Ministry of Education
POLITEHNICA University of Bucharest
Doctoral School of Industrial Engineering and Robotics

DOCTORAL THESIS

RESEARCH ON DEVELOPMENT OF A CUSTOMISED ADAPTIVE EQUIPMENT FOR SPORTS TRAINING

PhD student,

TUNSOIU Nicolae

Scientific supervisor,

Prof. dr. ing. ec. Cristian-Vasile DOICIN

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SUMMARY

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RESEARCH ON DEVELOPMENT OF A CUSTOMISED ADAPTIVE EQUIPMENT FOR SPORTS TRAINING

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ABBREVIATION LIST

Crt. no.	Abbreviation	Name
1.	ABS	Acrylonitrile butadiene styrene
2.	AFC	Asian Football Confederation
3.	AM	Additive Manufacturing
4.	CAD	Computer Aided Design
5.	CAF	Confederation of African Football (Confédération Africaine de Football)
6.	CANMEBOL	South American Football Confederation (Confederación Sudamericana de Fútbol)
7.	CEN	European Standardisation Conformity (Conformitè Europëenne de Normalisation)
8.	CNC	Computer Numerical Control
9.	CONCACAF	The Confederation of North, Central America and Caribbean Association football
10.	CPU	Central processing unit
11.	DMD	Direct Metal Deposition
12.	FEA	Finite Element Analysis
13.	FEM	Finite Element Method
14.	FDM	Fused Deposition Modeling
15.	FIFA	Fédération Internationale de Football Association
16.	HIPS	High Impact Polystyrene
17.	MEX	Material extrusion
18.	OFC	Oceania Football Confederation
19.	PET	Polyethylene terephthalate
20.	PLA	Polylactic acid
21.	PVA	Polyvinyl alcohol
22.	PVC	Polyvinyl chloride
23.	SBC	Single-Board Computer
24.	SLA	Stereo-lithography
25.	STL	Standard Template Library
26.	TPU	Thermoplastic Polyurethane
27.	UEFA	Union of European Football Associations

INTRODUCTION

This PhD thesis is the result of about six years of work to design and manufacture a product to help a wide range of athletes, from professionals who train daily to people who occasionally play a sport using a ball. Introducing an innovative product to the mass market involved carrying out market research to identify the market potential.

Based on the existing data on the number of athletes playing ball sports, the PhD thesis proposes an approach for the development of new products in general and equipment for ball sports training in particular. The developed product is intended for training football players playing in various positions within the tactical game, as well as for other sports involving the use of a ball of various sizes. The PhD thesis also follows the steps of a new product development methodology, starting with the analysis of the specific needs of the product's field of application and ending with the testing and validation of the prototype.

The thesis makes contributions both in the development phases, establishing from the specifications of the developed product, taking into account the customer requirements resulting from their questioning, to the determination of the architecture of the developed product, consisting of independent systems from the perspective of production processes, to the economic analysis, establishing the cost-effectiveness of the production process of equipment for ball sports training, to the detailed design, to the determination for each component of the manufacturing processes, i.e. the manufacture of a prototype of adaptable equipment for ball sports training.

The advent of new additive manufacturing technologies has allowed components to be rapidly produced and tested in the final prototype. Using the same technologies, components with complex geometries were also obtained. This has allowed the final assembly to contain components that have been manufactured from plastics, which will allow the final prototype of the sports training equipment assembly to be easy to make/manufacture.

Some of the components have been prototyped in several construction variants. Following validation of each component, they were assembled and tested on the prototype. Following tests, both local, on certain critical sub-assemblies, and general, on the whole product prototype, its functionality was demonstrated and final modifications were made to validate the final product.

After removing previously discovered errors, the product was tested in practice by a group of users. This stage involves optimising the sports equipment for certain critical sub-assemblies, components of the product, to obtain the commercial version. The last stage means finalising testing and launching the product on the market, as well as developing related services.

The development of customised adaptable sports training equipment using new manufacturing technologies is a real help for people who are passionate about ball sports, making the work of the people who use it easier.

Definitions

Training

Sports training "is the systematic and continuously graded pedagogical process of adapting the human organism to intense physical and mental effort in order to achieve high results in one of the forms of competitive exercise" [T01].

Product development

Product development may involve the modification of an existing product or the formulation of a completely new product that satisfies the desire of a newly defined customer or market niche [U02]. In the following we will assume that product development is the set of activities that starts with the identification of a need and ends with the manufacture, sale and delivery of a product.

Design

In the thesis design is the main element on which the sports equipment for throwing balls is created. With the help of design, concepts are developed on the basis of which the final product is developed.

Production process

The production process is the set of activities carried out with the help of means of production and natural processes for the organised transformation of work objects into finished products [I01].

In the author's conception, the production process is defined in the thesis as the set of technological operations used to transform raw materials into finished products.

Simulation

Simulation is a model for analysing the designed product, which aims to observe the effects on certain parts of the whole and to evaluate the existing performance [M09].

In the paper it is accepted that simulation is the method of verifying, using a dedicated software application, from a deformation point of view, critical designed components within the product assembly.

Finite element analysis

Finite element analysis (FEA) is the simulation of a physical phenomenon using a numerical mathematical technique called the finite element method (FEM) [E04]. In this thesis, finite element analysis is used in simulations performed for critical components and uses mathematical methods to perform the simulations.

STRUCTURE AND CONTENT OF THE THESIS

The PhD thesis consists of 9 chapters and 7 appendices, containing 192 figures and 35 tables, presented in 240 pages.

In the first chapter, general information on the current state of demand for sports training products and future demand provisions is presented. In the second chapter, an analysis of the methods and techniques used in ball sports training was carried out in order to develop the geometric model of the required trajectories to be used in the product development. In the third chapter, the general objective of the PhD thesis was determined, which is the development of a ball sport training equipment, and also specific objectives were determined that will lead to the precise results. In the fourth chapter, customer requirements were evaluated, as later the requirements were changed into specifications. In the fifth chapter, elements of determining the overall product function and primary functions are presented. Based on the critical product functions and the results of external research, concepts were developed, which were analysed and the best performing one was developed in the next steps. In the sixth chapter, the geometric model developed in the context of the research in this paper was taken as a starting point and each element required to make the sports equipment was designed. In the seventh chapter, the previously designed components were validated by simulating functionalities and finite element analysis for critical components. In the eighth chapter, custom components were obtained through additive manufacturing and standardised components were purchased. In the ninth chapter, the assembly steps of the prototype systems and their integration into the final assembly were presented.

JUSTIFICATION OF THE CHOICE OF THEME

Sport is where people who are passionate about movement are trained by coaches or practice these activities on their own. Playing sport brings with it the need for sports equipment, from sports clothing to the materials needed for a full workout.

Globally, large numbers of professional and amateur football players require training equipment to develop their kicking and catching skills from different directions.

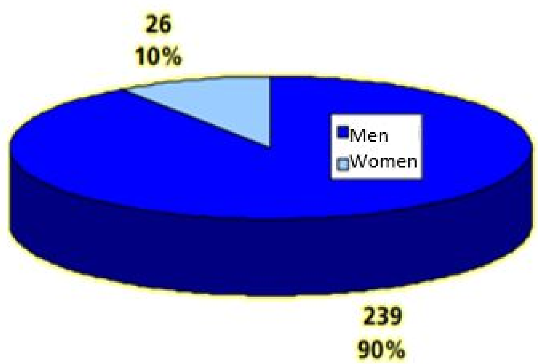
I chose to develop a ball training equipment because there are a number of needs in the sports field for which there is no research and a high demand for sports equipment and also to meet the need and demand for this type of equipment on a national and continental level.

CHAPTER 1
THE STATE OF PLAY ON BALL TRAINING EQUIPMENT

The performance results achieved by the athletes are mainly due to the training they do prior to competition. For successful training, coaches need equipment to make their work easier and to be able to give their players sufficient preparation time. For example, in football, a coach has to take countless kicks of the ball to practise training techniques. Thus, the development of automated sports equipment that can throw the ball at a speed and trajectory desired by the user is useful in a coach's work.

1.1. Statistics

Football is a team sport played between two teams of 11 players each. At the beginning of the 21st century it was played by more than 250 million players in over 200 countries, making it the most popular sport in the world [G05]. In the latest FIFA Big Count publication in 2007, it was found that 10% of all football players are female (Fig. 1.1) [F01].



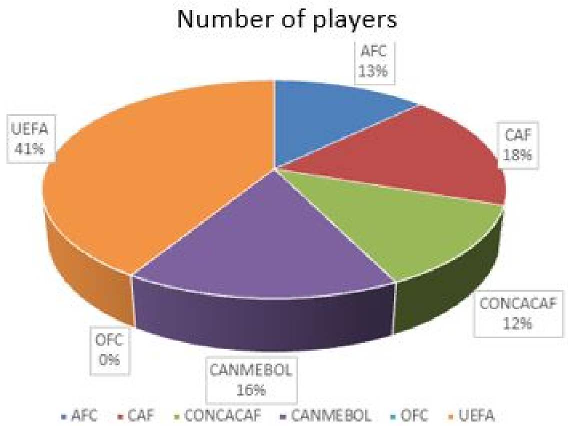


Fig. 1.1. Distribution by gender, millions [F01] **Fig.1.2.** Number of players by confederation [I03]

Football is a global sport that is played on all continents, and most players are from Asia and Europe, according to the latest statistics published by FIFA in 2019 (Fig. 1.2).

Geopolitically, football is among the top 10 world sports played on all continents. The most dominant continents where football is played and watched by more than 600 million supporters annually are: South America, Europe and Africa (Fig. 1.3).

At local level, the university sports club Știința București operates within the University POLITEHNICA in Bucharest. This is a student training club, which is aimed at young people seeking complete personal development through school and sport. Like American and Western European universities, Știința București aims to transform ambitious students into high-performance athletes and ambitious athletes into individuals who are concerned about their career and professional training.

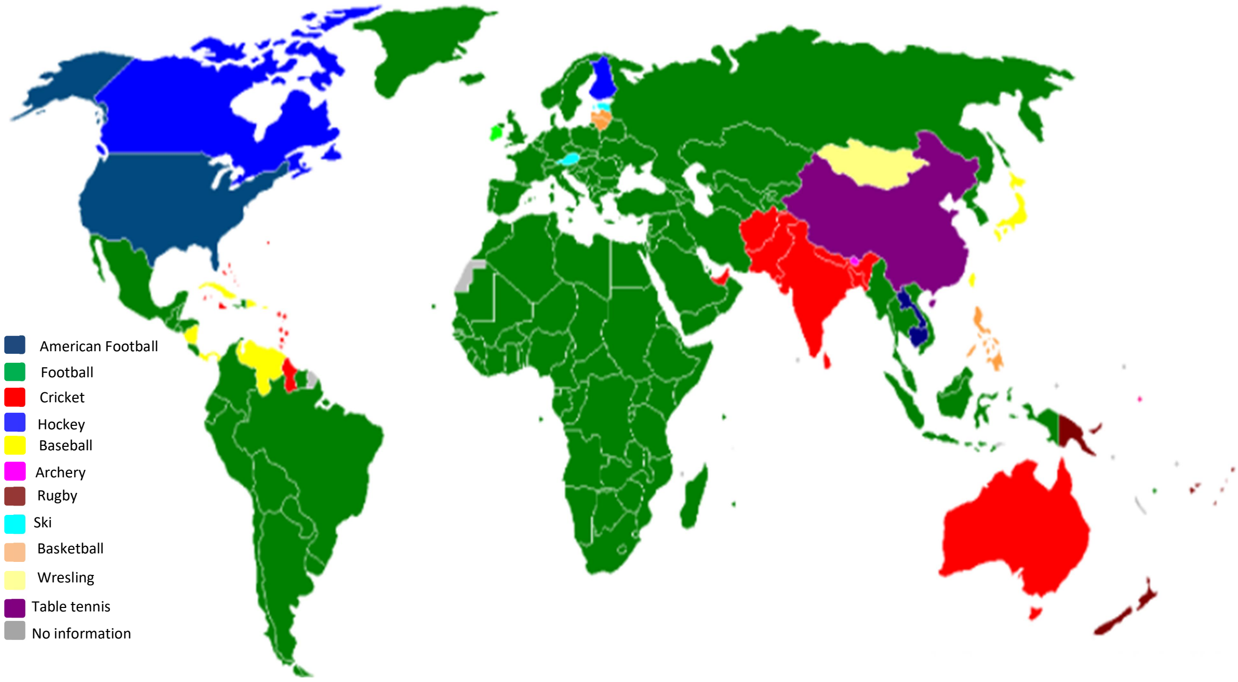


Fig. 1.3. World map of major sports [D05]

1.2. Standards and regulations

One of the CEN standards that contains some elements about the equipment needed to play and test football is: CEN/TC 136/WG 22 - "Gymnastic and field of play equipment" with reference EN 748:2013+A1:2018 - "Field of play equipment. Football goals. Functional and safety requirements, test methods".

Ball sports are generally quite dangerous, which implies the application of standards for the protection of players. To this end, the European Commission created Directive 89/686/EEC - "Personal protective equipment".

1.3. Market analysis

Before developing a product, the manufacturer must inform itself about the market in which it operates, i.e. carry out a detailed analysis of the market. The sporting goods covered by sale and purchase agreements are very diverse and the conditions for matching supply and demand are different in time and space and can be broken down into market segments.

1.3.1. Global market

Football is a game with a long history that officially began in the 19th century in Britain. The market for ball throwing equipment has been around since 1995, when Sports Attack started in Reno (USA) [P09].

Sales of the equipment began in the United States where a large number of high schools and colleges purchased the equipment for school practice classes.

1.3.2. European Market

At present, only companies in Europe sell sports equipment that they buy from American manufacturers.

1.3.3. Market capacity

Only professional level football teams that are organised within FIFA will be taken into account to analyse market capacity. Within each confederation there are a certain number of professional football clubs (Fig. 1.4). At the top of the ranking is UEFA with a number of 1567 clubs, followed by CAF with 682 clubs, and just one club behind is the AFC with 681 clubs [I03]. Market capacity is given by the number of professional football clubs that train constantly and may need the equipment shown. As can be seen, the largest number of football clubs in the world is in Europe, which means a varied range.

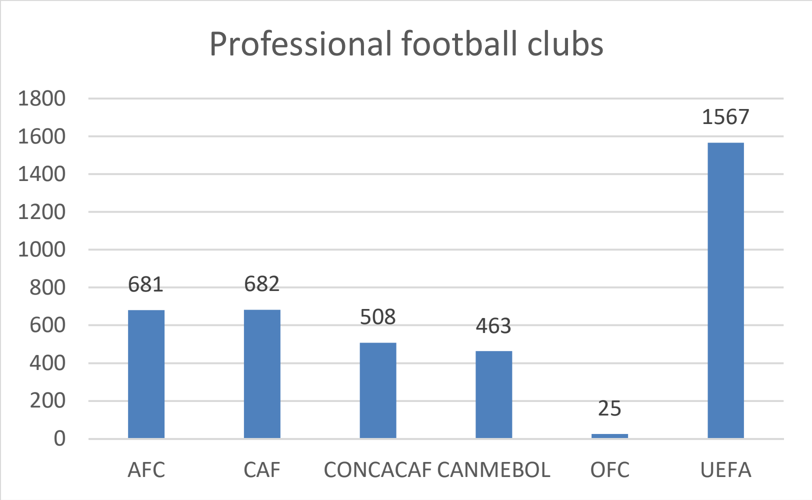


Fig. 1.4. Number of professional football clubs [I03]

1.3.4. Market area

The market for the sale of football throwing equipment has a well-defined spatial dimension, namely: South America, Europe, Asia and Africa.

1.3.5. Market structure

Analysing all the characteristics of the market for selling football training equipment, it can be seen that the market in Europe is the first place where marketing would have a real impact.

1.4. Categories of sports products for ball sports

Optimal achievement of the goal-training-performance combination involves various physical, technical, tactical, psychological and social factors. Physical training is the methodological area that highlights the specific approach to sports training [C13]. Successful training requires the use of sports products that facilitate work and offer multiple benefits. The most commonly used equipment is for passing actions between players, passing and shooting in certain angles or directions.

1.5. Additive manufacturing in sport

An additive manufacturing (AM) process begins with the generation of a three-dimensional (3D) model using computer-aided design (CAD) applications. The 3D CAD model is saved in a standard *.STL (Standard Tesselation Language) format. The software application used splits the *.STL format into individual layers, which it then transfers as individual instructions to the additive manufacturing equipment. [U01].

FDM is a technology that involves the layered deposition of a molten, filament-like plastic material using a heated nozzle (Fig. 1.5) [U01].

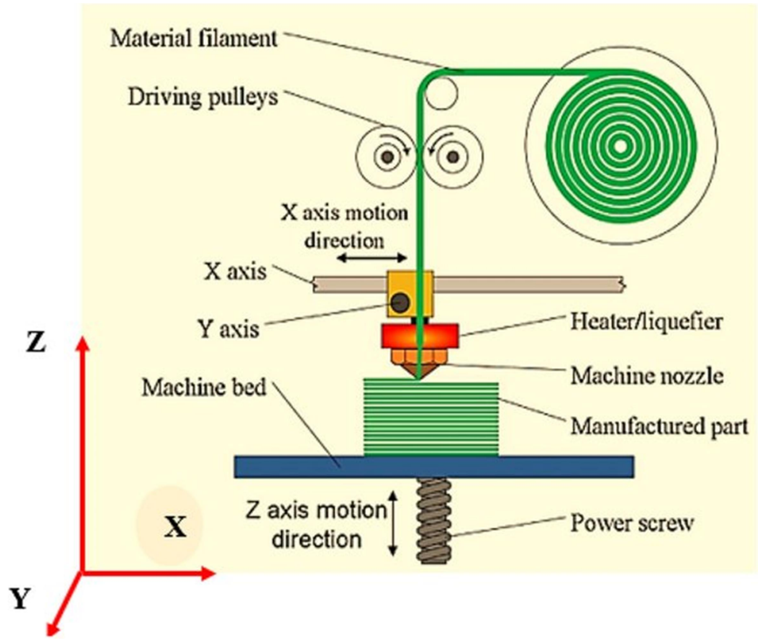


Fig. 1.5. FDM system [A02]

1.5.1. Additive manufacturing statistics.

Additive manufacturing is implemented in many different industries, as can be seen in Fig. 1.6. The main industry using additive manufacturing, with a percentage of 23%, is the jewellery industry, followed by the toy industry with a similar percentage, but it can be seen that the sports industry is also starting to use additive manufacturing in the production of sports equipment.

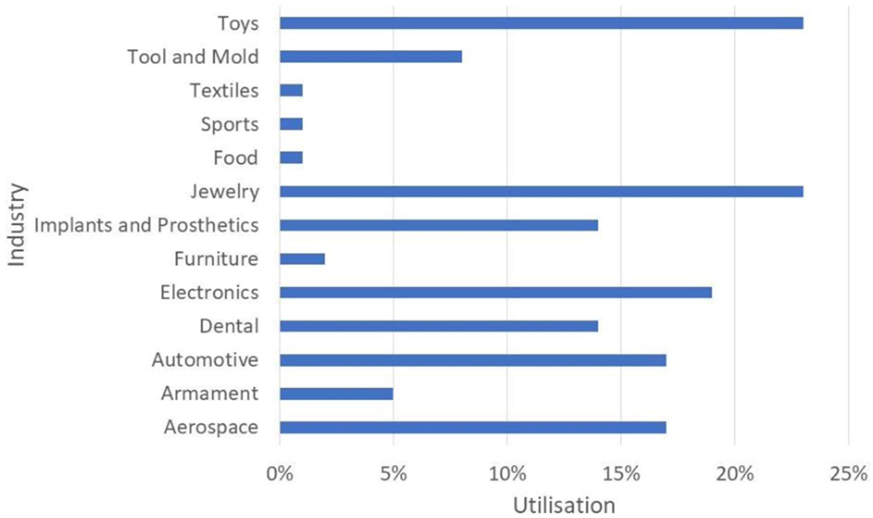


Fig. 1.6. Use of additive manufacturing in industry [M04]

1.5.2. Sports equipment obtained by additive manufacturing

In sport, customer requirements and preferences are evolving rapidly. The rapidly changing market leads to high competition. The use of additive technologies can have a significant impact on the duration of the entire product development, commercialisation and launch cycle [M02]. Some of the most popular sports equipment made by additive manufacturing are nose protection, helmets and foot protection.

1.6. Conclusions

In this chapter the current state of the art of ball sports and the equipment needed to develop a professional player was analysed. Statistics on football showed that it is played in more than 200 countries, with more than 3900 clubs and more than 128,000 professional players. Given the much larger number of football enthusiasts, it can be said that a person wishing to become a professional player must put in many hours of training and physical play on the pitch. Increasing demand in the market for ball throwing equipment has contributed to the development of the subject of this thesis.

CHAPTER 2
THE STUDY OF BALL SPORTS

Ball sports are among the most popular sporting activities in the world, dating back more than 2000 years [G07]. The participation of players of both genders in ball sports leads to an increase in the number of training sessions and the effort coaches put into their physical preparation.

2.1. Training

Sports training is not a recent development. In ancient times, people trained systematically for military or sporting purposes. Even today, athletes train to achieve a specific goal. Physiologically, the aim is to improve body functions and optimise sports performance [B04].

The following are several types of training, both defensive and offensive, for field players:

a) Corner kicks

The corner kick is executed by a fielder sending the ball towards the 16-metre box to practise both the defensive phase, i.e. how to position the players to be able to push the ball away, and the offensive phase, with the aim of scoring.

b) Crosses into the 16-metre box

Crosses into the 16-metre box are very common in football, and training is needed both in the defensive phase, when the defenders have to clear the danger, and in the offensive phase, when the aim is to score in the opponent's goal.

c) Aerial balls for training forwards and defenders

One of the important phases for forwards and full-backs are long balls sent from different areas of the pitch, which must be picked up, especially by the forwards or rejected by the full-backs.

d) Counter-attacking exercises

In football there are several types of tactics that are tackled by different teams. One of these tactics is the counter-attack. This involves immediately after recovering the ball in one's own half, passing it directly to the forwards, who speed off towards the opponent's goal.

e) Attacking and defending drills

This type of training is similar to crosses in the 16-metre box, the difference being that this time the full-backs also take part in the phase.

f) Exercises to train controlling and receiving passes

As can be seen in Fig. 2.6, 3 types of exercises take place: short passes at ground level, volley passes, and headbutts to the team-mate; all with the aim of training the control but also the reception of passes.

Football is played with 10 field players and a goalkeeper. Since training is the key to success for field players as well as goalkeepers, the following are specific types of ball training for goalkeepers:

(a) Single-area kicks

In this type of drill, field players have to kick in the same area of the goal to prepare the goalkeeper, and it is also a good training for them to get used to frame shots.

b) Low, medium or high shots

Goalkeeper training requires a lot of effort from goalkeeper coaches, especially when it comes to individual training, whether we are talking about low, medium or high shots.

c) Penalty kicks

Penalty kicks, or kicks from 11 metres, can be decisive in a game, so they need to be carefully prepared. As can be seen in Fig. 2.9, a player, or goalkeeper coach, takes a kick from 11 metres, the aim being to develop certain reflexes of the goalkeeper.

d) Training quick reactions to powerful shots

Reflex can be one of a goalkeeper's strengths. In Fig. 2.11 it can be seen how the coach throws the ball to a player near the goal, who hits the ball hard on the volley, and the goalkeeper with a sensational reflex, manages to parry the incoming shot.

It can be seen that coaching field players and goalkeepers in football is a complex activity that requires dexterity and preparation time from the coaches. From simple kicks, to distant and complex shots, the kicker needs many hours of training for the best accuracy. The complexity of training increases with the performance of the players and the team.

2.2. External equipment research

For all the types of training described above, the best solution is throwing equipment. They work by throwing or hitting the ball, making it much easier and more precise to practice all the exercises. The main objective of these types of equipment is to help players perfect their skills. To date, several types of equipment have been patented.

CHAPTER 3
OBJECTIVES AND RESEARCH DIRECTIONS

The study on the development of an adaptable sports training equipment that throws footballs for different training sessions is mainly based on the design and construction of an equipment that uses a new method of kicking the ball, compared to other existing equipment, the way of throwing the ball, by kicking with a paddle with a shape similar to the foot paw.

The main objective of the PhD thesis is to develop a sports ball-throwing equipment (for football, handball, futsal, etc.) based on an innovative principle, which can be used in training with both players and goalkeepers.

The methodological reference elements are represented by the following steps and analyse several aspects, which are specific objectives:

● Analysis of the current state of the art of ball throwing equipment, especially for football and analysis of the market in order to observe the necessary volume of equipment. The market for football teams worldwide was studied;

● Documentation of football training and techniques used, in order to be able to implement the desired ball trajectories;

● Studying existing patents and extracting general ideas of how a new equipment should work;

● Realization of several concepts for the design of a new and innovative equipment and application of a method for selecting the optimal concept.

● Defining the operating process of sports equipment, calculating trajectories and sizing component motors;

● Market research and cost calculation of the product to be developed;

● Detail design of ball throwing equipment, both 2D and 3D.

● Stress simulation of some parts of the resulting assembly to observe the strength that the sports equipment provides.

● Analysis and use of an additive manufacturing technology to make custom components of the developed prototype;

● Construction of ball throwing equipment using two types of components: additively manufactured and purchased;

● Testing of the resulting equipment and making some improvements necessary for proper operation; Based on the results obtained from the tests, some component subassemblies were structurally modified;

● Presentation of future developments for the obtained equipment.

CHAPTER 4
ANALYSIS OF USER REQUIREMENTS AND SPECIFICATION OF TRAINING EQUIPMENT

Product development usually refers to the stages involved in the evolution of a product from concept or idea, through manufacturing, market launch and on to recall and scrapping.

Customer requirements were obtained through data collection using forms containing specific questions on product functionality and appearance. Based on the answers received, the main requirements expressed by users were selected.

4.1. Setting user requirements

The process of developing a new product starts from the needs of the users. In most cases, the products developed must meet user requirements in order to be sold.

The potential market for selling the developed product is represented by sports clubs, private coaches, individuals who are passionate about ball sports and want to train individually and sports equipment companies.

The first step in product development is "Identifying customer needs" [T13]. Identifying customer needs involves determining the product that customers want and is central to the whole process [U02].

4.2. Data collection

It was considered appropriate to collect the raw data needed by customers using two methods: interview (15 interviews) and Google form (15 forms) [T13].

4.2.1. Identifying customer needs through interview

Interviews are conducted on the basis of an Interview Guide, where questions are structured in 4 sections. The interview sheet consists of 4 sets of questions of 3 questions each and is completed by football enthusiasts and representatives of existing football clubs.

4.2.2. Identifying customer needs

Interpreting all the information collected from customers, both through the Google questionnaire and the interview sheet, is key to turning needs into features. The needs identified by customers are used to define exact product specifications, to generate and select product concepts for further development. Based on the identified needs and the analysis of competing products, different concepts for training equipment will be developed.

4.3. Competitive products

Product specifications set out in precise and measurable detail what a product must do to meet the identified needs of customers. They do not explain how to address these customer needs, but rather outline what is being attempted to meet the needs. Ideally, specifications are established early in the product development phase and are followed through the design and engineering stages.

4.3.1. Analysis of competing products

There are currently 8 ball throwing machines on the market with different prices, detailed in the thesis.

4.3.2. Completing the competition table

Products with similar functions to the chosen product were selected for benchmarking. To observe existing competing products, marketing research was conducted.

The characterisation of competing products is based on the following criteria: ball control, developed functions, main technical characteristics.

4.4. Establishing the list of characteristic sizes

An important step in the product development process is the determination of product specifications (Table 4.1) [T13]. The conceptual design of the product and its architecture is based on these values, which are determined according to the specifications of competing products to ensure a competitive advantage.

Tab. 4.1. Determination of requirements [T10]

	Requirements \ Sizes	Modular	Audible warning	Remote controlled	Max. shooting speed	Shooting distance	Supply voltage	Moisture protection	Mass	Overall dimensions	Throwing frequency	Throwing system type	Ball storage system	Programmable	Warranty	Angular speed	Ball size setting	Direction configuration	Price
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Can be used for different ball sizes											●	●				●		
2	Easy to use			●								●		●					
3	Simulates real life situations correctly			●	●	●					●					●		●	
4	Is stable enough while working								●	●									
5	Provides a strong resistance structure									●					●				
6	Is easy to handle								●	●									
7	Is innovative	●										●		●					
8	Has high efficiency				●	●	●			●	●		●	●				●	●
9	Is safe to use		●				●	●											
10	Provides notification before each ball is released		●																
11	Has an attractive design	●								●									
12	Has an affordable price																		●
13	Has high productivity			●	●	●					●		●	●					
14	Can be programmed			●										●				●	
15	Is modular	●																	
16	Has a high pulling speed				●	●						●				●			
17	Launches at long range			●	●	●						●							

4.5. Establishing the relative importance of sizes

The relative importance of the magnitudes must be in close correlation with the relative importance of the primary requirements characterised. Thus, a value that characterises a primary requirement of relative importance 5 will take on the same level of importance.

4.6. Identifying objective values

Limit values and ideal values for each quantity (Table 4.2) are set according to the ideal objective, i.e. the best possible result, and limit values are set as values that allow the product to be commercially viable [T13].

Tab. 4.2. Limit values

No.	No. Requirements	Size	Relative importance	Units	Limit value	Ideal value
1	7,11,15	Modular	5	Yes/No	2 module	4 module
2	9,10	Audible warning function	3	Yes/No	Yes	Yes, ON/OFF function
3	2,3,13,14, 17	Remote controlled	4	Yes/No	Yes, distance > 2 m	Yes, distance > 10 m
4	3,8,13,16, 17	Maximum firing speed	5	Km/h	100	140
5	3,8,13,16, 17	Shooting distance	5	m	50	80
6	8,9	Supply voltage	5	V	220	220
7	9	Moisture protection	5	Yes/No	Yes	Yes
8	4,6	Mass	4	Kg	120	30
9	4,5,6,8,11	Gauge dimensions	4	mm	1200x1000x800	500x600x500
10	3,8,13	Launch frequency	5	Balls/min	5	30
11	1,2,7,16, 17	Type of throwing system	3	Type	Wheels/discs	Wheels
12	1,8,13	Ball storage system	5	Yes/No	Without storage system	Yes, with 20 of balls
13	2,7,8, 13,14	Programmable	3	Yes/No	Yes	Yes
14	5	Warranty	3	No. of years	2	5
15	3,16	Angular velocity	4	Yes/No	Yes	Yes
16	1	Ball size setting	5	Yes/No	Yes, size 5	Yes, sizes 3, 4 and 5
17	3,8,14	Direction setting	5	Yes/No	Yes	Yes
18	8,12	Price	4	€	7000€	2200€

CHAPTER 5
FUNCTIONAL ANALYSIS AND PRELIMINARY DESIGN OF TRAINING EQUIPMENT FOR BALL SPORTS

Functional analysis is an approach that consists of a complete description of the functions and the relationships between them. The result is a systematisation, prioritisation and validation of the functions [U01]. Functional analysis is performed for the ball throwing equipment, generating concepts based on the specifications obtained in the previous chapter.

5.1. Functions of sports throwing equipment

The establishment of product functions contributes to the realisation of concepts for the developed product and the application of a methodology for the selection of the optimal concept. On the basis of the selection matrix developed, the best concept is selected for economic analysis.

5.1.1. General function

The identified need for a sports ball throwing equipment with user controllable speeds and directions, as well as the requirements of potential customers, led to the establishment of the overall product function. Thus, the general function of the product is to throw balls with different speeds and in different directions.

5.1.2 Main functions

A process of analysis of the overall function of the product will result in the main and then the secondary functions. The main functions allow the service to be performed at different stages of the products in their life cycle [U01]. The main functions of the ball sports training equipment are listed in Tab. 5.1:

Tab. 5.1. Main functions [T10]

Function number	***Main product functions***
$Ø_1$	To set the direction
$Ø_2$	Configure pull speed
$Ø_3$	Set angular speed
$Ø_4$	Program the pull frequency
$Ø_5$	Store balls
$Ø_6$	Set ball size
$Ø_7$	To fix on the contact surface
$Ø_8$	Have modular structure
$Ø_9$	Set the status of the signalling operation

$Ø_{10}$	Transport to and from the training ground

5.2. Critical functions

The determination of critical functions is done by ranking the main functions using the ranking matrix which is obtained by comparing the main functions with each other, two by two, and assigning a weight according to the importance of the function. Following the analysis of the ranking matrix and the function weights, the critical functions were determined (Tab 5.2).

Tab. 5.2. Critical functions [T10]

Function number	*Critical product function*	*Weight*
$Ø_1$	To set the direction	0.161054
$Ø_2$	Configure pull speed	0.168375
$Ø_3$	Set angular speed	0.139092
$Ø_5$	Store balls	0.102489
$Ø_6$	Set ball size	0.131772
$Ø_8$	Have modular structure	0.086603

5.3. Generating conceptual solutions

Given the characteristics of the equipment required, the archive of solutions has a very large volume of variants, which cannot be fully analysed. Thus, possible conceptual solutions have been selected that can be analysed. Following the selection and by multiplying the total number of conceptual solutions on each criterion, we obtained: 3 x 3 x 7 x 2 x 4 = 504 conceptual solutions that should be analysed [T10].

Following the conceptual solution archive, the sports training equipment was structured based on 5 main characteristics, namely: power supply, storage system capacity, storage system type, setting of throwing intervals and ball throwing. All these were the main elements on the basis of which the concepts were made, integral concepts made for the application of the optimal selection methodology from which the concept analysed in detail in this thesis results.

9. Concept I

The characteristics of concept I are shown in Tab. 5.3.

Tab. 5.3. Concept I

Device powering	Storage system capacity	Storage system type	Setting release intervals	Ball release
AC or DC power supply	Multi-ball capacity	Spiral + Rolling	Programmable intervals	Impact

The equipment (Fig. 5.1) is powered either from the mains (220 V) or from a 24 Vdc battery; the equipment will contain a storage system which will have a storage capacity of 20 balls, both in the upper tub (1) and on the spiral slide (2). Programming of the equipment will be done using the programmable interface, and the launching system consists of a paddle (7) that simulates the natural movements of the foot, thus imprinting the ball with the desired trajectory [T10]. The ball is sent from the bowl (1) down the chute (2) to the positioning area, where it stops in a stopper that is operated by the rotation of the paddle. When the paddle (7) is operated, the stop is lowered and the ball leaves the equipment through the outlet (5). For maximum mobility, the equipment is positioned on 4 wheels (6) and can be moved by means of the two handles (3) on either side of the lower casing (4). The lower housing (4) incorporates the mechanical part and the motors that drive the blade (7).

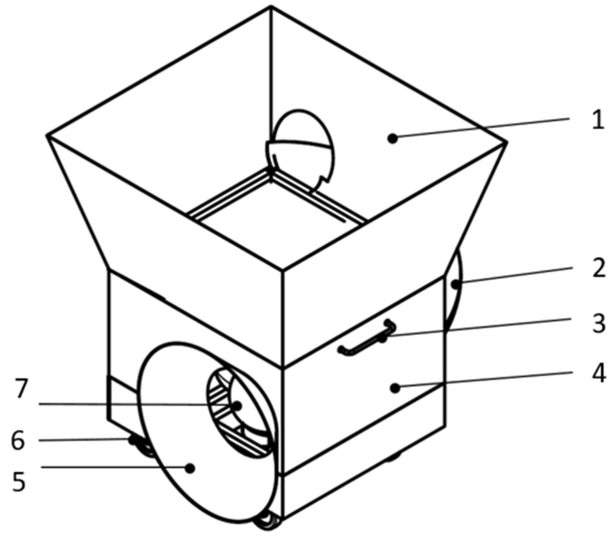


Fig. 5.1. Concept I [T10]

5.4. Selecting the optimal concept

Next, the optimal concept to be developed in the future will be chosen. In order to choose the optimal concept, a methodology is used that contains two steps:

a. Concept sorting

b. Concept evaluation

5.4.1. Sorting concepts

In the concept sorting stage, the 9 integral concepts of the product to be developed, obtained in the concept generation stage, are analysed. The concept generation stage resulted in nine product concepts. For each sorting criterion, the degree of satisfaction of each concept was determined by comparison with the reference concept.

5.4.2. Evaluation of concepts

As a continuation of the concept evaluation process, the evaluation matrix of the selected concepts was produced (Table 5.4). Four integral concepts A, C, H and I were chosen. As a result of the concept evaluation, concept I was ranked 1 with a total score of 3.33 and will be analysed for further development.

Tab. 5.4. Concept evaluation matrix

		Concept							
Selection criteria	Weight	A		C		H		I	
		Ratings	Weight	Ratings	Weight	Ratings	Weight	Ratings	Weight
1.	**10**								
1.1.	5	3	0.15	3	0.15	3	0.15	3	0.15
1.2.	5	4	0.2	4	0.2	3	0.15	3	0.15
2.	**20**								
2.1.	6	1	0.06	1	0.06	3	0.18	4	0.24
2.2.	4	2	0.08	2	0.08	3	0.12	4	0.16
2.3.	3	4	0.12	4	0.12	3	0.09	3	0.09
2.4.	3	4	0.12	4	0.12	3	0.09	3	0.09
2.5.	4	2	0.08	2	0.08	3	0.12	4	0.16
3.	**10**								
3.1.	3	1	0.03	1	0.03	3	0.09	3	0.09
3.2.	3	2	0.06	3	0.09	3	0.09	2	0.06
3.3.	4	2	0.08	4	0.16	3	0.12	3	0.12
4.	**15**								
4.1.	2	4	0.08	5	0.1	3	0.06	3	0.06
4.2.	2	4	0.08	5	0.1	3	0.06	3	0.06
4.3.	2	5	0.1	4	0.08	3	0.06	3	0.06
4.4.	4	1	0.04	2	0.08	3	0.12	4	0.16
5.	**10**								
5.1.	5	2	0.1	2	0.1	3	0.15	4	0.20
5.2.	5	1	0.05	1	0.05	3	0.15	3	0.15
6.	**10**								
6.1.	5	5	0.25	4	0.2	3	0.15	3	0.15
6.2.	5	5	0.25	4	0.2	3	0.15	3	0.15
7.	**10**								
7.1.	4	3	0.12	4	0.16	3	0.12	3	0.12
7.2.	3	2	0.06	5	0.15	3	0.09	4	0.12
7.3.	3	3	0.09	4	0.12	3	0.09	3	0.09
8.	**20**								
8.1.	10	2	0.2	1	0.1	3	0.3	4	0.4
8.2.	5	4	0.2	4	0.2	3	0.15	3	0.15
8.3.	5	3	0.15	3	0.15	3	0.15	3	0.15
Total score		**2.75**		**2.88**		**3**		**3.33**	
Rank		**4**		**3**		**2**		**1**	

5.5. Product architecture

The architecture of the developed product will consist of 4 systems: actuation, resistance, embedding and interfacing (Fig. 5.2). Each system has a well-defined role within the larger ball throwing equipment assembly [T10].

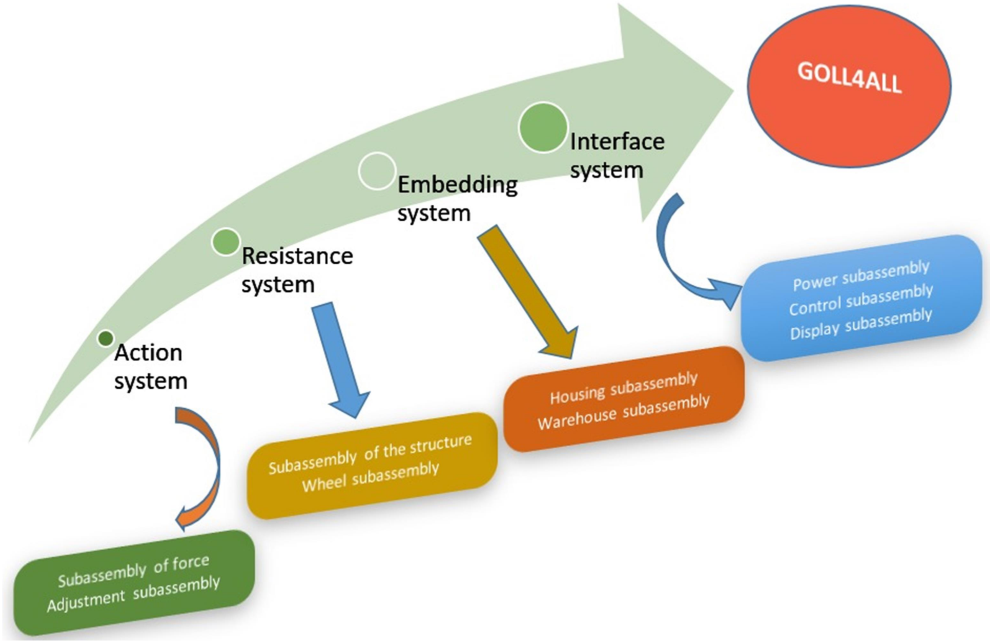


Fig. 5.2. Product architecture [T10]

5.6. Economic analysis

Economic analysis involves the investigation of a phenomenon or process from an economic point of view, which implies, correlatively, the highlighting of the efforts dimensioned by the consumption of material, human and financial resources, as well as the effects, circumscribed to the results as useful social values [R09].

Pricing of the products purchased from the shops was done through advanced search on the online websites of the different shops and choosing the product at a low price and the required quality. For products manufactured on CNC machine tools or by additive manufacturing, prices were calculated according to the methodology presented in the thesis.

Table 5.5 shows the cost for each component of the ball sports training equipment, both for parts purchased from shops and for parts made of steel, sheet metal or made by 3D printing. The total cost of the developed prototype is 4295 RON.

Tab. 5.5. List of products

System	Subassembly	Component	Quantity	u.m.	Unit price	Total price
Drive	Force	Main engine	1	pcs.	497	497
		Secondary engine	2	pcs.	130	260
		Anchor bushing	1	pcs.	69.67	69.67
		ID 15 elastic bushing	1	pcs.	10	10

		Bearing RA ID 15	1	pcs.	5	5
		Drive shaft	1	pcs.	78	78
		ID 15 bearing	1	pcs.	5	5
		Drive arm	1	pcs.	39.86	39.86
		Toothed wheel 1	2	pcs.	40	80
		Toothed wheel 2	2	pcs.	40	80
		ID 10 bearing	2	pcs.	5	10
		Paddle	1	pcs.	99	98.94
		Screw M12	6	pcs.	2.19	13.14
		Nut M12	6	pcs.	0.38	2.28
		Screw M5	8	pcs.	0.13	1.04
		Screw M5	8	pcs.	0.13	1.04
		Nut M5	16	pcs.	0.04	0.64
	Adjustment	Secondary motor 2	1	pcs.	370	370
		Lead screw	1	pcs.	410	410
		Elastic bushing	1	pcs.	10	10
		Spacer	4	pcs.	8	32
		Plate	1	pcs.	67.84	67.84
		Stopper	2	pcs.	28.75	57.5
		Clamping flange	1	pcs.	44.04	44.04
		M6 screw	4	pcs.	0.17	0.68
		Nut M6	4	pcs.	0.06	0.24
Resistance	Structure	Profile 25x25	9	m	1.01	9.09
		Horn	24	pcs.	3.5	84
		Screw M5	48	pcs.	0.13	6.24
		Nut M5	48	pcs.	0.04	1.92
	Wheels	Wheel	4	pcs.	7.3	29.2
		Screw M8x15 mm	16	pcs.	0.36	5.76
Embedding	Housing	Handle	2	pcs.	38	76
		Turntable	1	m^2	35.11	35.11
		Lower housing	1	m^2	35.11	35.11
		Upper housing	1	m^2	35.11	35.11
	Warehouse	Cavity	1	m^2	35.11	35.11
		Guide	1	m^2	35.11	35.11
		Ball slide	2	m	50	100
		PVC elbow for slide	2	pcs.	71.2	142.4
Interface	Power	Power cable	3	pcs.	11	33
		Transformer	1	pcs.	29.75	29.75

		Motor source 1Nm	1	pcs.	215	215
		Switch source	1	pcs.	49	49
		Motor source 9Nm	1	pcs.	245	245
	Control	Motor driver 9Nm	1	pcs.	355	355
		Rasbperry Pi 4	1	pcs.	279	279
		MicroSD card	1	pcs.	49	49
		Motor driver 1Nm	2	pcs.	35	70
		Accelerometer and gyroscope	1	pcs.	15	15
		2-channel relay	1	pcs.	7	7
	View	Display	1	pcs.	74.97	74.97

CAPITOLUL 6
DETAIL DESIGN OF TRAINING EQUIPMENT FOR BALL SPORTS

This chapter presents all the necessary elements for the physical realisation of the developed product. It also reviews the equipment on each designed subassembly. The final assembly is structured by subassemblies and systems, according to the architecture presented in the previous chapter.

6.1. Design of the drive system

The design of the equipment starts with the drive system, with which balls of different sizes can be hit, which is composed of two sub-assemblies (Fig. 6.1):

✔ Force subassembly (1)

✔ Adjustment subassembly (2)

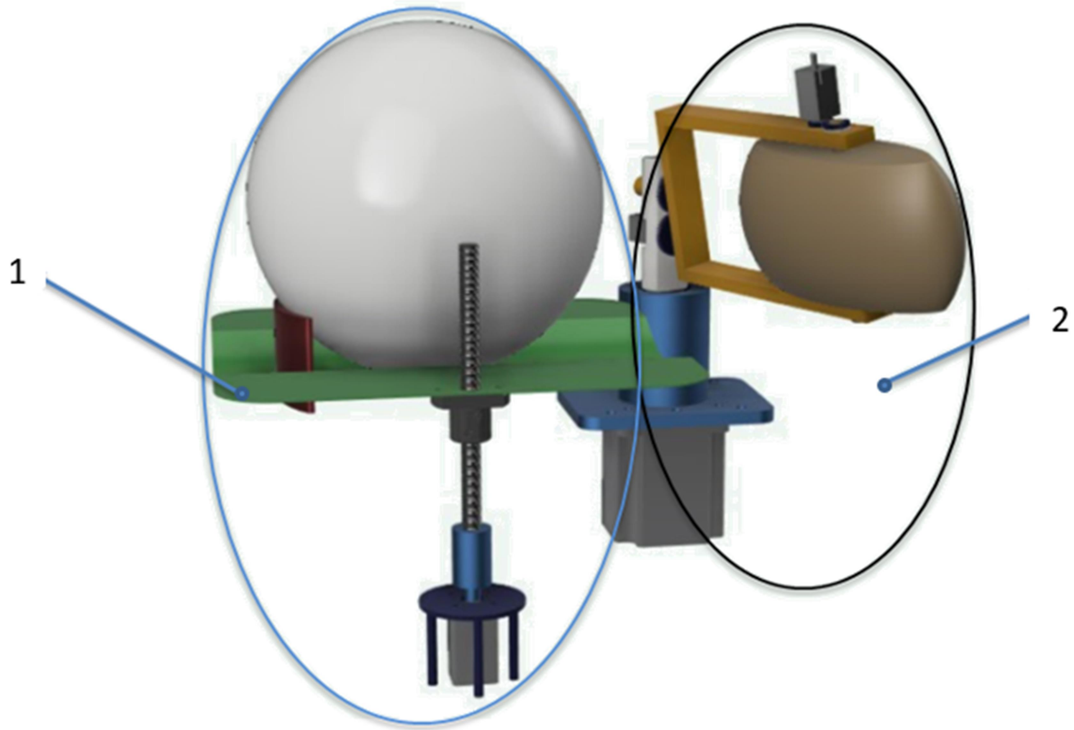


Fig. 6.1. Drive system

6.1.1. Force subassembly design

The force subassembly is used for hitting the ball with the paddle, Fig. 6.2.

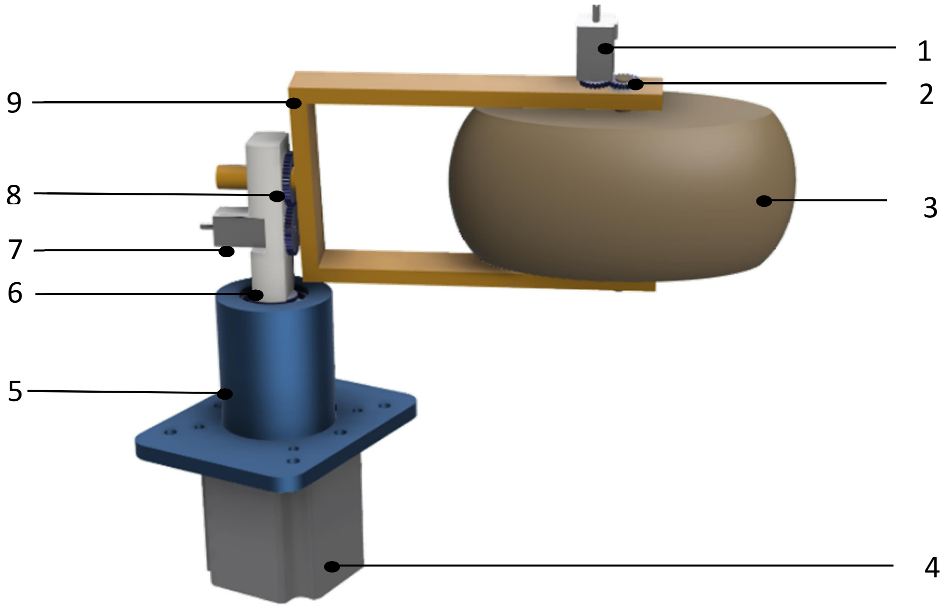


Fig. 6.2. Force subassembly

a. Main engine

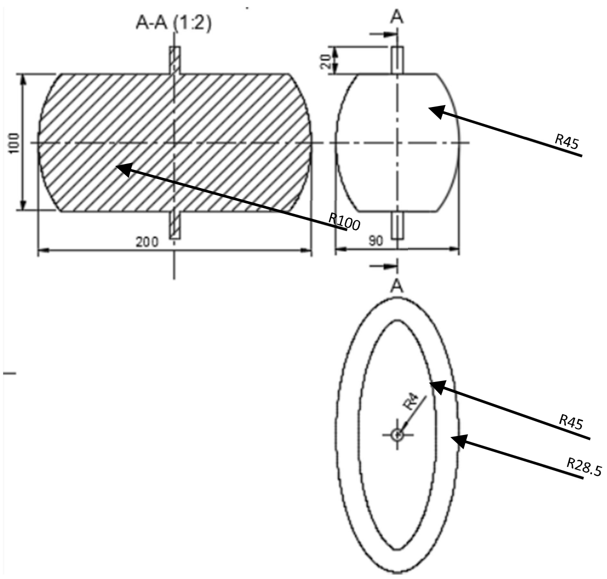
The correct choice of motor was made after calculating the force required to drive the force subassembly, which will impart a set speed and direction to the ball.

b. Steering motor

A football player can kick the ball at many points, so that the trajectory of the ball depends on the point of contact between the foot and the ball. In order for the developed equipment to be able to kick the ball at different points, two stepper motors will be used, as they offer high positioning accuracy.

c. Paddle

The paddle is used to hit the ball, with the speed and direction set by the user. The paddle is driven by the main motor and can rotate 360° around the drive shaft, Fig. 6.3.

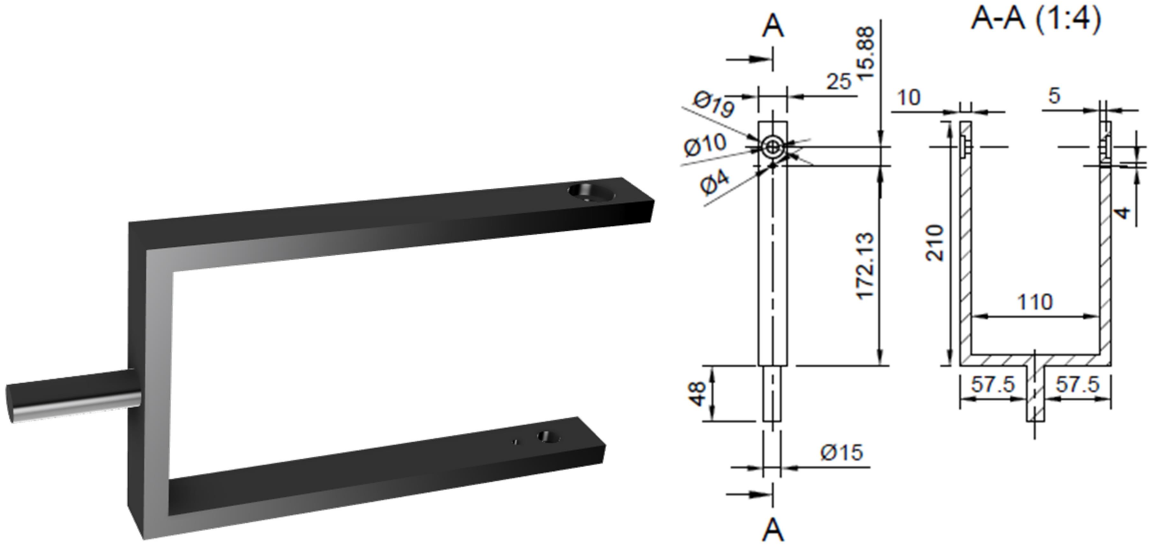


a) 3D Model **b)** Dimensions

Fig. 6.3. Paddle

d. Drive arm

The drive arm (Fig. 6.4) is used to support and orient the blade in the xOy plane. It has been designed according to the striking vane and the secondary motor driving the vane in the xOz plane.



a) 3D Model **b)** Dimensions

Fig. 6.4. Drive arm

e. Drive shaft

The drive shaft acts as a link between the main motor and the drive arm.

f. Anchor bushing

The anchor bushing is designed so that it can be assembled with the main engine to support it by gripping the square pipes in the centre of the strength structure.

g. Gear wheels

In the developed product, gearwheels will be used to transmit the force from the secondary motors to the drive arm and the vane.

h. Elastic bushing

The elastic bushing is used to transmit torque between the motor shaft and the drive shaft.

i. Bearings

Bearings generally support and guide oscillating and rotating machine elements - such as shafts, axles or wheels - and transfer loads between machine components [R11].

6.1.2. Adjustment subassembly design

The adjustment subassembly is used to position different types of balls at the desired height so that the paddle can hit the ball at the points desired by the user. The adjustment sub-assembly consists of a plate (4) supporting the ball which stops in the stopper (5). In order to be able to hit different sizes of balls, the plate (4) can be lowered and raised by means of a lead screw (1) which is driven by a motor (3). The motor is supported by the clamping flange (2) which is positioned on the lower housing, Fig. 6.5.

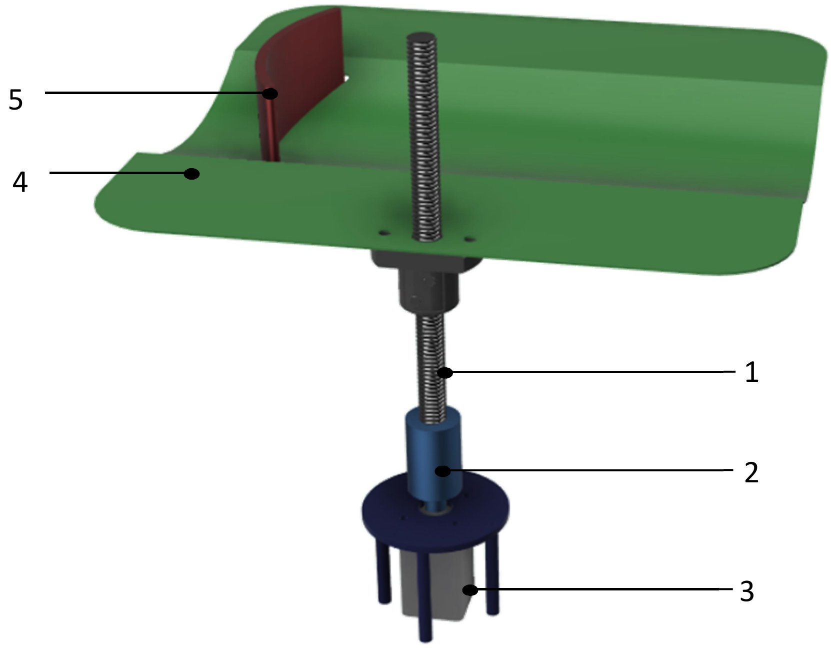


Fig. 6.5. Adjustment subassembly

6.2. Resistance system design

The strength system is the frame of the developed equipment, which will be used to hold the embedding subassembly. It is designed to give the product easy mobility and maximum stability.

6.2.1. Subassembly design of the structure

The structure's subassembly consists of square section pipes of size 30 x 30 mm (STAS 6086-80), which are fastened at the corners with angle brackets and nut bolts. These give stability to the ball throwing equipment and will be used for the attachment of the outer casings.

Strength calculations are carried out in the elastic range so that the piece will last much longer. As the allowable stress (σ_a) for a structured steel is 120 Mpa it follows that the strength condition $\sigma_{max} < \sigma_a$ is met, and the optimum value of the axial modulus of resistance is determined for the dimensioning calculation. The strength condition $\sigma_{max} \leq \sigma_a$ applies.

If $\sigma_a = 120$ MPa ⇒ $\sigma_{max} = \frac{Mîmax}{Wy}$ ⇒ $W_y = \frac{Mîmax}{\sigma max} = \frac{3910,87}{120} = 32,59\ mm^3$

It can be seen that at Wy = 32.59 mm^3 in the structure a stress equal to the allowable stress is reached. The value of Wy = 32.59 mm^3 corresponds to a cross-section of much smaller dimensions than the square pipe of size 30 x 30 mm.

6.2.2. Design of wheel/earth connection sub-assembly

The wheel/ground linkage subassembly is used to move the developed equipment relatively easily. This sub-assembly consists of 4 wheels placed in the corners of the lower housing and 16 M8x15 mm bolts for clamping.

6.3. Design of the embedding system

The embedding system includes most of the housings that are clamped onto the metal frame of the equipment in order to provide a high degree of safety to the developed product.

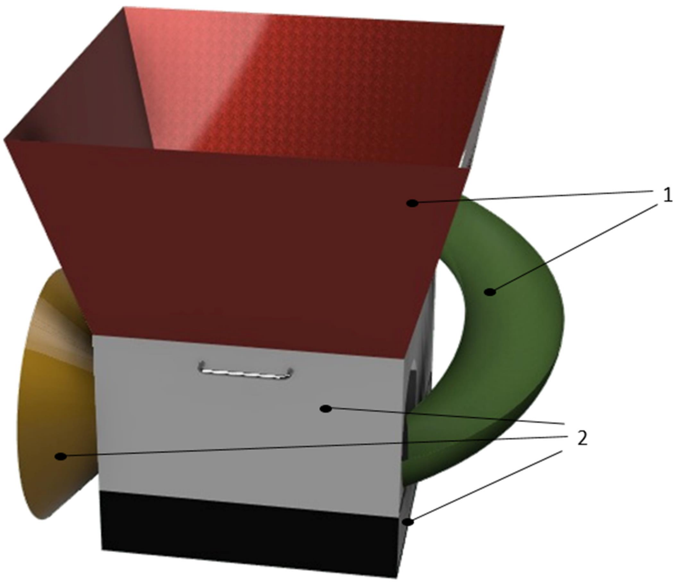


Fig. 6.6. Embedding system

6.3.1. Housing sub-assembly design

The housing subassembly is designed to give the developed equipment a pleasing appearance and ergonomic shape.

a. Handle

Handles are used for easy towing of the product.

b. Platform (fixed platform)

The fixed platform is used to support the drive system of the product. In Fig. 6.31 shows the shape of the 3D designed platform.

c. Lower housing

The lower casing is made to hold the wheels, but also to enclose the electronics used, which is the most important aspect in the choice of dimensions.

d. Upper housing

The upper casing (Fig. 6.7) serves to protect the user, and inside it is the operating system of the developed equipment.

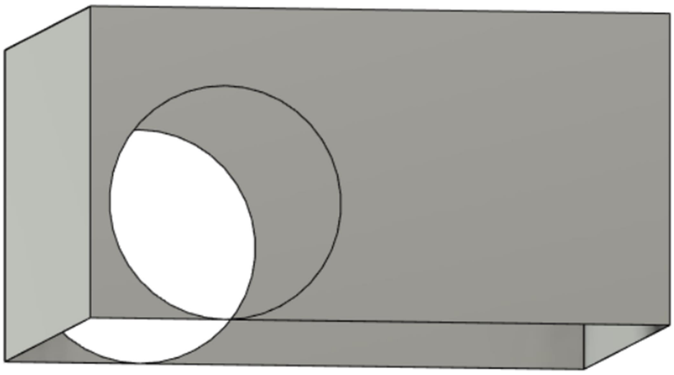


Fig. 6.7. Upper housing

6.3.2. Design of the shed subassembly

The storage sub provides storage for a large number of balls, which allows the user to train for a longer period of time.

6.4. Interface system design

The interface system is composed of power, control and display subassemblies.

6.5. Design of the final assembly

Assembling all the systems presented will result in the product that will be fully developed by the end of this work. In Fig. 6.8 both front and back views of the developed equipment with its components can be seen.

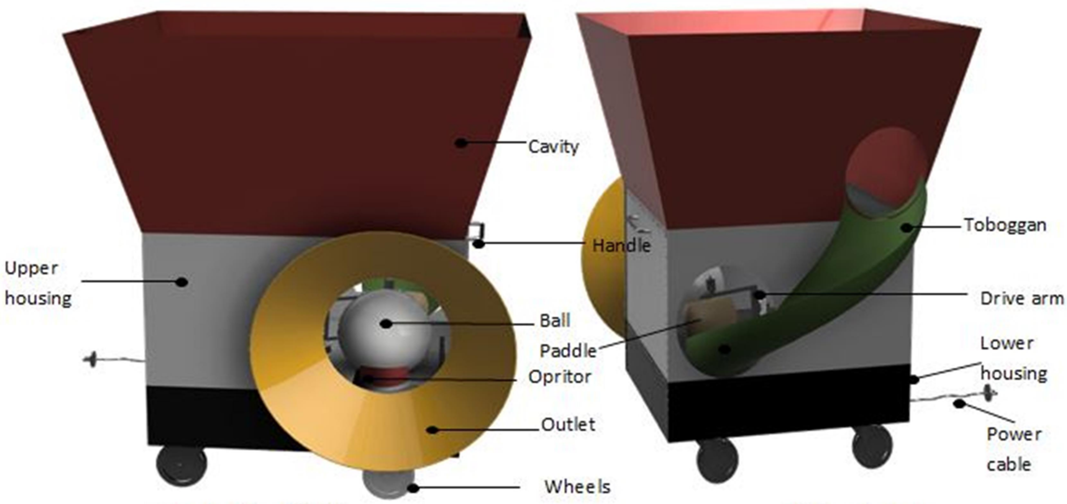


Fig. 6.8. Sports ball throwing equipment - 3D model

CHAPTER 7
MODELLING AND SIMULATION OF ASSEMBLY OPERATION

The development of new technologies and design and simulation applications has enabled engineers to numerically model innovative products that they can observe working with simulators.

7.1. Definition of physical processes

7.1.1. Critical components

By analysing the final assembly, the aim is to carry out static simulations for several critical elements that will be stressed during the ball striking motion: the paddle, the arm and the drive shaft. The critical elements are part of the force subset with which the ball striking is performed and represent the most important part of the equipment.

In finite element analysis the critical elements are subjected to a moment equal to the maximum moment developed by the motors, 10 Nm. The same simulation algorithm will be applied to each element, assuming that the parts are made of plastic material - PET, as used for the manufacture of the prototype.

7.1.2. Simulation algorithm

Paddle

From the simulation, it can be seen that the minimum factor of safety is 15 (Fig. 7.1), which shows that the paddle is resistant to the imposed conditions.

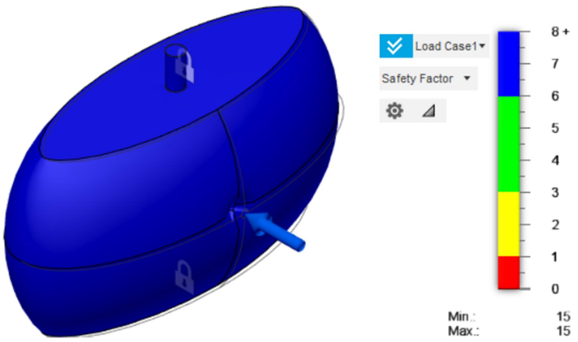


Fig. 7.1. Safety simulation [T10]

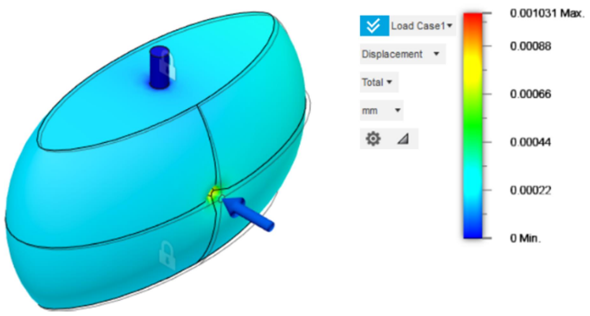


Fig. 7.2. Simulating the deformation of the padle [T10]

It can be seen that its maximum degree of distortion is 0.001 mm (Fig. 7.2), which means that the applied force will have no negative effect on the deformation of the blade and thus on the trajectory of the ball.

Drive arm

The second critical element to be simulated is the drive arm.

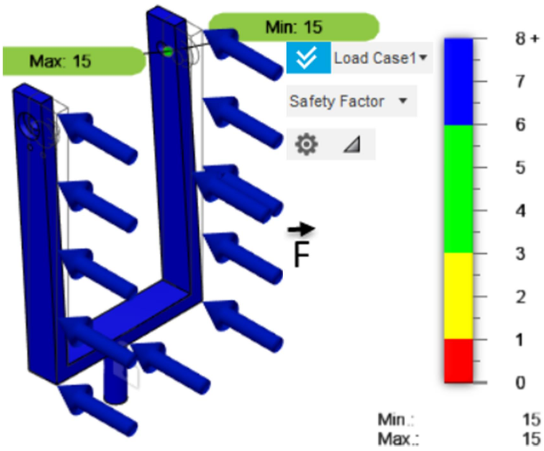


Fig. 7.3. Safety simulation

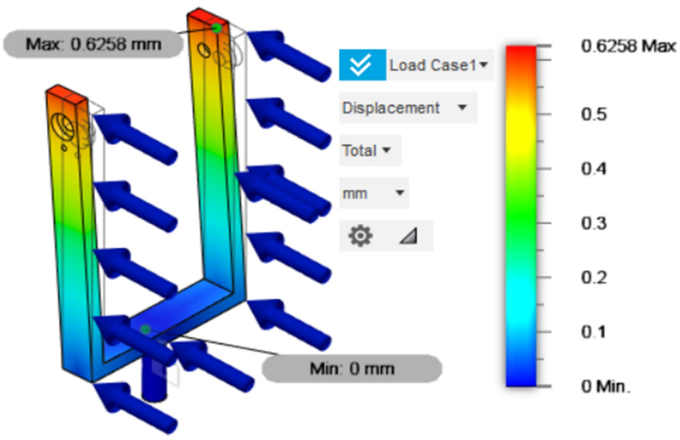


Fig. 7.4. Simulation of drive arm deformation

From the simulation it can be seen that the drive arm has a minimum safety factor of 15 (Fig. 7.3), which means that it will withstand the imposed conditions, and the maximum displacement of the drive arm is 0.6258 mm (Fig. 7.4) in the upper part of the arms, which means that it will not influence the ball movement trajectory.

Drive shaft

The third critical element that will be subject to static simulation is the drive shaft, which connects the main motor to the drive arm.

The finite element analysis shows that the safety factor has a minimum value of 6.96 (Fig. 7.5) and the maximum deformation is 0.2 mm (Fig. 7.6), which can be compensated from the motor movements and does not influence the ball motion path.

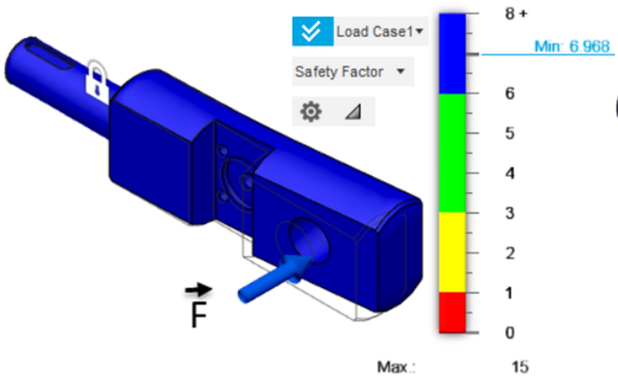


Fig. 7.5. Safety simulation

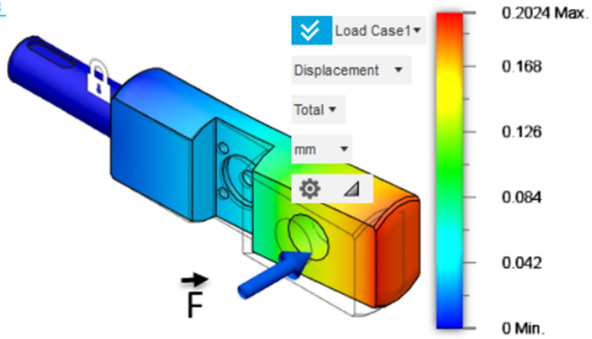


Fig. 7.6. Simulation of drive shaft deformation

7.1.3 Results

The simulations carried out for the three critical elements, obtained by additive manufacturing with PET filament, showed that they withstand the required conditions and the materials chosen for manufacturing are compliant.

7.2. Determination of blade rotation angles

To determine the angle of rotation of the paddle in the two working planes, so that the trajectory of the ball strikes the desired point, the origin of the reference system is considered to be the point O (0, 0, 0) which is positioned and fixed in the centre of the football goal, at the same height as the centre of the ball in the sports equipment Fig (7.7).

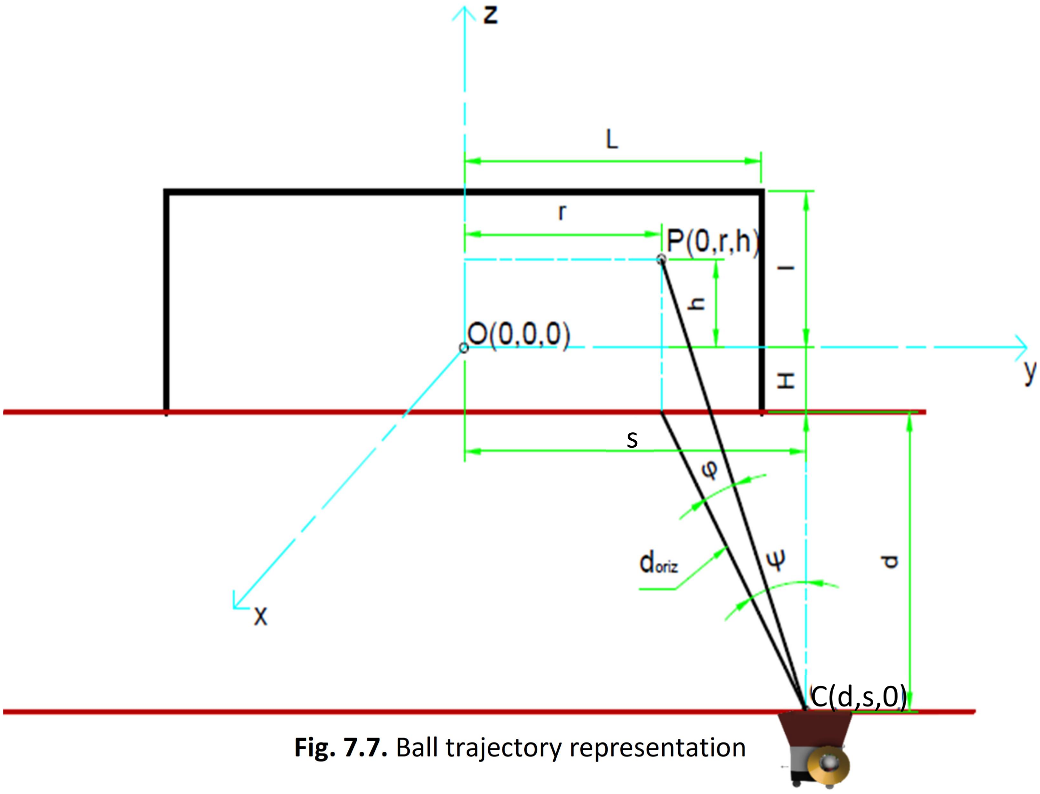


Fig. 7.7. Ball trajectory representation

Mathematical calculations to find rotation angles yield the following formulae:

$$\alpha = \arcsin\left(\frac{-R\sin(\phi)}{\sqrt{(a\sin(\Theta)\cos(\sigma))^2+(c\cos(\Theta))^2}}\right) - \arcsin\left(\frac{c\cos(\Theta)}{\sqrt{(a\sin(\Theta)\cos(\sigma))^2+(c\cos(\Theta))^2}}\right) \quad (7.1)$$

$$\beta = \arcsin\left(\frac{p\cos(\alpha) - q\sin(\alpha)}{\sqrt{p\cos(\alpha) - x\sin(\alpha)^2+q^2}}\right) - \arcsin\left(\frac{||u\Theta\ x\ u\sigma|| * \cos(\varphi)*\cos(\Psi)}{\sqrt{p\cos(\alpha) - x\sin(\alpha)^2+q^2}}\right) \quad (7.2)$$

Thus, the angles of rotation of the blade in the two working planes, xOy and xOz, can be determined analytically using formulas (7.1) and (7.2) and a certain trajectory is imparted to the ball according to them.

7.3. Representation of 2D trajectories

The main purpose of the developed product is to throw the ball on a certain trajectory and at a certain speed. In order to observe which trajectories the ball can travel when launching from the equipment, the contact points between the ball and the blade hitting it will be analysed.

Fig. 7.8 shows the angle of release of the ball that is at a tangent to the blade. The two trajectories that the paddle can have and the contact area where the paddle hits the ball can also be seen. As a result of the two trajectories, the paddle hits the ball and imparts a velocity to the ball. Given that the shot travels diametrically opposite through the ball, it can be seen that the angle of release of the ball through the outlet is 76.87°.

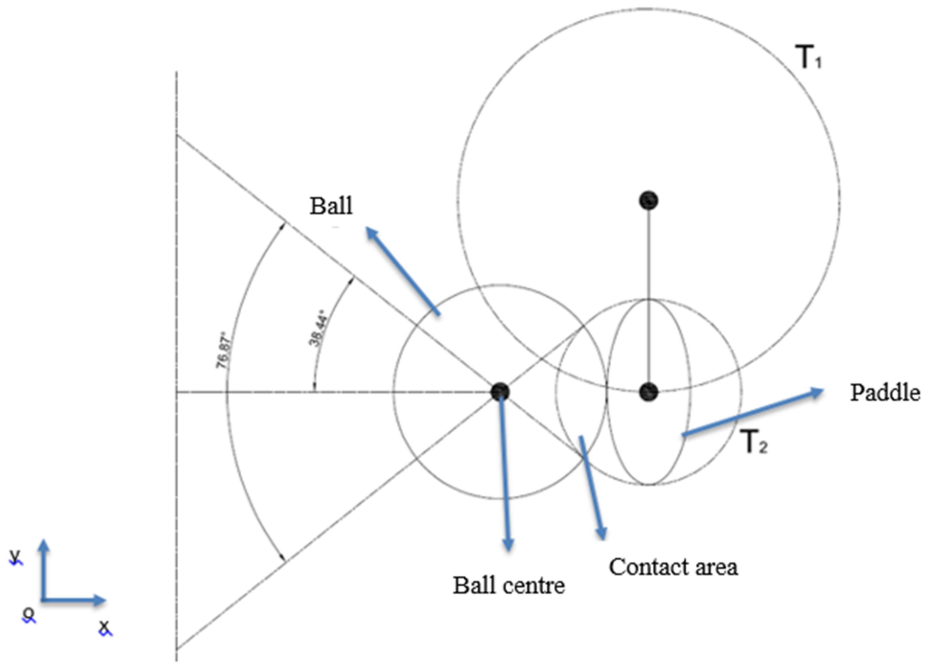


Fig. 7.8. Angle of clearance of the ball in the xOy plane

The trajectory imposed by the vane in the xOz plane makes the points of interference (1) between the ball and the vane right at the intersection of the trajectory with the ball. As in the analysis in the xOy plane, the vane hits the ball and the impressed force is transmitted diametrically opposite through it, imparting a clearance angle of 31.58° (Fig. 7.9).

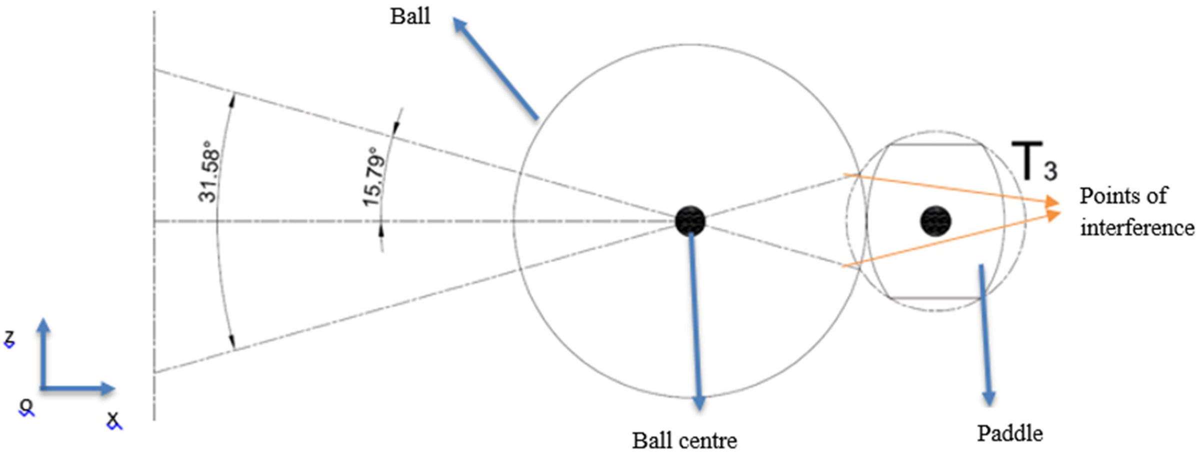


Fig. 7.9. Angle of clearance of the ball in the xOz plane

7.4. Representation of 3D trajectories

The analysis of the trajectory simulation, performed in the previous subchapter, has been divided into the two planes, namely xOy and xOz. After combining the ball propagation directions in the two planes, it was found that the contact area between the vane and the ball is large enough so that the printed velocity and trajectory are accurate.

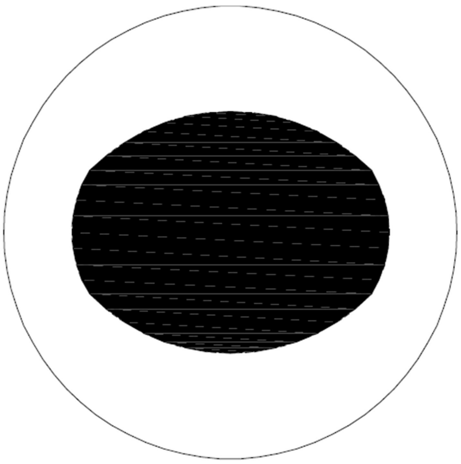


Fig. 7.16. 2D ball striking surface

Fig. 7.17. 3D ball striking surface

CHAPTER 8
MANUFACTURE OF TRAINING EQUIPMENT COMPONENTS

Component manufacturing is a whole process of activities that contribute to the final product. Depending on the existing technologies, technologies that make parts easy, fast and resistant are studied and chosen.

8.1. Process selection

The selection of the technological process is based on established evaluation criteria (Fig. 8.1) [F02].

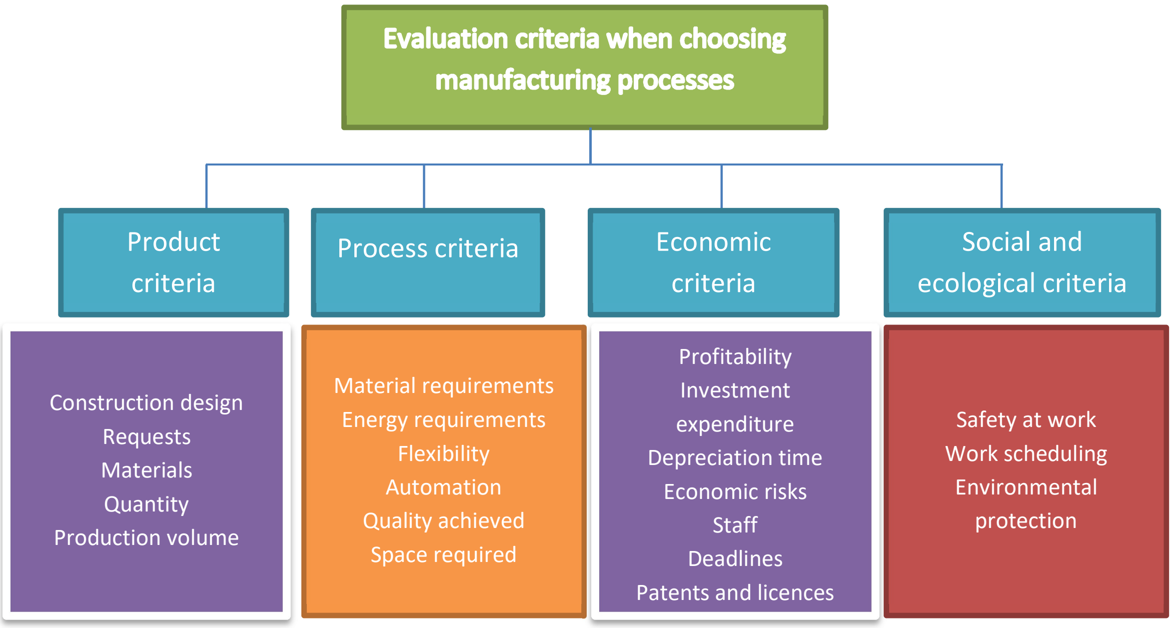


Fig. 8.1. Evaluation criteria when choosing manufacturing processes [F02]

The components of sports equipment (Fig. 8.2) are made by: subtractive and additive manufacturing technological processes, and there are also purchased components.

Sub-assembly components are obtained as follows:

- purchased: motors, elastic bushings, bearings, screws, nuts, lug nuts, drivers, motor sources, wheels, grips;
- additively manufactured: anchor bushing, drive shaft, drive arm, vane, gears, spacers, stopper, clamping flange [T10].

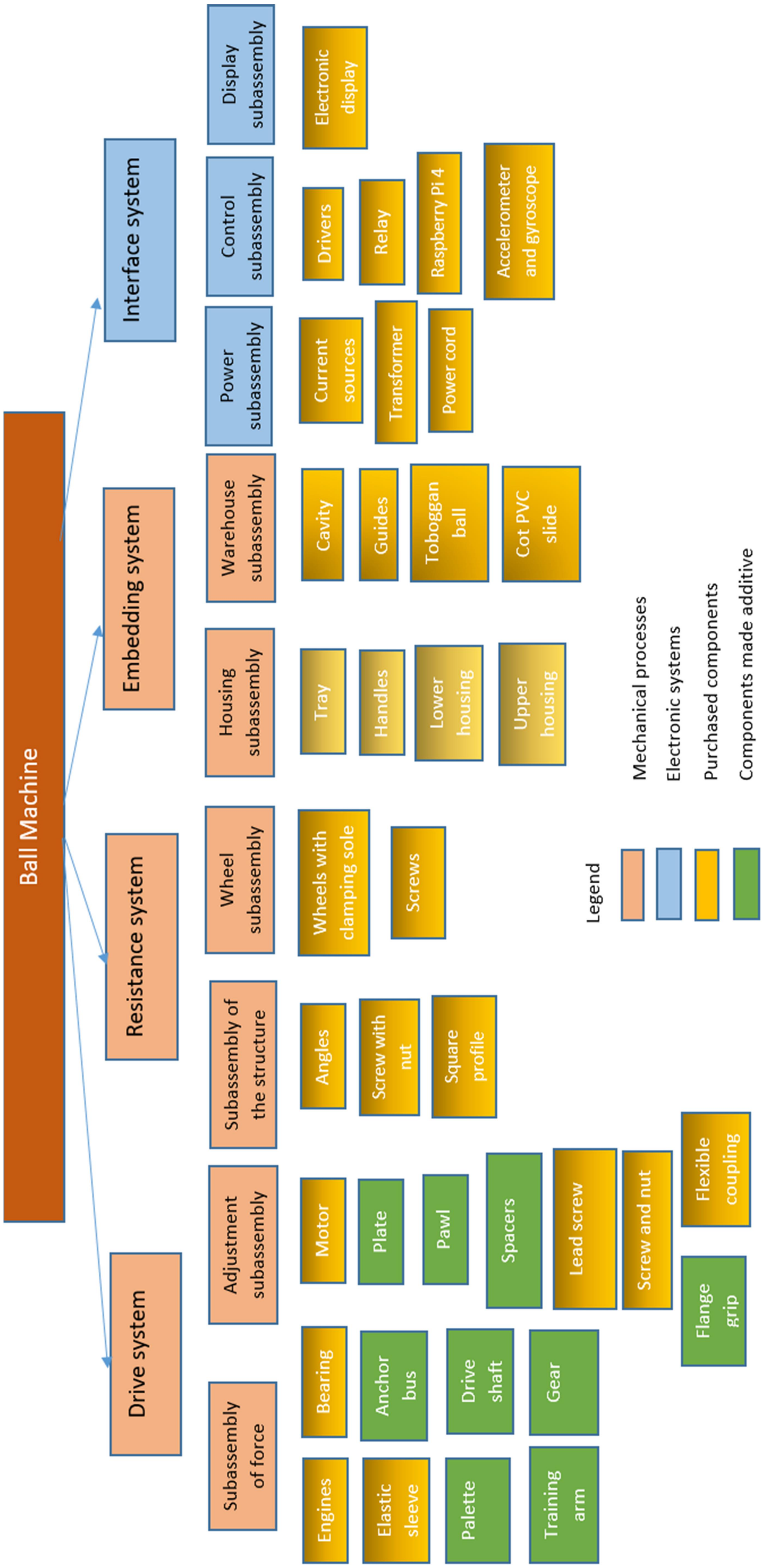


Fig. 8.2. Tree diagram of the assembly [T10]

8.2. Manufacture of mechanical components

In the developed product, the two subassemblies that were mechanically manufactured are the structure subassembly and the housing subassembly, as they are critical elements in the construction of the equipment. They are the first subassemblies made that provide strength and shape to the developed product.

8.3. Manufacture of additive components

The most widely used technology in additive manufacturing is FDM technology because it offers the possibility of making functional prototypes from various thermoplastic polymers. The material used (also called filament) passes through an extruder, where it melts and becomes liquid and is then selectively deposited, layer by layer, through a nozzle that moves along the xOy and xOz axes according to the geometry of the 3D part.

8.3.1. Equipment and materials used

The Zortrax M300 Plus printer was used in the additive manufacturing process to print large parts in one piece. Most of the components in the product's force system are made by additive manufacturing, due to the custom shapes and sizes specific to the product developed. The materials used for 3D printing of parts are Polyethylene Terephthalate (PET) and Z-HIPS which have the following properties, Tab 8.1.

Tab. 8.1. Properties of materials used

Crt. no.	Property	PET	Z-HIPS
Mechanical properties			
1.	Friction coefficient	0.18 - 0.4	0.2
2.	Hardness - Rockwell	80 - 96	109
3.	Tensile strength	2.10 - 90.0 MPa	34.3 MPa
4.	Elongation at break	4.00 - 600 %	79 %
Physical properties			
5.	Density	1.3 - 1.4 g/cm^3	1.13 g/cm^3
8.	Viscosity test	62.0 - 86.0 cm^3/g	71 cm^3/g

8.3.2. Manufacture of components

All additive manufacturing components were designed in Fusion 360 design software. In order to 3D print the components of sports equipment, they have to go through a preparation process that consists of obtaining STL files containing only the surface geometry of a three-dimensional object and converting them into .gcode files. The .gcode files are generated by inserting the STL files into Z-Suite and setting the following parameters for 3D printing:

❑ material type: Z-HIPS;

❑ for the part support the automatic shape will be chosen at an angle of 45 degrees;

❑ layer thickness: 0.19 mm;

❑ normal profile with grid pattern;

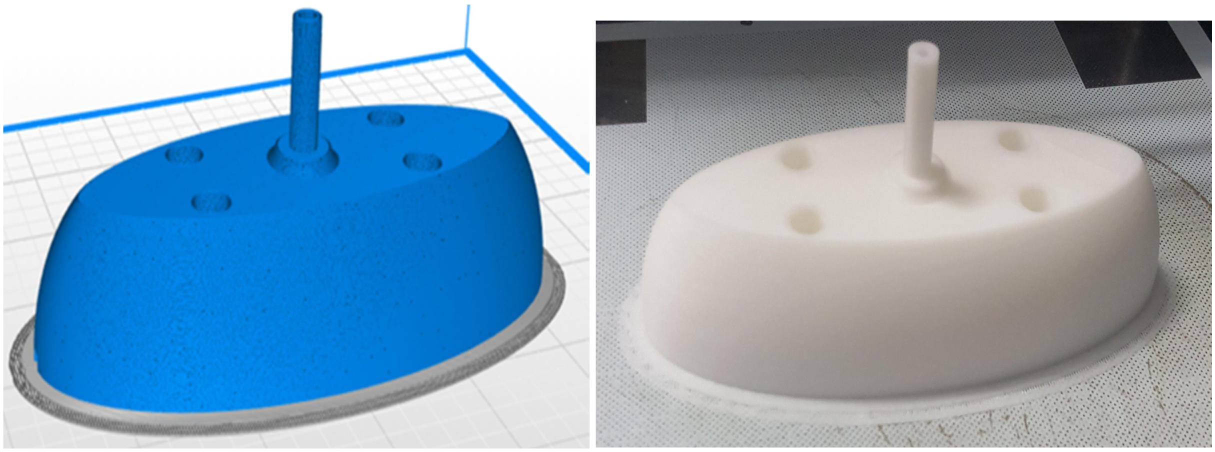
❑ filling density: 50%, because the equipment is intended to be light and at an optimum price, and the parts, following the analysis in the previous chapter, have a high degree of safety;

The paddle has been manufactured on the Zortrax M300 Plus printer, from Z-HIPS type material, to ensure the required component strength with the following printing parameters (Tab.8.2).

Tab. 8.2. Paddle printing parameters

Parameter	Value
Print time	1d 22h 6m
Material quantity	250.80m (620g)
3D printer	Zortrax M300 Plus
Support	30°
Material	Z-HIPS
Nozzle diameter	0.4 mm
Layer	0.19 mm
Filling	50%

Parameter	Value
Outline filling	0.40
Top contour	0.24
Maximum wall thickness	2.63 mm
Print speed first layer	100%
First layer offset	0.30 mm
Backing layer	7
Substrate offset	0.22 mm
Substrate density	3.00 mm



a. Simulated model b. Physical component

Fig. 8.3. Paddle [T10]

The drive arm is the support inside which the pallet is fixed. Fig. 8.4 shows how the part is oriented on the build platform through a capture during the parameter setting process in Slicer software, Z-Suite.

Tab. 8.3. Drive arm print parameters

Parameter	Value	Parameter	Value
Printing time	13h 59m	Outline filling	0.40
Material quantity	64.54m (160g)	Top contour	0.24
3D printer	Zortrax M300 Plus	Maximum wall thickness	2.63 mm
Support	30°	Print speed first layer	100%
Material	Z-HIPS	First layer offset	0.30 mm
Nozzle diameter	0.4 mm	Backing layer	7
Layer	0.19 mm	Substrate offset	0.22 mm
Filling	50%	Substrate density	3.00 mm

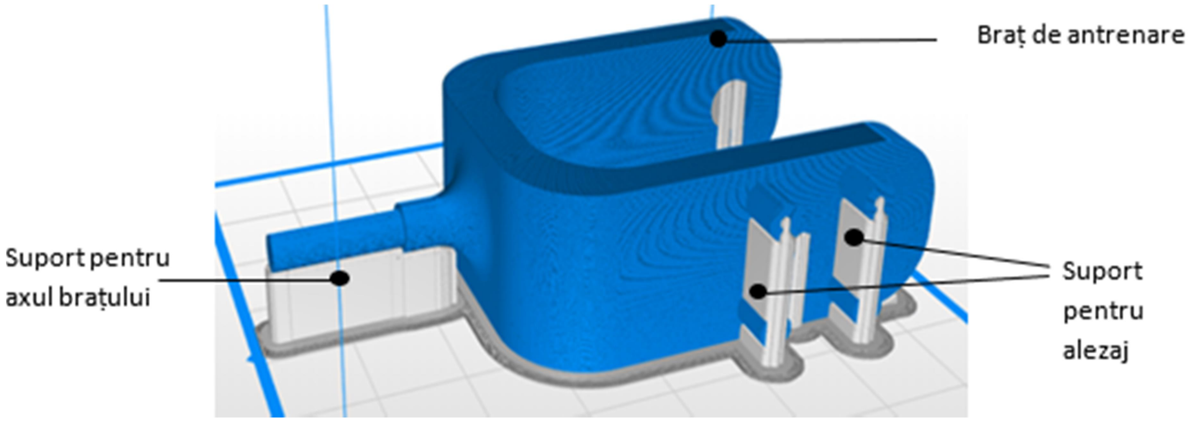


Fig. 8.4. Training arm, simulation in the Z-Suite application

8.4. Electronic system design

In making the sports ball throwing equipment, motors were used to move the paddle, a microcontroller, a gyroscope for position management, a sensor for sending commands from a remote control, an Arduino board for communication between the motors and the application, switching sources and motor drivers. All of these were interconnected and could lead to the realisation of the electronic system.

8.4.1. Electronic components

Stepper motors are used in the developed equipment because they provide the required torque and are cheaper than other motors used for prototypes.

The power subassembly will contain all the power sources used for the operation of the developed equipment. Since several types of motors are used, the power supplies used are intended for each type of motor as follows: 60V/350W switching source, 12 V/120 W switching source for the lead screw.

The control sub-assembly will be used for starting the motors required for ball striking. The control subassembly consists of the following elements: motor drivers, Arduino Uno development board, accelerometer and gyroscope, two-channel relay, LCD display.

8.4.2. Electronic circuit

Fig. 8.5 shows the general schematic of the electronic system for the developed product with all electronic links between components.

The electronic circuitry consists of electronic elements that must satisfy the main function of the equipment, i.e. to hit the ball with a speed and direction desired by the user. The wiring diagram shown in Fig. 8.26 has the components in Tab. 8.4.

Tab. 8.4 Electronic components

Crt. no.	Component name	Crt. no.	Component name
1	24V switching source	**10**	Accelerometer and gyroscope
2	Driver A4988	**11**	Infrared sensor
3	Secondary motor plane position xOz	**12**	Arduino Uno
4	Driver A4988	**13**	Breadbord
5	Driver A4988	**14**	Main motor
6	Motor screw driver	**15**	Secondary motor xOy plane position
7	Switching voltage source 12V	**16**	Switching power supply 60V/350W
8	Solenoid valves	**17**	DM860A driver
9	Two-channel relay		

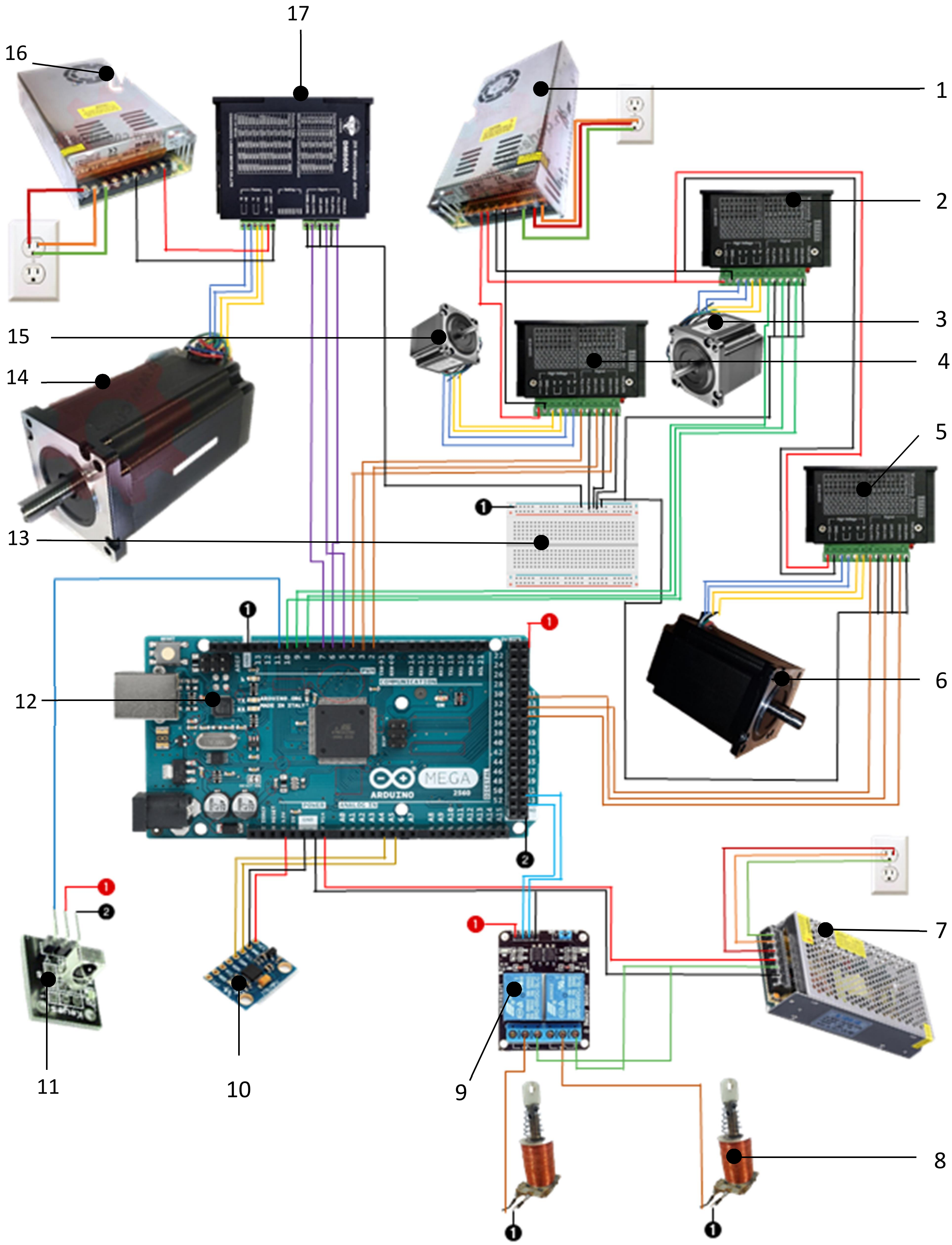


Fig. 8.5. General scheme of the electronic system

8.4.3. Logical scheme

To control the system, a remote control is used, consisting of a numeric keypad from 1 to 9 and a button marked "OK" and an infrared sensor that is plugged into the Arduino Uno board, which receives a signal from the remote control.

The equipment can be set in 3 modes by the user. The main mode of operation, in which the equipment is set automatically by the designer, will be described based on the following algorithm, which consists of two steps to prepare the equipment:

1. Step I: Selection of the area where the ball will be hit (Fig. 8.6).

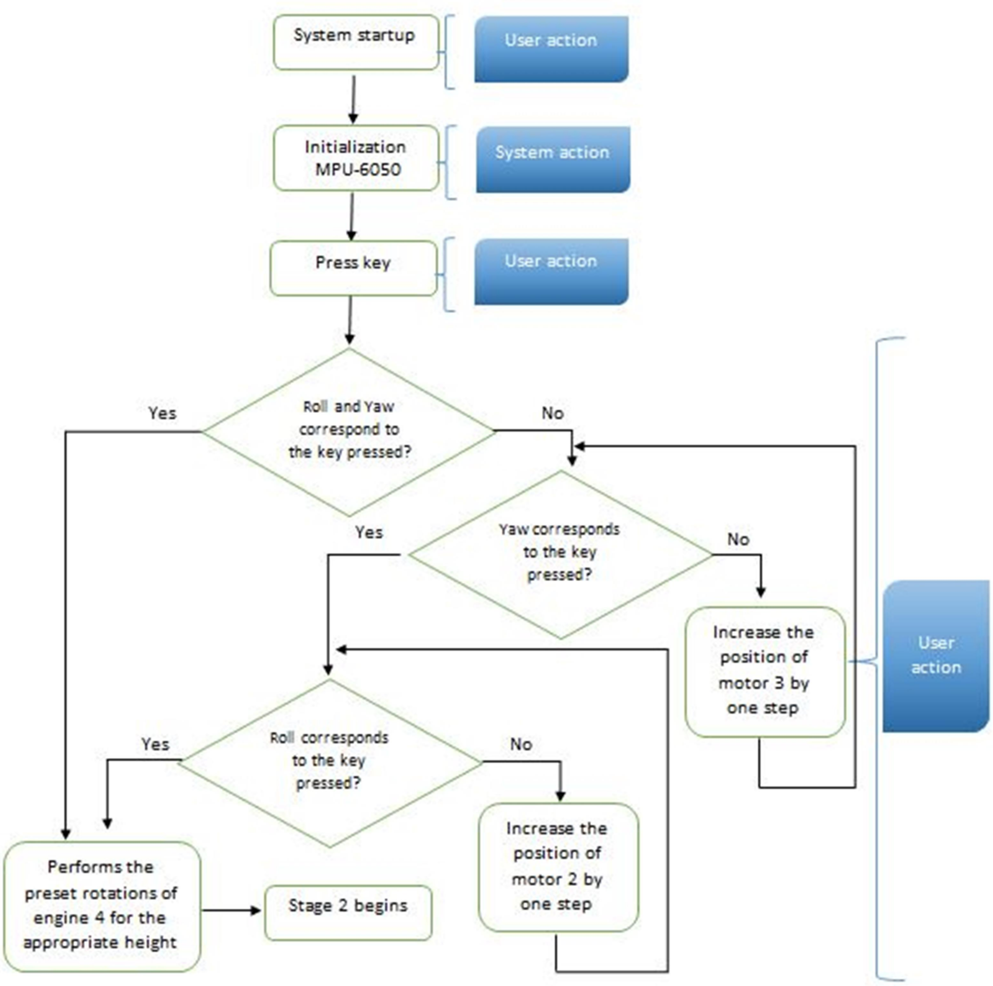


Fig. 8.6. Logical scheme of stage 1

2. Stage II: choosing the speed at which to hit the ball.

8.4.4. Code structure

Programming the Arduino Uno board is done by writing source code in a programming language that is recognised by the board. The following is the source code from which the ball thrower was programmed.

CHAPTER 9
ASSEMBLY AND TESTING OF PROTOTYPE SPORTS TRAINING EQUIPMENT

A basic type of manufacturing operation is assembly operations, where two or more separate parts/parts are joined to form a new entity.

9.1. Product assembly

The developed product required several types of demountable assemblies which together with the related components detailed in the previous chapter, the final assembly was realized (Fig. 9.1).

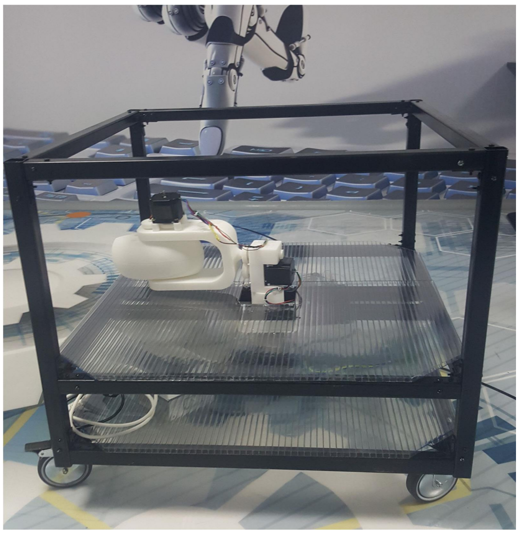


Fig. 9.1. Final assembly

9.1.1. Demountable assemblies

Several removable screw-nut assemblies were used in the product for different component parts of the assembly.

Fig. 9.2. Main engine assembly

Fig. 9.3. Paddle assembly

9.1.2. Motion transmitting assemblies

The transmission of motion from the motors to other components was achieved by assemblies: with wedges, with couplings, with bearings and with gears.

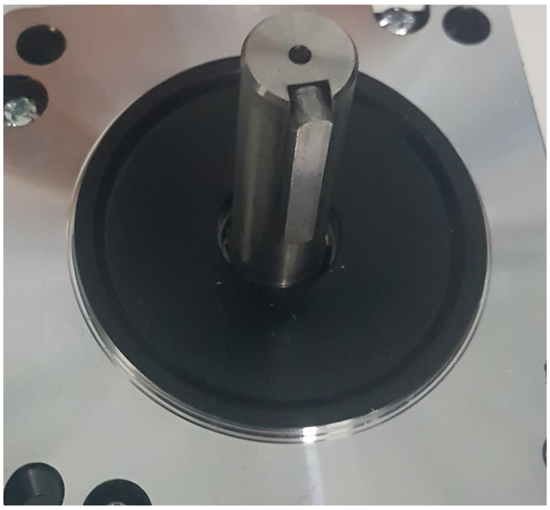


Fig. 9.4. Main engine assembly with wedge

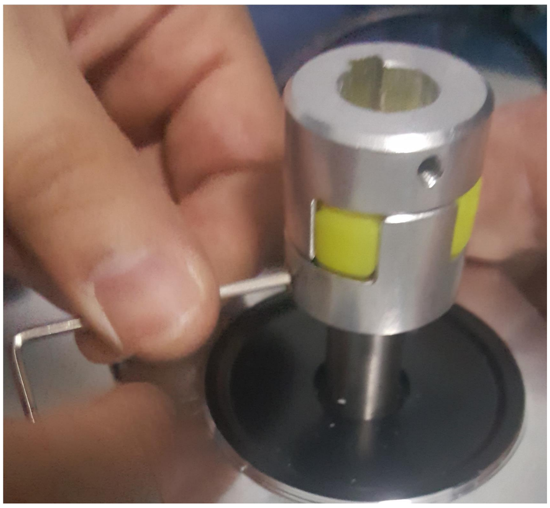


Fig. 9.5. Assembling the elastic coupling

9.1.3. Subassemblies of equipment obtained by assembly

One of the steps in the construction of the equipment was the assembly of the force system with the strength structure system (Fig. 9.6).

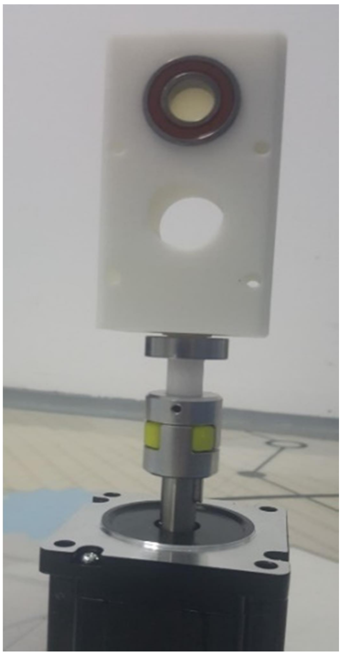


Fig. 9.6. Assembling the engine with the shaft

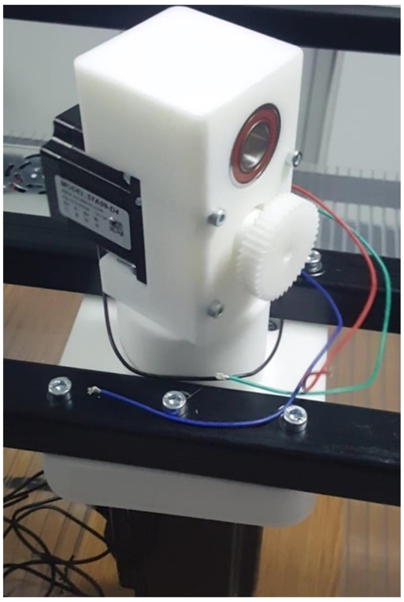


Fig. 9.7. Secondary engine assembly

Continue with the assembly of the force subassembly (Fig. 9.7) and the assembly of the blade with the drive arm and secondary motor Fig. 9.8.

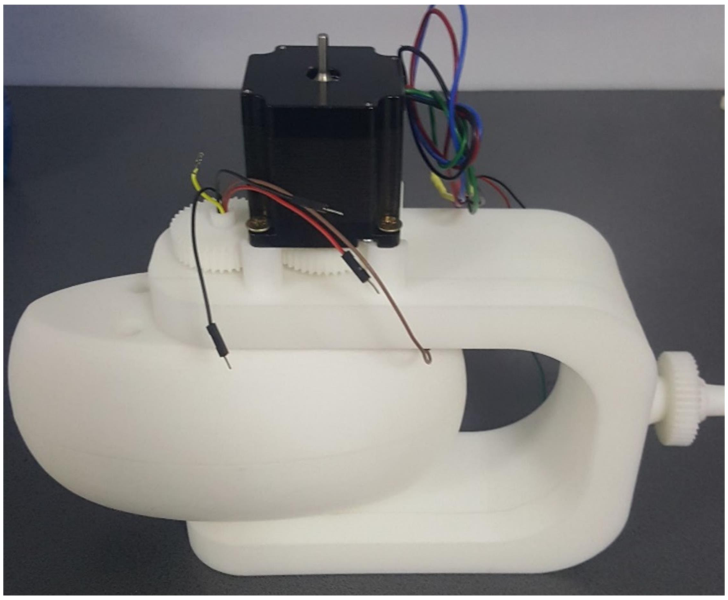


Fig. 9.8. Assembling the drive arm blade with the drive shaft

9.2. Product testing

Detailed design, component manufacture and assembly resulted in the sports ball throwing equipment to be tested for functionality.

9.2.1. Software testing

Using an Arduino Uno board gives us the possibility to use its default software applications. Thus, for software testing, the Android Software application (IDE) is installed on a test laptop by running the arduino.exe file. The final version of the source code was obtained after testing the initial code four times, due to the errors that occurred, but also to the inconsistency of some functions with the functionality of the equipment.

9.2.2. Electronic testing

After entering the source code, the application reads the information sent by the gyroscope and performs the commands sent by the remote control. In Fig. 9.9. shows the test process for gyroscope operation at point 0. This will be the starting point for each operating cycle, as well as the "home" point for the off mode of the equipment.

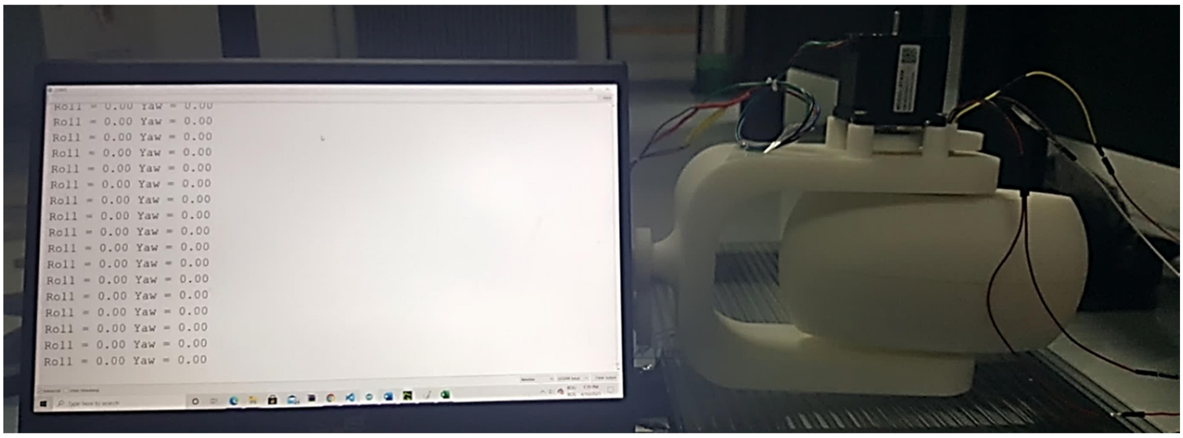


Fig. 9.9. 0-point gyroscope testing

Tests show that the paddle hits the ball at the points indicated by the user.

9.2.3. Prototype optimization

Mechanical testing was an important step in the prototyping process, as it allowed to highlight defects or inconsistencies in the component design process. Thus, it was necessary to adjust the components for their assembly:

- ✓ The drive arm has been adjusted so that there is the possibility of assembling the two parts that form the blade, but especially for the possibility of assembling the gears and the secondary motor that gives the blade direction in the xOy plane.
- ✓ The drive shaft has been adjusted so that the secondary motor can be assembled to steer the arm and blade respectively in the xOz plane.
- ✓ The motor housing that drives the ball position adjustment platform has been redesigned so that it can be mounted on the lower housing of the equipment and provide stability to the motor.
- ✓ The paddle has been redesigned and made of two half-pallets to integrate the gyroscope and accelerometer.
- ✓ The anchor bushing has been adjusted so that it can be assembled with the main engine, but also with the metal bars of the structure located in the centre of the equipment, and so that a tight connection can be made between the engine shaft and the drive shaft so that there is no play or vibration.
- ✓ The drive arm shaft that was assembled in the shaft bore, and the sprocket that was assembled on the arm shaft, have been replaced by a modular shaft, which has an integrated sprocket that meshes with the wheel driven by the secondary motor on the drive shaft, transforming the drive system into a modular system that can be easily assembled and disassembled, the modular shaft having two elliptical ends to prevent it from rotating, and being assembled with covers.

CONCLUSIONS

The main objective of the PhD thesis is the development of equipment for sports training with balls. The realisation of this objective is outlined in nine chapters where the main steps in the development process of the new product are presented.

Thus, in order to achieve the main objective of the PhD thesis, a market analysis has been carried out which includes the identification of the types of sports that use balls as central objects of their activity. Also, through this analysis, the most popular global sport that uses the ball in its practice, football, was identified, for which the types and techniques of training were identified, and for which the technical and material conditions for their optimal performance were established. The requirements of the users who play this sport at amateur and professional level have been linked together with reference to a product that will meet the needs identified for the two market segments. Following the analysis, the existing needs in this field were concretised and the requirements of the customers were correlated with the specifications of the developed product. A desk research on the history, evolution and current trends in the development of ball sport training equipment and a literature review on theoretical and experimental research in the field of sports was also conducted, which allowed to understand the current capabilities of ball training equipment on the market and helped to create the concepts developed for the ball sport training device.

Throwing techniques and the necessary trajectories of the balls were examined. Based on the study, a model was defined that defines the possible distance, speed and trajectories of the ball during training, as well as the exact distance, speed and trajectories of the ball required by the coach for a given type of training.

A 3D model of the ball sports training equipment has been developed and the possible 3D trajectories that the ball may have during the use of this equipment have been simulated. According to the data obtained from the development of the 3D model, it was possible to design the product architecture with the established specifications. The detail design for each component was carried out, a prototype of the ball sports training equipment was designed and manufactured. The elaboration of a detail design for the chosen concept allowed the simulation of the functionalities in the virtual environment and the preparation of manufacturing strategies for each component.

The final stage consisted in carrying out experimental studies with the sports training equipment for testing. During the tests, the components of the assemblies that did not meet the desired conditions were identified, so they were redesigned and reintegrated into the new version of the final prototype. This led to the optimisation of the initial prototype and the production of a second, improved version.

OWN CONTRIBUTIONS

Following the research and the results obtained, the following own contributions are summarized:

1. Analysis of all training techniques for each player position in football;
2. Development of a geometric model for modelling and simulating ball trajectories;
3. Design of nine different, original conceptual solutions of equipment for ball sports training;
4. Detail design of the selected equipment concept;
5. Simulation and validation of materials and geometry for critical components;
6. Perform economic analysis for the prototype and cost estimation;
7. Realization of optimized models for robustness;
8. Development and implementation of the equipment data acquisition system that reads the position of the actuator blade in real time and transfers the information to the processing system;
9. Development and implementation of an equipment drive system based on stepper motors with gears and bearings;
10. Test and validate the prototype of the product obtained.

FUTURE RESEARCH DIRECTIONS

Analysing the results, it is emphasized that future research can reach the following directions:

- Observation and analysis of the functionality of a similar product, on a sample of users, over a limited period of time, in order to best address their needs;
- Designing, modelling, developing and implementing a parameterised equipment for ball sports training that will allow customisation for each type of surface;
- The design, modelling, development and implementation of parts through generative design, which will lead to an entire manufacturing process with an optimised structure;
- Optimisation and implementation of force systems using higher power motors;
- Optimisation of battery power system;
- Development of a software application that allows different methods of blade actuation, but also for continuous monitoring and communication with the coach to evolve the progress of each individual player;
- Development of a command and control interface with the help of which the user can manage the schedule and the range of the equipment.

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