TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING

Department of Electrical Power Engineering and Mechatronics

EE70LT

Projectile motion exhibit for OÜ MUSEKO

MASTER THESIS

MECHATRONICS PROGRAM

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Tallinn, 2017

AUTHOR’S DECLARATION

Hereby I declare, that I have written this thesis independently

No academic degree has been applied for based on this material.

All works, major viewpoints and data of the other authors used in this thesis have been referenced.

Thesis is completed under the supervision of Mart Tamre

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Author: ....

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Thesis is in accordance with terms and requirements

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Supervisor: ....

/signature/

Accepted for defence

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Chairman of .... theses’ defense commission: ....

/signature/

TTU

School of Engineering

THESIS TASK

Student ....Kristjan Kikkas, 153065MAHM........ (name, student code)

Study programme, main speciality: ......MSc Mechatronics......

Supervisor: ......professor, Mart Tamre...... (position, name)

Consultants: ......mechanical engineer, Ardi Blumkvist, MUSEKO...... (position, name, company)

......mechanical engineer, Erki Suurküla, MUSEKO......

Thesis topic:

(in English) ......Exhibit research and development for OÜ MUSEKO......

(in Estonian) ......Ekponaadi uurimus ja arendus töö ettevõttele OÜ MUSEKO......

Thesis proposal

1. Introduction

a. Problem statement
   i. Describe what you are trying to do
   ii. Clearly state the question being addressed
   iii. When appropriate formulate a testable hypothesis

b. Describe the motivation, who is interested in the solution

c. Summarize the expected results and their significance

2. Background

a. Describe current understanding of the problem, existing solutions and the barriers of these solutions

b. Review of the pertinent literature and references

c. Justify your approaches

3. Methodology

a. Describe your approach to address the problem, identify any key new insights and/or approaches

b. Describe how the success of the research will be measured

4. Research Schedule

5. References

Proceeding steps outline
Thinking about what interest you → select a thesis topic proposal → conduct your research → choose your supervisor → completing literature review → planning outlines → conducting your research → writing your thesis → defense presentation → composing journal/conference papers.
The typical length of a master thesis proposal is expected to be 3-5 pages.

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Thesis proposal

1. Introduction

a. Problem Statement

There will be a new science center in Poland. Company MUSEKO where I am working is creating full-service exhibition design for this Poland science center. Our client in Poland is expecting us to build stunning exhibitions that are attractive, intuitive to use and work flawlessly. I am going to design and create exhibit that describes projectile motion using client input that allow experimental verification of the existence of relationships between the range of projectile and angle of launching, and launching force – that is the initial velocity, mass of tossed item, gravitational force and aerodynamic drag.

b. Describe the motivation, who is interested in the solution

Motivation of taking this thesis is to make attractive exhibit that meets all the requirements of client input and that this exhibit will explain visitor's physical phenomena of projectile motion. Visitors can make different tests with exhibit that illustrate scientific determinism.
Client is interested in the solution of exhibit and give feedback if something is missing out.

c. Summarize the expected results and their significance

Expected results will be workable exhibit that meets the requirements of client input and help visitors to understand projectile motion phenomena, how to change parameters to get right projectile so that you are able to shoot ball to the basket. Special attention need be paid to safety issues – limited access to crumple zone of worktop mechanism and reducing launching forces. Exhibit need to be safe to use. This exhibit will be unique prototype that have never made.

2. Background

All client criteria are written down to the Detailed Description of the Exhibition document. Client wants an exhibit that consist a worktop with adjustable tilt, supported by the platform. There are platform and work tilt minimum dimensions that are need to follow. Angle of tilt is adjusted by driving mechanism that is activated manually by visitors in the range from vertical to horizontal position. The projectile launcher should be mounted to the worktop that will toss balls at specific angle and speed towards the basket – located on the opposite side of the worktop. Basket/target need to be shifting along the horizontal edge of the work tilt. Also, it need to be enable shifting launcher along the vertical edge of the worktop. In the worktop is integrated displays that displays current parameters that are measured by different sensor that are in the work tilt: the tilt angle of the worktop, the angle and height of the launcher so that parameters make subsequent analysis of video recordings possible. Video camera is attached to the movable worktop on the construction perpendicular to it and moving along with work tilt.

As much as I have done research there are no exhibit that our client is required. There are similar projectile systems that launch balls or disc.

3. Methodology

For making this project we have three big deadlines – initial, executive and detailed design. For every step, we get client feedback how our work is done, is it going in right direction.
First I start to research to find ideas how to make this exhibit and using SolidWorks to make design. Research if someone have done similar thing, looking different system what are similar to the projectile motion physical phenomena. If I got idea how to do it I will starting to make prototypes to test different solutions to see feedback.

Also, there will be meetings with client to discuss how to make exhibit better and how to proceed different criteria's.

4. Research Schedule

In this table I am describing approximate deadlines and tasks. All dates and task can change during the work.

Nr	Description of task	Deadline
1.	Analyzing client Detailed Description of the Exhibition document. Making criteria list and research	**End of January**
2.	Analyzing different overall solutions for exhibit and selecting right one	**Early February**
3.	Choice of projectile launcher system, driving mechanism and materials to use. Choice of sensors, displays, camera, linear slide bearings etc.	**End of February-March**
4.	Development of exhibit. Prototyping	**March-April**
5.	Joining all pieces together and cable carriage	**Early May**

5. References

For this thesis, I will mostly refer client Detailed Description of the Exhibition document where I get all the information what I need to develop. There will be different drawings made in SolidWorks where I can refer my progress and client feedback what was wrong or missing for this stage. Definitely there will be lot of references from web page.

CONTENTS

PREFACE

Thesis topic evolved during working for the company MUSEKO OÜ. The company was working on a project in Poland science center called EC1, where was necessary to design and develop a variety of exhibits according to customer input called SOE (Detailed description of the exhibition document). For this thesis topic, I have picked out one of the exhibits that I was developing that describe visitor´s projectile motion phenomena. Projectile motion exhibit design, development, preparation lasted from the summer of 2016 until the spring of 2017 at MUSEKO OÜ where consultations and guidelines were given by Tõnis Pae, a development manager, Erki Suurküla, a mechanical engineer and Ardi Blumkvist, a mechanical engineer.

LIST OF ABBREVIATIONS AND SYMBOLS

BOM	Bill of materials
COTS	Commercial off-the shelf
SOE	Detailed description of the exhibition (Szczegółowy Opis Ekspozycji**)**
TTL	Transistor-transistor logic

1. THESIS INDRODUCTION

The aim of the thesis was designing projectile motion exhibit for the Poland science center EC-1 path 2 “Development of knowledge and civilization”, according to costumer input detailed description of the exhibition (SOE) and make changes according to customer feedback. The company MUSEKO OÜ request had been ready to make an exhibit a predetermined period of time and within budget, ensuring the safety and design standards of the exhibit.

Aim is that visitors of the science center observe phenomena individually, to experimentally discover principles and laws that govern them and to create hypotheses during the interaction with exhibit, using visitor's natural curiosity. Therefore, experimental stand must be interactive and inspire visitors to engage in either individual or cooperative educational process, in a form that does not overwhelm with formality but it is nevertheless based on scientific methods, exposing their values. Visiting must not be deprived of elements of fun, joyful interaction, the full enjoyment of discovered rules and laws. Main recipient of the educational value are children at the third stage of education (aged 13-16) and above.

Given exhibit objective is to allow experimental verification of the existence of relationships between the range of projectile and angle of launching and launching force- that is the initial velocity, mass of tossed item and gravitational force and aerodynamic drag [1].

Thesis was divided into 5 major phases.

1. Getting to know exhibit requirements and standards. The initial generation of ideas and client feedback
2. Designing exhibit worktop and stands.
3. Selection of mechanical parts – tilting and launcher mechanism, pneumatical components
4. Selection of electronical parts – sensors, display and camera
5. Exhibit safety and cost analysis

Designing exhibit 3D models and manufacturing drawings I used SolidWorks 2017 Standard software. Strength analysis was made using SolidWorks Simulations software.

Working on master’s thesis introduced various material properties and fastening methods. During the work, I learned how to make manufacturing drawings and strength analysis using SolidWorks and how to manage the project - communicate and have meetings with the client and subcontractors. In addition, acquired knowledge about pneumatic components, sensors and their operating principles.

2. REQUIREMENTS AND BACKGROUND

The purpose of the background study was to examine the exhibit specificities and challenges. Made clear client requirements and physical phenomena what this projectile motion exhibit must demonstrate. I studded if there is anything made of the same or whether there are tools or similar exhibits made that help me generating ideas and demonstrate the phenomena.

2.1 Exhibit client requirements

All the information on which the exhibit must look like and what is it’s exactly function is prescribe by client at SOE, which contains the required elements and manner of functioning, based on which the thesis was drawn up. Exhibit warranty period is 2 years and lifetime 5 years. All prescription must adhere.

Required elements for projectile motion exhibit from SOE [1]:

- The stand consists of a worktop with adjustable tilt, supported by the platform that has minimum dimensions of 2,5 m (L) x 1,5m (W) x 0,5 m (H). Tilt table worktop of the stand has minimum dimensions of 2,5 m x 1,4 m.
- The angle of tilt is adjusted by driving mechanism activated manually by visitors in the range from vertical to horizontal position. The surface of the worktop having low coefficient of friction supported by a rigid structure.
- The launcher should be mounted to the worktop and it will toss balls at specific angle towards the baskets – Objectives located on the opposite side of the worktop
- Next to the launch should be installed an angular scale. Main scale calibrated in 10°, auxiliary one in 5, so that visitors could consciously adjust the angle of the shot, still not using the metering and displays.
- To the worktop, next to the launcher should be mounted the container-net or a basket for the "ammunition": balls made of various materials, e.g. light wood, tough sponge, plastic. Balls should be made of non-toxic materials, in various colors depending on the material used to make them.
- Perpendicular to the worktop, along its upper and lower edges, should be mounted the stop to prevent the ball from falling off the stand, but not disturbing free positioning of the launcher and aim. Properly secure the boundary vertical edge.
- In the platform should be integrated the mechanism adjusting the worktop tilt angle, controlled by visitors with a physical manipulator integrated in the direct vicinity of the tilting mechanism.
- The stand equipment includes also several (at least 5) shapes of buildings, trees, mountains made of e.g. thick sponge with a thickness of approx. 10 cm to simulate obstacles. Sizes of items are intended to enable arranging them on the lower worktop's

stop (and possible mounting) so that Visitors have to throw balls over the shapes to hit the target on the opposite side of the worktop.

- The stand should be equipped with video camera attached to the movable worktop on the construction perpendicular to it and moving along with it at a distance that allows recording video sequences of balls flights.
- In the worktop integrate displays that displays current parameters: the tilt angle of the worktop, the angle and height of the launcher so, that these parameters make subsequent analysis of video recordings possible.

There was also manner of function for this exhibit where client clearly described how they see this exhibit should do. Requirements that I needed to follow [1] :

- Visitors can adjust the strength of the shot of the ball, position of the launcher along the vertical edge of the worktop, worktop tilt and to adjust the position of the target along edge within the distance of 0,5 m from its end.
- Pressure gauge at the "loading" post should indicate the current value of the pressure inside the tank and colors should indicate ranges of low, medium and high pressure.
- Launcher must have secure releasing mechanism.
- Initial speed sensors are measuring this speed at each shot and display its value on a dedicated display integrated in the worktop.

2.2 Exhibit design requirements

Exhibits design was based on a historical building in interior design to maintain a design feature. EC1 is an old non-operating power plant, which is built converted into science center. Exhibits design must meet the following requirements [2]:

1. Design
    - Buttons must be placed at a height of not less than 0,7 m and not more than 0,8 m.
    - All edges should be rounded 2mm MIN, as well as all corners have to be rounded to 5 mm MIN. No sharp burs or leftovers are allowed from designing and manufacturing methods, in areas where visitors can come in contact.
    - All item corners that exist under 1,2 m height should be the rounded to the minimal radius equal to 5 mm; in some case, it is acceptable to attach permanent protection such as rubber corners.
    - Any kind of screws have to be also countersunk for flushed panels or domed if they extrude. Use black colour as well as for dark colour exhibits or parts.
    - All exhibits must comply with standard PN-NE 15372 16139: 2013, which means fire certificate class and hygiene certificate.

2. Material Requirements

- Preferred structurally homogeneous materials (plywood, plastic, powder coated black steel or stainless steel) with rounded corners.
- Materials laminated with thin layer, less than 0.8 mm, are prohibited.
- All elements of the exhibits should be made of durable material, as resistant to damage as possible.

3. Accessibility

- Push buttons should be easy to operate, visible and easy to comprehend. The color code and the form of buttons to be standardized for the entire exhibition - particularly for the START button on kiosks and media interactions. Controls must be arranged and operated intuitively, accessible and easy to find. Their arrangement should be comfortable for both right and left-handed persons.
- All the elements in a display should be visually accessible to all visitors. All cased displays should fall within the general optimum viewing band of 0,75–2 m (Figure 2.1). Ensure everything is visible from a wheelchair.

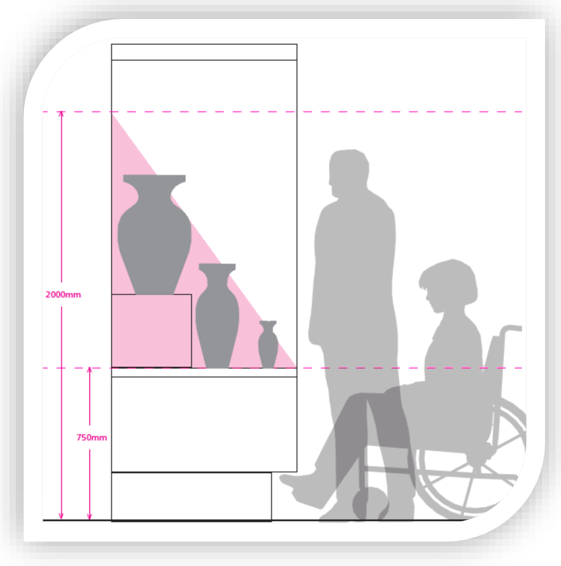


Figure 2.1 Viewing band [2]

- Desk cases should be no higher than 0,8 m.
- Stands must also be adapted for use by persons with motoring disabilities as well as visually/hearing impaired (Figure 2.2).

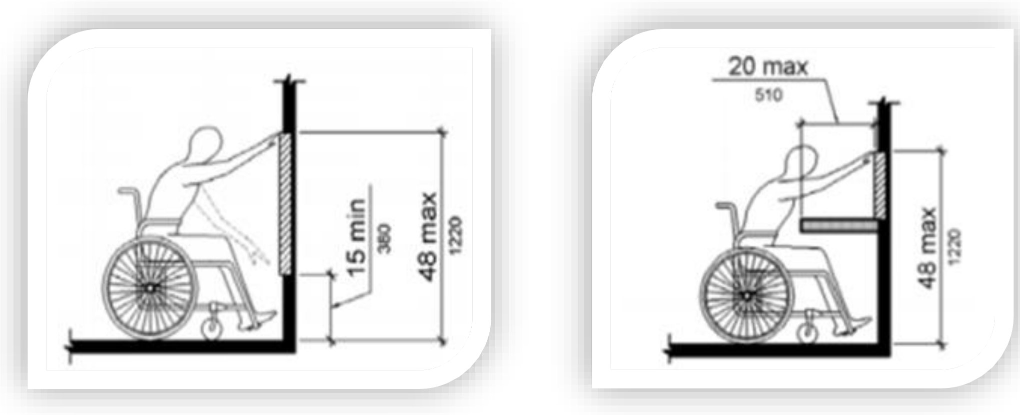


Figure 2.2 [2]

4. Maintenance Requirements
    - Elements of controllers shall be made in technology and materials which ensure long-lasting, trouble-free operation and easy replacement in case of failure. Components shall withstand as much as possible the assumed exploitation of 500 000 visitors a year.
    - The exhibits should have service door for easy access to internal parts of the exhibit.

2.3 Projectile motion and similar exhibits research

A projectile is object thrown in air or space and the curved path along which the projectile travels is what is known as trajectory.

Projectile motion is a form of motion in which an object or projectile is thrown near the Earth's surface, and it moves along a curved path under the action of gravity only. The implication here is that air resistance is negligible. The only force of significance that acts on the object is gravity, which acts downward to cause a downward acceleration. Because of the object's inertia, no external horizontal force is needed to maintain the horizontal velocity of the object [3].

After researching about similar exhibits about projectile motion, there was no information about exhibits where projectile motion was demonstrated and could help me to generate ideas how to design my exhibit. I found different systems and launchers which could indicate projectile motion and helped me to generating ideas.

2.4 Exhibits working principle

The exhibit is to allow experimental verification of the existence of relationships between the range of projectile and angle of launching, also launching force – that is the initial velocity, mass of tossed item, gravitation force which change is simulated by tilting the tabletop and aerodynamic drag [1].

Short description of functioning:

Visitors can adjust the strength of the shot, the choice of the material (weight) of the ball, position of the launcher along the vertical edge of the worktop, worktop tilt and to adjust the position of the target along lower edge within the distance of 0,5 m from its end.

In the basic version two parameters will be used: angle of projectile launcher and strength of the ball shot, which must be accessible for visitors in a quick and very intuitive manner. Other parameters will be used less frequently during group classes.

Instructions for use

Without logging in:

- For loading ball the angle of the launcher need to be up to 90 degree and worktop tilt need to be between 80 to 85 degrees when using launcher protecting case.
- Without launcher protecting case but ball into cannon.
- Regulate worktop tilt with crank
- Adjust the position of the launcher and angle with pole which is attached to the launcher.
- Adjust the position of the target
- Inflate the compressed-air tank to the desired pressure, to accumulate the energy suitable for the shot.
- For shooting ball need to push ARM and LAUCNH button simultaneously
- Observe ball projectile

After logging in:

- Extra option to record footage of the projectile along with its parameters
- Obstacles are accessories that allow to perform additional tasks.

2.5 Analysis of ideas, client feedbacks and final exhibit outcome

The first thing was to pick out projectile launcher system that will be used for the preparation of exhibit. The selection made between the tree projectile launcher system, which the pros and cons are shown in Table 2.1

Table 2.1 Comparison of projectile launchers

	Advantages	Disadvantages
1.Vernier Projectile launcher [4]	Finished product Same launching system that described in SOZ Durable Secured launching system Data-collection interface and software compatibility	Clumsy design – hard to integrate with exhibit worktop
2. PASCO projectile launcher [5]	Finished product Easy to integrate with exhibit worktop Optional photogate mounting	Unsecured launching mechanism Many fragile details that visitors can break Can't customize according with the terms of reference
3. Self-made launcher [6]	Easy to make launcher in accordance with the terms of reference Easy to measure launching speed, angles and position of launcher Using discs – easy to use different materials for an ammunition	Using discs – bigger friction can affect the results Need to development for final product

Phase of initial design

First, I made preliminary design, where the customer was required to show exhibits main features and the design, how this exhibit is going to look and where will be key components. In Figure 2.3 it can be seen that exhibit consist two bearing stands, which going to support work top. The camera, which monitors real-time projectile flight path is selected by our project partners Qumak and MAE. Camera location is selected so that the whole table is in view of the camera field of view. Valve wheel is used to control mechanism that adjusting the work top tilt angle and 3 digital display meters are used for giving information about exhibit parameters.

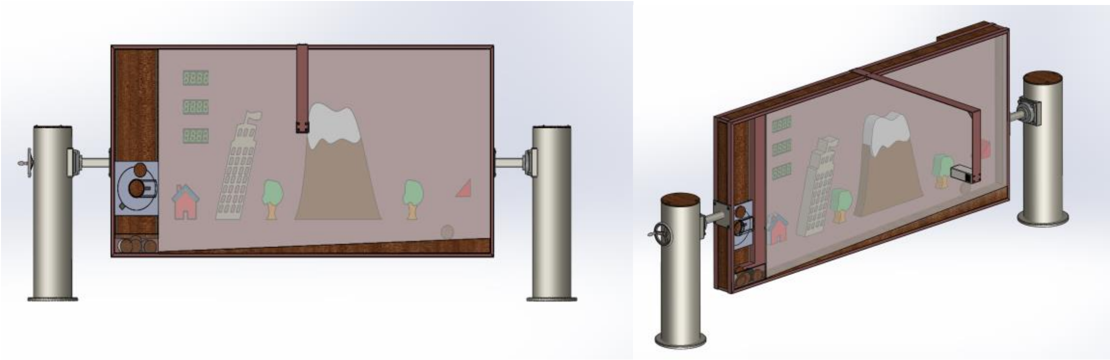


Figure 2.3 Exhibit initial design [7]

Self-made launcher was selected, which files discs (Figure 2.4). Improvised system is very compact because I can change the design and purpose according to the design of the exhibit. Using flywheel for launching disc. Discs can be pushed into flywheel with mechanism. System velocity can be change electronically by changing the engine speed. To change the angle of the launcher system I will use two gear-wheel, which can electronical control by stepper motor. Stepper motor has the advantage of precise position without feedback. Positioning the system up-and-down I had an idea of using toothed belts and linear bearings, similar to a conventional x-axis of a 3D printer. All the changeable parameters will be change by electronically so that visitors can use buttons that are top of stand and change launcher parameters from a distance.

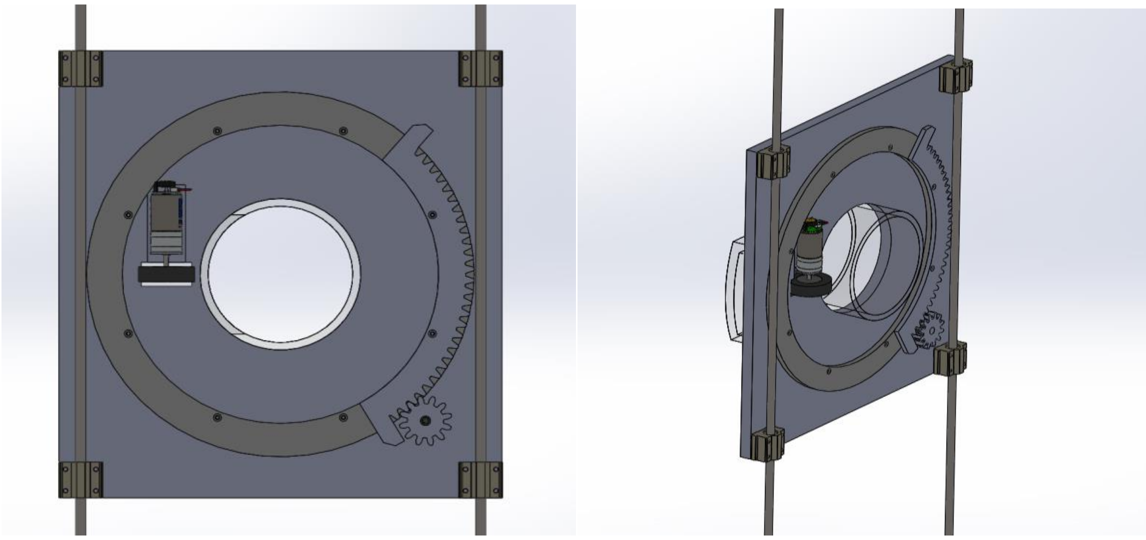


Figure 2.4 Self-made launcher [7]

Client feedback for initial design

The customer was satisfied with the initial design in the overall picture. Things that the client wanted to find out in the next phase:

- User-friendly affixing targets
- Change target shape and target to move only horizontally
- Change camera location if it is possible
- New launching system. Client does not like shooting discs, creates too large coefficient of friction and may change result.

Phase of executive design

For executive design degree of precision must be level from where all the main components are shown in exhibit model and including all of components datasheets. I made changes according to customer feedback.

I changed the mechanical side (Figure 2.5). Work top made of aluminum profile but change shape of post using steel profile instead of tube sheet which provides rigidity and strength to the stands. Three digital panel meters are replaced with on big RGB screen panel type because there is more space for text and numbers that need to be displayed.

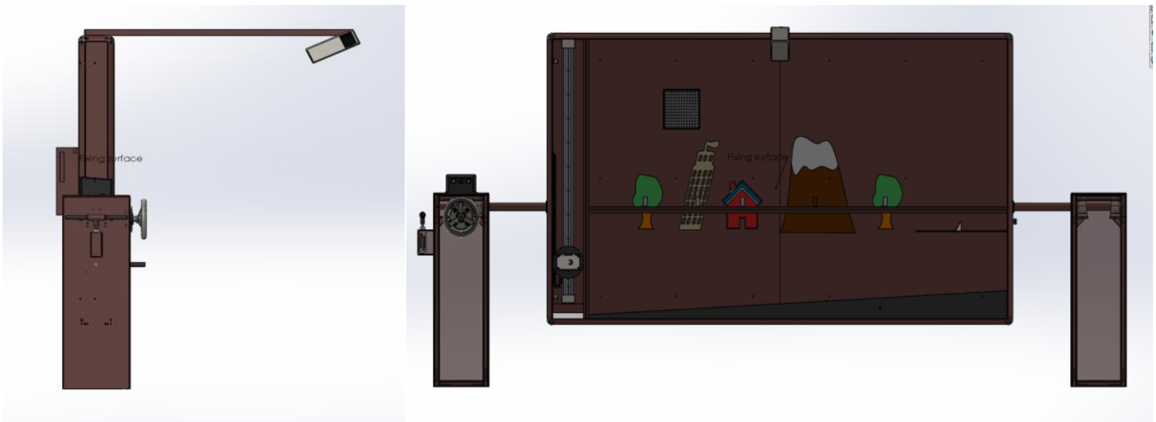


Figure 2.5 Exhibit executive design [7]

Exhibits target was revised to target of the basket and made initial requirements change, the target can only be moved horizontally 0,5 m from the right edge. For obstacles aluminum profile was added across the table top (Figure 2.5) where can be attached obstacles.

Launching system was replaced with a Vernier projectile launcher, since client didn't like discs as use of ammunition. They wanted to use this system because they have previously been in contact with this launcher system and they know how it works.

I change the launcher for the user-friendliness for the exhibit (Figure 2.5). The idea was to modify the product into two parts: the cannon and the exhaust system. Cannon fixed to the work table and exhaust system is carried out on the stand where visitors have better access to pump desired pressure to the system and launching cannon.

Client feedback for executive design

- To put level sticker to differentiate the floor where the tree, building etc. from above ground level
- Show on drawing how the table goes from vertical and stops horizontal
- Make camera perpendicular to work top on arched axis positioned in the middle of the table as it is now. The arch will start from one side of the width to the other
- Indicate in drawing the axis angle limitations, include limiters in documentation
- Bigger knob of adjusting the target
- Increase diameter of the target hoop
- Re-design the launcher – do not separate its components, but put them all together

Client most considered problem was about launcher. Problem was when I separate its components it would affect launcher system pressure. There will be pressure drop between cannon and electrical valve when I will use a longer tube and launcher would not able to launch desired distance.

Phase of as built design

As built design is final exhibit CAD model (Figure 2.6), where has considered all the customer's comment and suggestions. Level of detail is maximum by adding all fasteners. Design and manufacturing drawing are made by as built design and go a subcontractor. The latest amendment to the as built design phase was replacement of camera to GoPro Session 5 by Qumak. Didn't add arched frame for camera because visitors would think that moving this arched frame can change the angle of the table. Took in the client changes. Adding one piece launcher to the worktop and connecting obstacles with magnet into work top surface. Both stand have added service hatches.

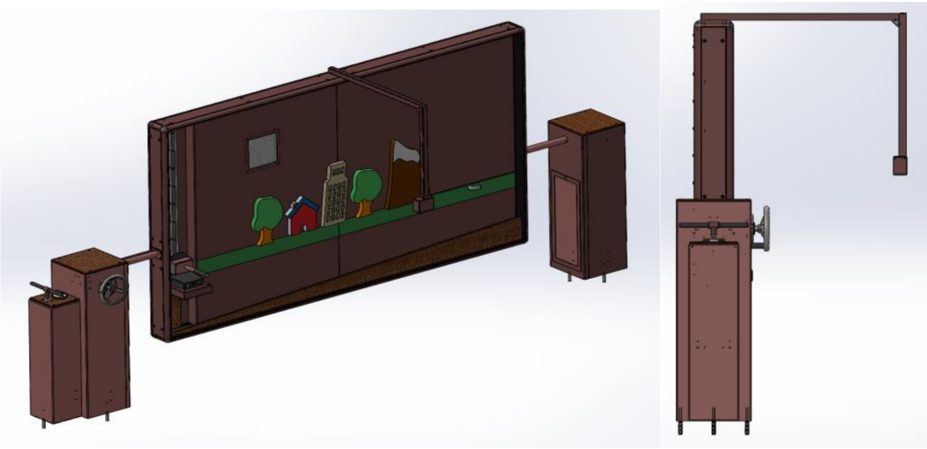


Figure 2.6 Exhibit as built design [7]

As built design consisted also standard stands as multimedia kiosk G01 and information plate Z01 describing exhibit functioning. Visitors can use kiosk to see record a footage of the projectile along with its parameters.

3. DESIGNING EXHIBIT

3.1 Mechanical part

Projectile motion exhibit consists two stand post and worktop (Figure 3.1). Worktop is connected to the stand with two shafts with flange and four M10 hex socket round head screws. G01 is standard multimedia kiosk and Z01 describing exhibit functioning. Visitors can use kiosk to see record a footage of the projectile along with its parameters – embedded in the footage using values displayed in exhibit. Kiosk containing content describing the history, the significance of the projectile motion discovery, the measurement technique and the figure of the scientist Henry Cavendish.

G01 and Z01 has already finished product. All the communication work between multimedia kiosk, sensors and camera footage are doing do to our partners Qumak and MAE.

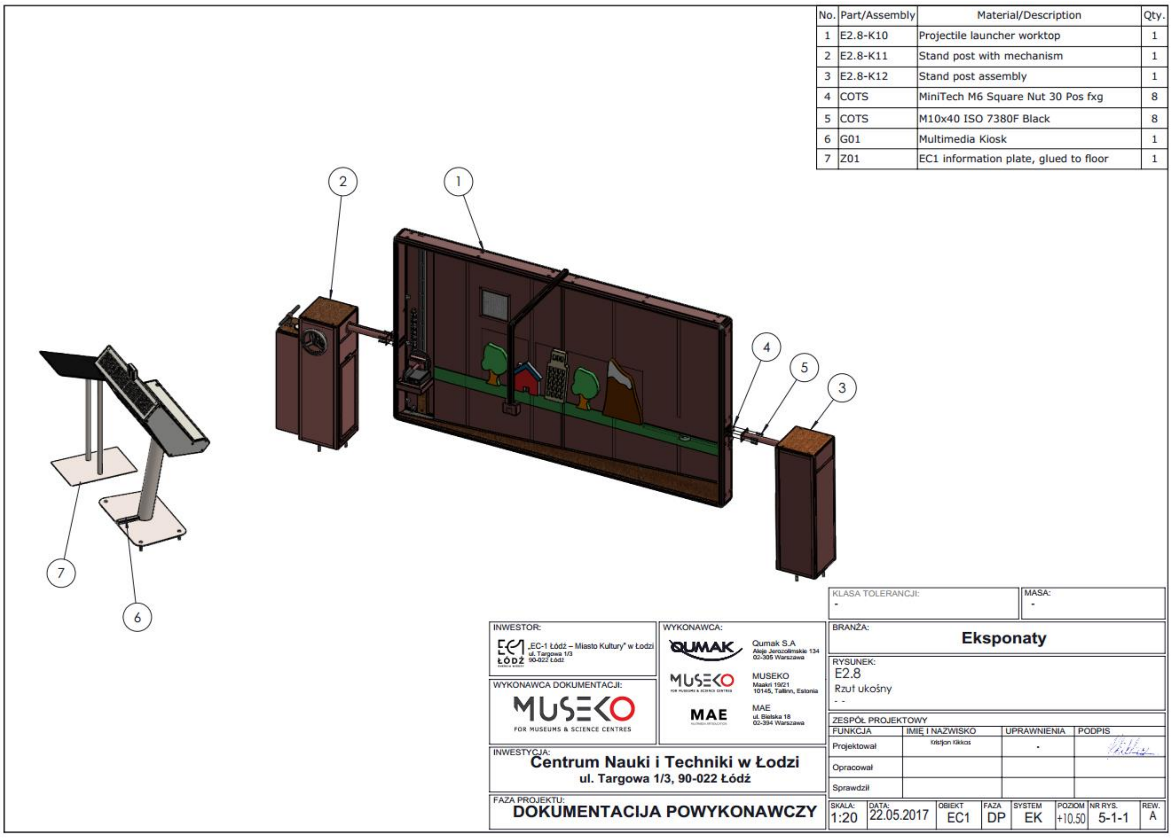


Figure 3.1 Projectile motion exhibit exploded view with BOM table [7]

3.1.1 Designing worktop

Worktop assembly

In figure 3.1 is showed worktop exploded view with bill of material. Tabletop consist frame, cover plates, obstacles, ball rail, camera, display screen, projectile launcher and target systems. Mass of worktop assembly is 90 kg. Tilt table worktop of the surface has dimension of 2,5 m x 1,4 m (Annex 2). Colors of material are selected based on moodboard that project exhibition designer made (Annex 1).

No.	Part/Assembly	Material/Description	Qty.
1	COTS	MiniTech ANGLE 30 R 90	8
2	COTS	MiniTech Screw block 30	68
3	COTS	MiniTech Power-lock fastener N30	21
4	COTS	MiniTech End cap 30x30 Gray	2
5	COTS	MINK_Strip Brushes	1
6	COTS	Ultrasonic range sensor SRF005	2
7	COTS	MiniTech M6 Square Nut 30 Pos fxg	24
8	COTS	M6x30 DIN 912_ISO4762	2
9	COTS	MiniTech M4 Square Netu 30 pos fxg	2
10	COTS	M3x6 DIN 7991-ISO10642	3
11	COTS	Hexagon nut M3 ISO4032-8 Zn	3
12	COTS	M6x10 ISO 7380-2 Black	71
13	COTS	Hex. socket screw with flange M6x30,ISO7380 black	9
14	COTS	Hex. socket screw with flange M6x16,ISO7380 black	4
15	COTS	M6 DIN 9021 SS	12
16	COTS	Hexagon nut M6 ISO4032-8 black	11
17	COTS	MiniTech ANGLE 30 GD	1
18	COTS	M6 DIN 985-ISO7040	3
19	E2.8-D001A	Antiqure copper textured aluminium sheet 2mm	1
20	E2.8-D001B	Antiqure copper textured aluminium sheet 2mm	1
21	E2.8-D002	Antiqure copper textured aluminium sheet 2mm	2
22	E2.8-D004A	Antiqure copper textured aluminium sheet 2mm	3
23	E2.8-D004B	Antiqure copper textured aluminium sheet 2mm	1
24	E2.8-D010A	Antiqure copper textured aluminium sheet 2mm	1
25	E2.8-D010B	Antiqure copper textured aluminium sheet 2mm	1
26	E2.8-D014	Antiqure copper textured aluminium sheet 2mm	1
27	E2.8-D015	Antiqure copper textured aluminium sheet 2mm	1
28	E2.8-D027	Obstacle - House	1
29	E2.8-D028	Obstacle-tree	2
30	E2.8-D029	Obstacle-Skyscraper	1
31	E2.8-D030	Obsticale-mountain	1
32	E2.8-K01	Antique copper tectured aluminium 30x30 profile frame	1
33	E2.8-K02	Target moving system	1
34	E2.8-K03	Projectile launcher system	1
35	E2.8-K06	Antiqure copper textured aluminium sheet 2mm with RGB LED Panel - 32x32	1
36	E2.8-K07	Ball rail assembly	1
37	E2.8-K16	GoPro Session connection assembly	1
38	Hex socket countersunk head screw	M6x12 DIN 7991-ISO10642 Black	22
39	Hex socket head cap screw	M6x30 DIN 912_ISO 4762 Black	3

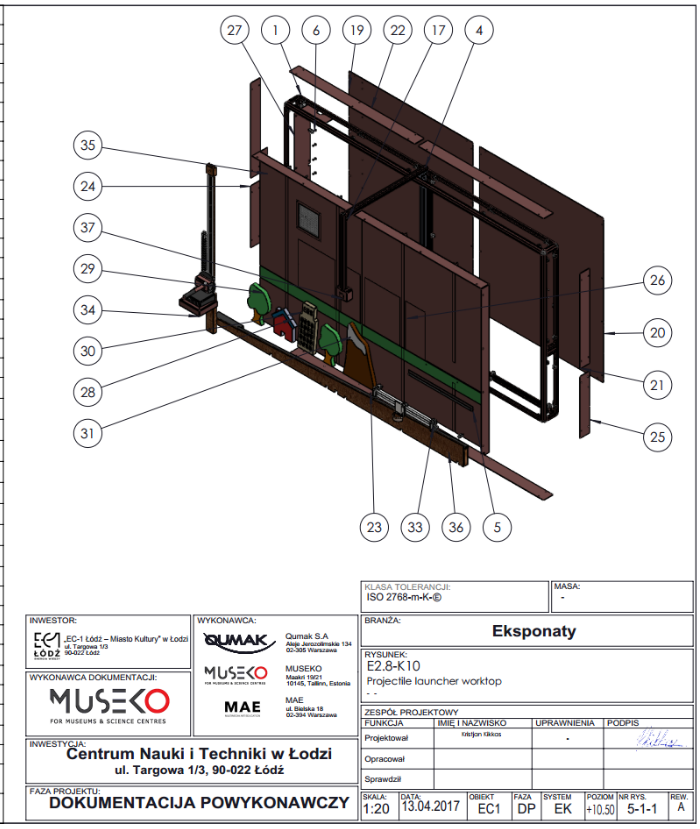


Figure 3.1 Tablet exploded view [7]

Worktop frame

For development worktop, I had to consider that a framework need to be as light as possible as the bearings and shafts that hold the worktop could not bend over. Section 2.1 and 2.2 criteria points were considered for design framework. Frame is made from Minitec 30 R90 aluminum profile. On the supporting structure are Miniteci 30x30 mm, 30x60 mm and 30x30 3G mm profiles (Figure 3.2). Frame mass is 13,2 kg. Using Minitec because it provides the most complete, flexible and easy-to-use T-slopped aluminum framing system on the market today.

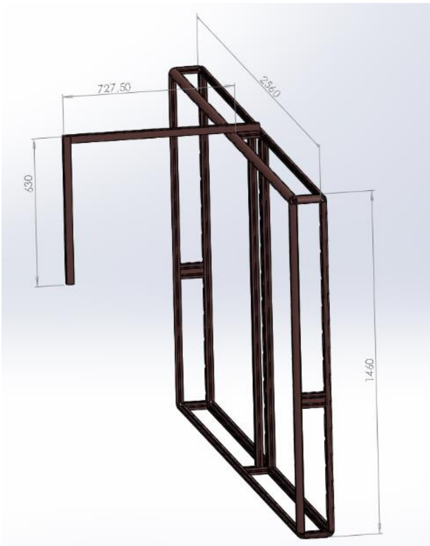


Figure 3.2 Worktop frame assembly [7]

In table 3.2 are properties of aluminum. Aluminum profile is widely used material for making various constructions due its T-slots that lets you use a variety of fasteners – nuts, bolts, clamping. I used aluminum because it as a lightweight material that is easy to process and it is durable (Table 3.1). Also, aluminum reacts with the oxygen in the air to form an extremely thin layer of oxide and is a non-magnetic material.

Table 3.1 Properties of MiniTech aluminum profile [8] [9]

Material type	Al Mg 0,7 Si EN-AW-6063 T66
Specific density, kg/m^3	2750
Tensile strength R_m N/mm^2	245
Yield stress $R_{p0,2}$ N/mm^2	200
Machining	Aluminum is easily worked using most machining methods – milling, drilling, cutting, punching, bending, etc. Furthermore, the energy input during machining is low.

Joining	Features facilitating easy jointing are often incorporated into profile design. Fusion welding, Friction Stir Welding, bonding and taping are also used for joining.

Table 3.2 Properties of aluminum [8] [10]

Density, kg/m^3	2700, a third of the density of the steel
Melting point, ℃	660
Tensile strength R_m N/mm^2	Pure aluminum 80…135 Alloys 600

Frame connections

Connecting frame with special Minitech aluminum profile fasteners, ensuring strong and rigid connections. Used different fasteners as needed. The profile corners are connecting by special clamping block Angle 30 R90 from Minitech (Figure 3.3), which ensures a smoot transition from one profile to another, gibing the frame spectacular design. For using this need to insert supplied M8 screws thru bracket and tighten with a 5mm hex key. Executable profiles are attached by power-lock fastener N30 (Figure 3.4), because the fastener is located inside the profile T-slot so the visitors do not see it.

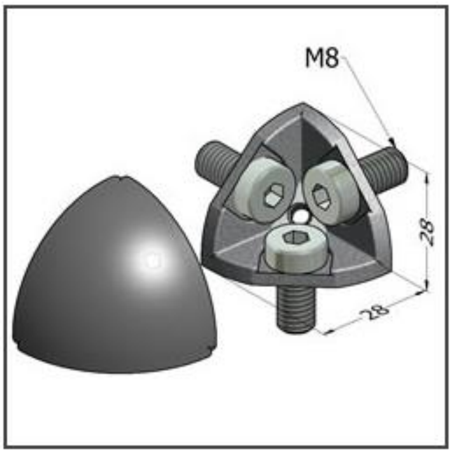


Figure 3.3 Angle 30 R90 fastener [11]

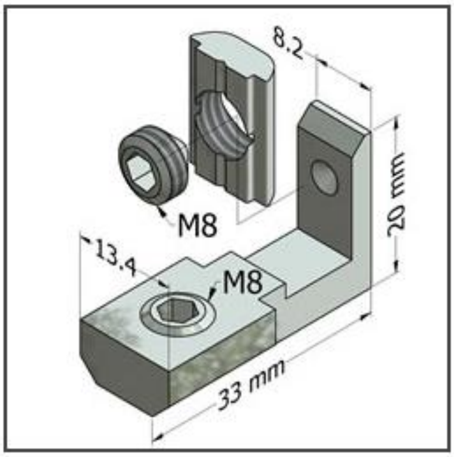


Figure 3.4 Power lock-fastener N30 [12]

For assembling fastener need to slide M8 nut over the L-shaped end of the fastener and tighten M8x6 set screw and then tighten opposing M8x8 set screw against profile. Recommended locking torque for both screws are 10 Nm. Both fastening method advantage is that no drilled access hole is required. The frame is not connected by the most frequent fastening method angle blocks, because this method does not leave space for fixing cover plates and it is not suitable for connecting 30 R90 profile.

Frame cover

Exhibits aluminum profile frame is covered with 2 mm aluminum sheets. Using aluminum to keep the tabletop weight low. Section 2.2 criteria points were considered for attaching aluminum sheets with profile. The selection made between 3 fastening method as seen in Table 3.3 and I apply first two methods ensuring an elegant design and profile of the panels to easily disconnect ensuring access to take care of the equipment's. Square nuts used to connect the worktop two inner sheets using 30 R90 profile T-slots where attach the plates with M6 hex socket countersunk head screws. 30 R90 profile peculiarity is that T-slots are only one side and because that I need to use screw block for connecting external plates. Plates are fixed using M6 hex socket round head screws.

Table 3.3 Comparison of sheet fasteners with profile [13] [14] [15]

	Advantages	**Disadvantages**
1.Square nut	• Easy to remove panels • Spring tab holds nut in position even in vertical t-slots	• Several components to connect panels
2.Screw block	• Easy to remove panels • Caged nut allows adjustment for hole alignment	• Several components to connect panels • Can't use with 30 R90 profile
3.Insert seal	• No extra components to connect panels	• Need to open aluminum profile frame to get access to the plate

Two 25 x 25 x 2 L-standard profiles are welded to the inner panel to ensure the rigidity of the aluminum sheet (Figure 3.5). Welded 2 mm metal sheets for inner panel to be used for attaching obstacles with magnets to the aluminum plate. Placement of metal sheet detects the obstacles usage area.

Screen mount

Incisions are made for panels, one for display attachment and second one for the moving target the display is attached to the 10-mm plywood. The cut-in opening is covered with 5mm clear Plexiglas. Plexiglas material advantages are low specific weight, good transparency and ease of processing [16]. The entire assembly is attached to the sheet with four M6 Hex socket countersunk head screws (Figure 3.5).

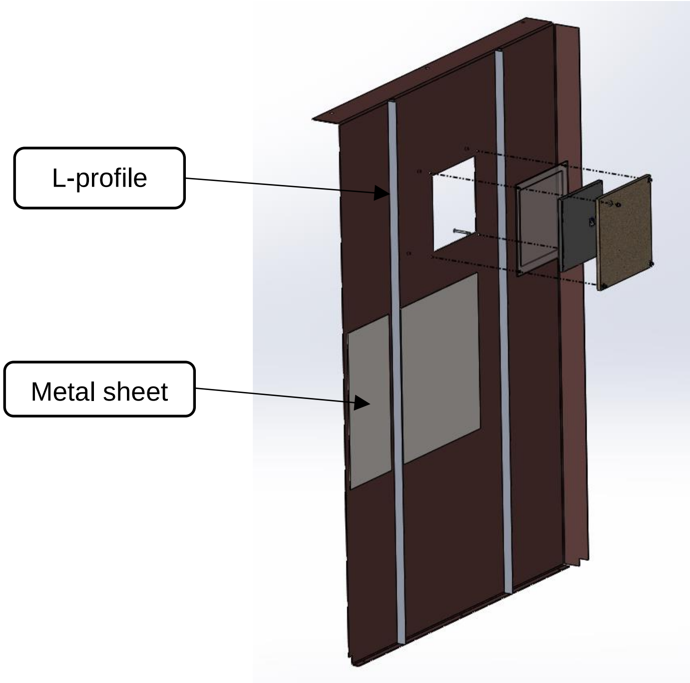


Figure 3.5 – Front panel assembly [7]

Obstacles

Obstacles are made from EVA foam thickness of a 0,3 m (Figure 3.6). It is a strong, flexible, formable and cheap material. Making obstacles from EVA foam because it is an extremely elastic material that can be sintered to from a porous material similar to rubber, yet with excellent toughness [17]. It is easy to process EVA foam to desired shape – house, tree and mountain. Obstacles are accessories in this exhibit that allow performing additional tasks for making hitting target more difficulty.

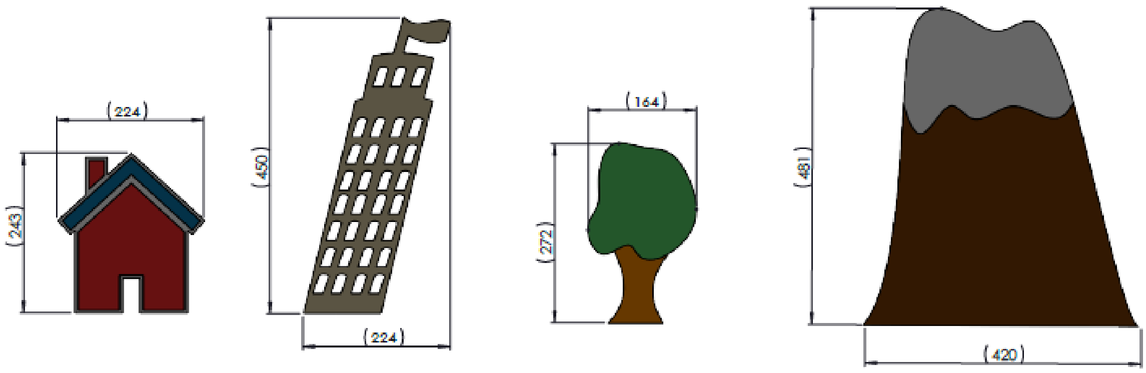


Figure 3.6 Obstacles [7]

Visitors can move obstacles for desired position. Inside EVA foam there are magnets so that visitors can connect them to the aluminum sheet where metal sheets are welded. Magnets was selected based on the tensile strength is not too strong so that visitors are can move and remove items if it is necessary but strong enough to keep the exhibit objects attached and not falling off when they are hit by launching balls. I made a prototype of the obstacle house with 3 magnets to select and test different sizes and tensile strength magnets.

Selected magnet parameters [18]:

- Size: Diameter– 25 mm, height – 10 mm
- Material: Neodymium (NdFeB)
- Coating: Nickel (NiCuNi)
- Type: Permanent magnet
- Grade: N45
- Max. Pull force: 232 N
- Weight: 0,037 kg

Ball rail

Ball rail purpose was ensuring that the balls reach back to the collection point for each possible scenario – flying against obstacles, hitting the edge of tabletops or fly to the basket. Section 2.1 was given the requirement that the ball need to be together in one place and visitors will be able to choose different material of balls. The original idea was to make a loading system that ensure automatic roll back to container-net and from there discs go to hand-made shooter itself automatically. Client didn't like self-made launcher system and so this option was not available.

Rail is made for rolling balls back to the one place. Ball rail angle of inclination is 3 degrees and it is made of plywood of a thickness of 8 mm (Figure 3.7). The plywood surfaces that are exposed to heavy ammunition is foam-coated that absorbs sound and energy so that the balls do not bunch over the exhibit edge.

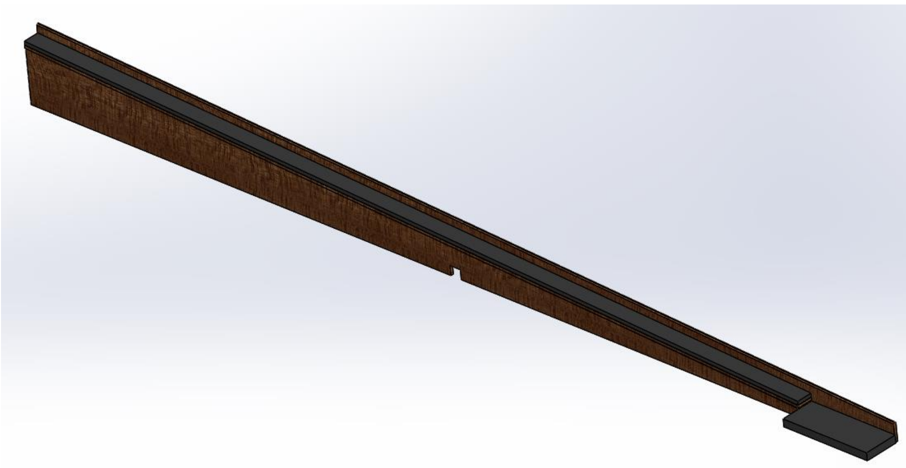


Figure 3.7 Rail assembly [7]

Camera cover and mounting

Camera is attached to the movable worktop on the construction perpendicular to it and moving along with it at a distance that allows recording video sequence of balls flights by MiniTechi 30x30 3G profile. The profile is special for its one T-slot where can be transported camera cables. Camera is protected by camera body made of aluminum sheet thickness of 2 mm. Camera housing is necessary to protect the camera form the visitors. Using GoPro HERO5 Session camera, selected by the EC1 project partner Quack how provide IT system performance. GoPro camera is attached to special Session mounting frame which connect to GoPro flat adhesive mount piece as seen in Figure 3.8. This mount is fixed to the cover plate with double-side tape. Aluminum housing can be removed if necessary by removing M6 hex socket countersunk head screws.

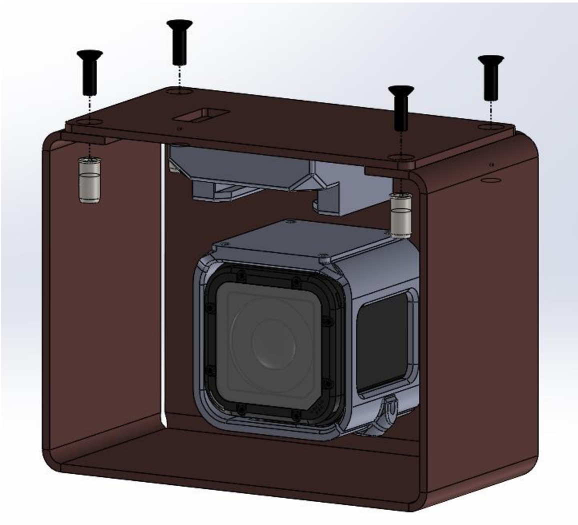


Figure 3.8 Camera assembly [7]

Target system

At point 2.1 there was requirement that adjust the position of the target along edge within the distance of 0,5 m from its end. Requirements were to have visitor's easy to use system that is lightweight, durable, compact and fits in between the frame. System need to be able to carry minimum 0,5 kg target. Using Igus products because they are 100 % self-lubricating and service life is very high without lubrication. Products are high dirt resistance and making low vibration and low noise. There is system at Igus webpage where I can put required parameters of leadscrew models to find right one (Figure 3.9). Not using system with motor because cost will be 3 time bigger and for this system there is no need to have automatic system control with buttons as the target position is changed only by staff when there will be group work.

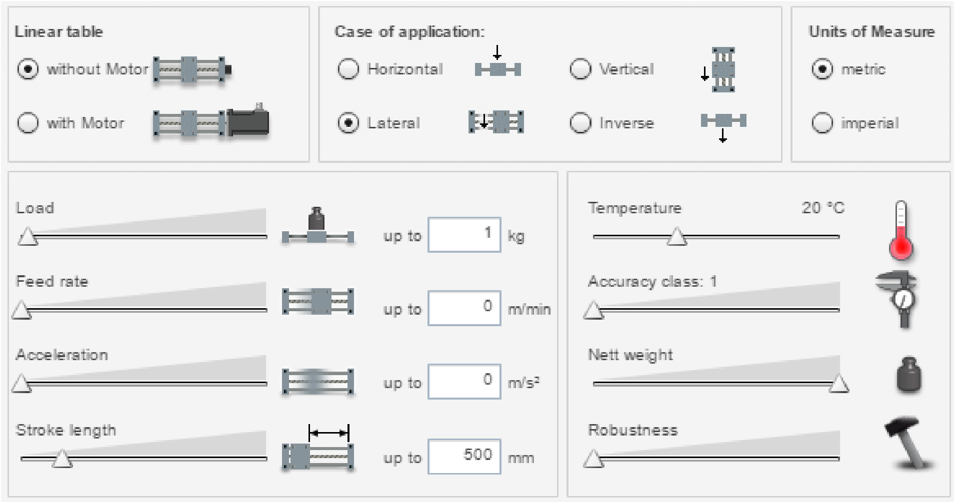


Figure 3.9 Inputs of model system [19]

Selecting Igus SHTP guide system since it is the cheapest which meets the criteria. It is compact fitting between the frame and can regulate guide with know (Figure 3.10).

Type	Drive	Installation size Ø	Shafts Shaft end support	Features	(Precision class)	Vmax [m/min]	rpm max [U/min]	[Nm]	Total price from EUR*
SHTP	10x2	12	Aluminium Plastic		1	1	500	0,16	96,16
SHTP	10x2	12	Aluminium Plastic		2	1	500	0,16	114,52
SET-F	10x2	25	Plastic		1	0,2	100	0,21	150,22
SET	10x2	25	Plastic		1	0,2	100	0,21	150,22
SLW	10x2	10	Aluminium Zinc die-casting		2	1	500	0,26	170,32
SHTC	10x2	12	Aluminium Aluminium		4	1	500	0,26	189,22
SET-F	12x3	30	Plastic		1	0,3	100	0,19	195,60
SET	12x3	30	Plastic		1	0,3	100	0,19	195,60
SHT	10x2	12	Aluminium Aluminium		4	1	500	0,27	210,22
SLWE-PL	10x2	10	Aluminium Zinc die-casting	PL	3	1	500	0,61	212,32
SLW	14x4	16	Aluminium Aluminium		2	1,6	400	0,37	260,52

Vmax: Max. feed rate [m/min]
rpm max: Max. spindle rotation speed [U/min]
Max. drive torque [Nm]
Precision class

PL: Preload
HTX: High temperatures
Mini: Miniature version
HYD: Hygienic Design
FF: Quick release

Selection
SHTP-02-12-AWM

Figure 3.10 Results leadscrew models [19]

Selected model parameters [20]:

- Part number: SHTC-12-AWM
- Overall length: 0,607 m
- Max. stroke length: 0,5 m
- Shafts/Shaft end support: Aluminum/plastic
- Weight: 0,7 kg
- Max. static load capacity: Axial 700 N and Radial 2800 N
- Accuracy class: 1

The first attachment end is attached to the worktop frame in the T-slots with flange and the second attachment end is attached to an aluminum sheet (Figure 3.11).

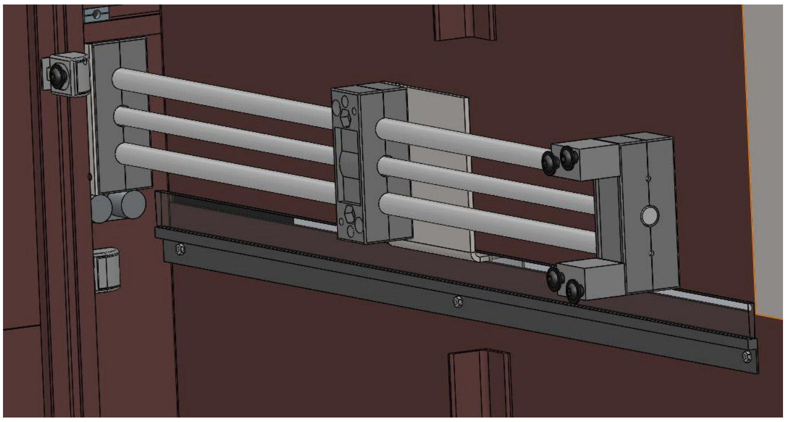


Figure 3.11 Module connections [7]

Target has been made in accordance with the wishes of client. It is like basketball basket; flange is connected to the guide where is wire with diameter of 5 mm and net is welded. Visitors can be seen protruding from the target basket that travels along the slot cut in the panel. The rest of the system is inside the worktop. The slot is covered with brushes that do not let dirt or details inside the worktop. Target can be changed along the horizontal axis 0,5 m with knob that reaches out of worktop (Figure 3.12).

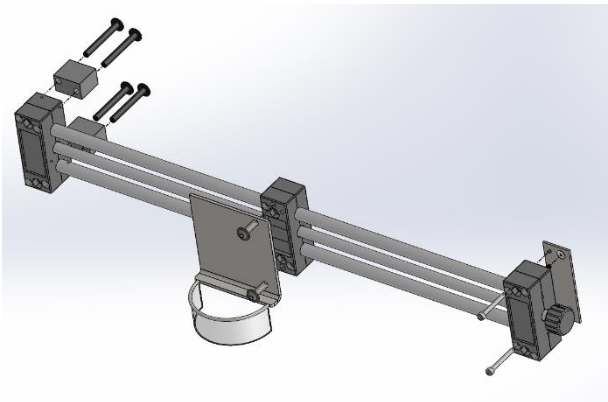


Figure 3.12 Target system assembly [7]

3.1.2 Designing stand posts

Material selection

Based on the material requirements outlined in section 2.2, the overall structure must be made of a structurally homogeneous material like plywood, plastic, powder coated black steel or stainless steel. The welded frame, side panels and shafts material is select from the hot-rolled structural steel S355J0 (1.0553). Side panels and shafts are powder coated with antique copper. S335J0 is a material that is suitable to use heavy loaded welds like crane and bridge structures. Stand post top cover material is RED-darkened plywood Tikkurila 3346. Colors of material are selected based on moodboard that project exhibition designer have made (Annex 1).

Structural steel properties [21]:

- Standard: EN10219
- Grade: S355J0
- Characteristic no: 1.0553
- Tensile strength R_m (N/mm^2): 470-630
- Yield strength R_e (N/mm^2) thickness 80 – 16 mm: 325-.355

Maintenance hatch

Both of stand post have maintenance hatch for easy access to internal parts of the exhibit, this case connecting anchors and computer. Since the exhibit has to be fixed to the floor four anchor points are attached to the stand. The standard anchors for this science center is shown in design manual [2].

Maintenance hatch is made of two 2 mm sheet metal which are welded together. Maintenance hatch locked by 7-pin tubular cam lock Industrials 241300-2502.1 that is outlined in the design manual (Figure 3.13) [2].

Figure 3.13 7-pin tubular cam lock Industrials 241300-2502.1 [2]

Stands strength analysis

Exhibits stands are required to withstand worktop load 900 N and potential extra load by visitor's total load up to 2500 N. Stands deformation in critical load situations must not be greater than 1 mm. Using CAD program SolidWorks Premium to perform simulations where is integrated in the FEM program package SolidWorks Simulation.

First thing was simplified model of the stand in CAD program SolidWorks as seen in Figure 3.14. It can be seen that the stand had fixed connections between ground floor (green arrows) and shaft is divided into mesh. Added load situation where a force acts on the stand bearing plates with 2500 N (orange arrows) and the force of gravity (red arrow)

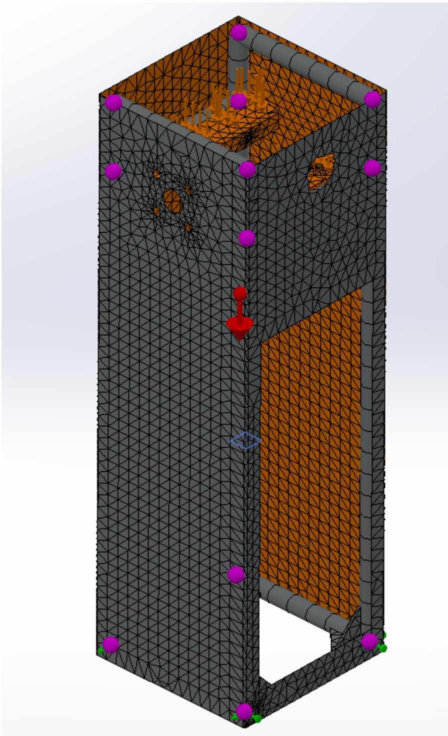


Figure 3.14 Mesh analyses of stand [7]

Below are simulated based on the points of attachment and influential forces the static nodal stress and the static displacement of shaft. Simulation results have generated a maximum stress of 181 MPa (Figure 3.15) which is below the yield strength.

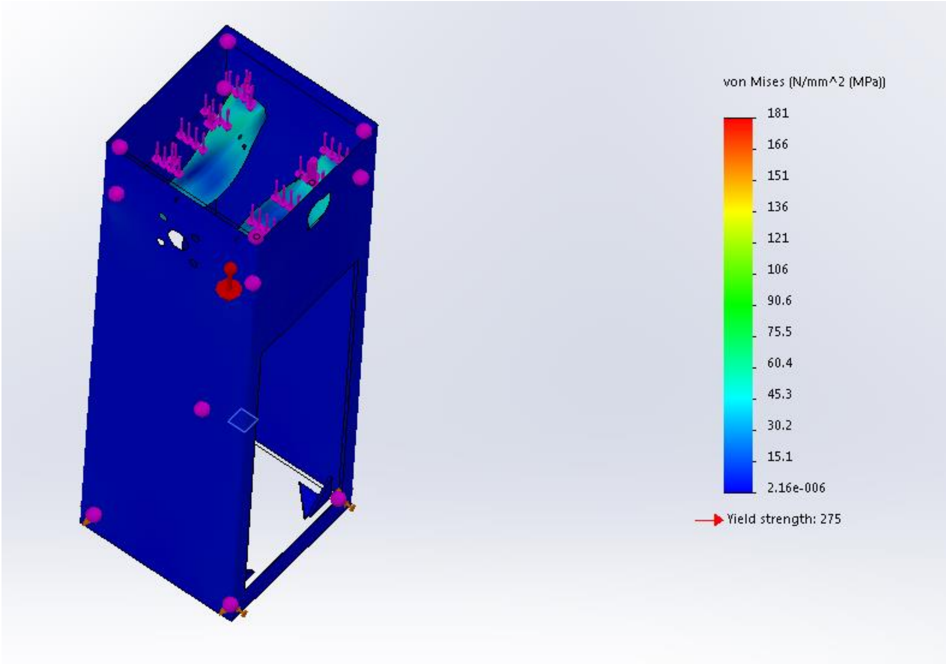


Figure 3.15 Static nodal stress analyses [7]

The simulation result shows that stand static displacement maximum value is 0,45 mm (Figure 3.16). The resultant deformation parameters remain within the required limits.

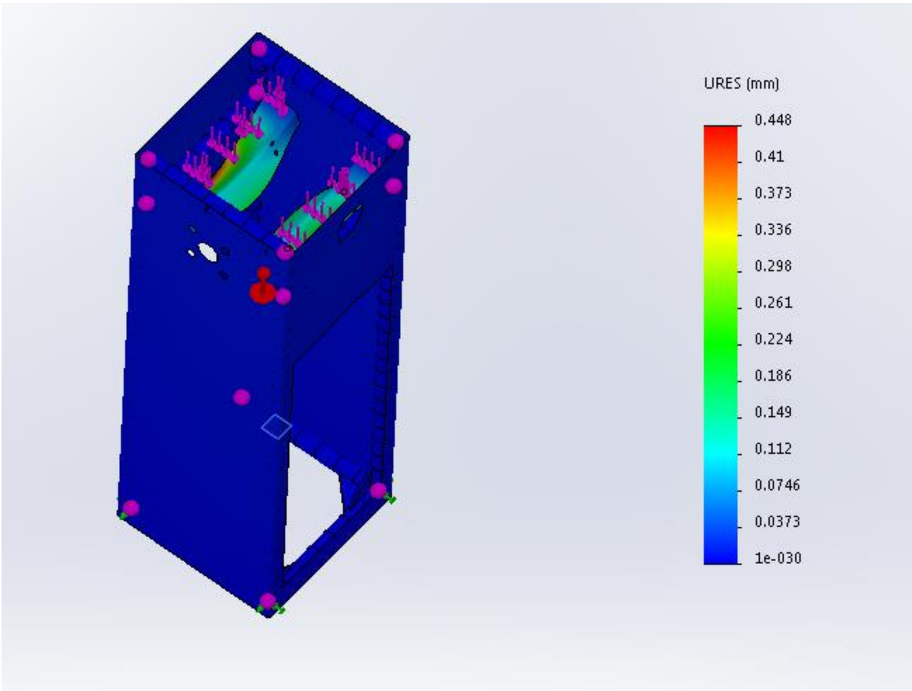


Figure 3.16 Static displacement of shaft [7]

3.1.3 Stand post with mechanism

Stand post consist computer that analysis measuring results, screen and is communicating with info screen. The angle of tilt is adjusted by driving mechanism by crank in the range from vertical to horizontal position. Pressure of launching system is regulated by hand pump (Figure 3.17).

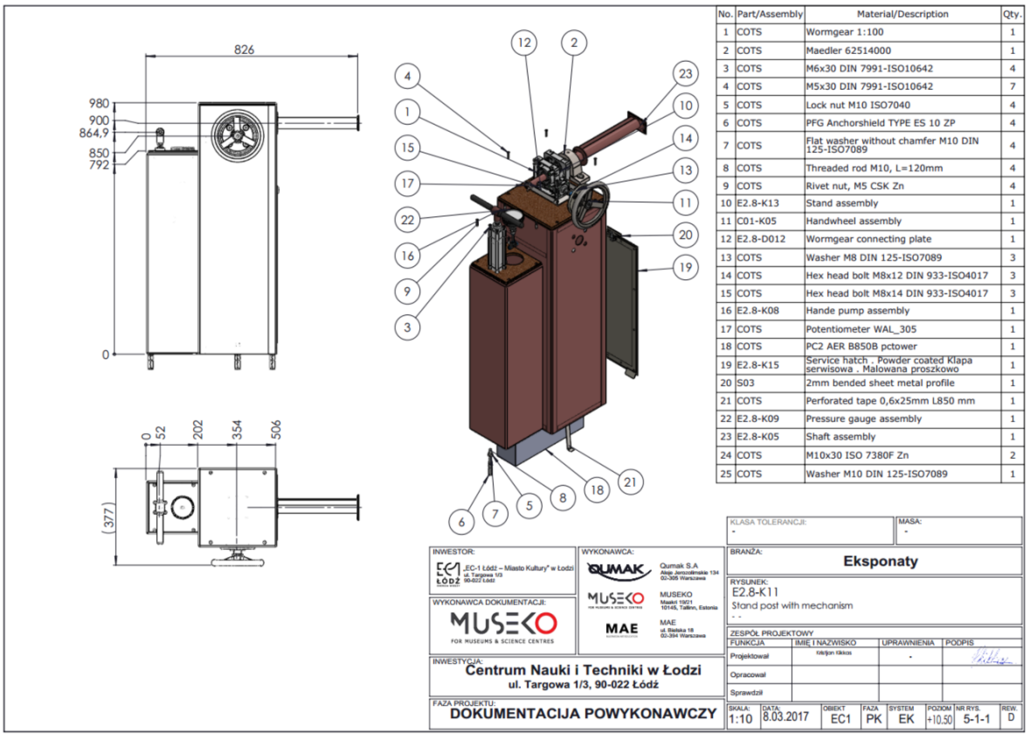


Figure 3.17 Stand post with mechanism exploded view [7]

Frame

Stand frame is made of 30x302 EN10219 square hollow section steel profile. In order to ensure the rigidity of the frame gusset plates are welded to the profile connecting points. 8 mm black steel plates are welded to the frame for connecting driving mechanism with stand. Selected 8 mm sheet metal to be able to make as deep of threaded holes for fixing mechanism with bolts. Cover plates made of 2 mm sheet metal are welded to the frame and powder coated with antique copper. The top plate is made of 12 mm fireproof plywood. Based on the requirements listed in the chapter 2.2 the plates are attached to the frame with four M6 hex socket countersunk head screws.

Strength analysis

Exhibits shafts and stands are required to withstand worktop load 900 N and potential extra load by visitor's total load up to 2500 N. Shaft deformation in critical load situations must not be greater than 2 mm.

First thing was simplified model of the shaft in CAD program SolidWorks as seen in Figure 3.18. It can be seen that the shaft had fixed connections between the bearings and the tilting mechanism (green arrows) and shaft is divided into mesh. Added load situation where a force acts on the shaft end with 2500 N (purple arrows) and the force of gravity (red arrow)

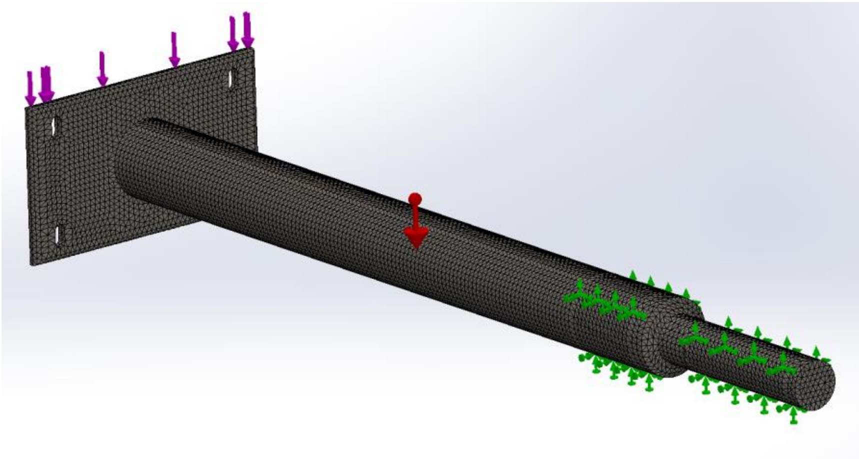


Figure 3.18 Mesh analyses of shaft [7]

Below are simulated based on the points of attachment and influential forces the static nodal stress and the static displacement of shaft. Simulation results have generated a maximum stress of 289 MPa (Figure 3.19) which is below the yield strength.

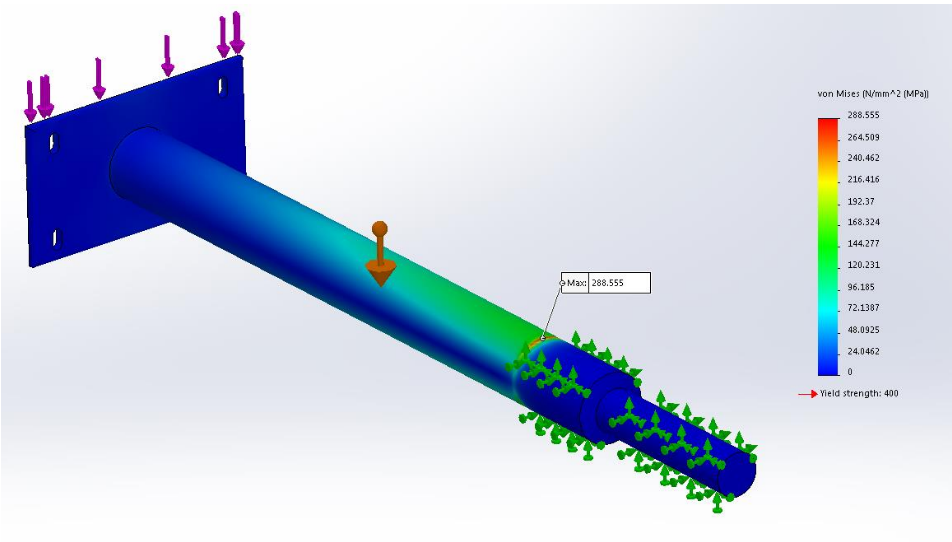


Figure 3.19 Static nodal stress analyses [7]

The simulation result shows that if the shaft diameter of 0,4 m is used shaft static displacement maximum value is 1,59 mm (Figure 3.20). The resultant deformation parameters remain within the required limits.

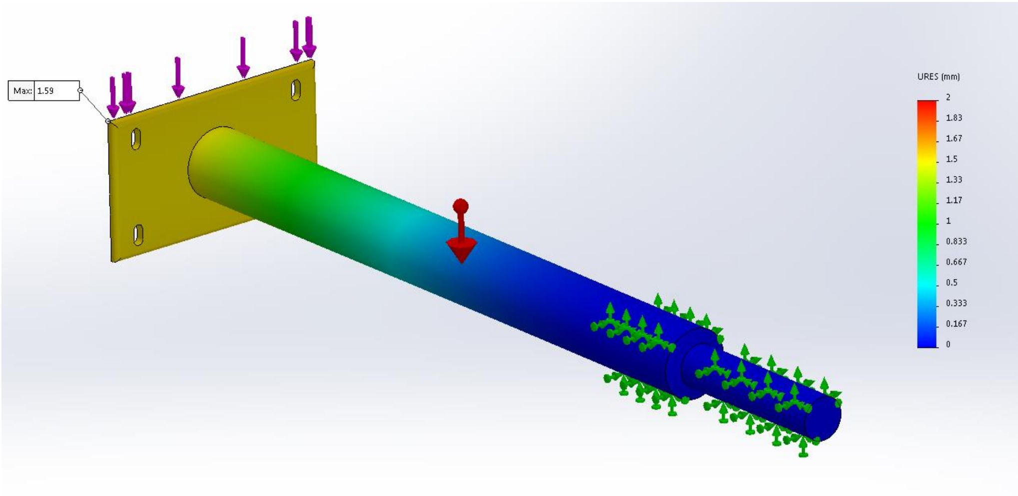


Figure 3.20 Static displacement of shaft [7]

Shaft

The purpose of the shaft is connecting worktop with stands and tilting system. For dimensioning distance between stand and worktop or distance between worktop and ground I had to take into consideration criteria of point 2.2. Length between tabletop and stand must be at least 0,3 m. Length between tabletop and ground must be at least 0.3 m so that visitors body parts can't stuck between moving exhibit parts. Shaft diameter *D*=0,04 m is selected according to the results of strength analysis (Figure 3.21). A third of shaft for stand post with tilt mechanism diameter is reduced to 0,025 m. It is necessary because the shaft have been connected also to the worm gear.

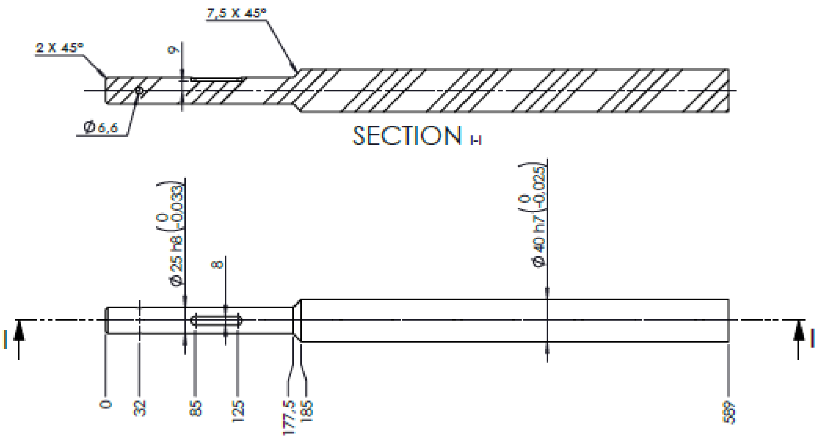


Figure 3.21 Stand post with tilt mechanism shaft [7]

It is seen in figure 3.22 that end of shaft is welded flange made of 8 mm stainless steel to help fix shaft with worktop. Flange is connected to worktop with four M8 bolts. There is sheet metal cover that conceals cables and pipes for protecting them from visitors.

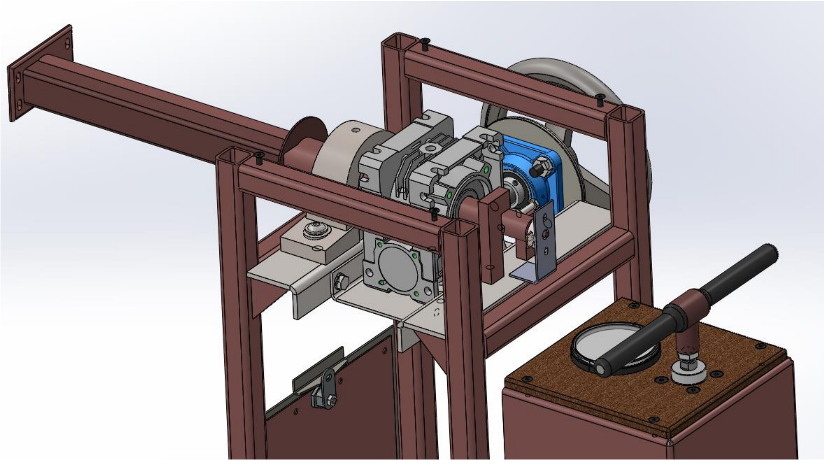


Figure 3.22 [7] Stand post with tilt mechanism

Bearings

To selecting bearing I had to be based on the dimeter of shaft which based on simulation. Bearing bore must be 0,4 m. Static bearing load must be at least 2500 N. Picked out Mädler Ball Pillow Block Bearing UCP208 (Figure 3.23). The shaft will get fastened with 2 setscrews (Figure 3.22). Lubricated for life at normal operating conditions. Re-lubricating is possible.

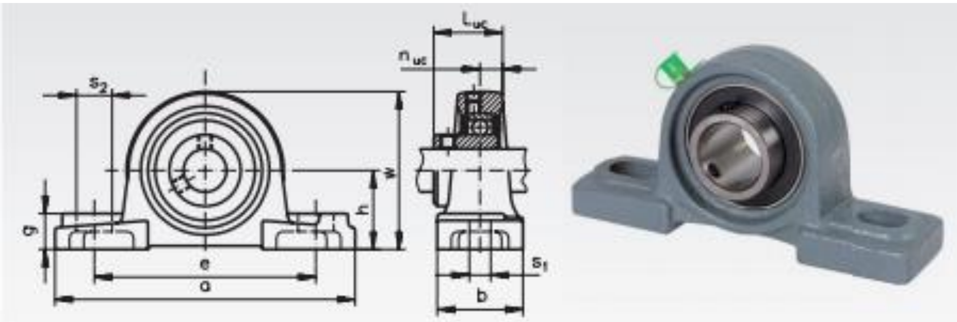


Figure 3.23 UCP bearings [22]

Selected UCP bearing [23]:

- Type: UCP208
- Bore: 0,04 m
- Bearing load rating dyn. C: 22,6 kN
- Bearing Load Rating stat. C_o 15,7 kN
- Weight: 1,97 kg

Driving mechanism

One of the requirements were that stand should be integrated the mechanism adjusting the worktop tilt angle, controlled by Visitors with a physical manipulator integrated in the direct vicinity of the tilting mechanism. For that gear system was selected.

Requirements of gear system were:

- Operate silently and smoothly
- Safety – tilting locking system
- At least 100:1 gear ration
- Compact
- Output shaft minimum radial load 2500 N

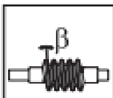
For adjusting the worktop tilt angle, I am going to use worm gear which output is shaft that connects worktop and input shaft is connected to the crank. Advantages of worm gear is that operate silently and smoothly and most important thing is that this gear is self-locking to prevent tabletop to move under its weight. Selecting worm gear ration 1:100 so that visitors have easy change tabletop angel by crank and preventing locking tabletop desired angle. Using HydroMec Q50 square worm gearbox that correspond to the desired requirements.

Gearbox Q50 parameters [24]:

- Weight: 3,25 kg
- Ration i: 100
- Output speed: 14 min^{-1}
- Output shaft diameter: 25 H8 mm
- Output shaft radial load: 2800 N
- Input speed: 1400 min^{-1}
- Input shaft diameter: 16 h6 mm
- Input shaft radial load: 380 N

The following Table 3.4 shows the different tables of reversibility for worm gearboxes according to helix angle ß and reduction ratio i.

Table 3.4 Reversibility for worm gearboxes [25]

	Q30	Q45	Q50	Q63	Q75	Q85	Q11	Q13	Q15
	i								
>25°		7		7	7	7	7	7.5	7.5
12° - 25°	5 7 10 15	10 14	7 10	10 15	10 15	10 14 20 22	10 16 20 23	10 15 20	10 15 20
8° - 12°	20	21	14 18	19 24	20 25			25	25 30
5° - 8°	30	28	26 36	30 36	31 40	28 38 46 52	30 38 45 53 64	30 40 50 60	40 50
3° - 5°	40	37 46 60	43 60 68	45 60 67 80	50 60 80	67 74 96	84 99	80 100	60 80 100
1° - 3°	61 80	70 102	80 100	94	100				

>25°	Totally reversible
12° - 25°	Statically reversible Quick return Dynamically reversible
8° - 12°	Variable static non-reversing Quick return in case of vibrations Dynamically reversible
5° - 8°	Statically non-reversing Return in case of vibrations Bad dynamic reversing
3° - 5°	Statically non-reversing Slow movement return in case of vibrations Low dynamic reversing*
1° - 3°	Statically non-reversing No return Low dynamic reversing*

With ration of 100 the selected Q50 gearbox provides statically non-reversing and no returning system as it helix angle ß is between 1 -3 .

Wormgear input shaft is connecteted thro ball flange bearings UCF204 to the crank. For this project common cranks was selected by costumer - Elesa ganter DIN 950-GG-200-K18-A. Cast iron crank diameter is 0,2 m and its bore diameter is 0.02 m with H7 tolerance. Weight of crank is 1,92 kg [26]. This crank system is connected standi with flange made of 8 mm sheet metal and four M10 bolts (Figure 3.24).

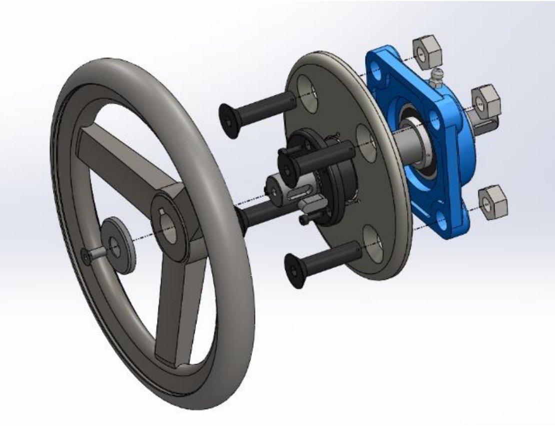


Figure 3.24 Crank system [7]

Ball flange bearing UCF properties [22]:

- UCF no: 204
- Bore: 0,02 m
- Bearing load rating dyn. C: 9,9 kN
- Bearing Load Rating stat. C_o 6,2 kN
- Weight: 0,59 kg
- 4 mounting holes

Regulating worktop tilt angle with two stops made of 12 mm stainless steel seen in the Figure 3.25. Trought shaft goes M8 bolt which define worktop maximum and minium tilt angle.

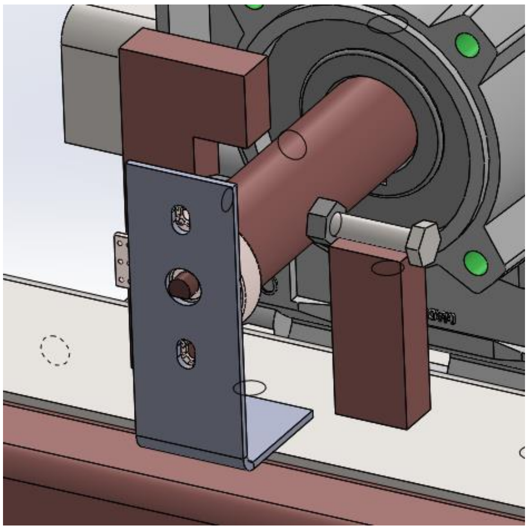


Figure 3.25 Angle limitations [7]

3.1.4 Second stand post

This second stand post consist frame, maintanche hatch and shaft with two same bearings as previos stand (Figure 3.26).

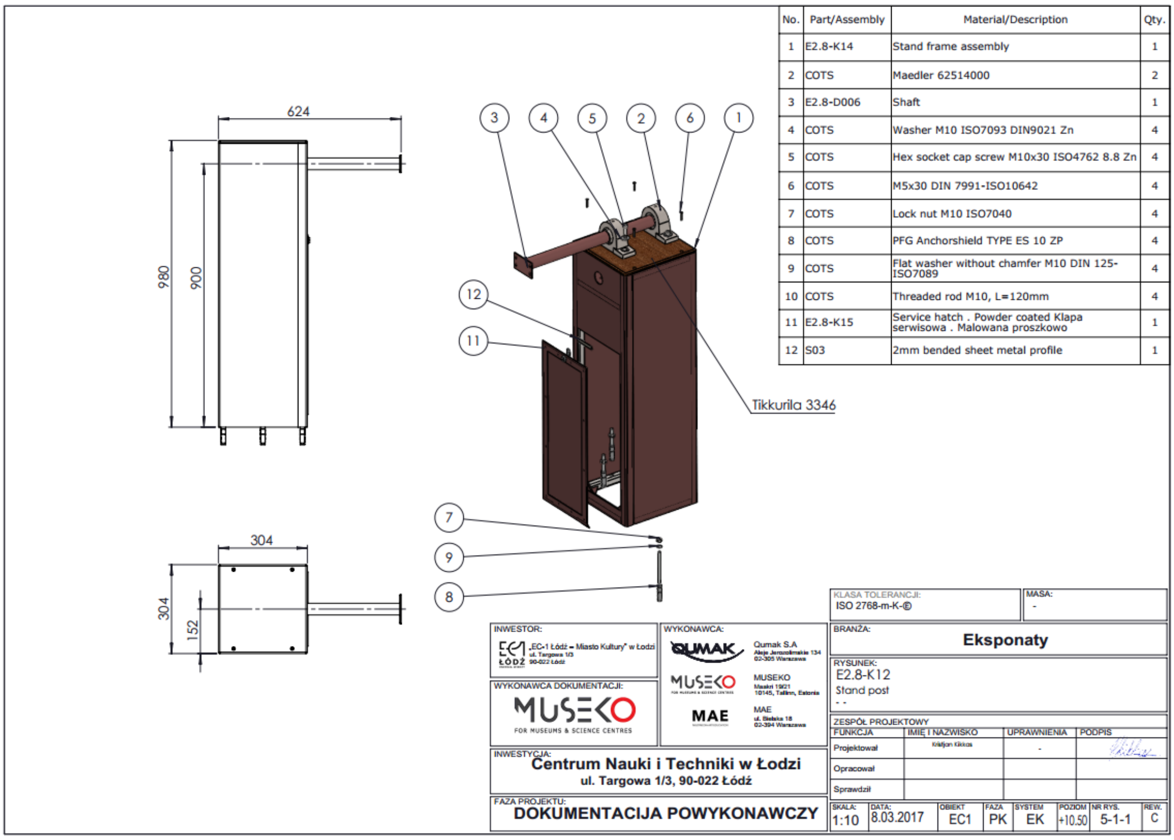


Figure 3.26 Second stand post exploded view and BOM list [7]

Frame

Second stand frame is also made of 30x302 EN10219 steel profile. In order to ensure the rigidity of the frame gusset plates are welded to the profile connecting points. 8 mm stainless steel plates are welded to the frame for connecting driving mechanism with stand. Selected 8 mm sheet metal to be able to make as deep of threaded holes for fixing mechanism with bolts. Cover plates made of 2 mm sheet metal are welded to the frame and powder coated with antique copper. The top plate is made of 12 mm fireproof plywood on the basis of the requirements listed in the chapter 2.2 the plates are attached to the frame with four M6 hex socket countersunk head screws. (Figure 3.27).

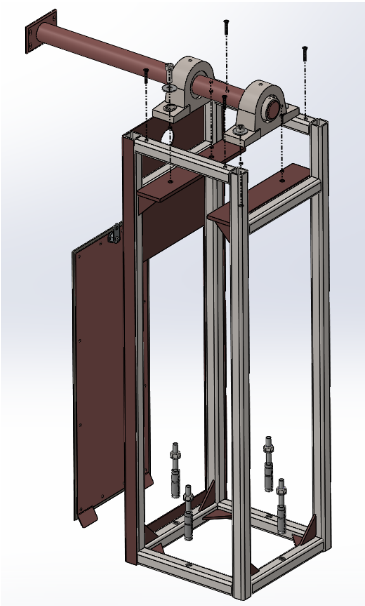


Figure 3.27 Second stand post [7]

Strength analysis

This shaft is also required to withstand worktop load 900N and potential extra load by visitors up to 2500 N. Shaft deformation in critical load situations must not be greater than 2 mm.

First thing was simplified model of the shaft in CAD program SolidWorks as seen in Figure 3.28. It can be seen that the shaft had fixed connections between the two bearings (brown arrows) and shaft is divided into mesh. Added load situation where a force acts on the shaft end with 2500 N (purple arrows) and the force of gravity (red arrow).

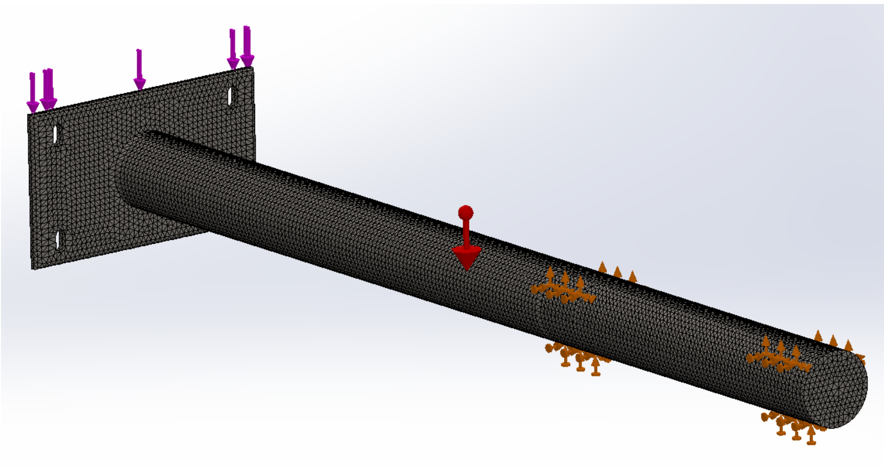


Figure 3.28 Mesh analyses of shaft [7]

Below are simulated based on points of attachment and influential forces the static nodal stress and the static displacement of shaft. Simulation results have generated a maximum stress of 251 MPa (Figure 3.29) which is below the yield strength 400 MPa.

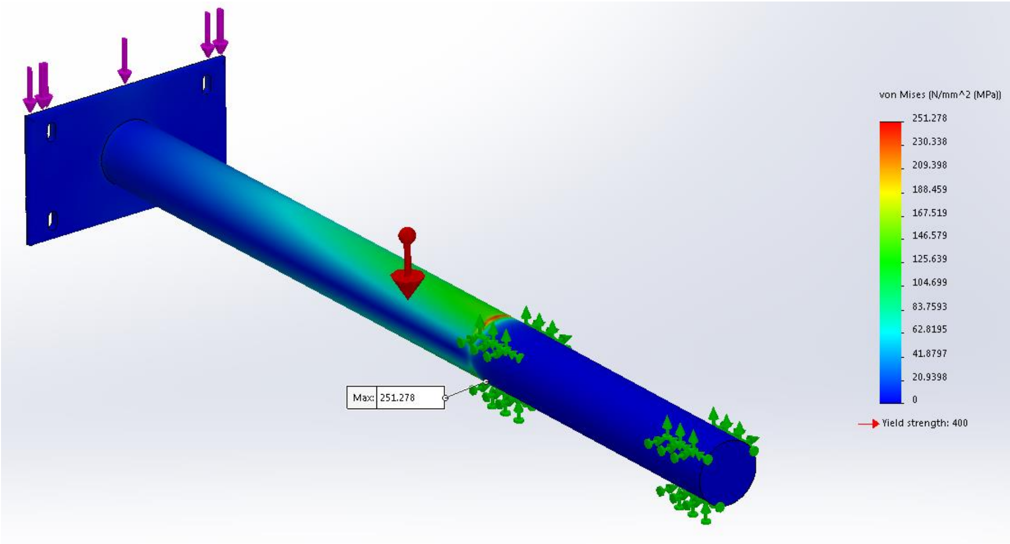


Figure 3.29 Static nodal stress analysis [7]

The simultasion result show that if the shaft diameter of 0,4 m is used shaft static displacement maximum value is 1,63 mm (Figure 3.30). The resultant deformation paramteres remain within the required limits.

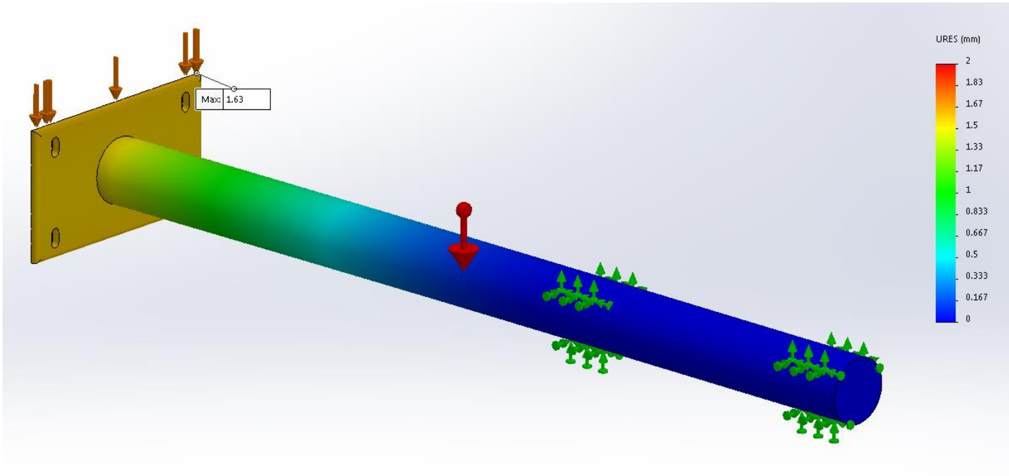
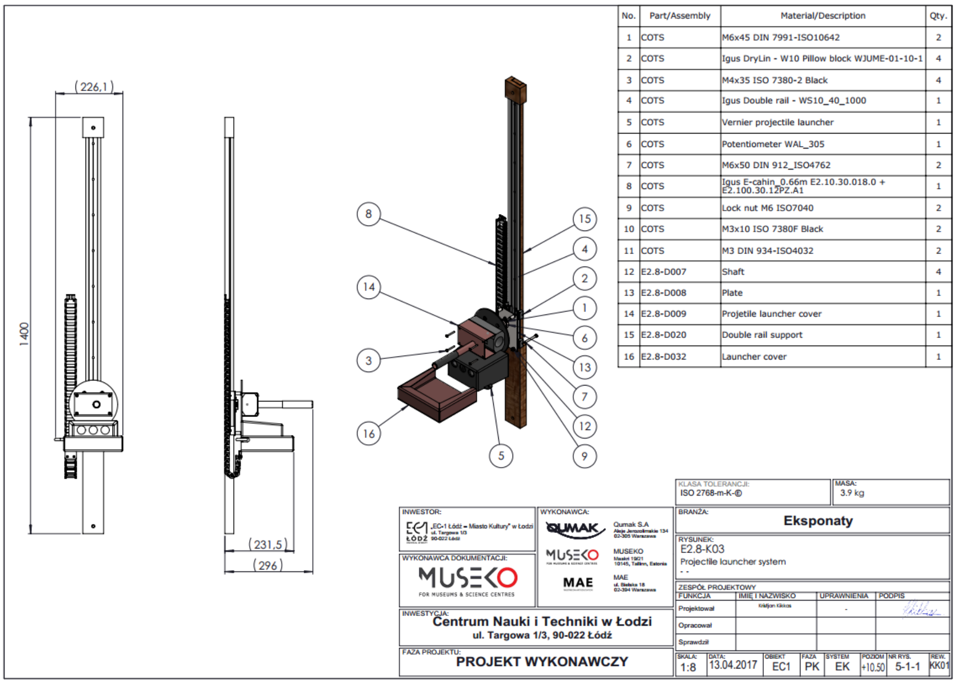


Figure 3.30 Static displacement of shaft [7]

3.2 Projectile Launcher-Pneumatic system

3.2.1 Projectile launcher system

Aim of this system is launch projectiles along the worktop surface. Visitors can adjust position of the launcher along the vertical edge of the worktop and toss balls at specific angle towards the basket. Exploded view with BOM table is shown in Figure 3.31. All the client requirements at point 2.1 are fulfilled.



No.	Part/Assembly	Material/Description	Qty.
1	COTS	M6x45 DIN 7991-ISO10642	2
2	COTS	Igus DryLin - W10 Pillow block WJUME-01-10-1	4
3	COTS	M4x35 ISO 7380-2 Black	4
4	COTS	Igus Double rail - WS10_40_1000	1
5	COTS	Vernier projectile launcher	1
6	COTS	Potentiometer WAL_305	1
7	COTS	M6x50 DIN 912_ISO4762	2
8	COTS	Igus E-cahin_0.66m E2.10.30.018.0 + E2.100.30.12PZ.A1	1
9	COTS	Lock nut M6 ISO7040	2
10	COTS	M3x10 ISO 7380F Black	2
11	COTS	M3 DIN 934-ISO4032	2
12	E2.8-D007	Shaft	4
13	E2.8-D008	Plate	1
14	E2.8-D009	Projetile launcher cover	1
15	E2.8-D020	Double rail support	1
16	E2.8-D032	Launcher cover	1

Figure 3.31 Projectile launcher system exploded view with BOM table [7]

Launcher mounting

For mounting launcher system to the work top, I have used Igus drylin® W double round rail guide. The drylin® W profile guides constitute a cost-efficient preassembled system. The design allows extremely high flexibility in design and a simple installation by the application of individual or double rails Hard-anodized aluminum is used as rail material and provides for the best friction and wear results by profile guides. The exclusion of lubrication also makes the system extremely insensitive to dirt and because of the cleanness it is well-suited for applications in clean and hygienic environments too [27]. Rail guide is connected to the plywood which is attached to the side of the aluminum sheet by M6 bolts.

Requirements for linear guides to move system along the vertical edge:

- Able to carry at least 10 N load
- Low cost
- Adjustable clearance

Using Igus drylin® WJUME-01-10 linear guides with adjustable clearance to adjust position of the launcher along the vertical edge of the worktop. With one turn, I can adjust the clearance manually to the desired clearance so that visitors can change position of launcher by hand and preventing carriage to fall down under the weight of its own.

Igus drylin® WJUME-01-10 linear guides with adjustable clearance features [28]:

- 100% lubrication-free
- Compact dimensions
- Weight: 0,043 kg
- Coy: 560N
- Coz^{+}: 560N
- Coy^{-}:250N

Vernier projectile launcher in connected to the slide table made of 2 mm metal sheet which is connected with 4 linear guides. Sensor is attached to the slide table to measure launcher cannon angle.

Launcher

Using Vernier projectile launcher to investigate important concepts in two-dimensional kinematics. Launching 3 material types' balls, steel, plastic and wood, at angles between 0 to 70 degrees and over distance up to 2,5 m. The solid, heavy base provides an easy-to-use and reliable setup. A pneumatic launching system provides excellent repeatability and allows setting the launch speed. Built-in photogates and angle markings provide easy and accurate measurement of the ball's launch velocity, allowing for precise quantitative analysis of projectile motion. There is opportunity to plug the device into a compatible data-collection interface [4].

Specifications of launcher [4]:

- Launch angle: 0 to 70 degrees
- Launch speed: 0-6 m/s
- Maximum launch distance: 2,5 m
- Internal photogate interval: 0,005 m
- Barrel diameter: 0,01746 m

Projectile has an easy-to-use dial, main scale calibrated in 10°, auxiliary one in 5°, allows setting the desired launching angle. A turn knob is set to the highest range and removed so that visitors will not be able to remove it and take away (Figure 3.32). The hand pump is used to pressurize the system and control the desired range pressure.

Dial *Knob*

Figure 3.32 Projectile launcer dial and Knob [4]

To initiate the launch, the launching system requires simultaneous engagement of the "Arm" and "Launch" buttons. This allows the ball to be launched quickly and easily, while still ensuring visitors safety (Figure 3.33).

Figure 3.33 Initiate the launch [4]

There are four I/O ports located on the base of the launcher, as shown on the Figure 3.34:

- **Interface** – For connection to a Vernier interface via the photogate cable. This connection also provides power to the VPL.
- **Ext. Switch** – For connection to accessory devices
- **Aux Input** – Receives input from future optional auxiliary devices
- **Power** – Allows you to connect an optional 5 V DC power supply for using the launcher when not using an interface.

Figure 3.34 Ports on the front of the base [4]

Prodection case made of 2 mm aluminium sheet is made for projectile launcher to protect and hide the ports and cables against visitors. Took advantage of system mounting holes seen in the Figure 3.34 to connecting prodection case with launcher. In the Figure 3.35 are shown prodection case and cannon case. Purpose of cannon case is to ensure safe loading method. The cover is welded onto the pipe with a bore diameter of 18 mm. Rubber is attached aroun the tube so that visitors would have better grip. Pipe has two addional task. Rotating tube can be changed cannon angle and moving tube up and down can change launcher system position along the horizontl axis of the table.

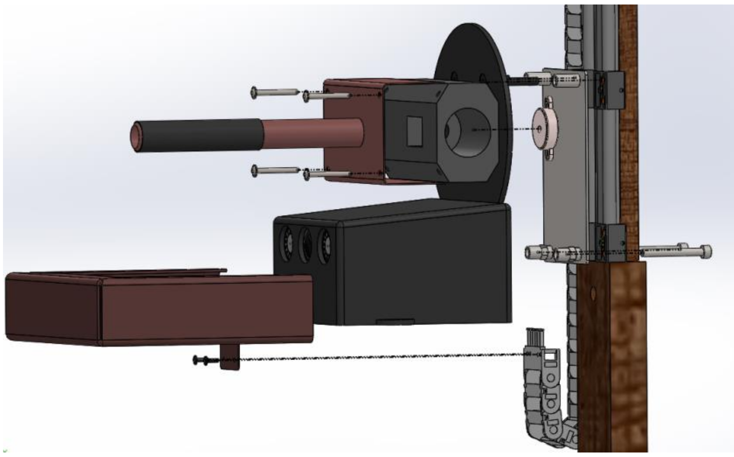


Figure 3.34 Projectile launcher exploded view [7]

Energy chain

Criteria for energy chain were that it must be as lightweight, compact and the maximum bending radius of 0,03 m so that it would save space. Calculating the bending radius, I also had to consider the bending radius of pneumatic tube. Along the energy chain launcher I/O cables, power cables, sensor cables and pneumatic tube are carried. Chain provides cables protection from visitors.
Selected E2.10 micro e-chains® (Figure 3.35). They are very small, one-piece energy chains with a low weight and therefore ideal for my exhibit. Cable-friendly with very smooth contours and low noise, built-in brake reduces noise.

E2.30 micro e-chains® parameters [29]:

- External width: 0,037 m
- Inner width: 0,03 m
- Bending radius: 0,015 m
- Travel distance: 0,64 m
- Max. fill weights: 0,7 kg/m

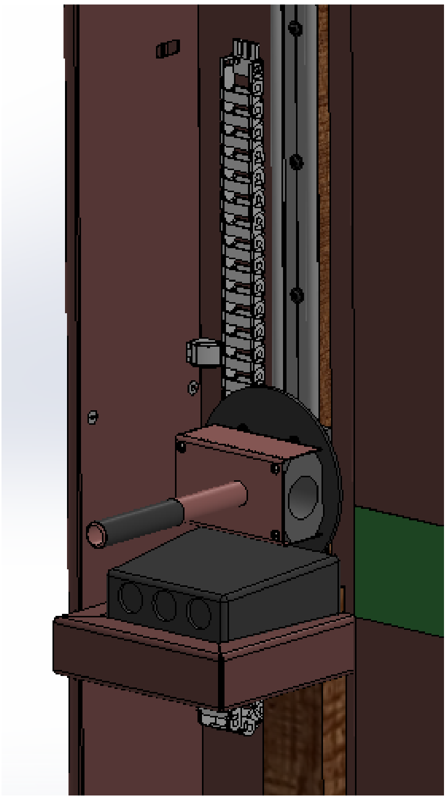


Figure 3.35 Energy chain in worktop

3.2.2 Pneumatic system

Launcher system works on pressure. Desired pressure to the system is pumped by hand pump. Next to hand-pump is pressure gauge where visitors can collect pressure data to correlate with their range data. Inside projectile launcher is small reservoir with an electrical valve where can be pumped into the pressure 0,9 MPa. To initiate the launch, the launching system requires simultaneous engagement of the “Arm” and “Launch” buttons which opening electrical valve insinde launcher.

Hand pump

Projectile launcher included hand pump seen at Figure 3.36 but I cannot use this in exhibit because it is not very resistant pump. Visitors will able to break current pump piston and pressure gauge because piston diameter is too small with any support and pressure gauge is made of plastic. Additionally, I replaced the pneumatic tubes for the tubes with smaller bending radius so it would be more convenient to carry them thru worktop and shaft to the projectile launcher system

Figure 3.36 Included hand pump [4]

Hand-pump that came from with launcher has been inconvenient to use by visitors due its small size. Replacing hand-pump with guide drive actuator and connecting this to the stand post with mechanism. Guide drive must have good protection against torsion, high resistance to torques and lateral forces so that visitor can’t bend guide stroke.

Therefore, two options were available. Using cylinders with bigger piston rod or drives with guides. The maximum force which is necessary to move the cylinder at 0.6 MPA must be 150 N so that visitors are able to move it.

Theoretical pull F^+ and push F^- force calculations for double-acting cylinder can be calculated by the formulas 3.1 and 3.2 [30]:

$$F^+ = p \cdot \frac{\pi \cdot D^2}{4} \quad (3.1)$$

$$F^- = p \cdot \frac{\pi \cdot (D^2 - d^2)}{4} \quad (3.2)$$

Where,

p – System pressure, MPa

D – Diameter of the cylinder of the piston, mm

d – Diameter of the piston rod of the cylinder, mm

π – Mathematical constant

Table 3.5 Festo double-acting cylinders theoretical forces at 0.6 MPa [31].

Forces [N]										
Piston ∅ [mm]	12	16	20	25	32	40	50	63	80	100
Theoretical force at 6 bar, advancing	68	121	188	295	482	754	1178	1870	3016	4712
Theoretical force at 6 bar, retracting	51	90	141	247	415	686	1057	1750	2827	4418

As seen in Table 3.5 and formulas that forces increases with the square of the diameter. In other words, doubling the bore will quadruple the forces. In order that the force developed by the cylinder remains below 150 N have to use guide drive with 16 mm piston which pull force *F+* = 121 N at 0.6 MPa. Because piston diameter is small I need to use drive with guides.

Replacement of projectile launcher hand pump is double-acting FESTO guided drive DFM, where piston rod is at one end (Figure 3.37). Drive and guide unit is in a single housing which provides minimal space requirement. Guide have rigid construction and it is maintenance-free. Excellent protection against torsion, high resistance to torques and lateral force to its large-diameter guide rods and four plain-bearing bushes [31].

Guided drive handle is made stainless steel and powder coated with RAL 7047. Handle diameter is 0.02 m and length 0.28 m to use this with both hands.

Figure 3.37 Double-acting FESTO guided drive DFM [31]

Guided drive DFM general technical data [31]:

- Function: double-acting
- Piston diameter: 16 mm
- Stroke: 100 mm
- Pneumatic connection: M5
- Operating pressure: 0,2 – 1,0 MPa

- Maximum speed: 0,8 m/s
- Theoretical fore at 0,6 MPa, advancing: 121 N
- Theoretical fore at 0,6 MPa, retracting: 90 N

Pressure gauge

Before inserting the ball into the launcher, the Visitor should first inflate the compressed-air tank to the desired pressure, to accumulate the energy suitable for the shot. Pressure gauge at the stand post must indicate the current value of the pressure inside the tank and sticker indicates ranges of low, medium and high pressure.

Because the launching system reservoir capacity is 0,9 MPa the gauge pressure range must be 0 to 10 bar. In this exhibit I am using WIKA Bourdon tube pressure gauge which can easily mounting to the panel with spring clips (Figure 3.38). Bourdon tube pressure gauges are the most frequently used mechanical pressure measuring instruments. Using biggest nominal size gauge so that visitors will be able to see clearly projectile launcher system pressure.

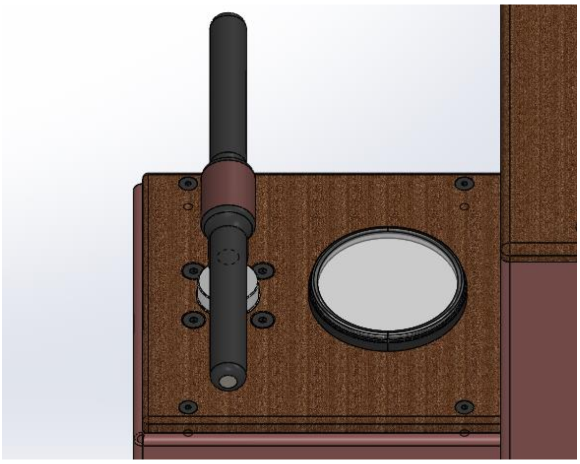


Figure 3.38Hand pump and pressure gauge [7]

WIKA Bourdon tube pressure gauge parameters [32]:

- Model: 111.25
- Nominal size: 0,08 m
- Unit of outer scale: bar
- Scale range: 0,1 MPa to 1,0 MPa
- Process connection: G1/4 B
- Connector location: center back mount
- Accuracy class: class 2,5

Bourdon tube pressure gauge – operating principle

When the internal space of the Bourdon tube is pressurized, the cross-section is thus altered towards a circular shape. The hoop stresses that are created in this process increase the radius of the c-shaped tube. Thus, the end of the tube moves by around two or three millimeters (Figure 3.39). This deflection is a measure of the pressure. It is transferred to a movement, which turns the linear deflection into a rotary movement and, via a pointer, makes this visible on a scale [33].

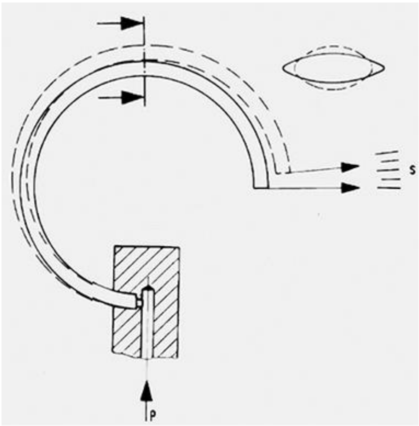


Figure 3.39 - The effect of pressure on a Bourdon tube [33]

Plastic tubing

Hand pump removed from projectile launcher and moved onto stand post and I had to choose new tubing for the launcher system. Tubes must have very good bending properties to carry them from launcher along energy chain and along the shaft to the hand pump. Minimum bending radius need to be as low as possible. If this radius is reached it leads to considerable reduction in flow. To measure this bending radius selected tubing is attached to a movable plate that is bent until the deformation results in a kink. As energy chain bending radius is selected 0,015 m there must be tubing bending radius less equal to 0,015 m.

Outside diameter of tubing must be 0,008 m for connecting with hand pump and launcher input, 0,006 m for energy chain. Tubing operating pressure must be at least 0,9 MPa.
In Table 3.6 are FESTO tubing comparison and I selected 6 mm PEN type plastic tubing for its low minimum bending radius 0,0135 m. Though in Table 3.6 is described that the best of bending properties should be PUN type tubes turned out that it is the worst tubes with minimum bending radius.

I am using 6 mm PEN type tubes with minimum bending radius 13,5 mm for carrying tubes from stand with mechanism to the tabletop and 8 mm PEN type with minimum bending radius 22,5 mm to connect with hand pump output and launcher input.

Table 3.6 Tubing comparison [34]

Type	Outside diameter (mm)	Inside diameter (mm)	Min. Bending radius (mm)	Weight (kg/m)	Best Properties
PEN	6	4	13.5	0.0148	High resistance to chemicals, hydrolysis, cleaning agnets and lubricants
	8	5.7	22.5	0.0233	
PUN	6	4	16	0.0192	Highly flexible plastic tubing. Highly resistant to stress cracks
	8	5.7	24	0.0302	
PAN	6	4	15	0.016	High termal and mechanical load capacities.
	8	5.9	22	0.024	

4. MEASURING

4.1 Measuring requirements

Client required that the stand need to be equipped with sensors to measure [1]:

- the angle of the launcher
- the angle of worktop tilt
- the initial speed of the ball
- the position of the launcher – altitude above the bottom edge of the worktop
- the position of the target - altitude relative to the launcher and the distance from it

Need to measure parameters to illustrate scientific determinism. The visitor acquires very similar experiment results from different sensor if input parameters are the same. In the worktop is integrated RGB LED panel that displays current parameters: the tilt angle of the worktop, the angle and height of the launcher so, that these parameters make subsequent analysis of video recordings possible.

Multimedia kiosk is also interface of the stand – there are sensor measurements of physical quantities, control of data saving and video recording.

4.2 Display

Display purpose in this exhibit to show visitors parameters about worktop tilt angle, the angle and height of the launcher. Display must be easy to read and clear picture to video recordings.

For showing parameters to the visitors there was two options how to do it. Using one big LED panel or using three small ones.

In the initial design phase, I was using three small miniature 4-digit binary-code decimal input display seen in Figure 4.1 [35]. It has very good viewing distance up to 7 m and clear picture and very easy to connect with a panel. Display connects directly to the devices which give 24V logic output with simple IDC (insulation-displacement contact) ribbon cable. As it is 4 digits display I need to use 3 displays to show parameters and add sticker to describing what values display is showing. It will take too much space in tabletop frame and I needed something compact.

Figure 4.1 Miniature 4 digit BCD input display [35]

As this miniature display can show only one parameter and taking too much space I decided to use the RGB LED 32x32 panel.

In the RGB LED panel all the information about launcher position and tabletop fits on the screen and there is no need to add explaining stickers. In the Figure 4.2 it can be seen that display is thin and it can fit to the tabletop.

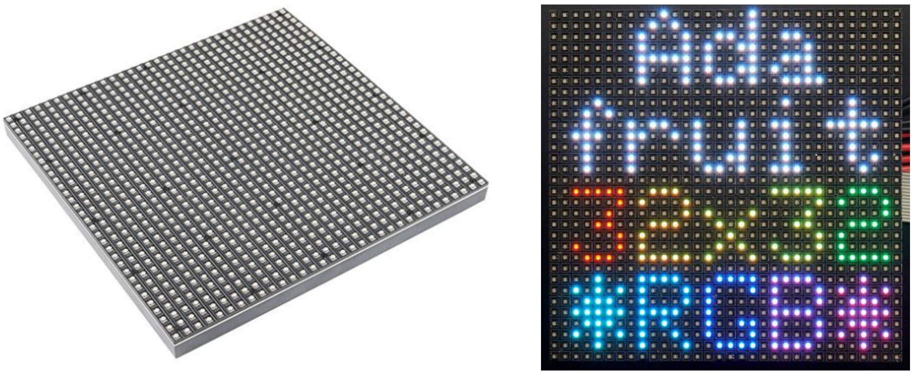


Figure 4.2 RGB LED panel – 32x32 [36]

RGB LED 32x32 panel parameters [36]:

- Dimensions: 0,19 x 0,19 x 0,01 (m)
- Weight: 0,2 kg
- 1024 RGB LED
- 1/16 Scan rate
- 3,3-5V supply voltage
- Dual IDC connectors

4.3 Sensors

Sensors are used to measure the parameters that are described and listed in section 4.1. The sensor values are displayed on the screen that is fixed to the side of the worktop surface so that visitors can analyze the results and draw conclusions on how different parameters change the projectile trajectory.

Exhibit consist three various types of sensors:

- Photogates
- Ultrasonic range sensors
- Angular position sensors

Photogates

Photogates are already installed to the Vernier projectile launcher to measure ball's launching velocity (Figure 4.3). Two photogates positioned within the launch chamber allow for precise determination of the ball's launch speed using Vernier's various software applications. To do this, the software records when the ball passes through the first gate and the second gate then calculates the difference, known as the pulse time. The average speed of the ball is then determined from the ratio of the separation distance of the photogates and the pulse time [4]. Distances between gates are 0.05 m.

Figure 4.3 Locations of internal photogates [4]

To measure the initial speed of the ball I use the Formula 4.1:

$$v = \frac{d}{\Delta t} \qquad (4.2)$$

Where,

V – ball average speed, m/s
d – distance between photogates, m
Δt – pulse time, second

Distance sensors

Ultrasonic range sensor and infra-red (IR) range sensor are widely used to measure distance. The ultrasonic sensor uses time of flight (TOF) method for distance measurement, which refers to the time taken for a pulse to travel from the transmitter to an observed object and back to the receiver [37]. To measure the distance the sound has travelled I use the Formula 4.2:

$$d = \frac{c_0 \cdot t}{2} \quad (4.2)$$

Where,
d – distance, m
c_0 – velocity of sound, m/s
t – time taken, second

The infra-red (IR) sensor works based on the detection of a specific light of wavelength in the range of 760 nm (IR spectrum), which is emitted by an IR Light Emitting Diode (LED). The distance can be measured based on the change in intensity of the received light (Figure 4.4). It returns an analog voltage that can be used to determine how close object is. For the IR sensor, color of the obstacle material could also affect the reading of the sensor [37].

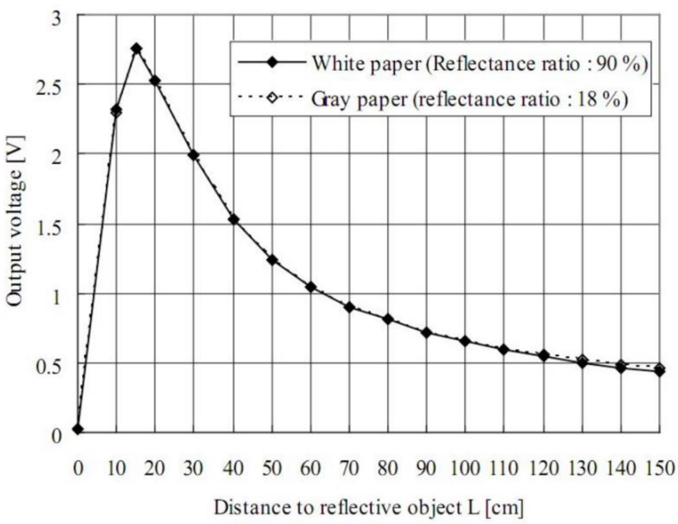


Figure 4.4 Sharp IR distance sensors analog output voltage vs distance to reflective object [38]

Using ultrasonic sensors to measure the position of the launcher and target. Criteria's for selecting sensor was that sensor need to have small dimensions in order to fit in between exhibits framework, cheap and able to measure the object in distance of 2,5 m. In exhibit SRF005 ultrasonic range sensors are used as they meet all the requirements and it is easy to connect, need three jumper wires and it low price sensor.

It was hard to find cheap IR distance sensor with long range measurement. Most of IR distance sensors are used for short range, up to 1,5 m (Table 4.1).

Table 4.1 Sharp IR distance sensors [38]

Output Type	Sensor	Detection Range	Typical Sampling Rate	Operating Voltage Range	Average Supply Current	Size
analog voltage (provides distance measurement)	GP2Y0A60, 5V	10 cm – 150 cm	60 Hz	2.7 V – 5.5 V	33 mA	1.30″ × 0.41″ × 0.40″*
	GP2Y0A60, 3V	10 cm – 150 cm	60 Hz	2.7 V – 3.6 V	33 mA	1.30″ × 0.41″ × 0.40″*
	GP2Y0A02	20 cm – 150 cm	26 Hz	4.5 V – 5.5 V	33 mA	1.75″ × 0.75″ × 0.85″
	GP2Y0A21	10 cm – 80 cm	26 Hz	4.5 V – 5.5 V	33 mA	1.75″ × 0.75″ × 0.53″
	GP2Y0A41	4 cm – 30 cm	60 Hz	4.5 V – 5.5 V	12 mA	1.75″ × 0.75″ × 0.53″
	GP2Y0A51	2 cm – 15 cm	60 Hz	4.5 V – 5.5 V	12 mA	1.06″ × 0.52″ × 0.56″

Selected ultrasonic sensor parameters [39]:

- Size: 0,43 x 0,2 x 0,17 (m)
- Sensitivity: Detect 3 cm diameter broom handle at 3 m
- Max range: 3 m
- Min range: 0,03 m
- Voltage: 5V
- Current: 30 mA Typ, 50 mA Max
- Frequency: 40 KHz
- Input Trigger: 2 uS min. TTL level pulse
- Echo Pulse: positive TTL signal, width proportional to range

Projectile launcher measuring sensor is placed onto the upper covering plate which is shown in Figure 4.4. It is not placed onto ground plate because there are launcher balls that visitors can take and disturb measuring results coming between the ultrasound. Sensor measure displacement of projectile launcher altitude above the bottom edge of the worktop. To get desired value sensor measures distance between launcher emitting ultrasound at 40 KHz that travels through air and bouncing back hitting launcher linear guide plate.

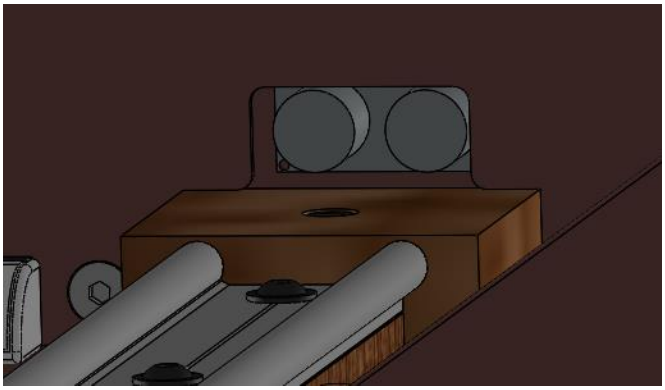


Figure 4.4 Sensor for measuring vertical position of the launcher [7]

Target measuring sensor is connected to an aluminum profile T-slots with flange (Figure 4.5). Measuring distance between launcher and target. To get target distance from launcher, sensor emits ultrasound at 40 KHz that travels through air and bouncing back hitting target linear guide. Sensor is measuring displacement of target. Displacement of target is added to primary target position to get distance between target and launcher.

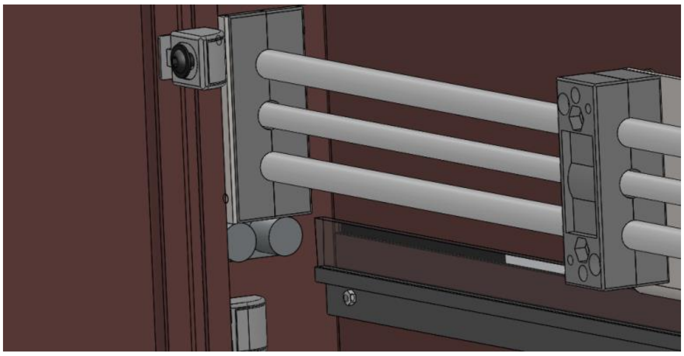


Figure 4.5 Sensor for measuring horizontal position of the target [7]

Angular position sensors

Worktop tilt angle and launcher launching angle is measured using angular position sensors as know conductive plastic rotary potentiometer. The function is to convert a mechanical rotational displacement into an electrical signal. In order to achieve this, the resistive track is placed on the fixed part of the potentiometer and the mechanical displacement to be measured is connected to the wiper assembly which moves on the resistive track (Figure 4.6). The track of the potentiometer is connected to a stabilized DC voltage which allows a small current flow. The voltage, when measured between the wiper and the input turret, is directly proportional to the position of the wiper on the track. The closer the wiper is to the end terminal it is wired in conjunction with, the less the resistance, because the path of the current will be shorter. The further away it moves from the terminal, the greater the resistance will be [40]. The potentiometer essentially functions as a variable voltage divider.

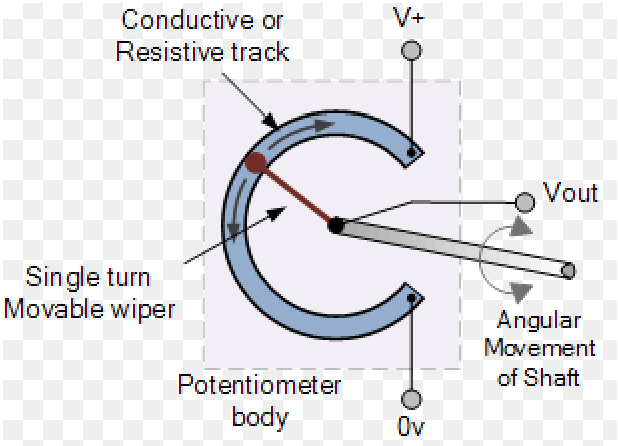


Figure 4.6 Principle of conductive plastic rotary potentiometer [41]

Requirement for sensors was to have compact design, must be small as possible in order to fit onto exhibit and easy to assembly to the objects that are measured. The sensor has to be cheap and capable of measuring at least 90-degree shift.

Selecting Contelec WAL 305 5K angular position sensor, because it has small hollow shaft, easy to connect with rotating shaft for measuring tabletop angel and launcher angle. Flat design and mounting with fixing plates making this sensor ideal to using because it fit perfectly to the exhibit (Figure 4.6).

Figure 4.6 WAL 305 angular position sensor [42]

Sensor electrical data [42]:

- Electrical angle: 340
- Repeatability: max 0.1
- Resistance: 5 kΩ
- Resistance tolerance: ± 20 %
- Independent linearity: ± 1 % of meas. Range
- Service life: 2 x 10^6 cycles
- Output: voltage divider
- Voltage: max 35V

Sensor mechanical data [42]:

- Mechanical angle: 360
- Weight: 0,03 kg
- Service life: 2 x 10^6 cycles
- Dimensions ø x H: 0,032 x 0,0095 m
- Hollow shaft diameter: 0,006 m
- Repeat accuracy: 0,3

Launcher angle sensor is connected to the slide table as seen in Figure 4.7. Hollow shaft is placed aligned movable launcher bolt which is connected to the sensor. Sensor measure bolt rotation as launcher angle.

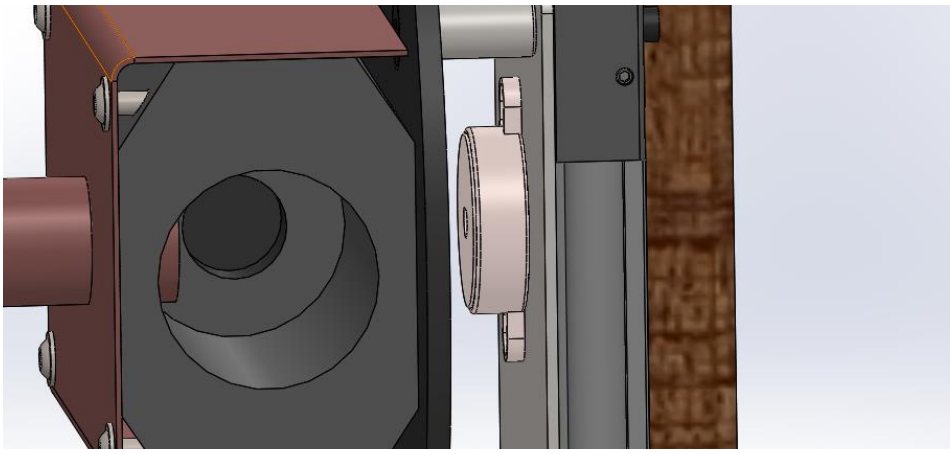


Figure 4.7 Sensor placements for measuring launcher angle [7]

To measure worktop tilt angle small shaft that fits sensor hollow shaft is welded into the center of big shaft that is connected to worm gear output. Sensor measure rotation of shaft. Bracket holds the sensor in place center of shaft diameter. Bracket is welded to the stand post profile frame (Figure 4.8).

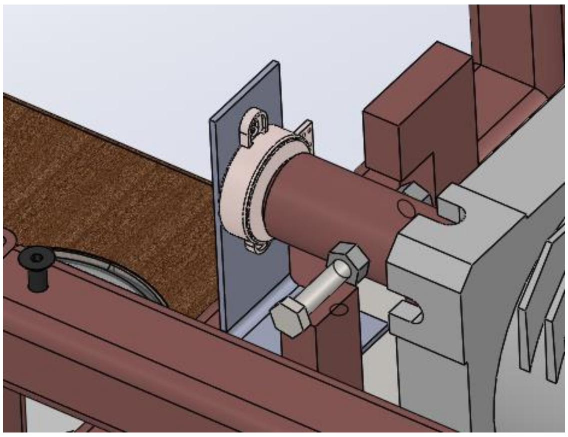


Figure 4.8 Sensor placements for measuring worktop tilt angle [7]

5. COST OF AN EXHIBIT

This projectile motion exhibit is custom made prototype that will be made only one time. In this chapter estimated cost of exhibit to MUSEKO is calculated as there will be added EC1 project partners Qumak and MAE cost of exhibit to get final number. The labor cost for this project is calculated based on 50 euros per hour salary, resulting around 7500 eur per 150 hour of modeling 3D model. The salary considered in the calculations is net salary, no taxes included. Build cost of exhibit is shown in table 5.1, where are shown our sub-contractor price query. Price query include exhibit materials, material processing, fastening, transportation and mounting in Poland. Component cost of stand is shown in table 5.2 and component cost of stands are shown in table 5.3. The total cost of exhibit is presented in table 5.4.

Table 5.1 Build cost

Component	Units required	Estimate price [EUR]
Exhibit build cost	1	9150
Transport (includes packing materials and packing)	1	200
Mounting	1	1000
Total		**10350**

Table 5.2 Work top COST components

Component	Units required	Price per unit [EUR]	Estimate price [EUR]
EVA foam obstacles	10	50	500
Ground sticker	1	5	5
Vernier projectile launcher	1	400	400
Ultrasonic range sensor SRF005	2	14	28
Igus Leadscrew modules - SHTP_02_12_500_HR	1	96	96
Igus E-chain	1	20	20
Igus Double rail – WS10_40_1000	1	44	44
Igus Drylin – W10 Pillow block	4	7	28
Potentiometer WAL 305	1	21	21
GoPro Hero5 Session	1	360	360
RGB LED panel	1	40	40
Total			**1545**

Table 5.3 Stands COST components

Component	Units required	Price per unit [EUR]	Estimate price [EUR]
Quarter-turn tubular cam lock	2	35	70
Wika 11.26.0 - Bourdon tube pressure gauge	1	40	40
Potentiometer WAL 305	1	21	21
PC - PC2 AER B850B	1	500	500
Bearing UFC204	1	13	13
Bearing UCP208	3	32	96
Worm Gear - B_Q50_FB__100,00_C_0_-M_B3	1	157	157

Crank - Elesa ganter DIN 950-GG-200-K18-A	1	52	52
Festo pneumatic drive	1	250	250
Festo fittings and tubes	1	50	50
Total			**1249**

Table 5.3 Exhibit total cost

Component	Units required	Estimate price [EUR]
Exhibit build	1	10350
Stands	1	1545
Work top	1	1249
Labor cost	150 hours	7500
Total		**20644**

The estimated cost for this project was around approximately 25000 EUR and estimated 3D modeling time 160 hours. The estimate cost for this exhibit is about 21000 EUR that is about 4000 EUR less than planned and workhours took 10 hours less than planned.

6. EXHIBIT SAFETY

Security and safety are very important factors to be taken into consideration in the construction of each of the exhibit. Safety requirement are described in the design manual and playground standard EVS-EN 1176-1:2008 that are fulfilled in this exhibit [2] [43]:

- Wooden equipment as cover plates are made of wood with a low susceptibility to splintering.
- Rough surface should not present any risk of injury. No sharp burs or leftovers are allowed in areas where visitors can come in contact. All edges are rounded 2 mm, as well as all corners have rounded to 5 mm.
- There shall be no protruding nails, projecting wire rope terminations or pointed or sharp-edged components. In this exhibit using only ISO 10642 black hex socket countersunk head screw and ISO 7380F hex socket round head screw to percent injuries caused by unintended contact with components.
- Pneumatic handle distance to the stand cover plate is 0,15 m. It ensures that visitors are able to use handle without hazards either they hand or fingers (Figure 6.1).
- In this exhibit is no crushing points between moving and stationary parts. Openings between stands and worktop or worktop and ground do not create head and neck entrapment hazards either by head first or feet first passage (Figure 6.1). Openings shall be not less than 0,31 m under the worst-case condition where children's can get caught.

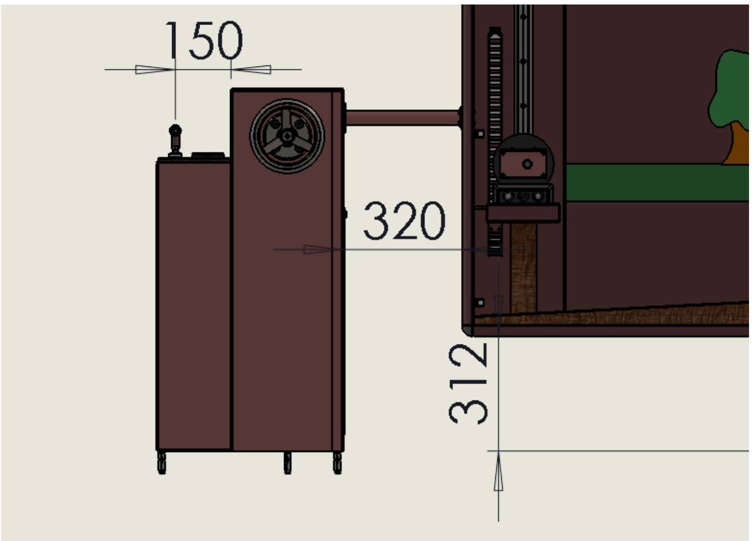


Figure 6.1 Exhibit openings

Biggest safety issue for designing this exhibit was how to secure safe worktop angle changes. Requirement was to ensuring statically non-reversing and no returning system. Change of worktop angle needed to be as slow as possible so that visitors are able to monitor and if necessary to move away from exhibit and camera that is reaching out of exhibit. To meet requires and ensure safe tilting mechanism worm gear with very high transmission is used. Worm gear provides statically non-reversing and no returning system.

Perpendicular to the worktop, along its upper lower and vertical edges, are mounted heavy foam-coated aluminum sheets the stop to prevent the ball from falling off the stand or hitting visitors, but not disturbing free positioning of the launcher and aim.

SUMMARY

The aim of the thesis was designing projectile motion exhibit for a company MUSEKO Ltd which is a custom – work for Poland science center EC-1, which will help visitors to understand the physical phenomena and to control the movement of the bodies. The aim of this was to produce affordable, dependable and safe showpiece based on customer requirements and the company's proposed budget for the exhibit and the limitation of time.

The fundamental principle of exhibits is to teach visitors how the different parameters, outlet angle, initial velocity, mass, angle of table, the shooter's height, affecting the movement of bodies and trajectory.

First, I met the customer requirements and wishes according to costumer input detailed description of the exhibition (SOE). I made it clear that the requirements of safety and industrial designs had to take into account in the design. In the work is done background research to analyze existing solutions to similar exhibits and completed the three design stages in coordination with the client for final exhibit design and operating principles.

In the thesis, using SolidWork software, 3D model and working drawings of the projectile motion system is done. Exhibit consists of two stands which carry the worktop made from aluminum profile, which tilt angle may be adjusted by turning the handwheel. Visitors have the opportunity to change projectile motion parameters. During the work selected pneumatic exhaust system and display that displays the parameters of the shooter. The parameters are measured by sensors and displayed on the selected display for visitors. During the design exhibit I learned about different properties of materials as well as mechanical and pneumatic systems and sensors.

The last step was the safety and design analysis of the exhibit. It has been shown exhibit product estimate cost.

In conclusion, I can say that I met the company and client's objectives modeling a safe and effective projectile motion exhibit. The company is satisfied with a work. Production drawings are sent to subcontractors and manufacturing is going on.

KOKKUVÕTE

Magistritöö eesmärgiks oli projekteerida ettevõttele MUSEKO OÜ keha liikumise demostratioonstend tellimustööna Poola teaduskeskusele EC1, mis aitab külastajatele aru saada ning kontrollida füüsikalisi nähtusi kehade liikumise kohta. Töö eesmärgiks oli valmistada soodne, töökindel ja ohutu eksponaat lähtudes kliendi nõuetest ning firma poolt ette pandud eelarvest ning ajalimiidist.

Esmalt tutvusin kliendi poolt kirja pandud nõuete ning soovidega mida eksponaat peab sisaldama. Tegin selgeks ohutus ja disani nõuded mida pidin arvestama projekteerimisel. Töös on tehtud tausta-uuring, et analüüsida olemasolevaid sarnaseid eksponaate ning lahedusi ning läbitud kolm disain etappi kooskõlastades kliendiga ekpsonaadi lõpliku disani ja tööpõhimõtted.

Demostratioonstendi tööpõhimõtteks õpetada külastajatele kuidas erinevad parameetrid, väljalaskenurk, algkiirus, mass, laua nurk, laskuri kõrgus, mõjutavad kehade liikumist ja trajektoori. Töö käigus projekteeriti SolidWork tarkvaras 3D mudel ja töö joonised keha liikumist kirjeldavat süsteem mis koosneb kahest tugipostist mis kannavad alumiiniumprofiilist tehtud kehade liikumist demostreerivat töölauda, mille nurka saab muuta keerates käsikangi. Külastajal on võimalik lasta kehade liikumist iseloomustavat palli töö käigus välja valitud pneumaatilisest laskesüsteemist ning kuvada laskuri parameetreid. Parameetrid on mõõdetavad välja valitud anduritega ning kuvatakse külastajatele ekraanil. Välja lastud palli trajektoori on võimalik järgi vaadata kaamera poolt salvestatud videolt ning teha järjeldusi, mis parameetrid mõjutavad palli lendu ning mis parameetritega on võimalik tabada sihtmärki. Projekteerimise ajal tutvusin veel erinevate materjalide omadustega ning erinevate mehaaniliste ja pneumaatiliste süsteemidega.

Viimaseks etapiks oli ohutus ja disain nõutet täitmine ning analüüs. Välja toodud on ekponaadi toote kalkulatsioon.

Kokkuvõtteks võin öelda, et täitsin ettevõtte ning kliendi eesmärgi ehitades valmis ohutu ja toimiv eksponaat, mis vastab nõuetele ning jääb eelarve piiridesse. Tehtud tööga jäi ettevõte rahule. Tootmisjoonised on edastatud allhankijale ning eksponaadi tootmine käib.

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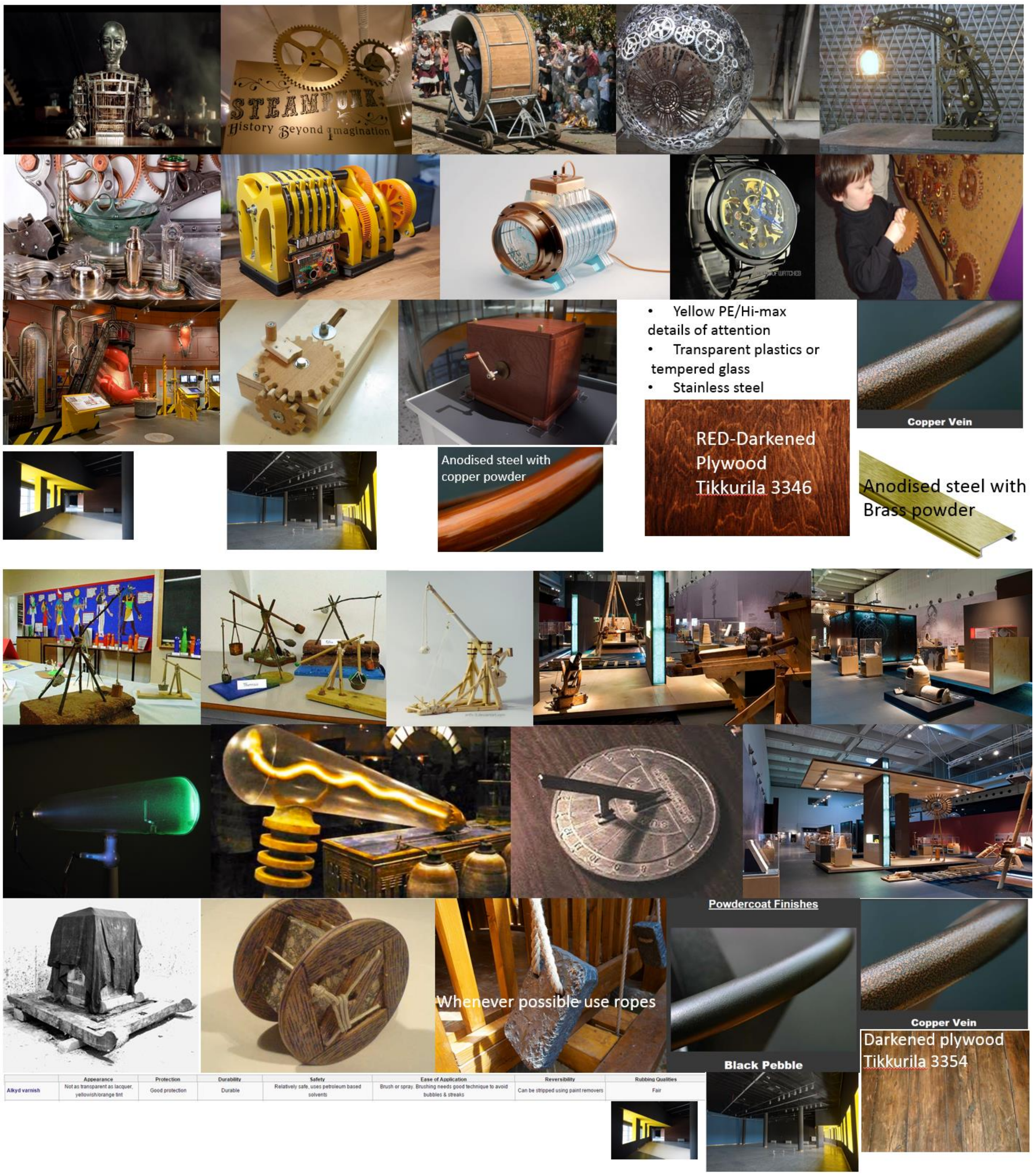
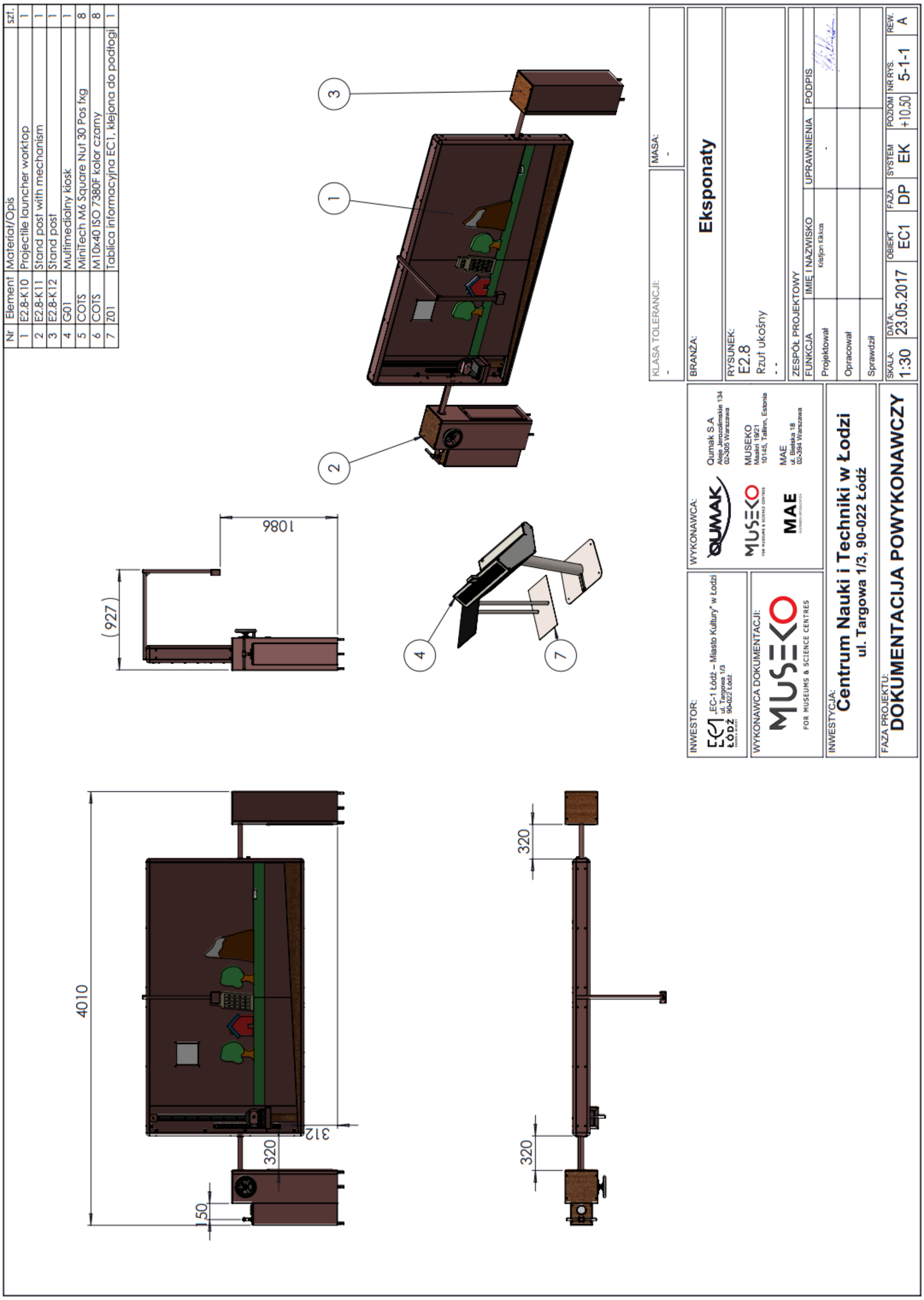
APPENDICES

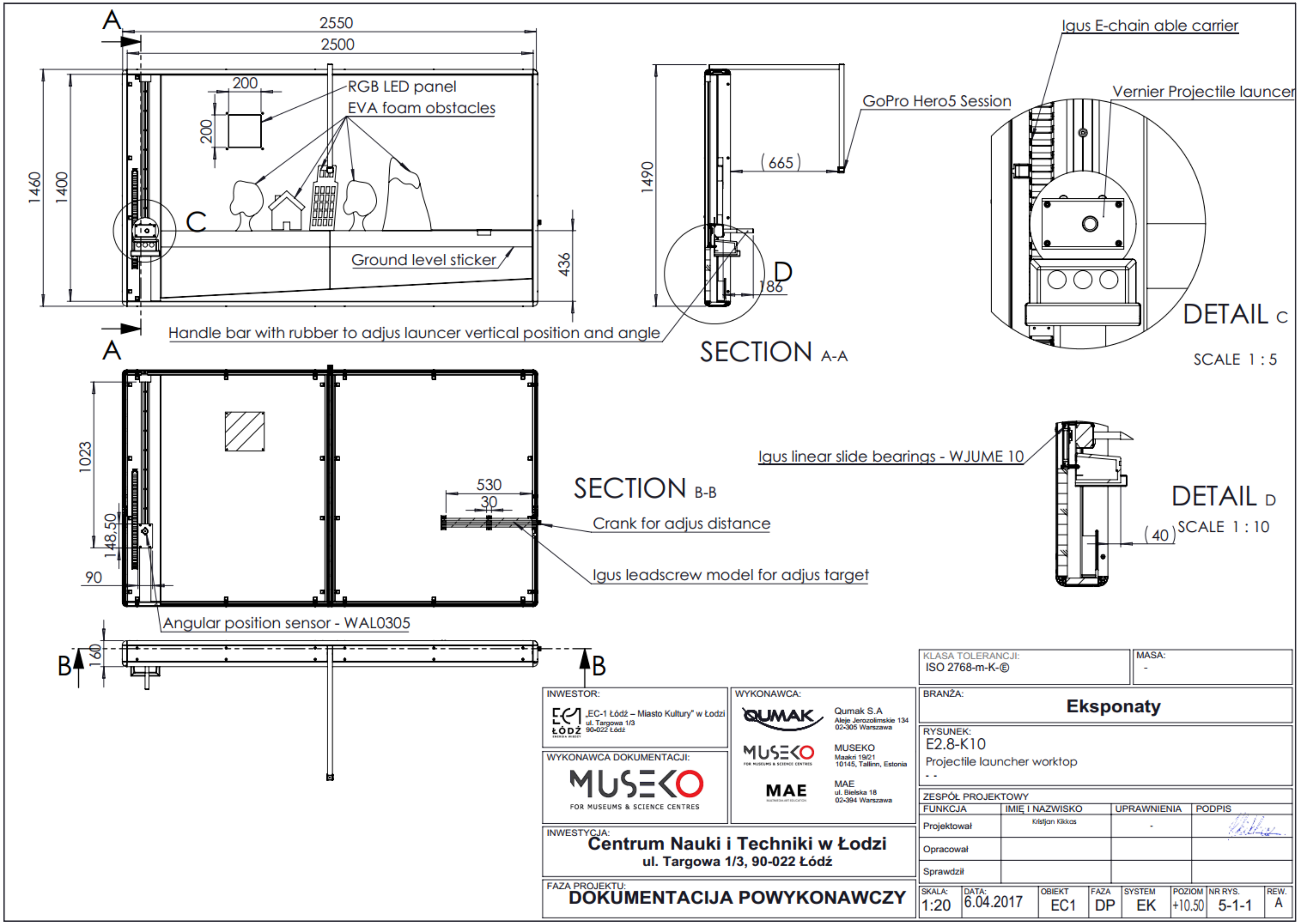
Appendix 1 Moodboard



	Appearance	Protection	Durability	Safety	Ease of Application	Reversibility	Rubbing Qualities
Alkyd varnish	Not as transparent as lacquer, yellowish/orange tint	Good protection	Durable	Relatively safe, uses petroleum based solvents	Brush or spray. Brushing needs good technique to avoid bubbles & streaks	Can be stripped using paint removers	Fair

Appendix 2 As-build drawings without BOM lists

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1400
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EVA foam obstacles
C
Ground level sticker
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Handle bar with rubber to adjus launcer vertical position and angle
A
A
1490
(665)
GoPro Hero5 Session
D
186
SECTION A-A
Igus E-chain able carrier
Vernier Projectile launcer
DETAIL C
SCALE 1 : 5
1023
148,50
90
530
30
SECTION B-B
Crank for adjus distance
Igus leadscrew model for adjus target
Igus linear slide bearings - WJUME 10
DETAIL D
SCALE 1 : 10
(40)
Angular position sensor - WAL0305
160
B
B
KLASA TOLERANCJI:
ISO 2768-m-K-Ⓔ
MASA:
-
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„EC-1 Łódź – Miasto Kultury" w Łodzi
ul. Targowa 1/3
90-022 Łódź
WYKONAWCA:
QUMAK
Qumak S.A
Aleje Jerozolimskie 134
02-305 Warszawa
MUSEKO
Maakri 19/21
10145, Tallinn, Estonia
MAE
ul. Bielska 18
02-394 Warszawa
WYKONAWCA DOKUMENTACJI:
MUSEKO
FOR MUSEUMS & SCIENCE CENTRES
BRANŻA:
Eksponaty
RYSUNEK:
E2.8-K10
Projectile launcher worktop
- -
ZESPÓŁ PROJEKTOWY
FUNKCJA
IMIĘ I NAZWISKO
UPRAWNIENIA
PODPIS
Projektował
Kristjan Kikkas
-
Opracował
Sprawdził
INWESTYCJA:
Centrum Nauki i Techniki w Łodzi
ul. Targowa 1/3, 90-022 Łódź
FAZA PROJEKTU:
DOKUMENTACIJA POWYKONAWCZY
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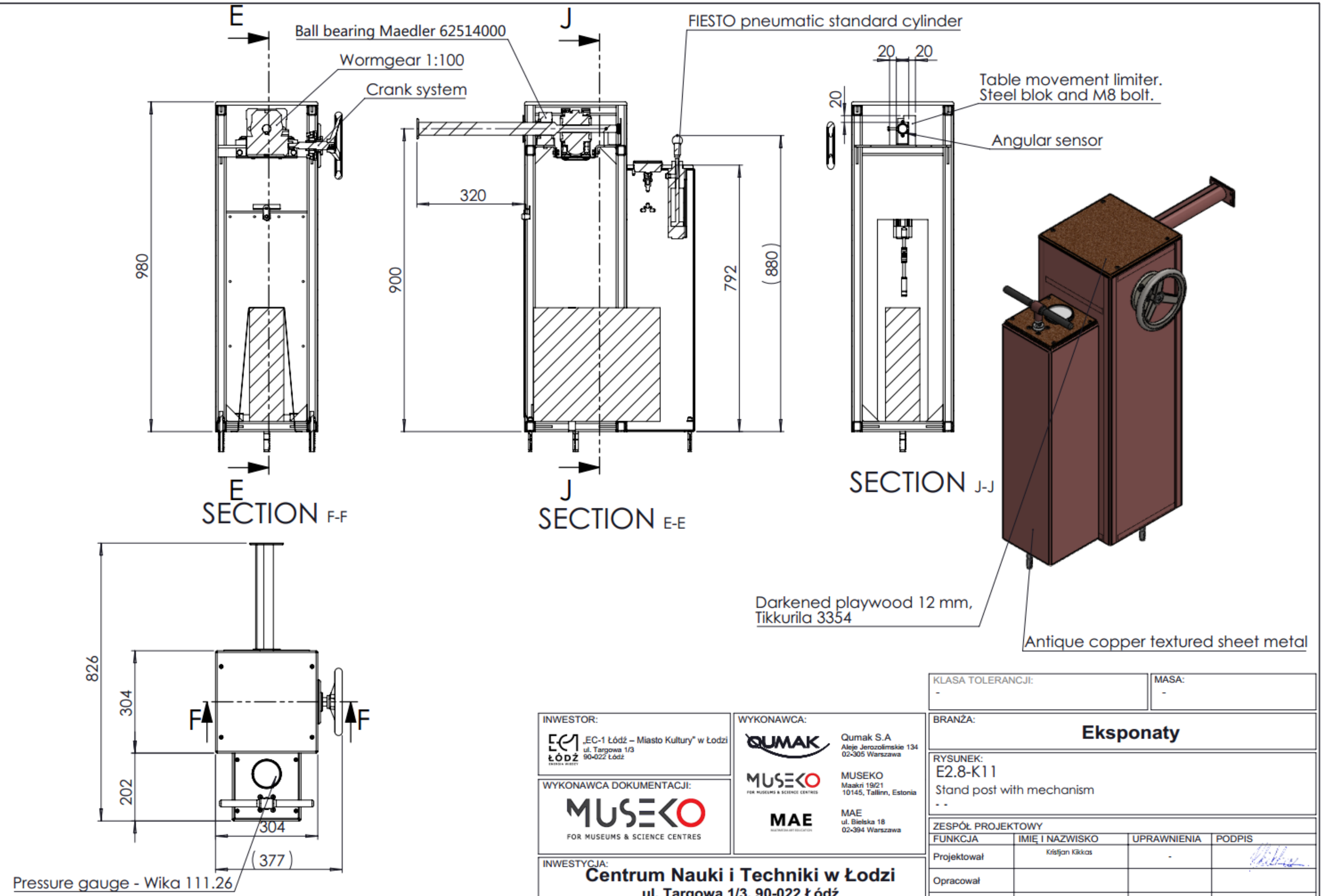

KLASA TOLERANCJI: -				MASA: -			
BRANŻA: **Eksponaty**							
RYSUNEK: E2.8-K11 Stand post with mechanism - -							
ZESPÓŁ PROJEKTOWY							
FUNKCJA	IMIĘ I NAZWISKO	UPRAWNIENIA	PODPIS				
Projektował	Kristjan Kikkas	-					
Opracował							
Sprawdził							
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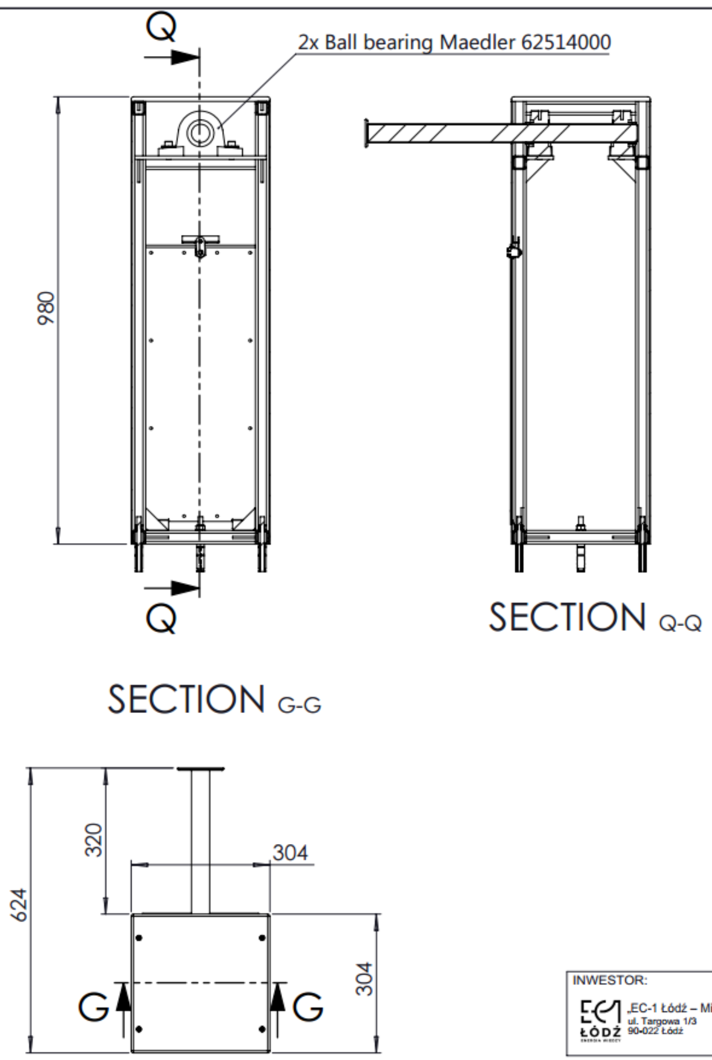
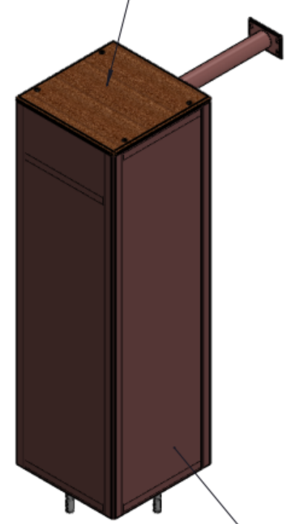
WYKONAWCA DOKUMENTACJI: MUSEKO FOR MUSEUMS & SCIENCE CENTRES

WYKONAWCA: Qumak S.A, Aleje Jerozolimskie 134, 02-305 Warszawa; MUSEKO, Maakri 19/21, 10145, Tallinn, Estonia; MAE, ul. Bielska 18, 02-394 Warszawa

INWESTYCJA: **Centrum Nauki i Techniki w Łodzi**
ul. Targowa 1/3, 90-022 Łódź

FAZA PROJEKTU: **DOKUMENTACIJA POWYKONAWCZY**





INWESTOR: „EC-1 Łódź – Miasto Kultury" w Łodzi, ul. Targowa 1/3, 90-022 Łódź	WYKONAWCA: Qumak S.A, Aleje Jerozolimskie 134, 02-305 Warszawa; MUSEKO, Maakri 19/21, 10145, Tallinn, Estonia; MAE, ul. Bielska 18, 02-394 Warszawa
WYKONAWCA DOKUMENTACJI: MUSEKO FOR MUSEUMS & SCIENCE CENTRES	
INWESTYCJA: **Centrum Nauki i Techniki w Łodzi**, ul. Targowa 1/3, 90-022 Łódź	
FAZA PROJEKTU: **DOKUMENTACIJA POWYKONAWCZY**	

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ISO 2768-m-K-Ⓔ	-

BRANŻA: **Eksponaty**

RYSUNEK: E2.8-K12
Stand post
- -

ZESPÓŁ PROJEKTOWY

FUNKCJA	IMIĘ I NAZWISKO	UPRAWNIENIA	PODPIS
Projektował	Kristjan Kikkas	-	
Opracował			
Sprawdził			

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