RAL 9005 or any closest
HZ01.001.200			1	+painting RAL 9005 or any closest
HZ01.001.300			1	+painting RAL 9005 or any closest
HZ01.001.400			1	+painting RAL 9005 or any closest
HZ01.001.500			4	+painting RAL 9005 or any closest
HZ01.001.600			1	+painting RAL 9005 or any closest
HZ01.001.700			1	+painting RAL 9005 or any closest
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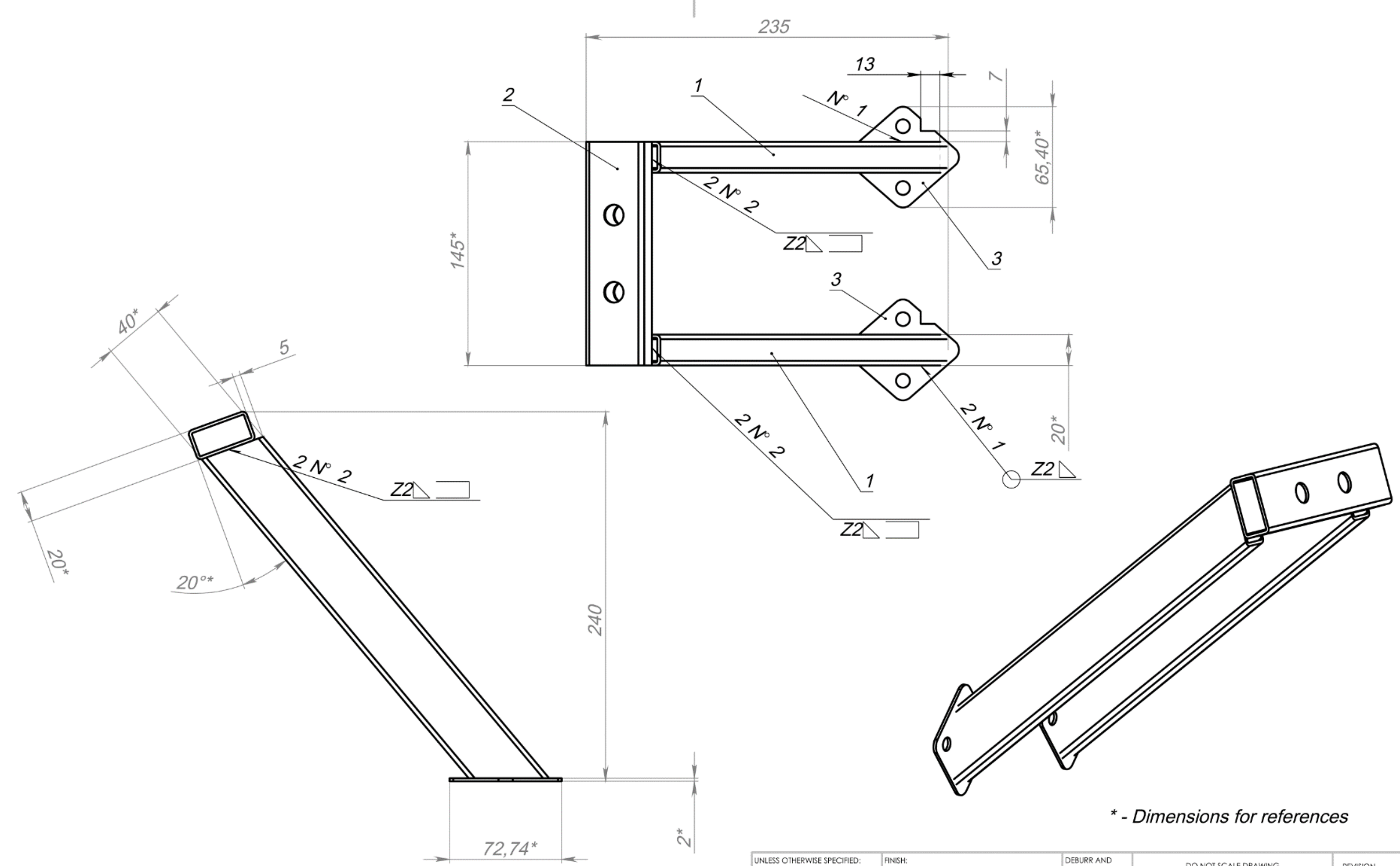
APPENDIX II



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TOLERANCES:
LINEAR: ±1
ANGULAR: ±1°

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

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APPV'D			
MFG			
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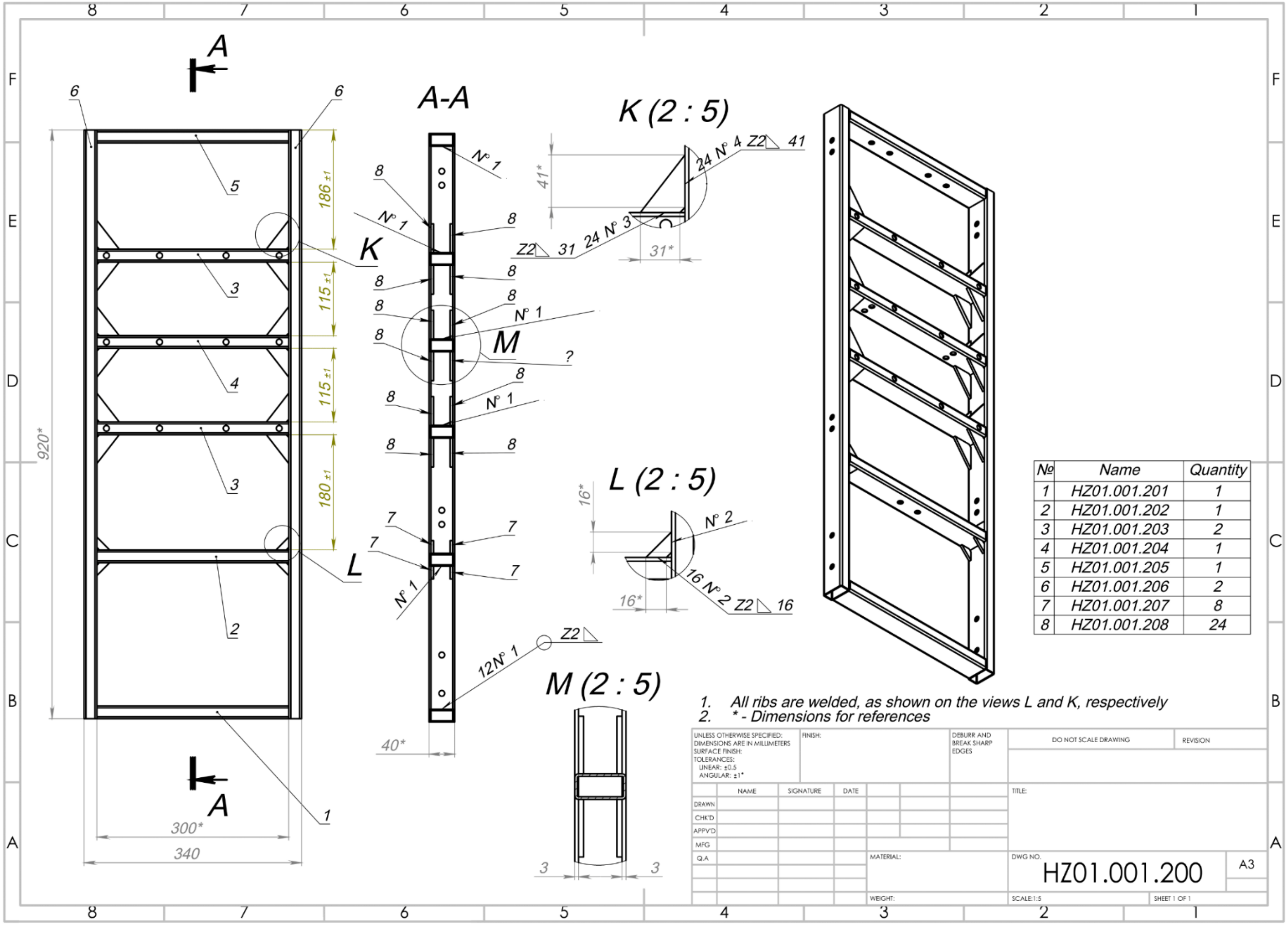

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5	HZ01.001.205	1
6	HZ01.001.206	2
7	HZ01.001.207	8
8	HZ01.001.208	24

1. All ribs are welded, as shown on the views L and K, respectively
2. * - Dimensions for references

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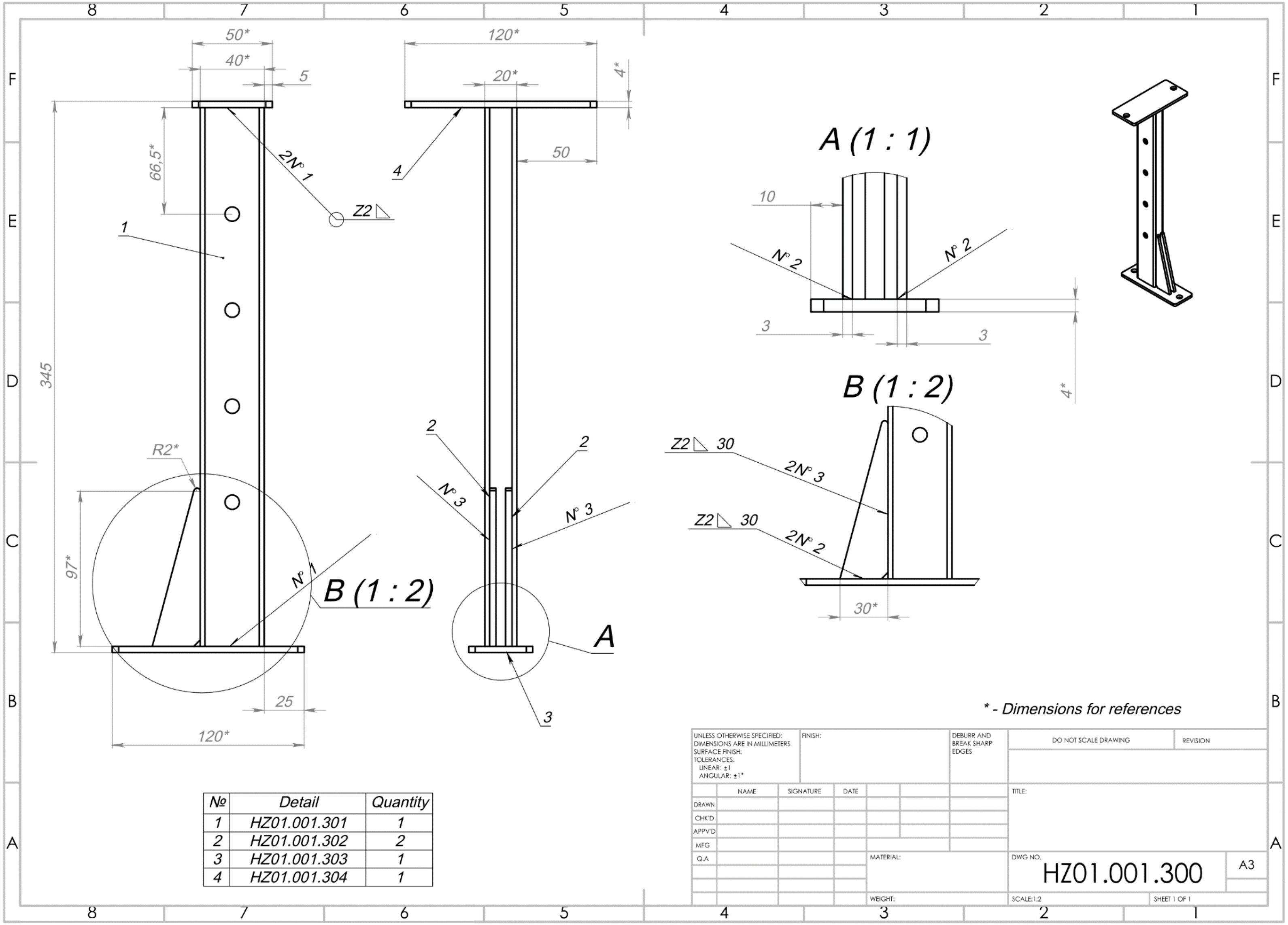

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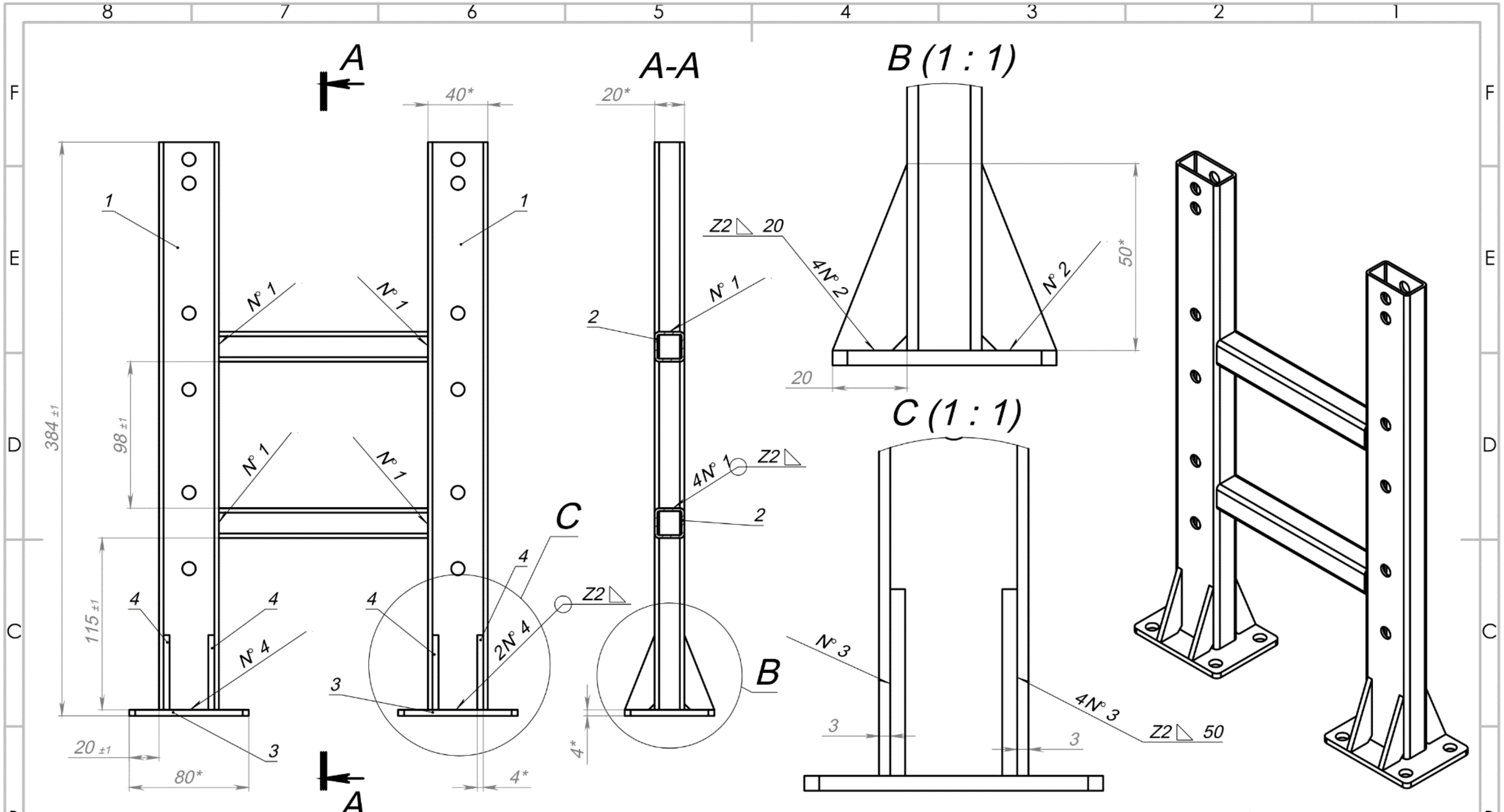

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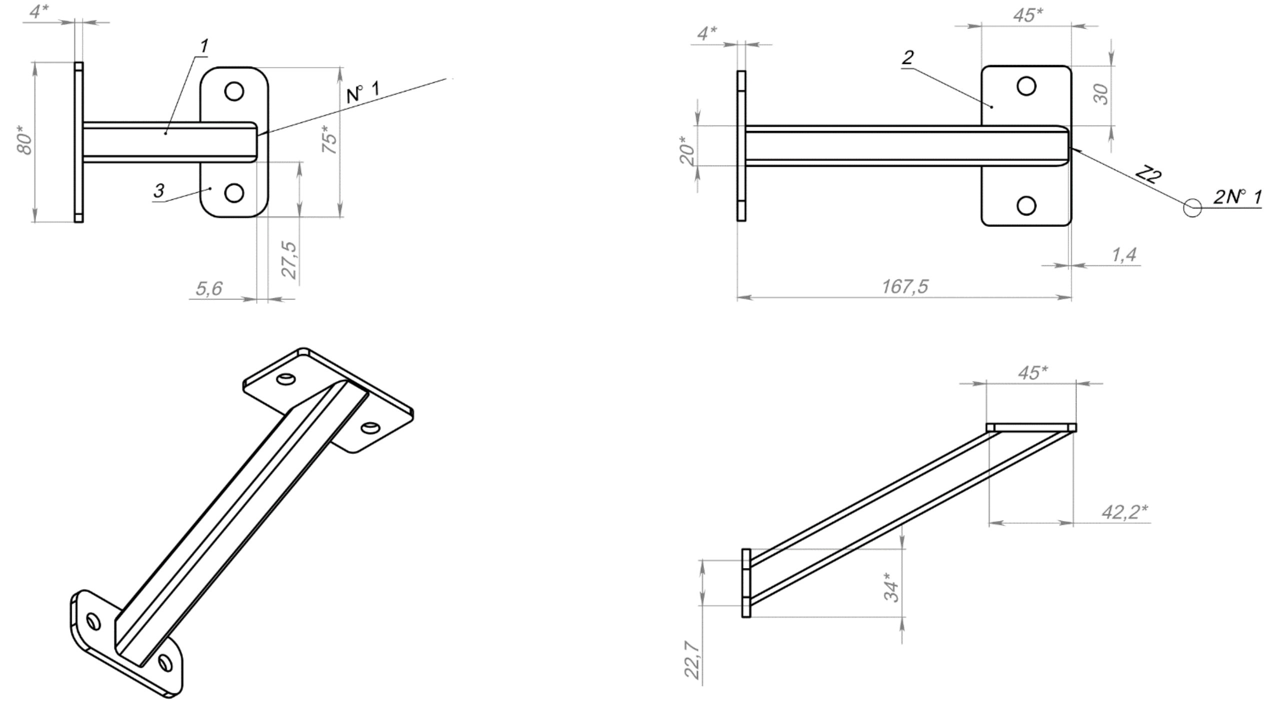

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DEBURR AND BREAK SHARP EDGES

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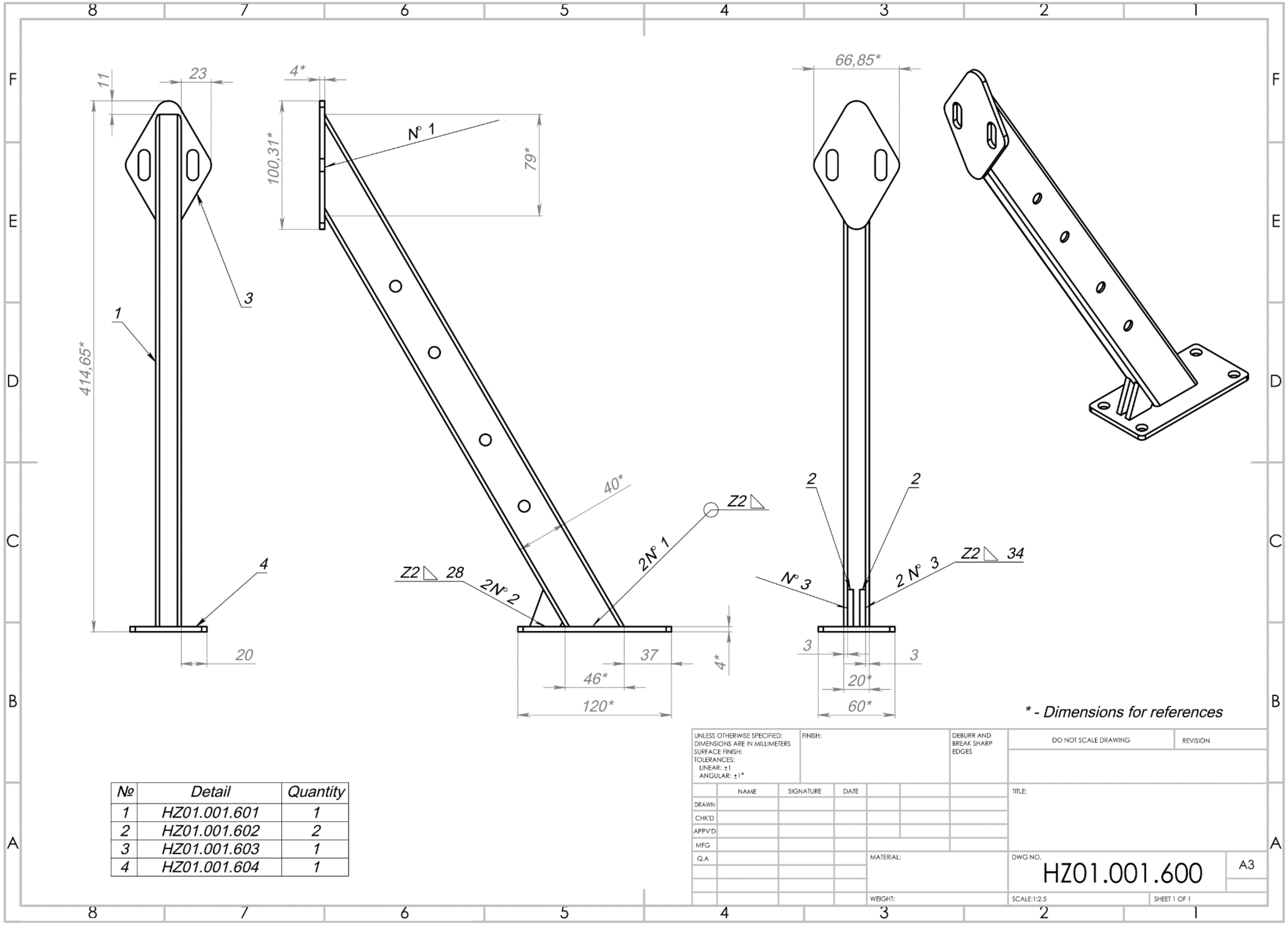

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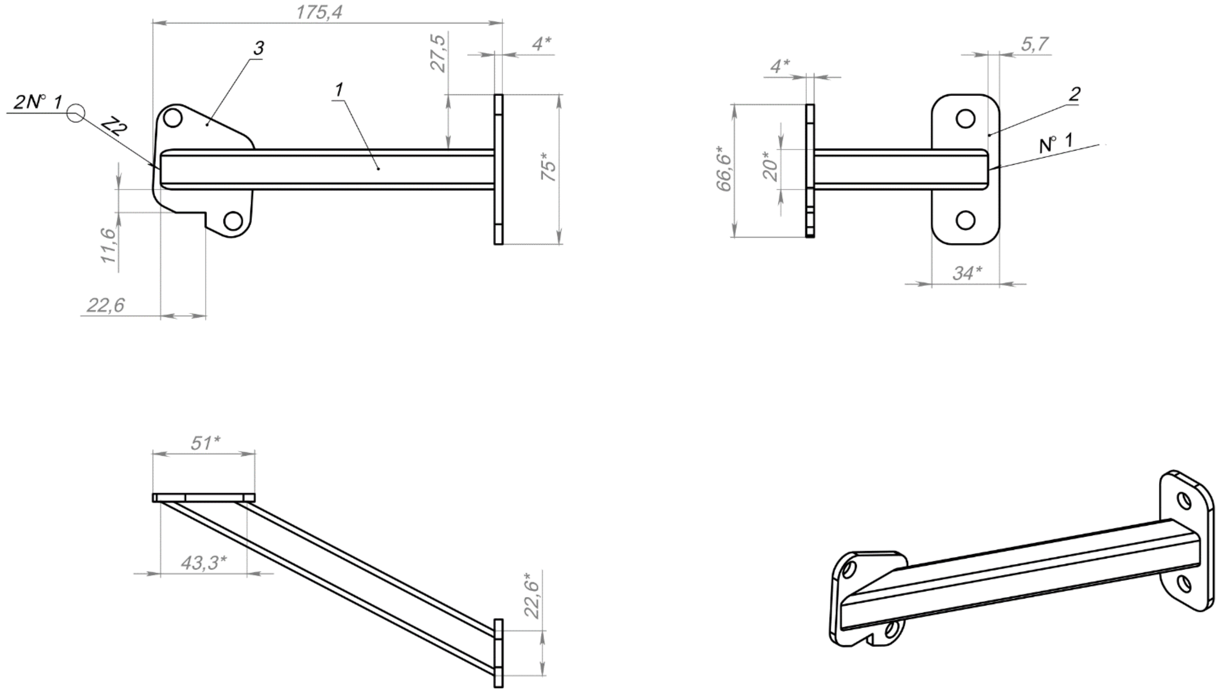
APPENDIX VIII



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ANGULAR: ±1°

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MFG			
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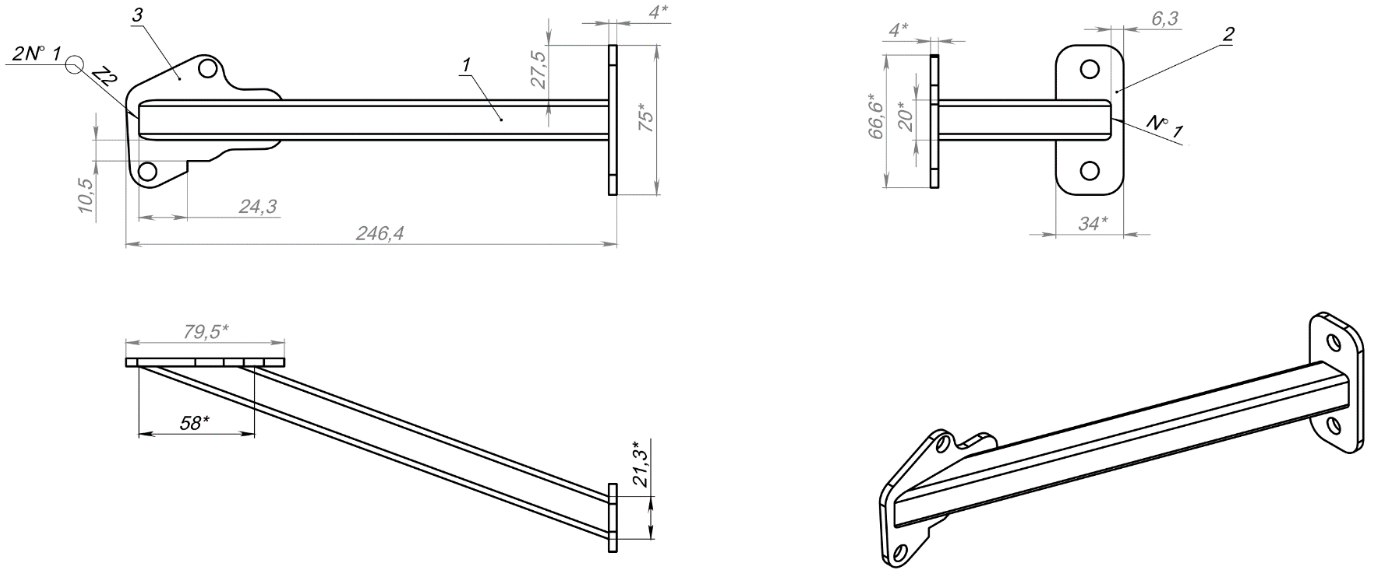
SHEET 1 OF 1

APPENDIX IX



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