UNIVERSITY OF SKÖVDE
School of Technology and Society

BACHELOR DEGREE

# Development of a prototype for a game including an industrial robot

**by**

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# Abstract

The aim of this essay is to describe the development of two prototypes, a physical one (as shown in figure 1 Physical robot game prototype) and a computer one (as shown in figure 2 CAD robot game prototype), for a ball game involving interaction with an industrial robot. The purpose of the game is to attract young people, especially young women, to engineering, for amusement or education, at exhibitions or other student environments.

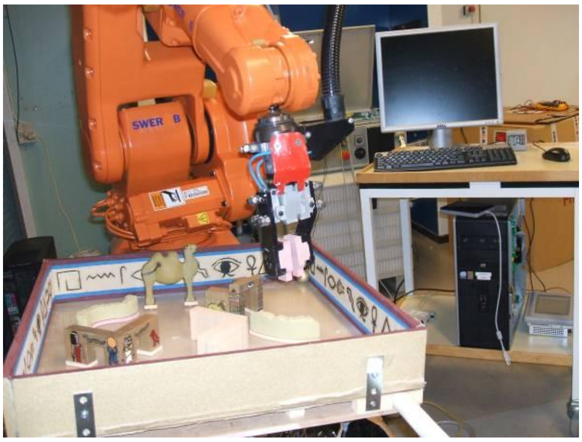

**Figure 1 Physical robot game prototype**

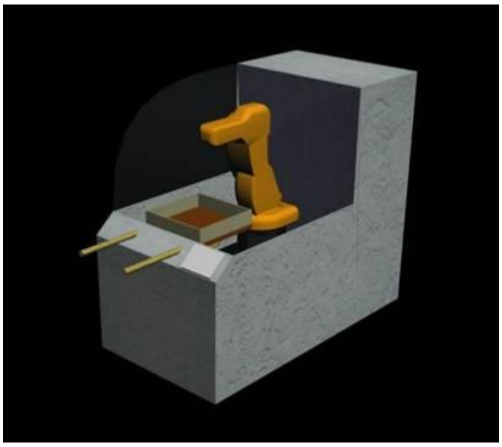

**Figure 2 CAD robot game prototype**

This project in Product Design Engineering was initiated by the Centre for Intelligent Automation, a research group of Skövde University who offered the task in cooperation with two other areas of engineering, i.e Automation Engineering and Computer Science. The entire robot game project was developed by a five-woman team, which resulted in three different projects belonging to each study.

The design engineering task was carried out by analysing the component needs, taking in consideration all the important factors involved, to recognize problems and limitations, and focus on prototypes. The development process included concept generation and evaluation, prototyping and detail design and testing and refinement of the physical prototype. As a result the prototype showed an intuitive way to play the game, and a 3D CAD (Computer-aided design) model was developed to show an alternative design which found solutions to some of the problems shown by the physical one.

# Acknowledgements

I would like to thank the following people who made this project possible. Firstly Anna Syberfeldt who was the manager of the project. Supervisors Christian Bergman who guided and followed all parts of process and Björn Kastenman who helped with the CAD program, Pro-Engineer. Other teachers, such as Stefan Ericson and Magnus Holm who advised on the assembly phase, were crucial in helping to finish the physical prototype Dan Högberg gave support on ergonomics and Ingalill Söderqvist reviewed the English. All students from the Product Design Engineering Programme gave me useful suggestions and, by keeping me company in the workshop, allowed me to keep working.

Finally I am grateful for personal support from family and friends especially Lindley McCarthy.

# Table of contents

# 1. Introduction

This report describes the final Product Design Engineering project for Bachelor's Degree students at the University of Skövde, Sweden.

## 1.1. Background

The purpose of this project is to develop the prototype for an interactive ball game with an industrial robot. This board game is intended to attract young people, especially teenage girls, to the engineering field for enjoyment or education. The main design task is to create a physical support to facilitate safe interaction between the intended target user and the game, which is to be played at exhibitions or other student environments.

This project was initiated by a research group from the University of Skövde called Centre for Intelligent Automation and the design engineering work described is a part of 3 projects. The entire robot game project was developed by a team of five persons from 3 different areas of engineering: two women from Computer Science invented the game, two other students from Automation Engineering programmed the robot and eventually the author of this report developed and made the physical game.

**Figure 3 Robot game project members**

The picture in Figure 3 *Robot game project members* shows the members of the 3 related projects with the manager, who coordinated the team. The robot and its base are seen in the middle. From left to right the members are Therése Almarsson and Annika Karlsson from Computer Science, project manager Anna Syberfeldt, Lara Aicart Verduch and Aranzazu Osma Osma from Automation Engineering, and Marisol Guijarro Chirosa from Product Design.

## 1.2. Degree project specification

There are many steps to start, carry out and complete a degree project in product design engineering. First of all, a specification of the degree project and a timeline, have to be approved. Defining the degree project specification document gives an overall idea of what is going to be developed, who will be involved, how long it will take, and whether or not it will be possible to judge if the stated aims and objectives are met. It is in this document that the background, conditions, objectives and the scope of the project are identified. The general objective defined in the degree project specification reflects the main goals and constraints that guide the designer development effort. In this case, the goal was to create a functional and supportive prototype for the ball game and to design and make a protective case. While there are always many aspects to consider in industrial design, the most important features to consider here were usefulness, ergonomics, safety and aesthetics. Therefore the main priorities were defined by the project members as creating the mechanical functions of the game and ensuring good interaction between the robot, the game and the user.

Apart from the principal design aspects, other detailed requirements were added to meet the aims of the robot game project. As it has been explained, the goal was to provide a functional physical prototype of the game for teenagers, specifically between 13 and 16 years old. In order to reach this target population, it was necessary to make the game easily transportable, and reduce the system volume. Therefore, a target width of 800mm x 800mm was established based on the robot scope. The idea of the early robot game project can be seen in figure 4 *Early sketch*. Additionally, other aspects like manufacturing, transportation and environmental concerns were important to consider.

Due to workshop limitations it was difficult to meet all project specification requirements in the physical prototype which needed to demonstrate an intuitive way to play the game, so a 3D CAD (Computer aided design) model has to show an alternative design as a better solution to improve the features that could not be reached on the physical prototype.

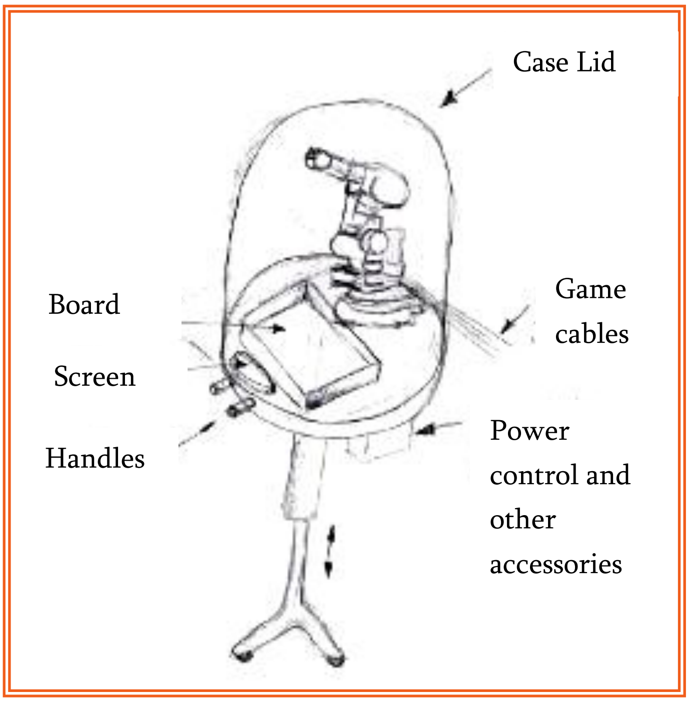


**Figure 4 Early sketch**

# 2. Pre-study

Design consists of transforming objects or specifications into solutions that can be materialized and that can fulfill the needs that originate in the problem. Therefore, once the problem is stated and the goals are set, a pre-study analysis is necessary. To determine what can be built and what needs to be designed in CAD it is necessary to identify the components of the system, analyze the functions of the game, the robot and the user, and recognize limitations to determine the product needs and specifications.

## 2.1. Analysis of the game

The Egyptian ball game that students from Computer Science developed consists of a labyrinth created by 5 obstacles moved by the industrial robot arm. The user controls the board and tilts it to earn points by rolling the ball over lights on the surface. In each path of the game, lights of different color shine randomly during two minutes to enable the user to earn as many points as possible. When two minutes have passed, the user stops moving the board and the robot picks up the obstacles to place them in different positions providing different labyrinth layouts. The figure 5 *Game computer simulation* below is a picture from a computer simulation of the game where the brown silhouettes are the obstacles, the red spots are the light points and the grey circle is the ball that is moved over the game board surface.

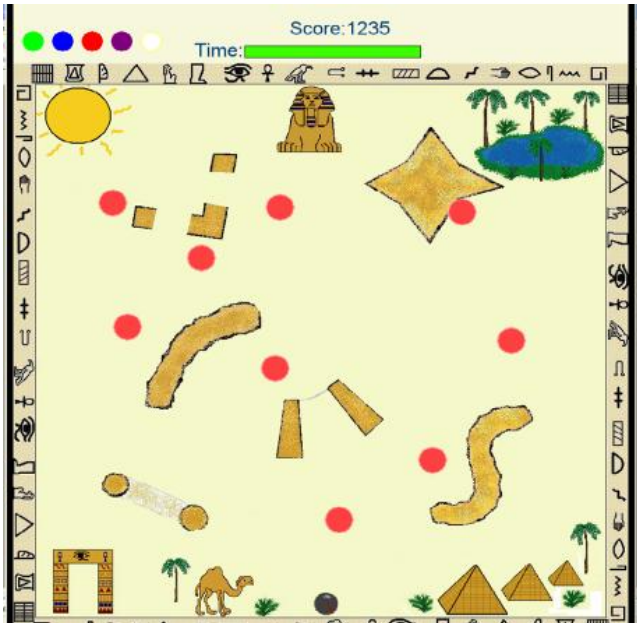


**Figure 5 Game computer simulation**

A game analysis identifies some details which have to be included in the prototype to address some of the problems. First, as the user plays by tilting a 500mm x 500 mm board it is necessary to design a mechanism to provide the board movement. This not only means the addition of a mechanism on the board to provide good motion control but also involves other components which have already been identified such as: 5 obstacles shaped to represent artifacts from ancient Egypt, an iron ball, LED diode lights to show the point spots, and inductive sensors that must be placed in the board to detect the metal ball and collect the points. Additionally, other game components such as a scoreboard and instruction screen, walls to limit the movement of the ball, or speakers to add music to the game are necessary. A lot of components are required for playing the game; therefore assembling the game components is another important function to solve. All these components, seen on the diagram below, have to fit together in the board to provide good feedback and good interaction between the game and the user. Additionally, the diagram shows two components not previously mentioned. The handles must permit the user to manipulate the board easily and safely and a casing must be designed to protect both the game and the user.

Finally another important question to resolve is arrangement and attachment of the obstacles. The obstacles must be easy for the robot to move, however they must also be able to stay in their position once placed on the board while the player uses the game. A pliers-like device which was called the gripper, was added to the robot and had to be adapted to the obstacle shapes.

The diagram below (Figure 6) shows the result of the game analysis. The three main parts: the user, the game and the robot, are related to different game components to provide good interaction and protection game.

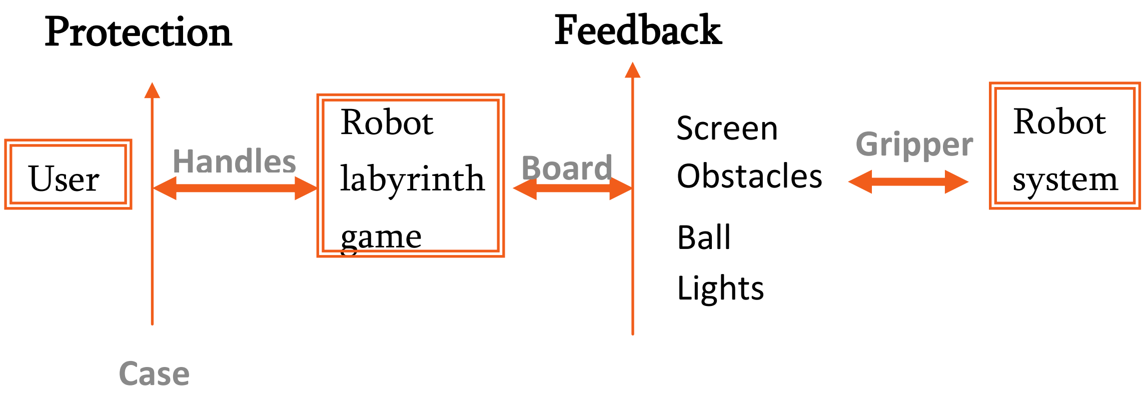


**Figure 6 Diagram of game components and functions**

## 2.2. Analysis of the robot and safety aspects

Although a pre-study has been conducted to identify solutions for the game functions, a pre-study of the robot is necessary to see how it affects the game functions and the degree project specification.

When studying the robot characteristics, the balance between the project specifications set, like safety, ergonomics and usefulness, became harder. The robot has a range of motion limitations that must be considered in the placement and movement of the obstacles. The movement, which has a scope of 810mm as the maximum length reached by the robot arm, differs from each height. The linear vertical movement can not be reached in the whole scope area which has to be considered when developing the attachment system of the obstacles. The movement area of the robot is illustrated in figure 7 *Robot movement area*. This movement scope affects the 500mm x 500mm board and influences its position, because the board must be placed at the right height to be ergonomically correct and at the same time placed within reach of the arm to be functional for the game.

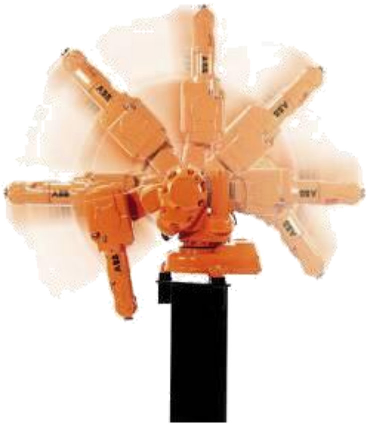

**Figure 7 Robot movement area. ABB Robotics (2009)**

Another aspect to consider about the robot is that this machine is not an individual product; it is part of a group of elements. The group is composed of big heavy components including a generator which weighs 350kg and measures 800mm x 945mm x 495 mm illustrated in figure 8 *power generator*; a computer, and a wide metal support to provide stability and accuracy for the 98kg robot. Smaller components including the transformer and the gripper are all linked with cable connections. The robot and all of the accessories are dangerous, and they must be isolated from the user to make it safe.

**Figure 8 power generator. ABB Robotics (2009)**

During this analysis of the robot, some sketches as seen in figure 9 *Early sketch, main project components* were drawn to help determine the size of the system.

Placing the robot on top of the generator minimizes the volume of the system and it also provides the stable base that the robot needs. Sketching the main components helped to set specifications and the approach of the safety aspects of the prototype.

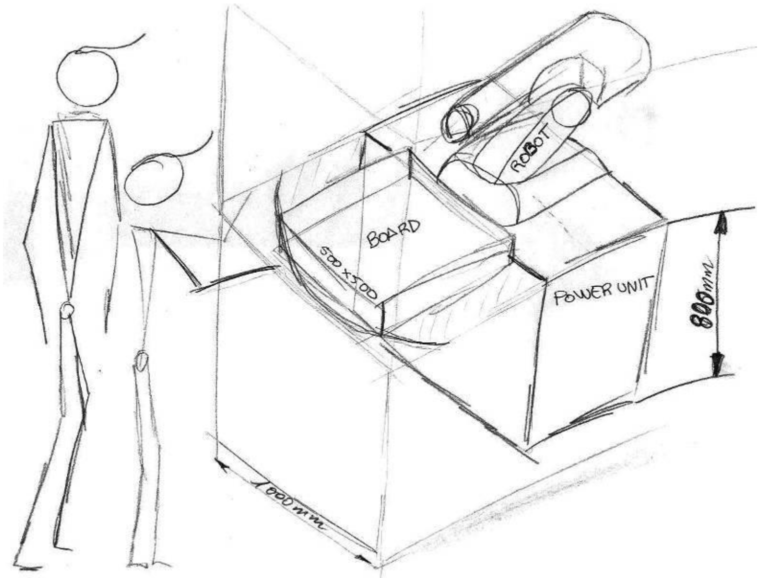

Figure 9 Early sketch, main project components.

Security is basically a combination of two concepts, protection and availability. A device is considered protected when the risk of injury from it drops to an acceptable level. Availability characterizes the reliability of a system or a device to perform its function at a given time or during a specified period. (Torres Rodríguez J. M. ,2006)

To evaluate the risk of injuries resulting from interaction with the prototype, a safety analysis is necessary. Dangerous parts need to be identified and necessary solutions have to be considered. In this system the main risk of injury stems from contact with the board handles which must allow for movement without pinching fingers. Factors like noise, vibration, illumination or climate do not have a considerable importance in the prototype; however they will be evaluated in an ergonomic checklist Appendix 1.

## 2.3. Analysis of the human factor

As this project has been designed to interact with young people, the human factor is one of the main ones to take into consideration. As mentioned in the degree project specification several additional factors need to be considered, namely, safety, ease of use, ergonomics and aesthetics. Ideally the system should be completely customized to meet the needs of 13 to 16-year-old adolescents, the main target group. This involves the technical maintenance, cleaning and transportation issues. Consideration of each user and their interaction with the product will help to define suitable product needs and specifications.

To account for the human factor, a user-centered design is employed to ensure that the product is easy to use, comfortable and is ergonomically correct. Eason (1989) developed a detailed process for user-centered design in which the technical system involves user participation and considers criteria for four factors: functionality, usability, user acceptance, and organizational acceptance (G. Salvendy. 2006). As a consequence of this theory ease-of-use is implicit in the concept of ergonomics. Because for this project it is not possible to have user participation to consider the four Eason factors instead the design has been done with an ergonomic checklist taken from the same manual (G. Salvendy. 2006), which will be the basis for assessing the human values in the final design. This ergonomic checklist found in appendix 1, questions seven important human factors: anthropometric, biomechanical, and physiological factors; factors related to posture (sitting and standing); factors related to information and control tasks; human-computer interaction; noise and vibration; and finally illumination and climate which are also related to safety.

A checklist is useful to evaluate general human factors, but more specific anthropometric data is necessary to develop a range of product sizes to tailor it to the target group. These details include the height to be able to play standing, the distance between elbows and the grip and the diameter of the handles. This data was found in the software Peoplesize 2008 and a summary table of the results can be found in appendix 2 *Table about anthropometric*.

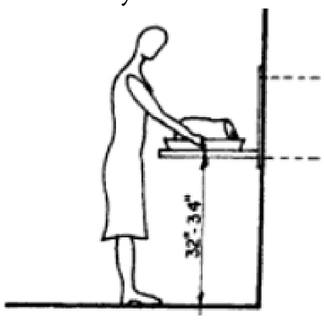


Figure 10 Sketch of the size of a table. Human Factors Design Handbook (1992)

Some information on ergonomic sizes for tables and furnitures to fix the height of the board was also researched. According to Human Factors Design Handbook (1992) this height must be for a standing position between 812 mm and 864 mm. Woodson, Tillman and. Tillman (1992),

# 3. Limitations

At the beginning two different prototypes were to be developed, a physical prototype to actually play the game, and a 3D computer model to demonstrate alternative designs as other possible solutions. However, so many limitations and constraints were discovered while studying the functions of the game and robot that the final project was focused on building a physical and functional prototype to enable the automation engineering team members to program the robot to pick up the obstacles.

During the analysis phase it became clear that the many components of the robot game project created such a complex system that it would be necessary to break the project into several subsystems. This project was not meant for mass production. Only one game had to be created and adapted to the resources in Skövde University. Therefore some goals and requirement aspects like a predefined size of 800mm x 800 mm for the general product, or manufacturing, transportation and environment aspects were eliminated from the project degree specification. When the pre-study was evaluated, it was clear that the project was a high-risk product, because the team assumed that the new product would be built around an established technological subsystem. In this case, that was Skövde University where the robot was situated and where the team worked. It was not possible to know if the product would work properly or if the team could develop and complete the project on time and within the specifications. Due to the high number of components and their characteristics, the physical prototype was developed to be situated in a lab. Therefore, the final product was not built to allow for transport to exhibition sites, only to allow the game to be played. The scope of the physical prototype is to be functional, providing a board game without a casing, and fulfilling the ergonomic and aesthetic aspects. The physical prototype would also take the functions and needs analysis of the game, robot and human factor into consideration. The 3D CAD model would focus on the safety aspects adapted to the final physical prototype. The construction of the physical prototype also had other limitations; it had to be as simple as possible due to limited resources. Only simple materials could be used and the ideas had to be possible to build in the workshop to finally obtain the solutions for the assembly of the prototype in the lab.

While in the pre-study, the robot was to be placed on top of the generator in order to minimize system volume, after testing it was discovered that this placement did not allow enough access to the generator. Although an optional case design for the product is included in a virtual model, this component is not necessary for the physical model because the robot system components do not affect the interactions between the player and the product. The existing final prototype is not going to be moved so convenience can dictate the physical location of the elements in the lab and minimizing the volume of the robot game project was not considered for the physical prototype.

Although the principal goal of the physical model is to show how to play the game, some safety aspects were also taken in consideration. The components of the system containing dangerous parts were not placed near the player. Also other edges, like the legs of the robot support, were covered with cardboard to provide a safe physical prototype in the lab. However, the safety measures would need to be increased if the system were to be used by young people. The 3D model includes a case which covers all safety aspects.

# 4. Setting needs and specifications

To get a better understanding of the product to be designed and to be able to follow a concrete scope, the fixed targets and the product elements were analyzed. This action was supported by a specific bibliography and checked with project members and supervisors. The analysis identified needs which provided information to justify the product specifications and evaluate concepts. The analysis also ensured that no critical project need was missed or forgotten and developed a common understanding of project needs among team members, separating "musts" and "wishes."

The process of identifying needs and setting product specifications is an integral part of the larger product development process that results from problem analysis and limit identification. This process became an extended step during the analysis phase, even including some sketches, as observed in the pre-study section with the provisional location of robot game components. Moreover this needs identification process also became an iterative operation that was repeated and developed parallel to the concept generation to clarify the product sub-problems to be able to solve them. The table of needs of each sub-problem is explained in detail in another section below. Nevertheless, the complete general table of specifications is shown here.

The list of requirements for the robot game system product, and later components, was created after answering the following questions: What is necessary? What can we do to reach these objectives? What are the functions? Trying to visualize the product in use and referencing literature about human factors and ergonomics to clarify and quantify the needs, the table of general product needs was developed. Based on the assumptions about the product already made by the team (functional, safety, ergonomics (ease of use) and aesthetic) and with other assumptions added like, durability, and ease of maintenance; the principal needs were identified and placed on the first column of the table of needs and specifications. This principal needs were identified as *primary needs*. More detailed needs were written in the next column, identified as *secondary needs*, which explain and measure the primary needs. The guidelines for writing needs stated by Ulrich K.T.& Eppinger S. D.(2004), were used to write this table. These advices expressing the statements independently of the solution but in terms of what the product has to do and as attributes of the product using a positive phrasing. Thus, the table of necessities and specifications answers the question: What is the function of the game project?

| TABLE OF NECESSITIES for the game project | | |
|---|---|---|
| **Aspects- functions or assumptions (principal needs)** | **The Game Project (GP) + verb + function**<br><br>**Primary needs (General)** | **The Game Project (GP) + verb + function**<br><br>**Secondary needs (Detailed)** |
| Safety | • The GP provides the appropriate housing to isolate the element in motion from the users and prevent them from mechanical hazard.<br>• The GP prevents fires<br>• The GP provides a use free of electric shocks.<br>• The GP prevents injury such as cuts or other physical harm.<br>• The GP provides a pleasant sound when in used.<br>• The GP provides adequate visibility and illumination for users. | • The GP has covered moving parts of the machine to prevent people getting their hands and clothing caught.<br>• The GP heater is located where it can not be touched.<br>• The GP has a structure free of sharp edges, corners etc.<br>• The GP uses a non-inflammable, non toxic and non slippery material.<br>• The GP provides sufficient clearance between the handle and the adjacent structure to minimize the possibility of scrapes. |
| Ergonomic (comfort + usefulness) | The GP is adapted to the target user because it takes in consideration the following aspects:<br>• Anthropometric (body sizes limitations), especially in the motion control<br>• Biomechanical (strength limitations)<br>• Psychological (Fatigue, discomfort posture)<br>• Environmental (temperature, vibration, light) | • The GP provides a range of motion control large enough so hand and finger surface contact is maximized.<br>• The GP provides an intuitive handle shape that feels good in the user's hands.<br>• The GP is adapted to the body size limitations such as height and hand size.<br>• The GP encourages suitable posture while manipulating the game.<br>• The GP parts move smoothly to prevent fatigue.<br>• The GP has the handle placed where it provides the best advantage for gripping and manipulating the game board.<br>• The GP signs are placed where they can not be covered by user hands or the robot.<br>• The GP provides good screen feedback to indicate the correct use of the game.<br>• The GP casing offers good system visibility without reflection. |

| **Aspects-functions or assumptions (principal needs)** | **The Game Project (GP) + verb + function**<br><br>**Primary needs (General)** | **The Game Project (GP) + verb + function**<br><br>**Secondary needs (Detailed)** |
|---|---|---|
| Aesthetic | • The GP creates positive responses: amusement, like, game attraction. | • The GP transmits good feelings through the output elements with sound (speakers) or light (illumination).<br>• The GP has smooth shapes that increase its aesthetic level and attraction.<br>• The GP colors are consistent with the themes of the game to create an aesthetic unit. |
| Game adaptation (mechanical solutions) | • The GP provides mechanical solutions for interacting with the game.<br>• The GP signs indicate game performance.<br>• The GP provides a smooth and accurate movement of the board through the motion control.<br>• The GP provides the appropriate components for good visibility of the game.<br>• The GP offers easy assembly of the elements.<br>• The GP has an appropriate support for the game board in order to prevent collision with the other components. | • The GP has a board that tilts with correct inclination to roll the ball in two directions at an accurate speed.<br>• The mechanical solution provides only the necessary two movement directions.<br>• The GP reaches a zero position in the board to allow the robot to move the obstacles.<br>• The GP is composed of various elements which are assembled and adapted to the dimensions of the board (500mm x500mm). |
| Durability | • The GP is durable. | • The GP has materials that last more than a year. |
| Maintenance | • The GP needs periodical maintenance.<br>• The GP has easily accessed components for simple maintenance. | • The GP requires periodic checkups to ensure the product is functional. |

**Table 1 NECESSITIES for the game project**

# 5. Concept generation and evaluation

The concept development phase is the most important during the project design process and includes different activities like investigation of the product concepts, development of design concepts and construction of experimental prototypes. The diverse methods used to carry out this process are described in the steps of the development of the prototype concepts.

Next, the different solutions that arose in the concept generation phase are exposed, which were evaluated, and where the last one is the one that finally was adopted as being the one that satisfies the majority of the requirements expressed in the table of needs and specifications for the robot game project.

## 5.1. Five-step concept generation method

The concept generation phase is basically a creative process. For this project, the concept generation was supported by the five-step method described in the book "Product Design and development" by Ulrich K.T.& Eppinger S. D (2004). The project is a complex system and this method helped to analyze and identify the key points of the concept generation process, because the system must be divided into several subsystems to be designed.

The five steps are:

1: Clarify the problem: Understand the problem and divide it into simpler sub-problems.
2: Search externally: Gather information from lead users, experts, patents, published literature, or related products.
3: Search internally: Use creative methods to collect different solutions and to adapt the knowledge of the designer to come up with new concepts.
4: Explore systematically: Use classification trees and combination tables to organize the thinking of the designer and to synthesize solution fragments.
5: Reflect on the solution and the process: Identify opportunities for improvement in subsequent iterations of the method or future projects.

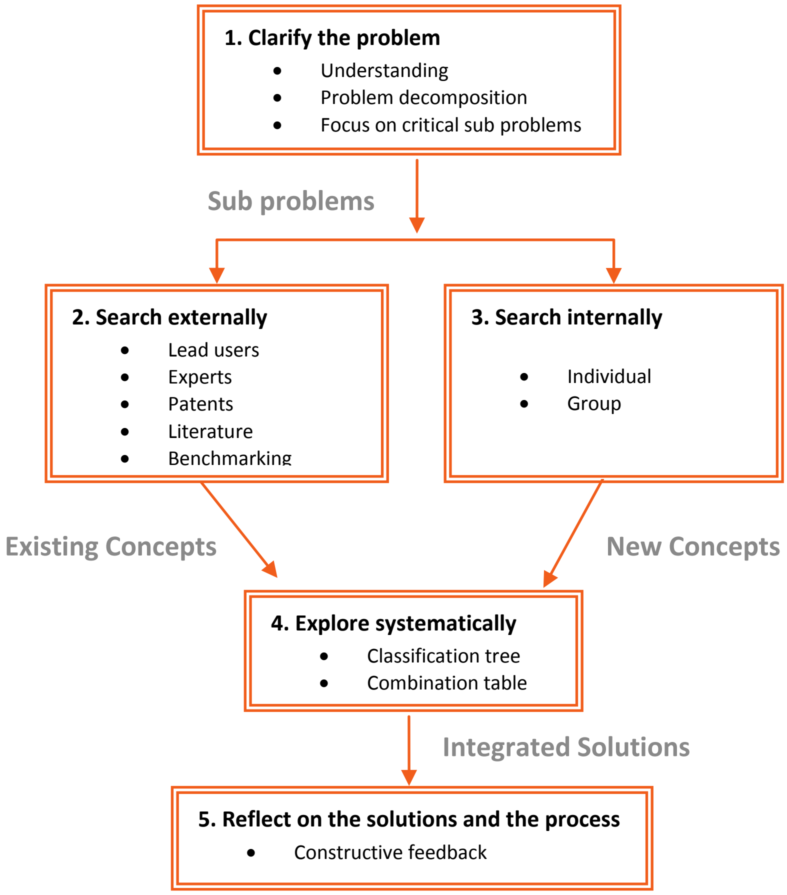


Figure 11 Ulrich K.T.& Eppinger S. D (2004) five-step process

Although concept generation is essentially a creative process, this structured method was helpful in directing this process. However it is also an iterative progression and despite the linear description of this method, the different steps were taken in diverse ways to solve each focus problem. More importance was placed on the three first steps and these were sometimes combined with some concept evaluation methods.

## 5.2. Clarifying the project

The first step in the concept development phase based on the 5-step method was clarifying the problem. In this case clarifying the problem meant a study of the interaction between the game project components to identify sub-problems of the system. These sub-problems are the keys which guide the development process to reach the final prototype concept as an integrated solution. Therefore, it is important to point out that there were two types of table of needs and specifications. After the pre-study, a table of needs and specifications was developed to evaluate the robot game project; taking into consideration the main project feature already specified in the previous point. And after clarifying the components of the game system and detecting the main design focuses, other tables of specifications were necessary for these sub-problems of the prototype.

## 5.2.1. Relation and classification of project components

The pre-study, which identified the game, the main components of the robot game system, and the development of the table of needs and specifications, are the drivers of the concept generation process. However, the analysis of the different functions of the product and the interaction between parts makes it necessary to choose the critical part to develop in the concept generation phase. The relation between parts and components is shown in the next diagram:

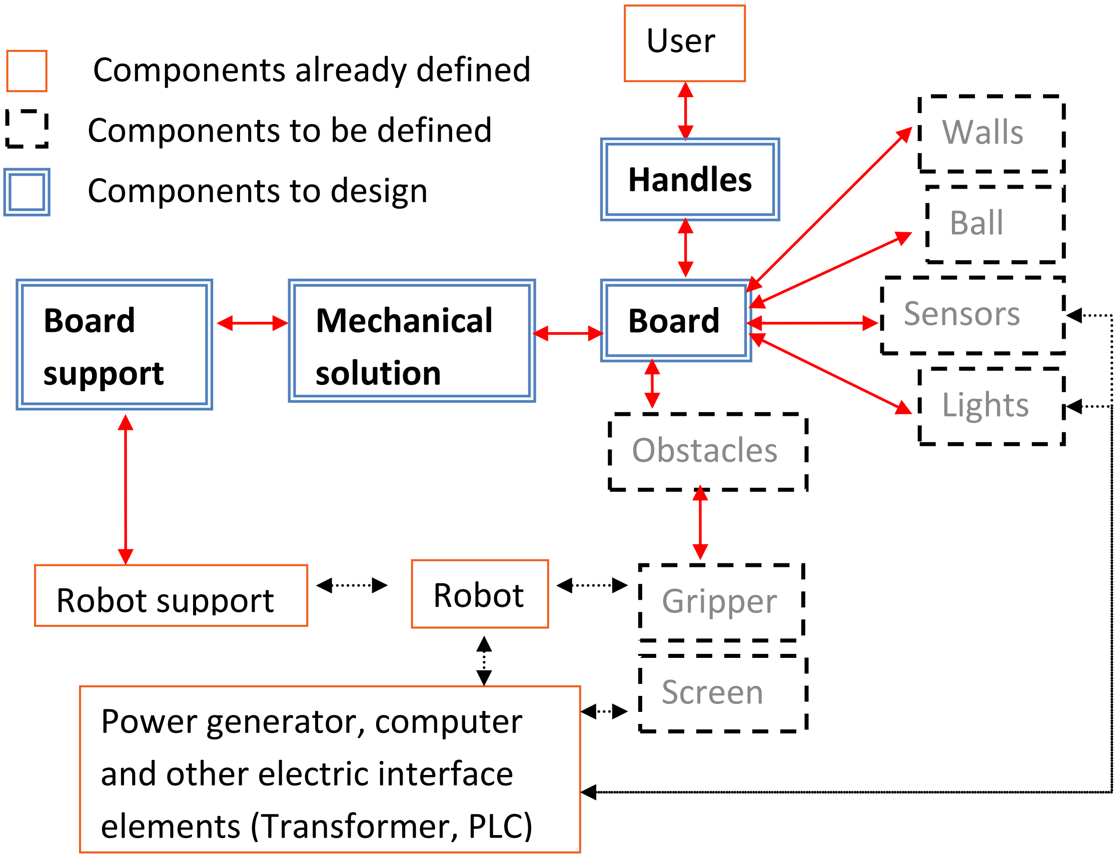


**Figure 12 Components and their relations**

This element analysis discovers three types of components:

- Components already identified and defined which are the user, the robot support, the power generator, the robot and the computer.
- Other components that had to be defined because they were required by the game and to which the rest of design components have to be adapted. They are the 15mm diameter metal ball, the inductive sensors, the LED lights, walls for the board, a board surface of 500mm x 500mm and the screen which were provided by the project manager when required during project development. The obstacles were designed by the computer science student based on the Egyptian theme selected and other game criterion.
- The third type of components were the ones that needed an entire design which included the handles, the board (only its size of 500mm x 500mm was defined and some materials were available for testing), the mechanism and

the board support. These were the sub-problems of the system game. They were the main targets in the concept generation phase.

The connections between these components were also analyzed; they are symbolized in figure 12 *Components and their relations* through arrows in two colors. Red arrows are connections that constrain and determine the components that must be designed. In addition, in some cases these red connections required new concept generation, development and design of new parts in the detail design phase. These elements have to provide the appropriate interaction between the main components and to fulfill their necessities while constructing the prototype (these elements are described under the headline "Prototyping and detail design"). Black arrows are connections to be solved by the automation engineering group. They are mainly electrical connections and these relations do not directly affect the development of the main components.

In conclusion, this analysis allows identification of four critical sub-problems that mean four key research and specification development. The sub-problems listed according with the number in following descriptions are: mechanical solutions for the board movement, the assembly of the board components which involves the board structure and its support, solutions for positioning the obstacles, and the handles.

It was detected from the beginning that the main sub-problem was to find a good mechanical solution within the specification for the game movement and with the limitation of the prototyping. Therefore, although the three last sub-problems had individual concept developments, they were always adapted to the mechanical solution for the movement of the board and different detailed specifications appeared during the process.

Next, a diagram shows the development process of the concept development and evaluation phase. Firstly an individual generation of ideas was done for each sub-problem. Due to the ambiguity of the concepts as possible physical solutions and taking into consideration the construction limitations when evaluating the ideas, the theoretical development became a practical and physical development. Although the four sub-problems had physical connections when assembled, the main sub-problem was the mechanical solution for the board movement, and the rest of the sub-problem solutions were adapted to this main sub-problem. After testing the different ideas there were three concept combinations referring to different possible mechanism solutions from which the final concept was selected.

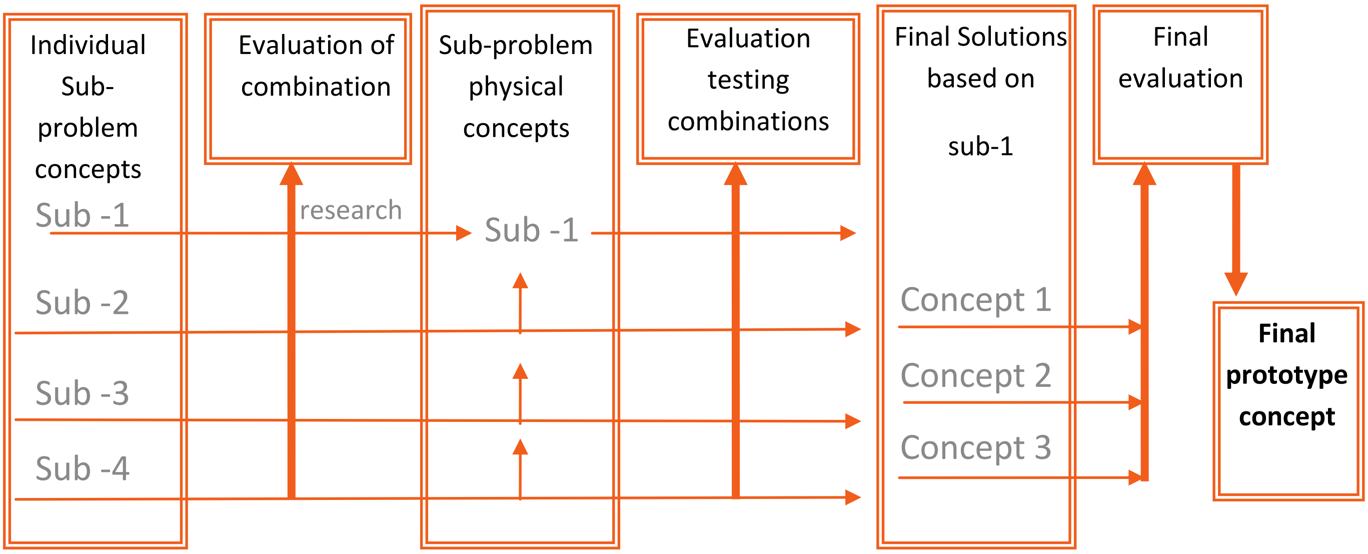


**Figure 13 Development process of the concept development and evaluation phase**

To explain the concept development, the process described in the previous diagram will be simplified into the steps marked in the five-step method; clarifying sub-problems, setting tables of sub-problem specifications, concept generations with internal and external research, and evaluation and selection of the ideas to look for the final prototype concept. It is important to reiterate the relationship and dependence of the sub-problem development from the first sub-problem with the rest until the final prototype concept.

## 5.2.2. Clarifying the sub-problems

Each critical sub-problem follows the five-step method as individual problems, which means an analysis to set needs and specifications as a first step. To clarify the sub-problems a list of needs was made and analyzed to see which needs were an obligation (O) or a wish (W). The needs statements follow the rule identified by Ulrich.& Eppinger (2004).

**Sub-problem 1**: To simplify the subject *The mechanical solution for the board movement* in the need statement, only the letter M has been written.

| Needs for the mechanical solution for the board movement (M) | Value |
|---|---|
| • The M has to reach a zero position to let the robot put the obstacles on the board surface | O |
| • The M provides 2 direction movements for providing a correct ball movement | O |
| • The M is easy to construct and able to be constructed in the workshop (it can also be ordered) | O |
| • The M is composed of readily available materials | W |
| • The M allows an easy movement with the minor resistance (less friction) | W |
| • The M has a structure resistant to the weight of the board | O |
| • The M is properly attached to the board and its base support | O |
| • The M can easily disassemble, permitting adding or accessing components | W |

**Table 2 Needs for the mechanical solution for the board movement (M).Value: O=Obligation, W=Wish**

From this table of needs some concepts needed to be defined to evaluate their feasibility, such as correct ball movement delimited by the speed reached with the board slope, and the weight of the board that the mechanism has to stand. These concepts are detailed under the headline Calculations.

**Sub-problem 2**: board component assembly

The components identified as part of the board assembly are: the sensors, the obstacles, the walls, the 500mm x 500mm board, metal ball, and the diodes. An illustration of these components are shown in figure 14 below.

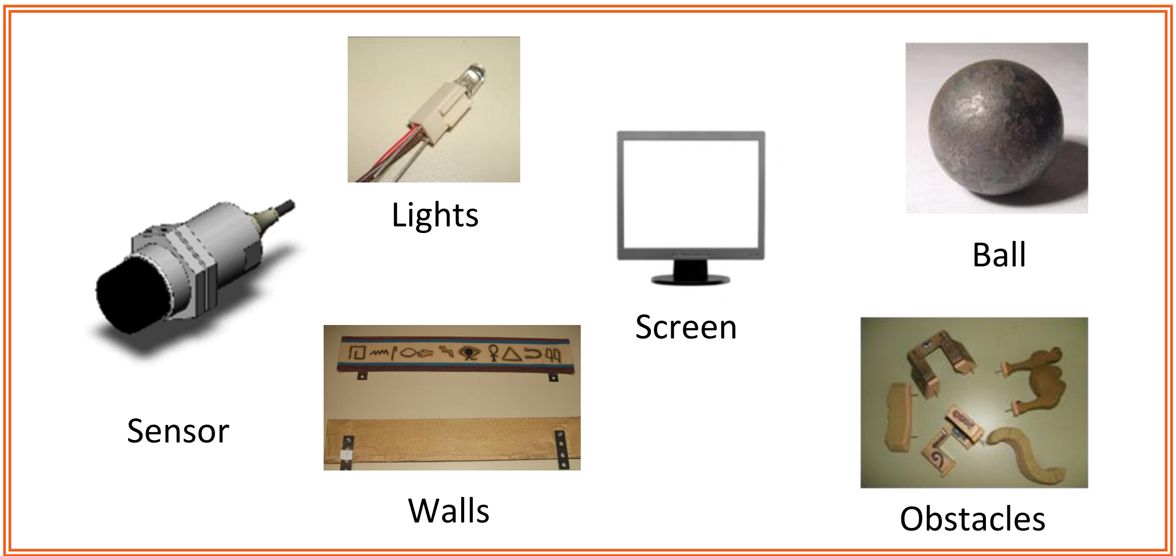


**Figure 14 Illustrations of some components**

To clarify the sub-problem an analysis of needs and the components was made.

| Needs of board component assembly (BCA) | Value |
|---|---|
| • The BCA provides the necessary stability on its base for playing the game | O |
| • The BCA is adapted to the movement mechanism of the board | O |
| • The BCA respects the sizes of young people and the desirable ergonomic height | W |
| • The BCA is easy to assembly so it facilitates access and maintenance to the board | W |
| • The BCA leaves space for the rest of electric components like PLC, screen and transformer | O |
| • The BCA has the eleven sensors provided in the correct position respecting its scope to fulfill the proper role in the game | W |
| • The BCA adds the provided walls designed for placing them around the 500mm x 500mm board | O |
| • The BCA has 12 diodes around each sensor and well connected without affecting the sensor sensibility | O |
| • The BCA attaches the handle in an appropriate ergonomic way | O |
| • The BCA has a element disposition thus the components have a provision that maximize functionality for the game as for maintenance | W |

**Table 3 Needs of board component assembly (BCA). Value: O=Obligation, W=Wish**

An important issue to define is the interaction between the board and the obstacles, to design an attachment system. To clarify the sub-problem a list of needs was made and analyzed to see which needs were obligations (O) or wishes (W):

**Sub-problem 3**: solutions for positioning the obstacles

| **Needs of solutions for positioning the obstacles (SPO)** | **Value** |
|---|---|
| • The SPO provides necessary strength to keep obstacle positioned while playing | O |
| • The SPO is adapted to the board component assembly | O |
| • The SPO is adapted to the obstacles | O |
| • The SPO permit good movement of the obstacles by the robot | O |
| • The SPO is easy to construct in the workshop | W |
| • The SPO has readily available materials and components | W |
| • The SPO maximizes the area for placing the obstacles for an easier robot operation. | W |

**Table 4 Needs of solutions for positioning the obstacles (SPO). Value: O=Obligation, W=Wish**

**Sub-problem 4:** solution for the handles

| **Needs of the handles** | **Value** |
|---|---|
| • The handles provide a good force transmission to move the board | O |
| • The handles have sufficient clearance between the rest of components to minimize the possibility of scrapes | O |
| • The handle shape is adapted to provide accurate movement | O |
| • The handles permit the movement in only two directions | O |
| • The handles have a safety cover | O |
| • The handles are adapted to the user hand sizes | O |
| • The handles are adapted to the board sizes and components | W |
| • The handles have feel nice to the touch on user's hands | W |

**Table 5 Needs of the handles. Value: O=Obligation, W=Wish**

## 5.3. Generating sub-problems ideas

The next step consists of creating new concepts not only for the sub-problems identified during the first step but developing new concepts for the overall game-system product, searching for solutions both externally and internally. To approach the robot game project, it was first necessary to solve the four sub-problems individually to evaluate and to select concepts with which to be able to explore the overall game system problem in the fourth step of the method.

### 5.3.1. Sub-problem 1 concepts

To come up with several concepts and mechanical solutions for the board movement, the external search was focused on the patent search. This search uncovered technical information which contains detailed explanations and drawings of complex systems for different ball games and maze games. The complexity of the products found made it difficult to adapt them to the present project. Also, some of them were patented recently and are protected. However, they provided ideas to develop more concepts in the internal search process for creating new concepts.

The internal search activity to create concepts consisted of using the information in one's memory to adapt the ideas to solve the problem. There are many creative methods to use in groups to produce a lot of ideas in a short period of time. As this project was developed primarily by one individual, the brainstorming process was a constant effort aided by analysis of physical surroundings to get as many inputs as possible. The process included sketching a quantity of ideas without regard to possible limitations to be able to evaluate a wide range of solutions. While performing the creative process most good alternatives arose from the combination of the features of several previous concepts

After reflection on all the ideas generated, the concepts which were too abstract were eliminated. Five that seemed possible to construct were selected for a matrix evaluation. Here are 4 simple concepts that are related to the physical result.

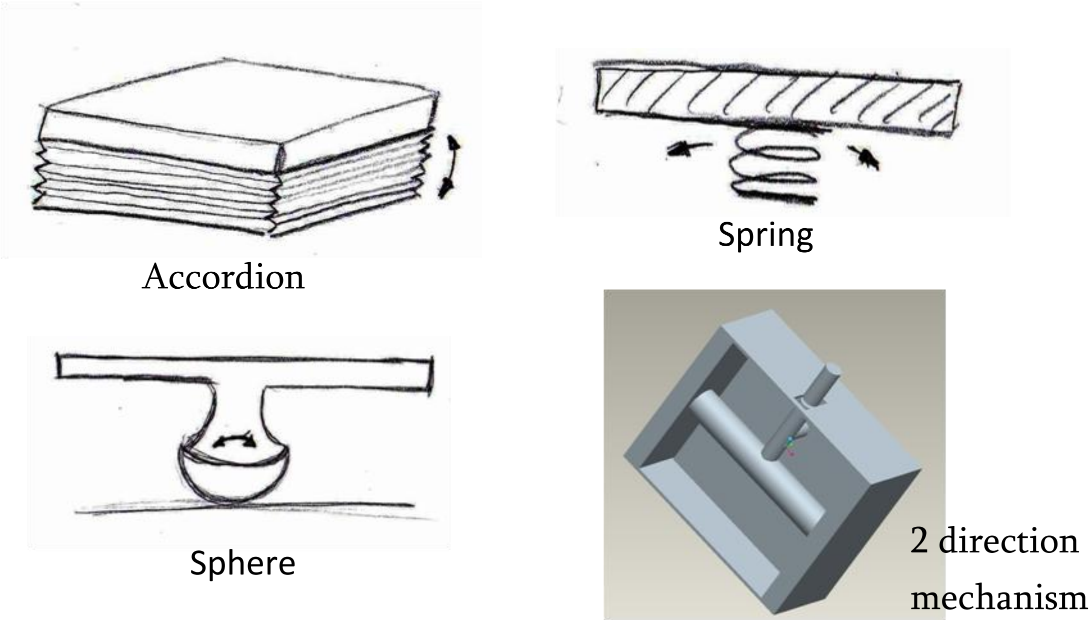


**Figure 15 Simple mechanism sketches**

## 5.3.2. Sub-problem 2 concepts

The assumptions that drove the board concepts were the use of a flat and transparent top surface, and the need to place sensors and LEDS on the bottom part. One early solution to reach this objective was placing the sensor and LEDs in the bottom support and the movement mechanism at the same level, so the only moving part of the component group would be the transparent top layer. This layout ensures also a good display of components preventing their movement, and it facilitates also their connections.

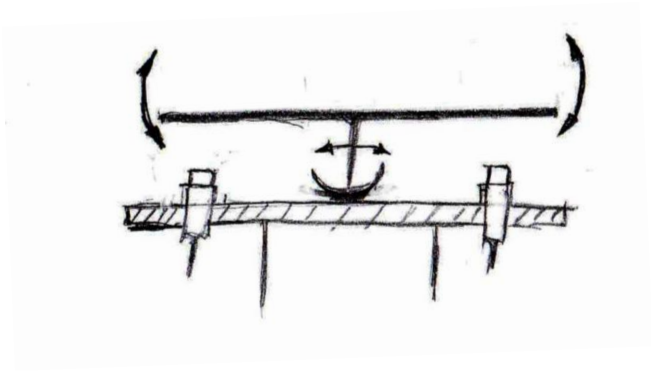

Figure 16 Sketch of first component board layout

A second better concept for a board consisted of two layers between the LEDs and sensors with the mechanism at the bottom, securing the coordinated movement between parts.

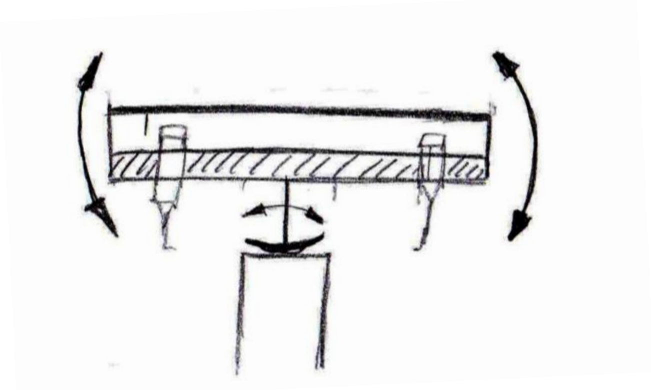

Figure 17 Sketch of the second board layout

This board concept with the double layer was developed for the final design.

### 5.3.3. Sub-problem 3 Concepts

The team agreed from the beginning on using an attachment system for the obstacles by means of magnets in the base, which would attach their position placing some metal components under the top board, as is shown in figure 18 *Sketch of the magnet obstacle attachment* So, different kinds of magnets were ordered.

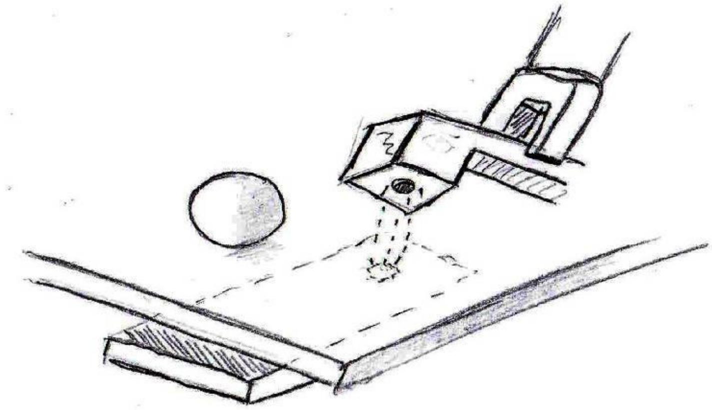

**Figure 18 Sketch of the magnet obstacle attachment**

As an alternative solution a nail system was also developed. This second concept allows attaching the obstacles on the board by matching two nails on their base which must go into small holes distributed on the surface of the board. An illustration of this concept is on figure 19 *Sketch of the nail obstacle attachment*

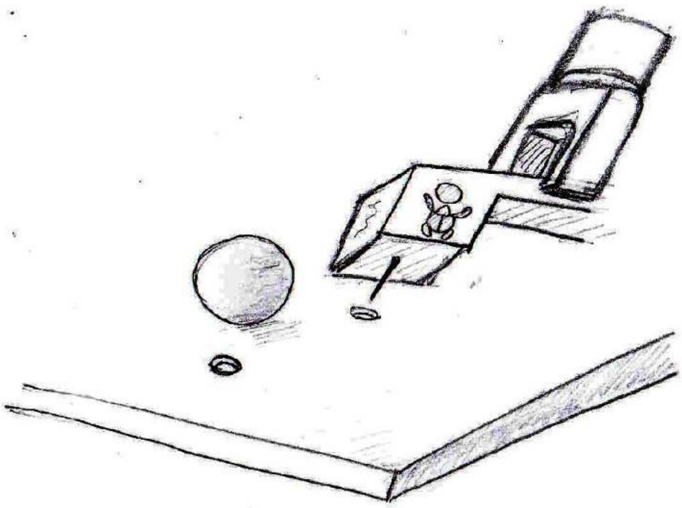

**Figure 19 Sketch of the nail obstacle attachment**

## 5.3.4. Sub-problem 4 Concepts

To come up with different ideas for solving the fourth sub-problem about the handles, some sketches were made, showing different position to hold the game board. The first idea was the "2-directions-handle", that is a system which is used in traditional small labyrinth games, where each handle controls an axis of movement turning the board from the sides. But because of the board dimensions the team agreed to develop more ideas for moving the board from the front of the game. There were concepts with two handles such as the "2 simple handle" concept in figure 20 or others with one axis and different shape extensions such as "the handlebar" or the "staring wheel concepts." There was a mechanism concept called “the two direction mechanism” that included a handle which is shown in the sub-problem 1 concepts step figure 15 *Simple mechanism sketches*.

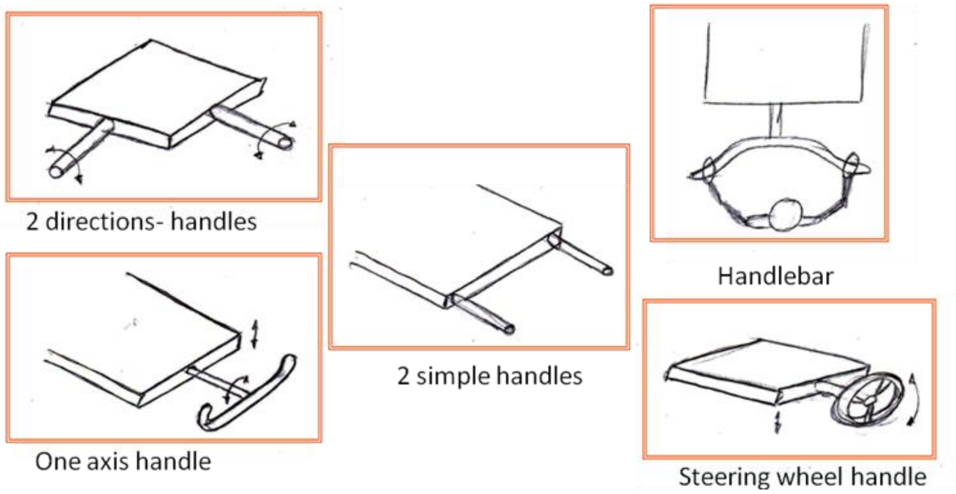


**Figure 20 Handle sketches**

# 5.4. Sub-problem concepts selection

While solutions to problems of the robot game project always referred back to the table of needs and specifications already developed, the criteria of the sub-problem concept evaluation was sometimes based on personal references by analyzing the specific sub-problem and the relations with the other components. Concept evaluation and selection was applied throughout the subsequent design and development process, thus as a result of the concept evaluation, one or more concepts were selected for testing or their development in further concept generation method steps.

## 5.4.1. Mechanisms selections

After the idea generation process, keeping in mind the list of needs set for this sub-problem, concepts were evaluated using various methods to choose the best solution. Firstly those concepts that seemed very abstract or which were illogical or too complicated were eliminated, and five concepts that seemed to be better solutions were selected using the two-stage concept selection methodology according to Ulrich & Eppinger (2004) This methodology is based on a method developed by the late Stuart Pugh in the 1980s and is often called *Pugh concept selection.* The first stage is called concept screening and the second stage is called concept scoring. Screening is a quick, approximate evaluation aimed at producing a few viable alternatives. Scoring is more careful analysis of these relatively few concepts in order to choose the single concept most likely to lead to product success. During concept screening, rough initial concepts are evaluated relative to a common reference concept using the *screening matrix*. After some alternatives are eliminated, the team may choose to move on to concept scoring and conduct more detailed analyses and finer

quantitative evaluation of the remaining concepts using the *scoring matrix*. Both screening and scoring stages use a matrix as the basis of a six-step selection process. The six steps are:
1. Prepare the selection matrix
2. Rate the concepts
3. Rank the concepts
4. Combine and improve the concepts
5. Select one or more concepts
6. Reflect on the results and the process

The screening step was developed individually, rating the statements and choosing the criteria based on the designer need and the problem needs already identified while clarifying this sub-problem. The matrix table result of this screening is shown in appendix 3. As the whole process was individually developed, personal opinion and good feelings about the concept evaluation during the process were a vague criteria, and the concept screening results were not satisfactory and none of the five concepts evaluated were clearly likely to be eliminated.

In order to find the optimal concept, the concept scoring step was discussed with the project supervisor and a session of concept evaluation was carried out in a group to see if it was possible to clarify the concept selection process, or find a favorite among the concepts. The 4 main concepts that were evaluated in the scoring step were the sphere concept, the accordion concept, the spring concept and the 2 direction mechanism concept. The four evaluation criteria statements were: the mechanism has an accurate two direction movement, the mechanism is easy to construct, the mechanism provides a good zero position and the mechanism does not need to stop the movement. Unfortunately because each person had a different intuitive perception of the efficiency of the concepts evaluated and some criteria were very indefinite, performance of this method based on Pugh's conceptual matrixes in an objective way was not possible.

After the inefficiency of the theoretical evaluation of the concepts by means of two-stage concept selection methodology, the choice of a solution became a practical task. Prototyping and testing should be the next step to find the solution, but due to the time constraints and the impossibility of building some appropriate concepts in the workshop, the materialization of the developed concepts about mechanical solution for the movement board were done looking at objects in the shops nearby and others found in the work lab. This external search ended up in different solutions which were possible to test and evaluate to find the suitable mechanism.

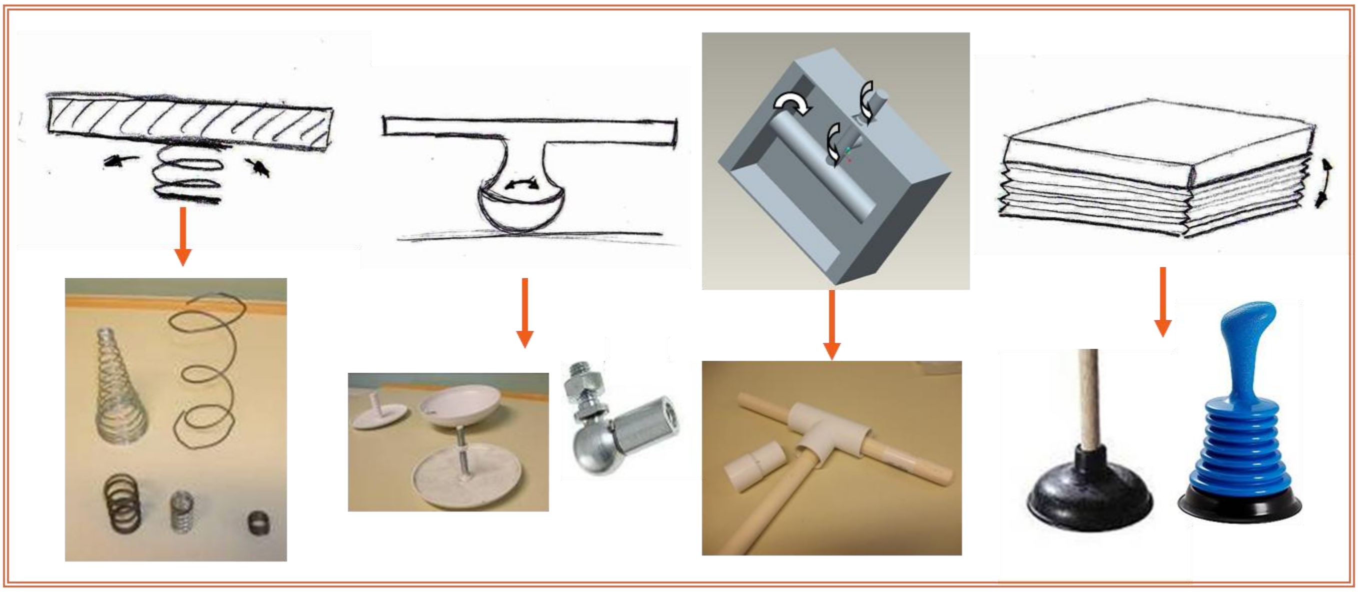

Figure 21 Analogy between mechanism concepts and market product solutions.

The mechanisms; the different springs, the concave screw surfaces and the ball-and-socket joint, the tubes for developing the two direction mechanisms, and the plungers were tested evaluating different criteria which are explained in the next table.

| Selection criteria |
|---|
| EASY TO ASSEMBLE AND CONSTRUCT |
| The construction of extra pieces lengthens the construction period |
| Easy to attach to the board |
| Easy to attach to the table support |
| Do not need extra pieces to control the movement |
| The mechanism does not limit the board thickness |
| Do I need help building the system? |
| The components can be built with the tools in the workshop |
| PROVIDE GOOD MOVEMENT (resistant to weight and stress) |
| The mechanism has no problem standing the weight tested |
| Different parts stop the movement |
| - handles |
| - table support |
| - mechanism |
| - frame |
| - other accessories (springs) |
| It provides movement in two directions |
| It has a good inclination (measurable) |
| The board weight does not affect the mechanism |
| A stable system can be easily reached in the support point |
| The weight of the handles permit a zero position |
| The handles can be any shape and position |
| OTHER CONSIDERATIONS |
| Mechanism made of durable material |
| Needs maintenance? |
| Easily available materials |

Table 6 mechanism selection criteria

The pieces were physically tested as is shown in the pictures below, measuring different features such as the influence of the weight in the tilting movement, the angle of the slope or the simplicity of the construction.

Figure 22 Picture of mechanism test

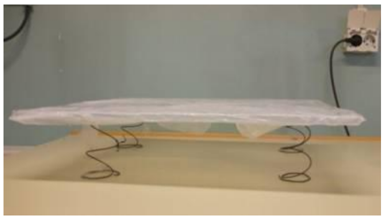

Figure 23 Springs testing picture

During the testing it was difficult to identify the criteria to evaluate the best solution, because the mechanism elements only needed to allow movement in two directions: a tilt forward and back and side to side. A solution needed to be found to stop the rotational movement. Possible ideas included a special frame or base to limit rotation. Other problems were how to stop the slope or how to attach the mechanism to the board and the base. After an evaluation of the pros and cons of each mechanism, the smooth plunger was selected.

In comparison with the other elements the smooth plunger had important advantages.
The plunger:

- Is easy to control the slope because plunger rims bend when standing the board weight and create a 12º inclination.

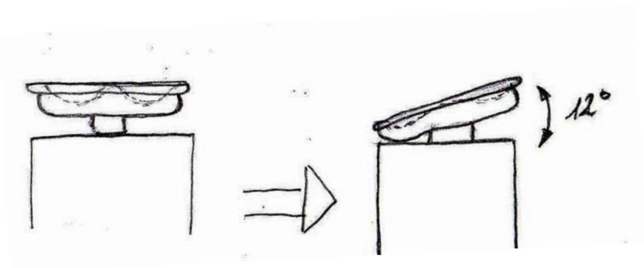


Figure 24 Sketch of the plunger movement

- Is easy to attach to the board by sticking the rubber to the bottom board
- Allows only minimum rotation, eliminating the need to stop this movement
- Allows a high probability of getting a zero position when the board is not touched for placing the obstacles
- Is easy to attach to the board support using the plunger stick which had a screw adapted to the plunger design
- Allows quick assembly as no extra piece is necessary to add to fulfill the needs

The plunger mechanism was chosen for the positive aspects in comparison with the other mechanism solutions. A more concrete table of pros and cons of each solution is evaluated in the appendix 4.

## 5.4.2. Board components assembly selection

The two possible board structures mentioned above were evaluated and tested with different mechanisms. First, to check the risk of non-detection of the ball in all board positions, it was necessary to measure the angle of the movement mechanisms that were available. With this test, first theoretically and then empirically, it was possible to evaluate the inclination of the board and to determine which mechanisms allowed excessive inclination. The specifications about these calculations are explained in the calculation section of this report and the different mechanisms used for that test in the concept selection section.

Having the lights and sensors attached to the bottom board and therefore isolating them from the movement of the game, as in the first board assembly concept, created disadvantages. The movement and distance from the board easily exceeded the maximum 30mm sensor range of sensibility. Additionally, having the tilting mechanism attached to the central area of the upper layer restricts the placement of the obstacles. Finally, the manner in which the tilting mechanism would be attached to the board made it difficult to offer enough resistance to play the game.

So, the two-layer board structure with the sensors and lights inside, and the smooth plunger as movement mechanism underneath was chosen as the concept. Then, the assembly was evaluated.

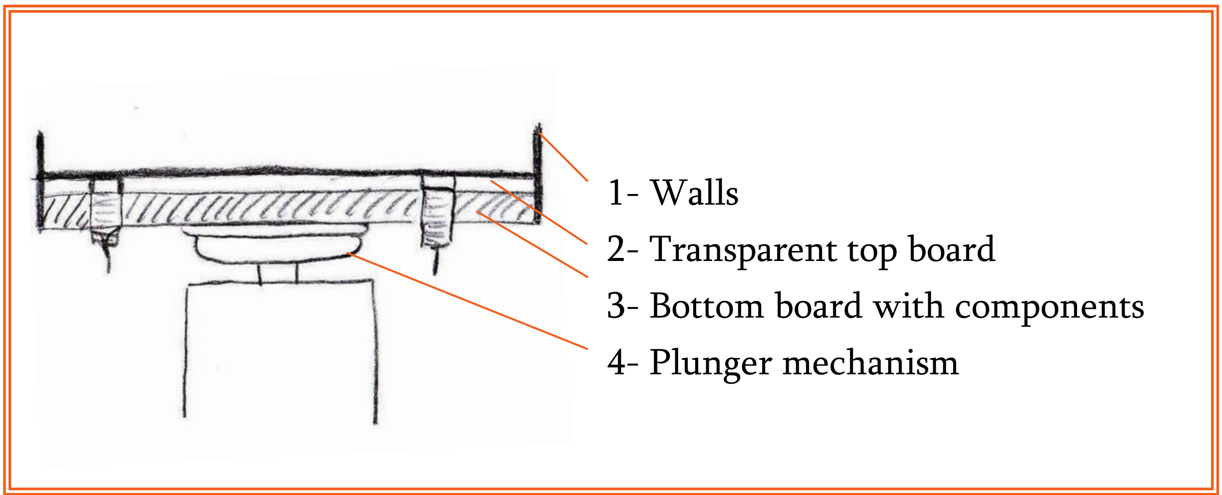


**Figure 25 Sketch of the plunger movement**

To define a proper board design different kinds of materials were tested. Advantages and disadvantages were evaluated to define the best solution to the problem.

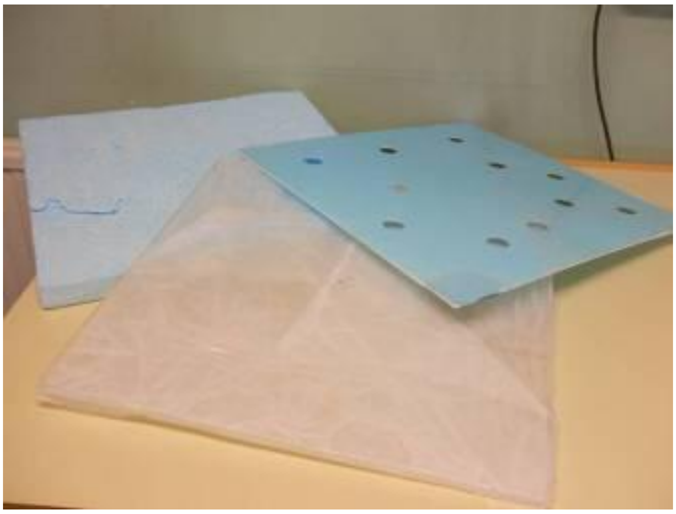
Figure 26 Testing boards

Noting the impossibility of achieving a good result with the materials available, once the final board concept was defined, the 500mm x 500mm board materials needed for the prototype were finally purchased to build it. The materials included a 3.5 mm thick sheet of plexiglass for the transparent top, and a 10mm thick Medium-Density Fibreboard (MDF) with enough resistance to stand the weight of the sensors. It was necessary to maintain a distance of 20mm between the layers in order to have room for the sensors and the LEDs. However, the lights needed to be located at least 15mm away from the sensors to not affect them, so a special support had to be designed, as well as another solution to hide the components from the transparent top layer. Also, the distribution of the sensors on the base of the game needed to be determined. Other problems to solve in the board assembly were how to attach the walls, and the handle and how to maintain a strong two-layer structure.

Theoretically, the board support should be easy to build by attaching a pole of the same diameter as the plunger handle to the plunger. This pole would have a wide base to serve as a foot of a table. The height of this structure would be ergonomically correct.

### 5.4.3. Obstacle attachment system selection

As mentioned before, the team agreed to use magnets to attach the obstacles to the board. Therefore, metal pieces needed to be included on the underside of it. The space for these metal components was limited by the board walls and the 70mm LED round support outlines that were situated around the sensors. Therefore the placement of the obstacle attachment system was determined. The detailed board assembly process is described in the prototyping section in the present report.

To carry out the testing of the magnet system, the free area for placing the obstacles was drawn in full scale to be able to sketch the desired placement of the obstacles as proposed by the computer science group (see appendix 5 for desired paths). The obstacle prototypes were used as templates and an overall defined position for them was traced in the area prepared.

The first idea which seemed to solve the obstacle attachment problem easily was placing a metal layer with the same dimension as the board under it, leaving holes for the LED's support. The advantages of this concept were that it was easy to assemble, because the metal layer could be screwed on the corners between the upper transparent board and the bottom board layer; and this concept also provided the maximum metal area for placing the obstacles. Nevertheless the metal plate proved difficult to manage and cut, so this concept was disregarded.

A second concept appeared since some small rectangular metal sheets were available. Trying to provide the maximum area for placing the obstacles within the desired position, an approximation with simple square shapes was made. Nevertheless it was still difficult to manipulate the metal to fit the defined area.

**Figure 27 Disposition of the metal layer on the board for the magnet attachment**

As the metal is hard to use and to cut, a third alternative concept for providing the metal support was offered by a special metal painting which was applied on the fabric that would be placed under the transparent board to hide the interior. Although several layers of paint were applied covering the maximum area for placing the obstacles on the fabric, the metal density support was much smaller than the previous metal layers. Therefore more powerful magnets were needed to obtain a sufficient attraction through the board to achieve appropriate obstacle attachment with the metal painting.

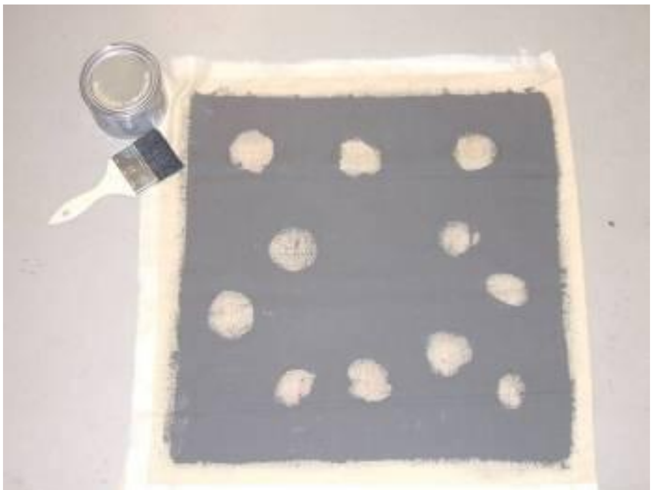

**Figure 28 Fabric painted with the metal painting for the magnet attachment**

After providing different solutions for the metal support needed for the magnet attachment system, the solutions were tested when magnets of different intensities and the final transparent upper board were available. Unfortunately it was not possible to find a combination among the elements tested that met the identified needs. The metal density provided by the fabric with the special paint proved insufficient. On the other hand, if the metal sheet was used, the magnets had to be strong enough to prevent the obstacles from moving when the ball struck them, but not so strong that the steel ball itself stuck to the obstacles. Therefore, when these problems appeared and none of the test solutions for the magnets worked, the nail attachment system for the obstacles was developed.

The disadvantage of the nail attachment system is that it limits the available area for placement of obstacles to only two points, so the board should have a very precise zero position for the robot to match the corresponding nail holes. The obstacles must remain stable with the movement of the board while playing and the movement of the ball must not be affected by the holes in the board. To minimize the possibility of error because of the deviations from the zero position of the board and to facilitate the robot operation, there is a strong dependence on the diameter of the board holes, and the diameter and length of the nails. The next step to detail this nail attachment system is to define the position of the holes to be drilled on the upper board and the sizes of the nails to be stuck to the obstacles and test their stability.

## 5.4.4. Handle selection

The selection of the handles depended on the movement mechanism used. The smooth plunger provides the two-direction movement required for playing the game. It allows for minimal rotation movement, but not sufficient to affect play, so the simplest handle design was deemed the best solution to the problem. Two simple handles, two sticks placed on each side of the front part, would work perfectly to move the board as needed. Moreover they could easily be attached within the two layer board assembly.

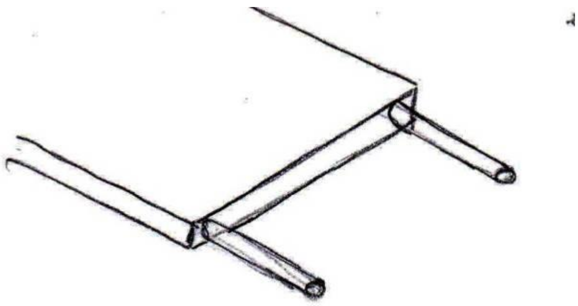

**Figure 29 Simple two handle concept**

The important aspect to consider in a detailed design was the ergonomic aspect. The distance between sticks and their length must be adequate for young people to optimize performance. Also the parts in contact with the hands must have an adequate diameter and smooth feeling.

# 5.5. Integrated solution: Reflect on the solutions and the process

As the principal needs of the product were to provide a game adaptation, referred to as the mechanical solution, the design of the game system focused mainly on solving the movement of the board and the motion control to provide an accurate board for the game. Even though there were many concepts and different evaluation methods were applied to find the best solutions, it was difficult to decide on one concept because it was hard to speculate on the physical performance and it was necessary to test the possibilities first. Concepts about the rest of components like the board support and the handles arose after first considering the mechanical movement solutions and the appropriate interaction between elements.

Therefore, as a result of this concept generation and evaluation phase, the final concept was composed of a two layer game board with a plunger as a movement mechanism in the bottom and two handles placed between layers to enable the user to manipulate the game. The top transparent layer would have to have small drilled holes in which to place the obstacles with the nail attachment system and all the concepts together must be adapted with a support in the correct position in front of the robot.

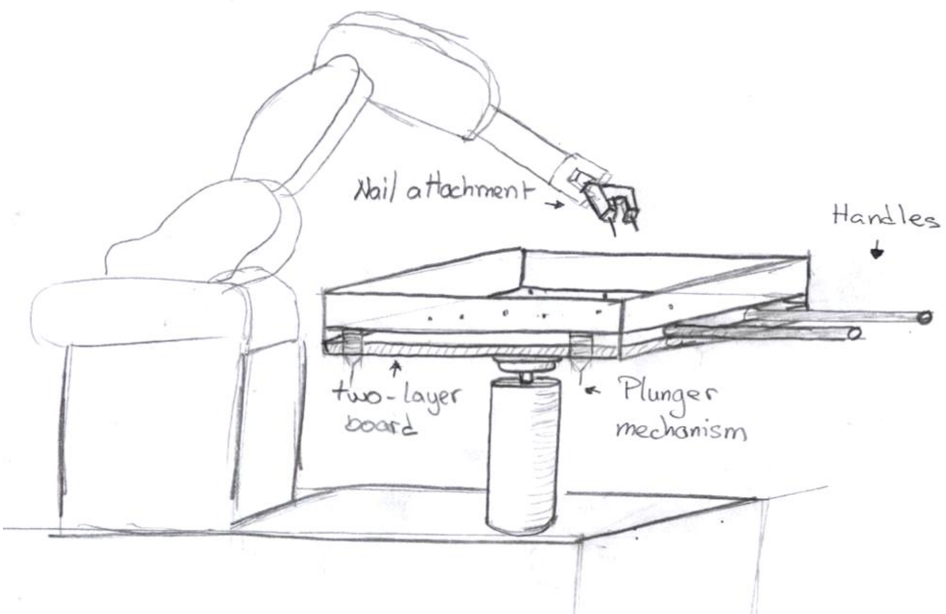


Figure 30 Complete system solution

# 6. Prototyping and detailed design

One of the main goals of this project is to complete a physical prototype of the game system in order to play the game. Therefore the prototyping process was an activity that was carried out in parallel with the generation of concepts in order to verify its functionality and thus gradually develop the project prototype. The construction description and the final game system product are described in this section.

## 6.1. Detailed design: preliminary prototyping

As one of the main tasks of the automation engineering group was to program the positions of the game obstacles with the robot, it was necessary to develop the obstacles in the early stages of the project. As soon as the computer science group provided sketches and dimensions of the obstacles, they were developed and built parallel to the construction of the other parts. The obstacles were made of polymer foam, available in the workshop and they were the first piece of the prototyping process. This physical obstacles and walls were painted with hieroglyphics by the computer science team to represent an Egyptian theme.

**Figure 31 Components of the prototype painted**

The team agreed to attach the obstacles to the board using magnets to allow the maximum space for them on the surface of the board. This permitted the computer science group to create free combinations and obstacle layouts for the game, although this obstacle attachment system was later changed. Once the needs of the game board were defined, and the prototype obstacle constraints were identified, the computer science group decided on 5 different suitable obstacle paths. This layout is available in appendix 5 *Obstacle paths sketches.* The requirements that the computer science group followed to design the obstacle location are shown in the next table.

| Needs of the obstacle dispositions (OD) |
| --- |
| • The OD respect the eleven sensor detection areas indicated by the diodes which are distributed on the board showing five blue points, four green points and two red points.<br>• The OD respect the position of the walls and are situated more than 20mm from the edges<br>• The OD respect a circle of 140mm in the center leaving space to place any of the |

| |
|---|
| movement mechanisms and the board support<br>• The OD will be based on the layout designed by the computer science group. |

Table 7 Needs of the obstacle dispositions (OD)

With the design of the desirable paths, a template of the sensor layout was made. This template was used to define the final board layers and the possible obstacle location based on the sketches of the game designers.

Figure 32 Template for the sensors and LED's disposition

Another element related to the finished obstacles was the gripper accessory. The obstacles designed by the computer science group following the Egyptian theme criteria were too small to be held by the robot gripper when this accessory was installed. Therefore an accessory was needed and it was necessary to carry out a new concept development to solve the problem.

Following the method to generate concepts to clarify this new sub-problem, the following needs analysis was done:

| **Needs of gripper accessory (GA)** | |
|---|---|
| **Primary needs** | **Secondary needs** |
| The GA grips the obstacle | • The GA adapts to the geometry of the obstacles<br>• The GA has a non slippery surface<br>• The GA keeps the horizontal position of the obstacles when gripping them to allow accurate performance |
| The GA is resistant to the pressure exerted by the robot when moving the obstacles | • The GA has a material that does not break while operating |
| The GA is easy to attach to the existing gripper | • The GA is easy to assemble and to disassemble |
| The GA is as simple as possible | • The GA is easy to build in the workshop<br>• The GA is easy to assemble<br>• The GA has a small number of pieces |

Table 8 Needs of gripper accessory (GA)

The solutions to the simple problem of the gripper accessory were based on calculations of the range of movement needed to pick up the obstacles (details about the measures of this range are explained under the headline Calculations). The distance between the existing sides of the gripper was shortened with a simple shape that reached the necessary range. The accessory part was a simple shape that was the negative of the gripper geometry, and provided a flat surface for holding things. Once built out of material in the workshop, the accessory was stuck to the existing gripper with a double-sided adhesive tape. Alternative solutions, such as sponges or other soft material were considered for the gripper accessory in order to better adapt to the obstacle shape, but the simple shape successfully fulfilled its role and all the obstacles could be picked up.


Figure 33 Gripper accessory

## 6.2. Detailed design: movement mechanism solution and table support

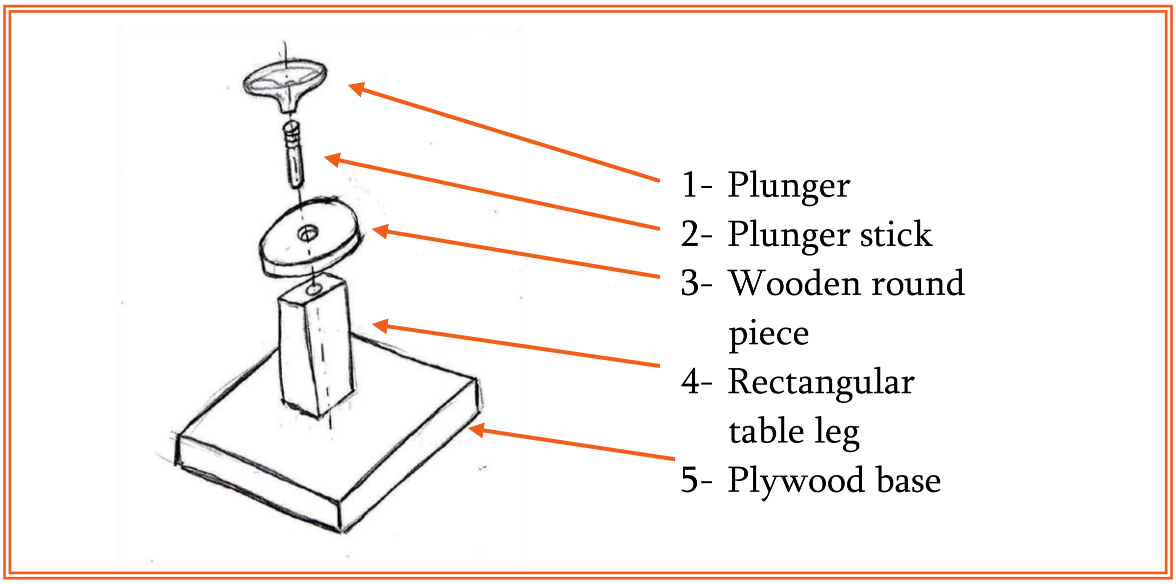


Figure 34 Game board and mechanism assembly explosion

The plunger (1), the mechanism chosen for the movement of the board, was first assembled on the foot of the board table. As it was not possible to find a rectangular table leg with the same diameter as the plunger, an additional round piece of wood was added (3) between the plunger and the rectangular table leg (4). The 450x450mm plywood base (5) was set on the metal robot base (which had been set on three wooden palettes) and attached with carpentry clamps as is shown in figure 35. The plywood panel and the rectangular table leg were screwed together as well as the round wooden piece. A hole was drilled on the to side of the round piece to insert the plunger stick (2), thereby attaching the mechanism to the foot of the table. Then the plunger had to be screwed into the stick to complete the assembly. The height of this apparatus was 847mm, the ergonomically correct height to be able to play the game (Woodson, Tillman and. Tillman ,1992).

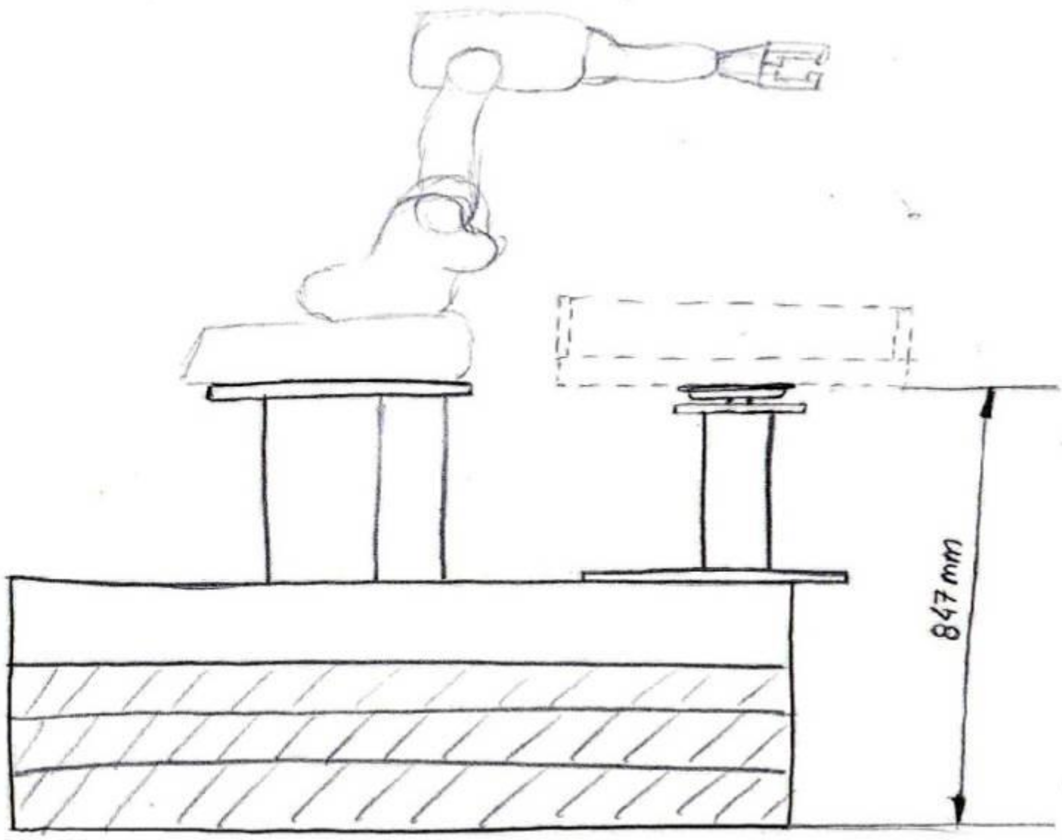


**Figure 35 Disposition of the support of the board on front of the robot.**

Using a special adhesive, it was easy to glue the rubber plunger to the bottom of the lower layer of the game board. This glue melted the rubber allowing it to stick to the wooden surface. The weight of the board provided sufficient pressure to ensure that the plunger remained permanently in place to play the game.

# 6.3. Detailed design: game board

The next sketch (Figure 36 Explosion view of the board components) details all the game board components to better explain the entire assembly.

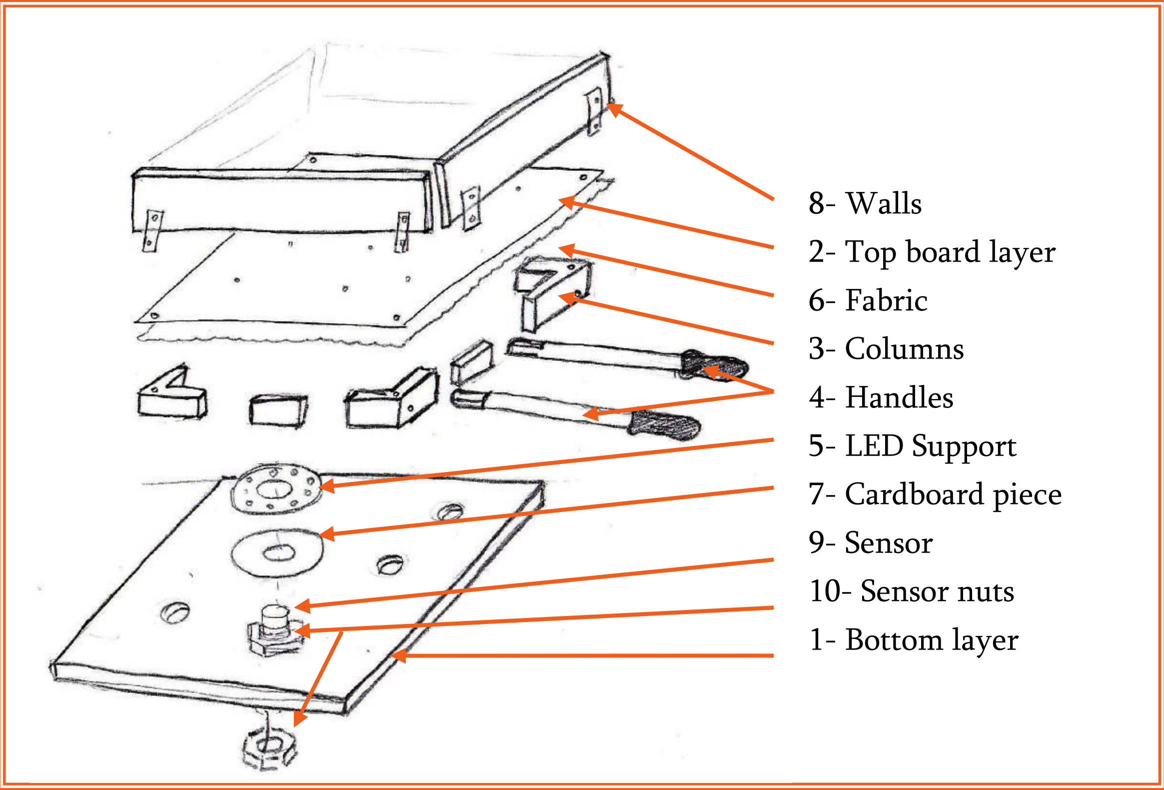


**Figure 36 Explosion view of the board components**

## 6.3.1. Bottom board layer (1) and top board layer (2)

The structure of the game board was referred to as a sandwich because it is comprised of two layers; the top plexiglass layer, and the lower layer made of MDF. To prepare the bottom board for assembly, eleven holes for the sensors were drilled in it using the previously prepared template. A different template was used to drill holes in the top layer for the nails to attach the obstacles.

In order to allow for a margin of error due to board movement, the diameter of the nails and the holes into which they fit was evaluated. As the narrowest nail had a diameter of 1.25mm, the holes on the board were 3mm to leave almost 2mm of range, ensuring that the robot was able to easily move and replace each obstacle, and to minimize the position deviations for picking up the obstacles again after playing.

To establish a definite position of all obstacles with two nails as points of connections, several factors were taken into account. The robot needed to know the starting location of the obstacles, so an initial obstacle distribution was established using the first path as a reference. To define the obstacle movement and position for the following sequences, not only the space available for placement on the board was taken into account, but also the width of the gripper when holding an obstacle was considered to avoid collisions during the placement process. Then a distance between nails on the obstacles was established, first considering the camel-shape obstacle since it was the most awkward. The nail positions on the other obstacles were all adapted based on the measurements of the camel. Finally the positions on the board were reduced to the minimum possible points, resulting in 19 hole points. The position of these points was made in the template together with the silhouette of the obstacles to be able to transfer and to drill them in the final upper transparent board.

Once the two layers were drilled, the sandwich structure board needed 20mm separation between layers in which to place the sensors (9), LEDs and other accessory components, including necessary reinforcement columns.

### 6.3.2. Columns (3)

In order to minimize the weight of the board on the sensors some columns were designed. Four of them had an "L" shape and were screwed onto the corners of the bottom board. These columns support the weight of the walls as well as the plexiglass. The dimension of the columns of these corners had square profiles of 20mm to have the appropriate holes on them to put long screws through the two layers and trying not to constrain the obstacle surface space. The figure 37 *Cross-section view of the board components* below shows the column distribution. There were smallest columns in the middle of each side, except on the front part where there were two small ones separated from the corners by the distance needed for the handles. The distance between handles was also intended to create an ergonomic standing position while playing, so some measures about anthropometrics were taken in consideration. As shown in appendix 2 about the anthropometric data of this report, the range of sizes of the arms at sides is between 302mm and 420mm, even 610mm in whole-body breadth, including the arms of a standing female. Therefore the handles were placed 50mm from the 500mm x 500mm board, to make a distance of 400mm, which is the average that best suits the anthropometric ranges and was possible to reach on the board side conserving the area to put the assembly pieces.

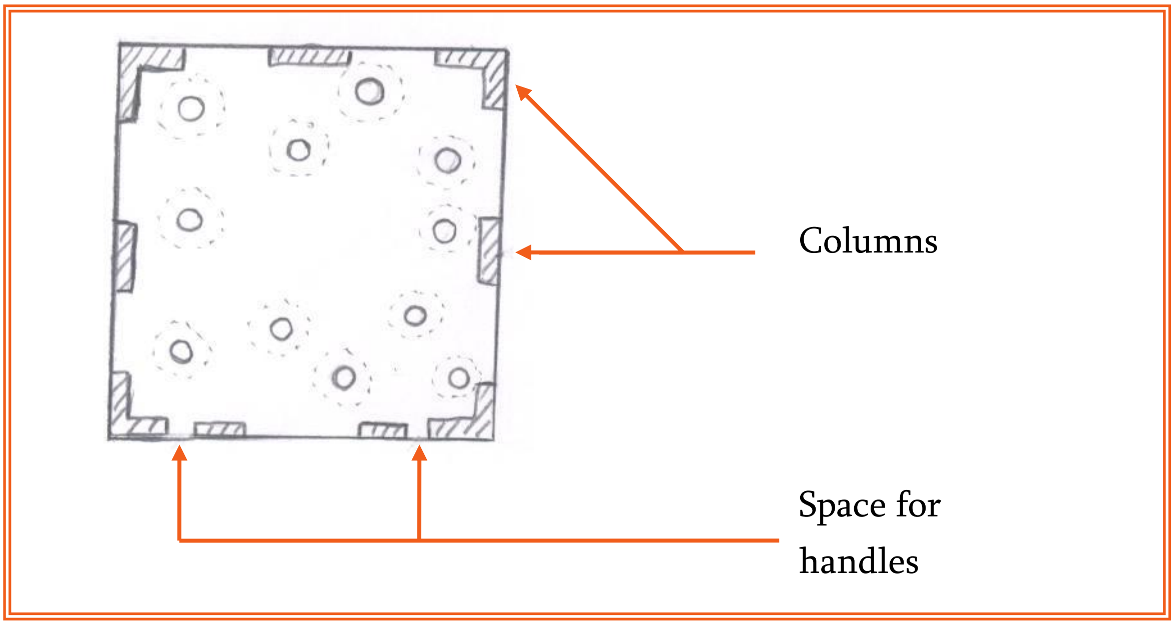


**Figure 37 Cross-section view of the board components**

## 6.3.3. Handles (4)

The length of the handle sticks was decided taking into consideration the average elbow height of an adolescent when standing (927mm and 1087 mm) to allow for a comfortable range of movement. Additionally, average arm length of adolescents was also considered (between 503 mm and 589mm) to enable players to reach the tactile screen and be able to watch the game ball easily. The screen is to be placed beside the board as shown in the computer model, although in the physical prototype the screen used for the scoreboard was the computer screen. The final length of the handles 250mm and a more detailed description of its measures can be found in the section "Calculations".

The diameter of the handles was 250mm and to attach them to the space in the board between columns, the ends were filed in order to give them a 200mm wide flat surface. Then they were screwed onto the wood in their corresponding places on the board. The diameter was referred to anthropometrics to be adapted to hand grip diameter, which is between 32mm and 41mm. Therefore a foam used for handlebars was added to increase the diameter and to make them smoother to the touch (as shown in figure 38).

**Figure 38 Handle with handlebar foam**

## 6.3.4. LED support (5)

A set of twelve diodes was used to show the user the position of the sensors. The number of LEDs was chosen by calculating the positions of the diodes placed around the sensor diameter. The sensor (9) is a metal detector, and therefore was activated when the set of twelve LEDs was placed near it. To stop this from happening the minimum scope for the LEDS not to affect the sensor was determined, and a support was designed that allowed them to be placed at the required distance (see appendix 6 for sensor specifications).

The LED support with a thickness equal to the height of the diodes was a circular piece that had a center hole to fit into the sensor, and it had equidistant holes to fit the group of light bulbs. These eleven pieces were constructed with the lathe and the driller machines using foam polymer material available in the workshop. This support achieved not only a good appropriate disposition of the lights but also a base for connecting them. The diodes were soldered, with the collaboration of the automation engineering group, according to the circuit with the suitable needed resistances. The specification about the circuit calculations is explained in the calculation section of this report.

Figure 39 Top part of the LED support

Figure 40 Back part of the LED support

## 6.3.5. Fabric(6) and cardboard pieces (7)

Although the concept at the beginning for the game was to show the position of the sensor using luminous points, finally that position was defined by a crown of light points. In order to win points in the game, the ball must pass through the center of the ring. To ensure that the LEDs could be seen properly through the transparent board, they must remain in contact with the top of the board surface. This ensures that the light does not fade or blur through the cloth stuck under this transparent top layer. The fabric was glued under the board to hide the interior of it and because the lights are powerful, the ring of lights appeared clearly through the cloth but without being too obtrusive.

Figure 41 Ring of diodes shinning through the fabric and the plexiglass board.

To ensure that these LEDs were in the correct position and to get the aspect that the figure 41 shows, it was necessary to add a piece of cardboard to the sensor head, between the sensor nut screwed onto the bottom board layer and the support designed for the diodes. The piece of cardboard was the same shape as the outline of the LED support and it did not only cover the distance of the sensor head for a good LED support position, but also isolated the circuit from the metal sensor nut to prevent short circuits.

### 6.3.6. Walls (8)

The last components to be assembled were the walls which were attached perpendicular to the edges of the top board with a metal sheet. This metal piece allowed the walls to be screwed to the columns and provided enough strength to play the game without the ball causing movement when it hit the frame (as shown in figure 42).

### 6.3.7. All-embracing view

All components are shown in the figure below which is a picture of the assembled board corner.

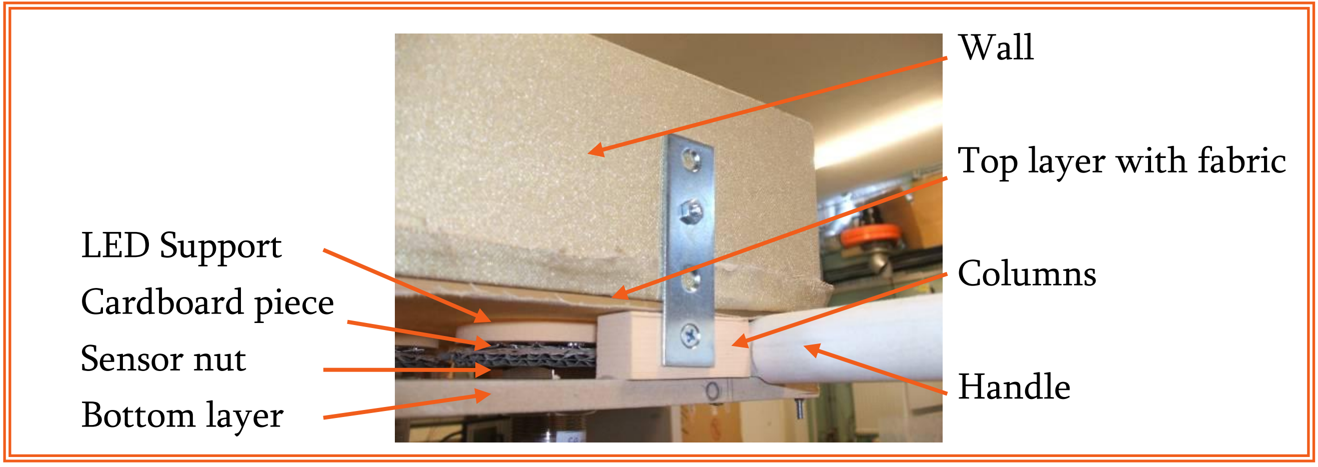


**Figure 42 Detailed components of the assembled board corner**

To put all the parts together, first the sensors connected to the PLC (Programmable Logic Controller, a device designed for multiple inputs and output arrangements for automation of electromechanical processes) were placed in the bottom board holes attaching their position with two nuts. Then, the cardboard isolation piece and the LED supports were placed on each sensor. The diodes were connected by colors from the support to the PLC. On the bottom board the columns and the handles were screwed before the upper board was placed on top and screwed on the corners to the columns. Finally the walls were attached in their perpendicular position and the bottom part of the board was glued to the plunger mechanism already joined to the base.

Additionally, another important stage of assembly was done at this point. To finish the development of the designed attachment system, the nails were added to the base of the obstacles. On a thin extra layer of the same obstacle material, the silhouettes were cut out to create obstacle supports. These supports were nailed respecting the fixed distance on the template for arranging the obstacles, and finally they were glued to the base of the obstacles.

Figure 43 View of the obstacle nail going through the board hole.

The pictures below show the result of the described prototyping process.

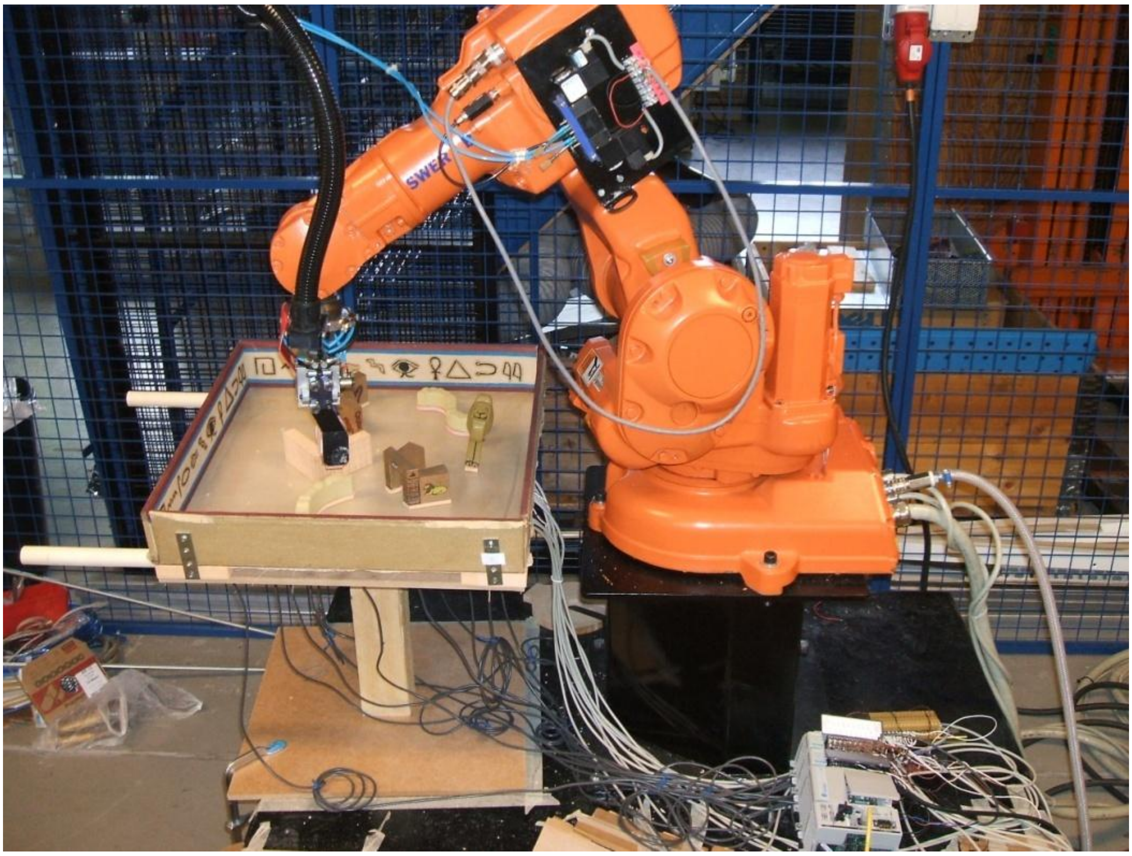

Figure 44 The final board with the robot after prototyping phase.

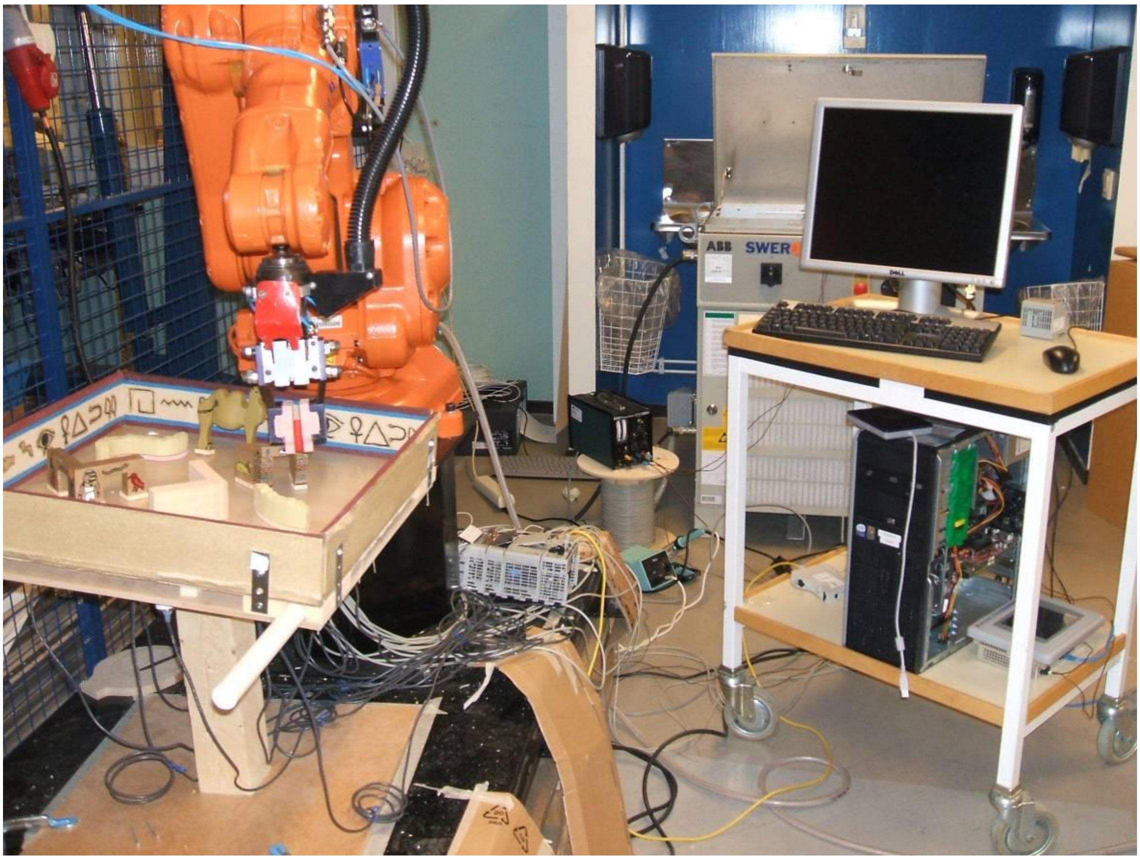

Figure 45 Robot game project system

# 7. Testing and Refinement

The final phase in the product development was to test the prototype and to find and fix any problems. In this case some changes to the obstacles, the board, the gripper and the mechanism were made to improve the attachment system and the possibility of programming the position of the robot.

While moving the board some obstacles, specifically the camel-shaped obstacle and the arc-shaped obstacle, were unstable because they kept leaning to one side. To solve this problem little blocks (as shown in figure 46) were made to be put within the layers to increase the length of the top board holes. The nails going into the deeper holes could therefore stop these obstacles leaning.

**Figure 46 Lateral board view with blocks within layers**

However, as linear vertical movement could not be reached by the robot gripper, the balance between the length of the nails and the size of the top board holes was reconsidered to facilitate the robot action. The team agreed to make 5mm holes and shorten the nails so the deviations of vertical robot movement were not so influential. On the other hand it was known that some obstacles with shorter nails were unstable; however, as it was more important for the robot to be able to place the obstacles in good positions, the instability of some obstacles was not considered to be a disadvantage. If the obstacles continued to lean after moving the board, they could be replaced by hand before the robot picked them up again.

Although the nail attachment system was adapted to have a 4 mm diameter range to place the obstacle nails, it was not enough for a successful robot operation because the plunger mechanism did not always return to the same position when the board was moved. Therefore little movements while placing the obstacles meant that the obstacle references programmed into the robot were lost. The solution for this unexpected problem was to completely stop the board movement providing an exact zero position. The balance of the plunger rubber was stopped as shown in figure 47. The brace (a) was placed manually between the plunger (b) and the wooden round piece of its support (c). To stop small twisting movements a screw (d) was added to a little part glued to the wooden round base that would connect the board. The screw, as well as the brace, needed to be removed for playing, but these two accessories were designed as a quick solution to enable a zero position to be programmed into the robot.

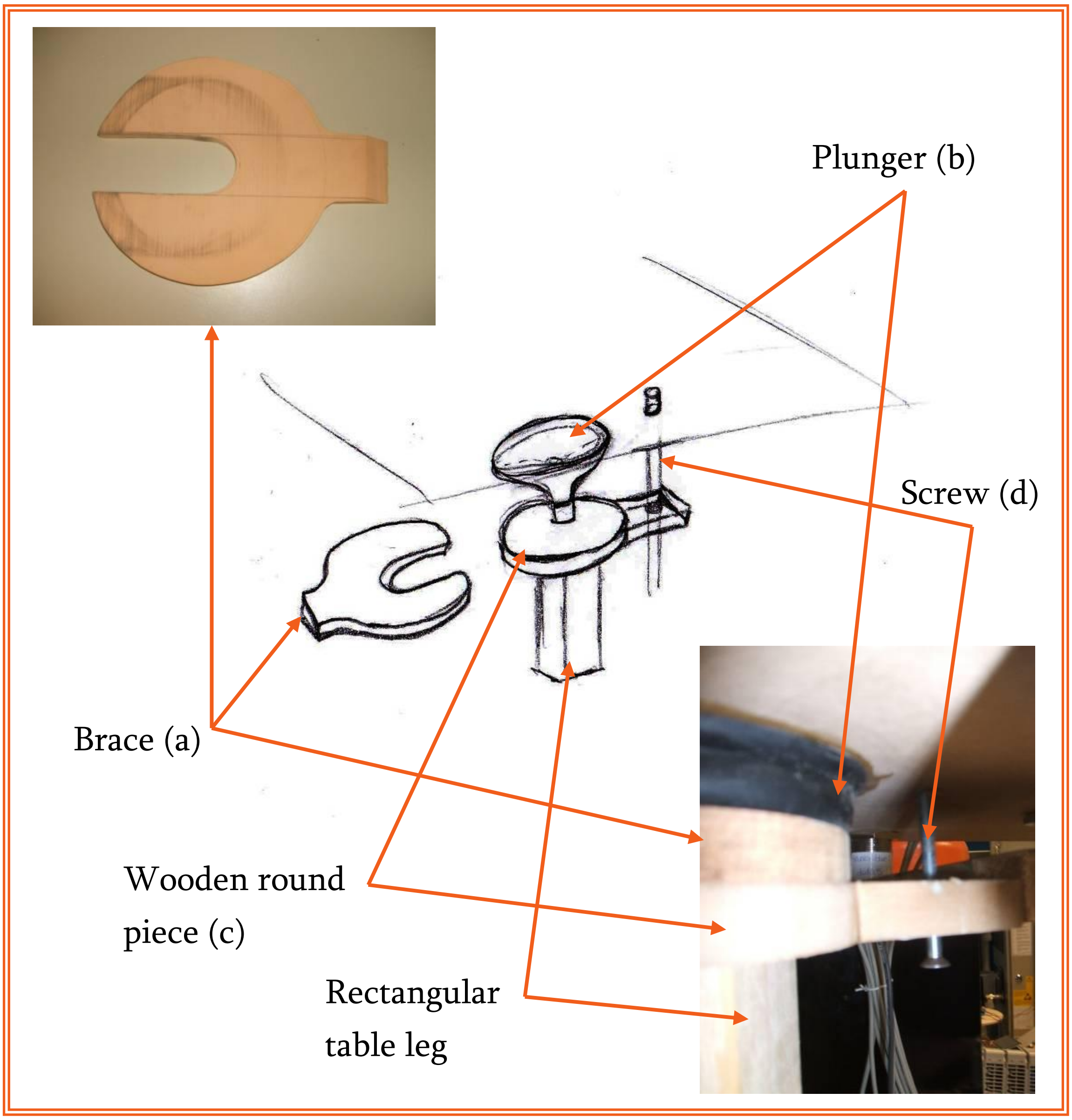


**Figure 47 The solutions to stop the balance of the board**

The disadvantage that the automation engineering group found while positioning the obstacles was that the strong robot could move the board position due to the possible incorrect manual movements while programming the obstacle positions. Therefore enforcements on the four corners of the board were inserted with wooden pillars (as shown in figure 48). This solution permitted the five paths of the game to be properly programmed, although the accuracy required for playing, that is having the exact zero position in combination with the movement on the board for winning points, was difficult to reach.

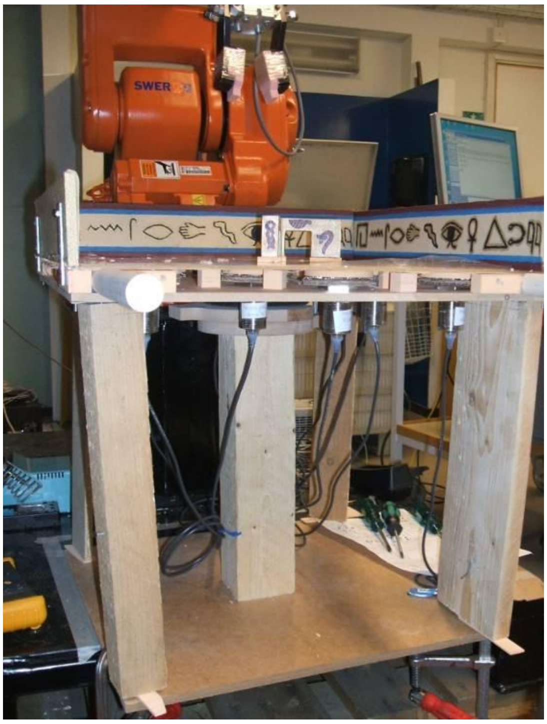

Figure 48 Board prototype with corner reinforcements

Finally the gripper accessory was necessary to be rebuilt because it broke and moved while testing. The size was calculated for picking up the obstacles, but the stress on the pliers-like device was too much and the differences between obstacle sizes caused this accessory to fail quickly. The new gripper accessory was made with a harder polymer foam material and it was stuck with sellotape around it and not only with the internal double-sided adhesive tape, to ensure its position as shown in picture 49.

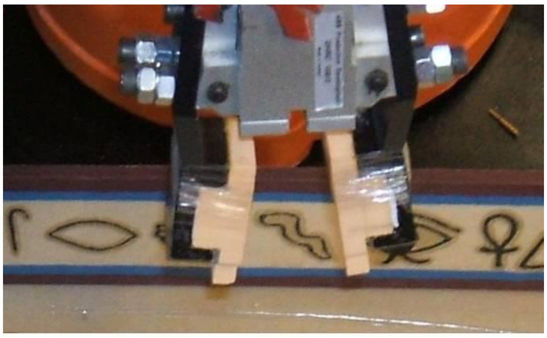
Figure 49 Rebuilt gripper accessory

The gripper accessory was a very simple solution for shortening the range distance between the pliers-like device and the obstacles' range, but this solution did not meet all the required needs. The gripper accessory did not keep the horizontal position of the obstacles when gripping them and thus allow accurate performance. The gripper's and the obstacles' faces were not parallel, the obstacle had small deviations in position each time they were picked up and that problem affected the vertical position for programming the robot. But these deviation problems were also solved when the board holes were increased to 5mm.

After those changes the automation engineering group could program the position of the robot to show a complete performance of the game.

# 8. CAD model

Although minimizing the volume of the game was not important for constructing the physical prototype, the robot system components are dangerous and to make a safe product they have to be covered. The CAD model was centered to solve safety aspects, so a lid was designed, taking in consideration the disposition and the volume of the game components to protect both the robot and the user. The needs of the CAD prototype are summed up in the next list.

| **Needs of the CAD prototype (CP)** |
| --- |
| • The CP respects the physical prototype's constructed components<br>• The CP substitutes the computer screen with the scoreboard and instruction tactile screen.<br>• The CP minimizes the volume of the assembly to cover it all with a case<br>• The CP has a safe case with good access for maintenance.<br>• The CP takes into consideration the safety aspect collected on the ergonomic checklist. |

**Table 9 Needs of the CAD prototype (CP)**

After developing some concepts the one chosen is shown below in sketch figure 51

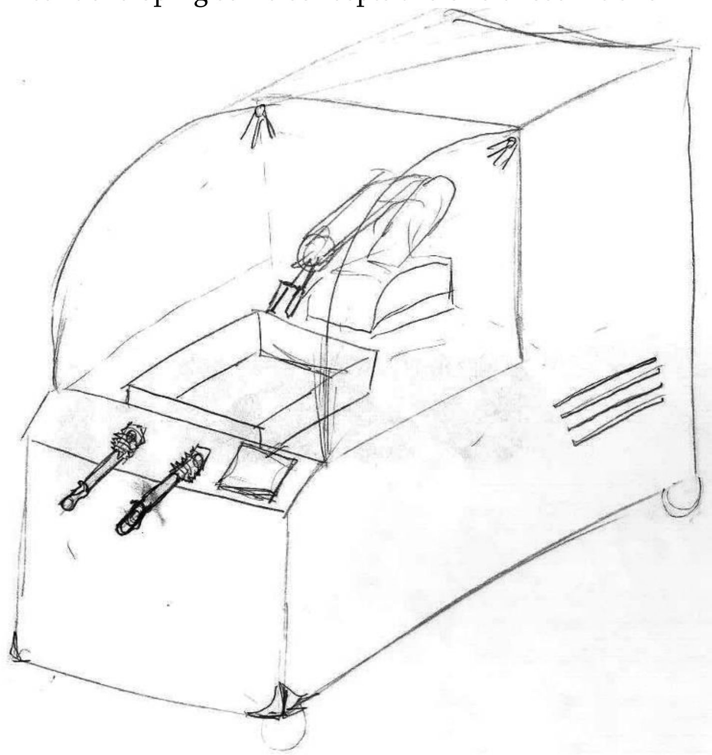

**Figure 50 Sketch of the computer prototype**

To protect the user from the moving parts, the handles were covered with a plastic that is used for joysticks. The structure of the case has space behind the robot to place the electronic components, such as the generator, the PLC, the transformer, and allows access to the back of the prototype case. On one side of the case there should be a ventilation grille to prevent overheating inside the system because of the electric components. The structure of the components are the same as the physical prototype, so the space under the board would be covered to hide the sensor and diode cables, but leaving space for desirable components like speakers. The tactile screen is placed on the right side on the front part beside the handles to allow easy control and observation. The part around the robot and the game board is made with a transparent material like methacrylate, so the game can be watched and secure. Additionally it has lights inside, within the range 200 to 800 lux, to improve visibility and to prevent shadows or reflection from external possible lights. The shape of this transparent case part is round to facilitate the robot's movements, to increase aesthetics and the front part can be opened if access by maintenance personnel is needed.

Some renders about the CAD model are shown below:

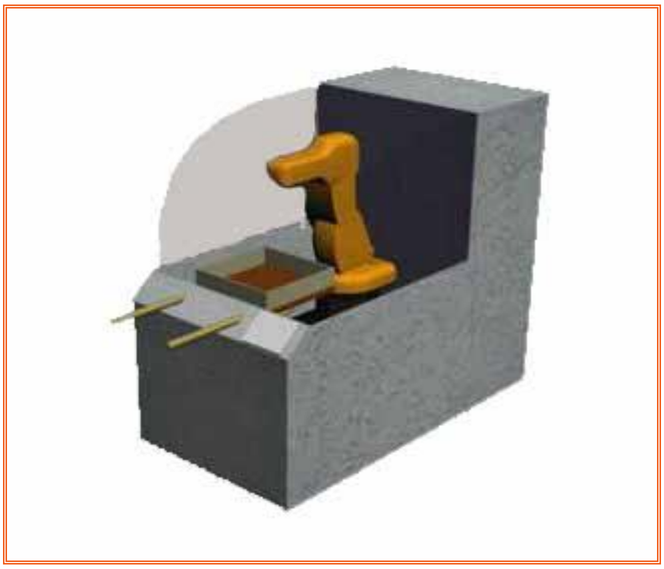

Figure 51 Perspective of the computer prototype

Figure 52 One-side uncovered case computer prototype to show the interior

# 9. Calculations

This point will explain different calculations made during the development process.

## 9.1. Electronics

To show the points scored in the game points via light circles on the board, 12 LEDs were connected in their supports. Before soldering the diodes and the resistance, the circuit was calculated. Three kinds of diodes were provided: blue and green bulbs which have about 3.1V at optimal 20mA and red bulbs which have between 1.9V and 2V at 20mA. 270Ω resistances and 62Ω ones were available. As the power supplied was 24V it was possible to connect 6 serial units of blue or green diodes with a 270Ω resistance and 12 units of red diodes with a 62Ω resistance. Knowing that the voltage sources and drops in series are $V_T=V_1+V_2+\ldots+V_n$, and following Ohm's Law which says that $V=I\times R$ and $P=I\times V$, the result of the connections and the number of electrical elements needed are shown in the next calculations:

For blue and green diodes $R = V \div I$; $270\Omega = (24 - 6 \times 3.1)V \div 0.02A$. As the resistance value was calculated from the power the calculations are $24V-(6\times 3{,}1\,V = 18.6W) = 5.4W \div 0.02A = 270\Omega$ and the graphic connection is:

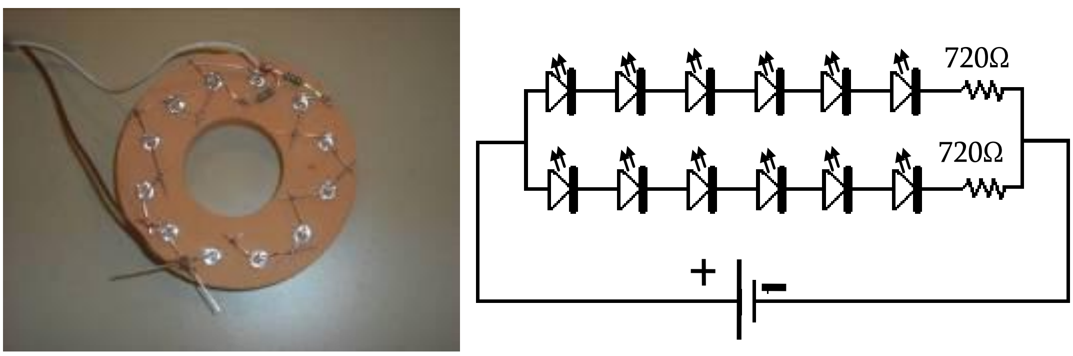


**Figure 53 The blue diodes circuit**

For red diodes $R=V\div I$, $60\Omega = (24-12 \times 1.9)V \div 0.02A$. As the resistance value was calculated from the power the calculations are $24V - (12 \times 1.9V = 22.8W) = 1.2W \div 0.02A = 60\Omega$. The closest resistance available was 62Ω, and the graphic connection is:

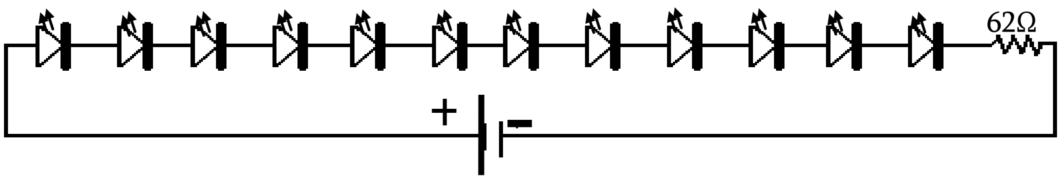


**Figure 54 The blue diodes circuit**

## 9.2. Board slope and ball speed

To specify and evaluate the different concepts to solve the mechanism's problem, tests were made to measure the board slope and the ball speed. First a range of the board angles was established using the ball rolling in a board prototype. The inclination of the board was reached by placing some blocks under one side and then moving them along and measuring the height and calculating the angle. With simple trigonometrical calculations and based on the feeling of the ball speed rolling, the accurate range of board slope in grades was around 2° or 3°, because it was felt that it was not too slow. Later, while measuring the mechanism inclination the maximum range was about 12° because more of a slope made the ball hit the walls when changing the direction of the board, due to the ball reaching a speed that followed its inertia and thus did not react to the board movement. Therefore the mechanisms that provided more than 12° or 13° did not give a good board movement and it was then a disadvantage The angle range chosen was between 10° and 12°. During testing some movement mechanism solutions provided different angles depending on the weight supported. Therefore the angle was measured with the mechanism supporting from 3.5kg, which was the sensor weight, up to 5kg which was the calculated maximum board weight.

## 9.3. Range of the gripper accessory

The obstacles were picked up by the robot gripper, a pliers-like device that was connected by the automation engineering group and it was adapted to the obstacles' sizes. To reduce the range of the gripper to reach the obstacle range, an extra piece was placed within the two elements. Designing this piece was very easy: some measurements were made to create an appropriate interface and a useful tool. The gripper range was between 32mm when closed and 65mm when opened. The range of obstacle thickness was between 15mm and 35mm. Therefore the 33mm range size of the gripper had to be reduced to the 20mm range size of the obstacles which was done by adding 10mm to each side. The gripper accessory changed the range to 12mm when closed and 42mm when opened, ensuring that all obstacles could be picked up along the whole gripper surface, and preferably in the middle.

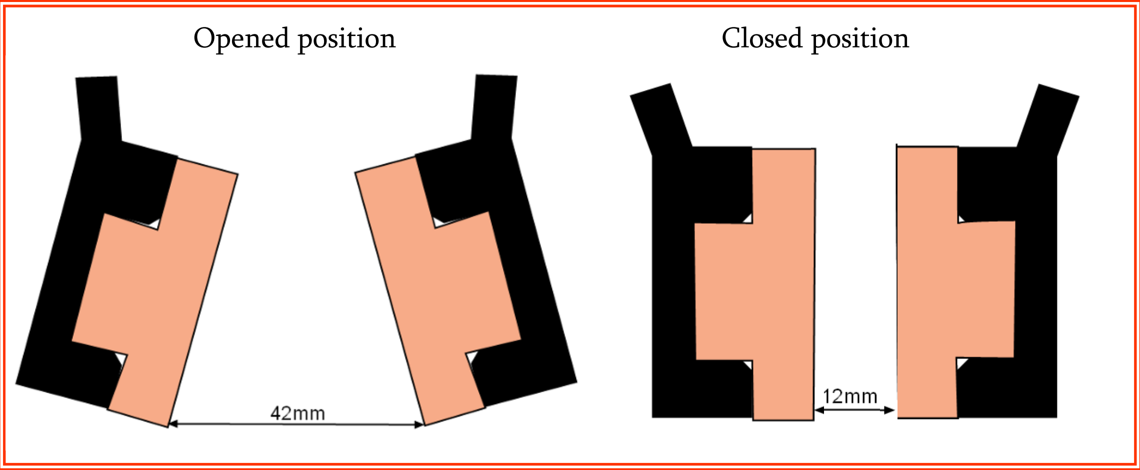


**Figure 55 The gripper range**

## 9.4. Length of the handles

The distance between the two handles on the front side of the board and also the length required to keep the height of board control in a correct position were calculated ergonomically. The average size of girls' hands was taken into account when calculating the diameter of the handle sticks.

Looking at the ergonomic data that can be found in the appendix 2, the hand grip sizes for teenage girls are between 30mm and 40mm. The diameter of the handles, including the bike foam rubber covers which provided a soft surface for controlling the board, was near 30mm, the appropriate grip diameter.

The distance between handles was fixed at 400mm based on data about the distance between elbows. The sticks' length was about 250mm to permit an accurate distance from the board both when it was straight but also prevented a large height difference occurring when it was leaning. The distance of the handle from the floor on the prototype was about 850mm, and with the 12° of movement, the height varied by 100mm, which gave a range between 840mm and 860mm. Based on anthropometric data on teenagers, and ergonomics data which sets the maximum height for tables to work in a standing position at about 864mm, the length of the handles is at the correct height for playing.

# 10. Recommendation for continued work

In the section called "Testing and refinement", some changes were made to the prototype due to problems which came up during testing and trying to program the obstacle positions. One of the main difficulties was to ensure a zero position needed for the nail system attachment. Once the table with this attachment system was constructed, the easiest way to provide a result in the given time was to stop the little movement board any way possible. The lack of materials and support by the manager during the testing process, made it difficult to try other possible solutions found later for using the magnets attachment system.

The magnets attachment system was removed because the ball was affected by the strong magnets and got stuck to the obstacles. A solution for this problem would be to replace the iron ball with an aluminum one. The metal sensor detects different types of metal but with a specific intensity depending on the distance. According to the table in appendix 6, found on Omrom Industrial Automation's webpage, iron can be detected up to 30mm, further than any other metal, but aluminum is also detected up to 12mm. Because the detection distance of the ball in the game is the top board thickness, i.e 4mm, the sensor would have no problem detecting an aluminum ball and this way the ball would not be affected by the magnets. Moreover, as the density of aluminum is lower than iron, and therefore lighter, an aluminum ball would not affect the obstacles' position as much as the iron ball when playing the game.

Changing the iron ball for an aluminum one might be a good solution for a better attachment system for the obstacles, but it would be necessary to test it first, developing a board with the magnet attachment system. Moreover with this solution the position of the obstacles on the board surface would not be so limited and the exact zero position would probably not be necessary. But if the aluminum ball doesn´t work and the magnets system can not be used, then it would be necessary to develop a functional solution for stopping the board. Using the nail system attachment, it would be necessary to develop a better mechanical solution that keeps the board in zero position while placing the obstacles, and later lets the user move the board while playing.

The accuracy of the nail system attachment is also limited by the position of the nails when the gripper picks up the obstacles. The gripper accessory was an easy solution for reducing the range and adapting it to the obstacle sizes. Nevertheless the gripper accessory did not reach the specifications because sometimes it gripped the obstacles in an unstable way which affected the robot placement with the nail system attachment. Increasing the holes to 5mm was the solution found to placing the obstacles with the nail system attachment, but this caused other disadvantages. A better fit between the gripper and the obstacles could be reached if the surfaces in contact were parallel, maybe adapting the obstacle shape to the gripper instead of the other way round. The obstacle shapes were first designed by the computer science group as they were one of the main parts of the game, but some restrictions might be necessary after testing to improve the game performance with the nail attachment system. A redesign of the obstacles with the same gripping distance would allow a unique position without movement when they were picked up. Moreover, it would be necessary to look for stable shapes that don´t lean while playing the game as the camel shape did.

The CAD model shows a safer game system covered with a case adapted to the physical prototype achieved. This visual solution could help create further physical prototypes that are better designed for testing with young people or even to be carried to exhibition sites. The CAD model system used the tactile screen as the scoreboard and instruction element, but it was not possible to install this in the physical prototype so the computer screen was used instead.

Materials were not a priority in the physical prototype; those provided by the project manager and easily available were used. However, for a further physical prototype , with the case added, a study of the possible materials would be necessary. With the right materials some safety aspects, such as preventing fires or electric shocks could be improved. Also, a non-reflective case used with the prototype would make playing the game easier. The durability of the game prototype also depends on the materials used and they must be suitable for their function.

Therefore, although the results of this project gave an overall idea of how to build a prototype for playing the ball game interacting with the robot, the results could be improved to reach both a game suitable for testing with its target group as well as a base for further work.

# 11. Discussion

## 11.1. Summary and conclusion

By comparing the results to the list of necessities of the game project, it is possible to assert that the prototypes gave satisfactory solutions for the principal needs of the project within the time and the materials available.

Safety aspects were taken into consideration in the physical prototype during construction and these were increased in the 3D model adding the case to the whole unit to provide the required protection.

Ergonomics were considered especially with reference to the anthropometric aspects as there were not too many limitations in biomechanical, psychological or environment aspects. The project geometry was adapted to the size of the target group for a comfortable game. Moreover the ergonomic checklist in appendix 1 showed a good general result when applied to the prototypes because 90% of the game questions were answered positively.

The aesthetics of the game were related to the theme and the computer science group painted some of the game´s elements to highlight this aspect with colors and shapes associated with ancient Egypt. Moreover the case included smooth lines and shapes not only for safety but also for aesthetic reasons.

The results for assessing the game functions in the physical prototype were acceptable, but the prototype did not meet all the objectives for a good game performance. The mechanical solution provided the soft and accurate movement that was required, as well as the geometry of the game elements. Nevertheless the prototype had some disadvantages related to the attachment system and the obstacles. The nail attachment system developed in the physical prototype required a very precise zero position for the table, more precise than expected. The zero board position was reached quickly to program the game and to show its performance, but it was not enough for good performance of the game with the target user. Therefore further work on the prototype to research how to maintain the zero board position with the nail attachment system, as well as other possible attachment systems, is required as suggested in the previous section.

Finally, testing durability was not an important part of the project, since this was just a prototype; however it would need to be considered for a future prototype. Maintenance was taken into consideration in the CAD model because the virtual design added a case which allowed access to the internal parts.

In summary, the physical prototype fulfilled the main objective i.e. to show how to play the game while the CAD model showed how to make the product safe and provided a good basis for continued work.

## 11.2. Personal opinion and further information

This project has been a great personal work experience. Although the game project was in group, the hardest task was to develop the product prototype solutions individually. The involvement of only one person makes the process of concept generation a hard task, resulting in lack of confidence when evaluating ideas and a bigger commitment by the rest of the team.

To carry out an individual design work, the weakest points and ideas were identify and rated as objectively as possible, trying to make a table of needs as selection criteria. Perhaps developing concepts and discussion in group is faster, more productive and easier to evaluate but checking and reviewing the concepts during the process allowed having a base of comparison to get appropriate solutions. Normally concepts are turned over to the customer specifications, but in this case the concepts were base on personal preferences, by its feel, and logical opinion. As the participation and communication within the student project team were not enough support, the pos and cons analysis and tests prototypes of each concept were the best way to create, develop and evaluate the project.

The necessary steps to start up, carry out and finalize a degree project in the area of product design engineering are many. First of all a specification of the degree project and a time plan have to be approved according to Skövde University methodology. Although a first planning is fixed on the degree project specification as an approximation of the design process, the product planning is updated as part of the project's strategic planning activity, because some delay can occur during the product development.

Steps in the process planned on the degree project specification can and should be performed simultaneously to make sure that the many plans and decisions are consistent with one another and with goals and constrain. However, reflection and criticism of consistency should be an ongoing process. As a result of the first steps, the project was set to 14 weeks in the project degree specification with all the main design phases scheduled: research, sketches, concept generating, model, tests, report writing and presentation. It took two weeks until all particular specifications were defined; still they later had to be reconsidered. This schedule also worked as a reported relationship because in the degree project specification is described the link between the people involved in the project. One weekly meeting with the main supervisor and another with the student team were set.

In my opinion the project had many parts to put together and a good communication and interaction was not achieved to finish both prototypes at the same time. As one of the main tasks of the automation engineering group was to program the positions of the game obstacles with the robot, from the beginning there was perceived the need to obtain a fixed position of the board and a disposition of the obstacles for letting them work in parallel while developing and constructing the other parts. This position was not achieved until the prototype had been totally finished due to the dependences of the components because of the diverse interactions among the elements, and the difficulty of reaching a functional prototype.

Therefore a communication between members as is also an important part for this group project. In this design engineering project there is a main supervisor and a subordinate supervisor who both support the student work, and a manager of the project who acts as a mediator not only between student groups of the team but also in relation with the supervisors. The project manager is responsible for budgets, updating schedules, meetings, performance evaluation and coordination; but the manager has no real authority or control of the project organization, which has to be scheduled and organized by each student group of the team. Although there was one compulsory meeting day fixed every two weeks not to lose the team work direction, most information exchanged and organized meetings were communicated by spontaneous emailing and direct conversation. Consequently, links were created often informally in spontaneous encounters while at work, which was easier since a computer with the necessary programs and internet was available in the same room as the components of the project were situated, facilitating this way the teamwork.

To support the communication of project status between the student and the supervisor, a document, VPD (Visual Project Description), was used. This document is a short presentation of the state of the project, usually used to report when meeting other people involved in a project, which improves the analysis of the design process by identifying the most important points. A VPD includes a title and a short description of the project describing the main goals. It is also includes some visual aids as a picture or sketch of the product showing the product shape, and rating colored symbols to estimate the important quality factors identifying which must be taken care of immediately, a time plan with important deadlines showing in a visual way the time situation, a "Right now" box describing what is done at the moment, what has happened since last time and what will be done next, and eventually a "Risk and threats" box discovering the problems and maybe proposing an alternative plan. The VPD was proposed by the main supervisor to facilitate also the communication and planning between the project groups, to make a timeline together, and to assist in the design process at the moment of taking important decisions or delivering important information for the project to continue smoothly. This document was introduced when half project planned time had passed, and it was not adopted by the rest of team members, but was helpful to keep the supervisor informed and to help the designer visualize the points of importance to keep on working in the right direction.

From my feelings in this project experience I can conclude that was hard to reach a good coordination during the game development. Computer science group first develop the idea and the obstacles, and the entire rest project was fit to it, so was hard to keep a good interaction and collaboration on the further approach of the game project results. Therefore it is better to work in group to develop a product but for getting good result it is important a good coordination between members.

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[i] The date system used in the references is the Spanish one which is: DD-MM-YYYY

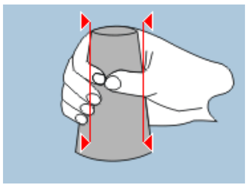
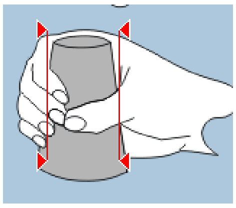
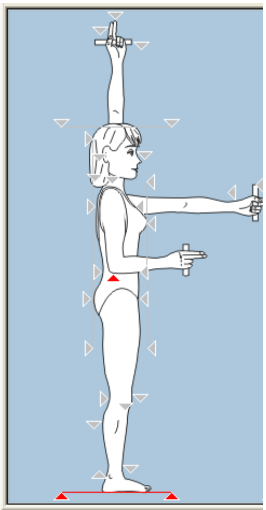
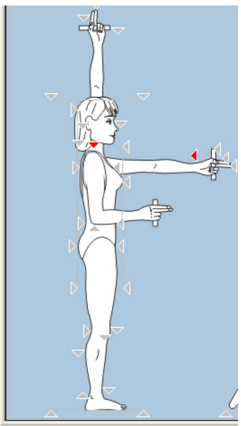
# Appendixes

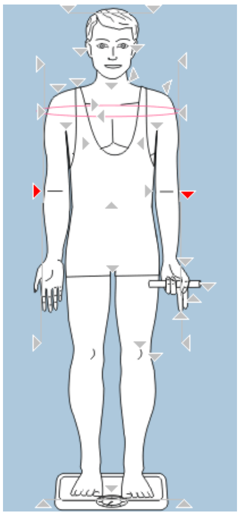
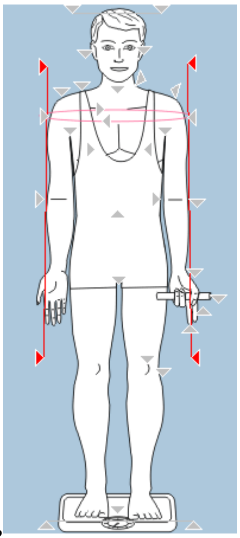
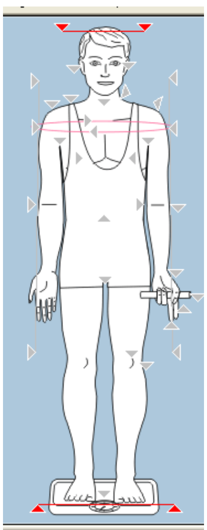
# Appendix 1. Ergonomic check list

1. Anthropometric, biomechanical, and physiological factors
   - Are the differences in human body sizes accounted for by the design? Yes +
   - Have the right anthropometric tables been used for specific populations? Yes +
   - Is the manual work performed close to the body? Yes +
   - Are any forward-bending or twisted trunk posture involved? No +
2. Factors related to posture (sitting and standing)
   - Is the work height dependent on the task? No +
   - Is the height of the worktable adjustable? No -
   - Has work above the shoulder or with hands behind the body been avoided? Yes +
   - Is there enough room for the legs and feet? Yes +
   - Is there a sloping work surface for reading tasks? Yes +
   - Are handles of tools bent to allow for working with the straight wrists? Yes +
3. Factors related to information and control task
   -Has an appropriate method of displaying information been selected? Yes +
   - Is the information presentation as simple as possible? Not counted
   - Has the potential confusion between character/letter size been chosen? Not counted.
   - Have text with capital letters only been avoided? Not counted
   - Is the text/background contrast good? Not counted
   - Is the location of controls consistent and is sufficient spacing provided? Yes +
   - Is the type cursor control suitable for the intended task? Yes +
   - Is the direction of control movements consistent with human expectations? Yes +
   - Are the control objectives clear from the position of the controls? Yes +
4. Human-computer interaction
   - Is the human-computer dialogue suitable for the intended task? Not counted
   -Is the dialogue self-descriptive and easy to control by the user? Not counted
   -Are touch screens used to facilitate operation by inexperienced users? Not counted
   -Is the type of help menu fitted to the level of the user's ability? Not counted
5. Noise and vibration
   - Is the noise level at work below 80dBA? Yes +
   - Is there an adequate separation between workers and source of noise? Yes +
   - Are acoustic screens used? No +
   - Is the transmission of vibration prevented? No -
6. Illumination
   - Is the light intensity for normal activities in the range 200 to 800 lux? Not counted
   -Are large brightness differences in the visual field avoided? Not counted
   - Are light resources properly screened? Not counted
   - Can light reflection, shadows, or flicker from the fluorescent tubes be prevented? Not counted
7. Climate
   - Are the materials/surfaces that have to be touched neither too cold nor too hot? No+
   - Are undesirable hot and cold radiation prevented? Not counted

| Number of question | Not counted | Positives | Negatives | Positive % from counted | Negative % from counted |
|---|---|---|---|---|---|
| 33 = 100 % | 13 = 39% | 18 = 55% | 2 = 6% | 90% | 10% |

# Appendix 2. Table about anthropometric data

| **Measurements from 5th-95th percentiles** | **User Group** | **Smallest (mm)** | **Largest (mm)** |
|---|---|---|---|
| Thumb-Index Finger grip diameter  | US Girl | 32 | 41 |
| | US Boy 12 | 30 | 40 |
| | US Female 18-25 | 33 | 44 |
| Thumb-Middle Finger grip diameter  | US female 18-25 | 41 | 50 |
| Elbow height, to underside of flexed Forearm  | German Female 18-25 | 946 | 1109 |
| | US female 18-25 Hi income | 927 | 1087 |
| | US female 18-25 | 923 | 1085 |
| Shoulder (Acromion) to Wrist crease  | US female 18-25 | 503 | 589 |
| | German Female 18-25 | 514 | 601 |

| | | | |
|---|---|---|---|
| Elbow to elbow breadth, Arms at side<br> | US Girl 12 | 304 | 420 |
| | US Girl 12 | 312 | 424 |
| Whole-body breadth (maximum, inc. Arms)<br> , | Female 18-25 | 381 | 610 |
| Stature<br> | US Girls | 1473 | 1699 |
| | US Girl 16 | 1522 | 1736 |

# Appendix 3.Screening tables.

Table 1

| **Aspects-functions or assumptions (principal needs)** | The system + verb + function<br><br>Secondary needs | SCORE |
|---|---|---|
| The MM provide a correct board and ball movements | • The MM provides an horizontal position when it is not manipulated<br>• The MM provides two direction movements<br>• The MM is resistant to the weight and stress of the board<br>• The MM provides a good inclination for a correct speed of the ball | 5<br>4<br>5<br>5 |
| The MM is easy to construct | • The MM is possible to be built by workshop machines<br>• The MM have a composition to which the university can support (materials, companies)<br>• The MM has an intuitive way to prove its efficiency and not to much aspect have to be studied or pre-tested | 4<br>5<br>3 |
| The MM has a good interaction with the rest of the components | • The MM is correct attached to other components on the board<br>• The MM permit an easy addition of other components or access to them | 4<br>3 |

Table 2

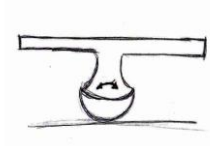
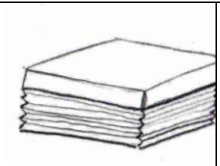
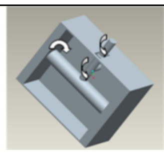
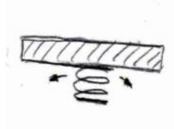
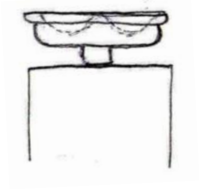
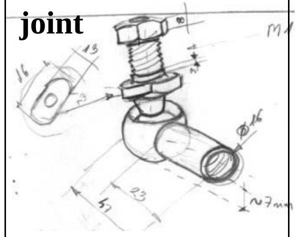
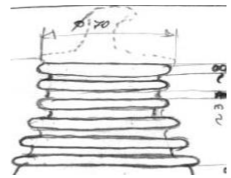
| Selection criteria | Concepts | | | | |
|---|---|---|---|---|---|
| | <br>**A**<br>**sphere mechanism** | <br>**B**<br>**accordion mechanism** | <br>**C**<br>**2 direction control mechanism** | <br>**D**<br>**One-spring mechanism** | <br>**E**<br>**Parallel movement mechanism** |
| provides an horizontal position | + | + | + | + | 0 |
| two direction movements | - | - | + | 0 | 0 |
| resistant to the weight and stress | + | + | + | + | 0 |
| good inclination | + | - | - | 0 | 0 |
| university can support (materials) | + | 0 | 0 | 0 | 0 |
| built by workshop machines | + | 0 | 0 | 0 | 0 |
| intuitive way to prove | + | + | + | + | 0 |
| correct attached to other components | 0 | 0 | 0 | 0 | 0 |
| permit an addition of components | 0 | 0 | 0 | 0 | 0 |
| Net score | 5 | 1 | 3 | 3 | |
| | | | | | |

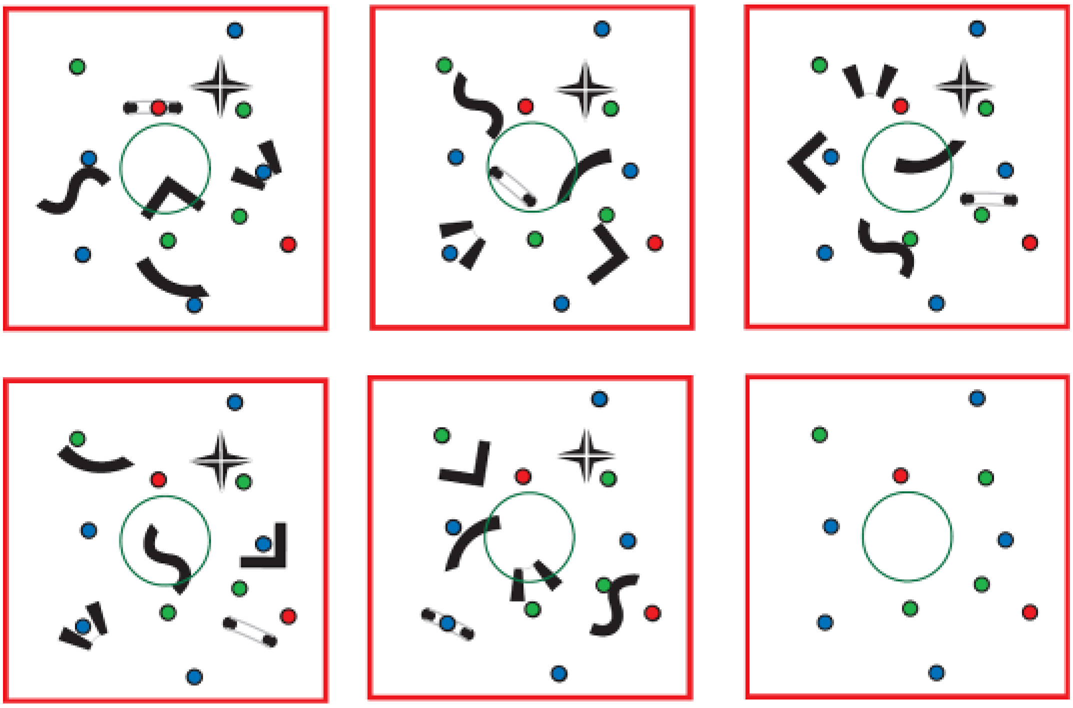
Table 3

| Selection criteria | Weight | A sphere mechanism | | B accordion mechanism | | C 2 direction control mechanism | | D One-spring mechanism | | E Parallel movement mechanism | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rating | Weight score | Rating | Weight score | Rating | Weight score | Rating | Weight score | Rating | Weight score |
| provides an horizontal position | 13,15 | 5 | 65,75 | 4 | 52,6 | 4 | 52,6 | 4 | 52,6 | 2 | 26,3 |
| two direction movements | 10,52 | 3 | 31,56 | 3 | 31,56 | 5 | 52,6 | 3 | 31,56 | 4 | 42,08 |
| resistant to the weight and stress | 13,15 | 3 | 39,45 | 3 | 39,45 | 4 | 52,6 | 4 | 52,6 | 3 | 39,45 |
| good inclination | 13,15 | 5 | 65,75 | 4 | 52,6 | 5 | 65,75 | 4 | 52,6 | 4 | 52,6 |
| university can support (materials) | 10,52 | 4 | 42,08 | 2 | 21,04 | 5 | 52,6 | 3 | 31,56 | 3 | 31,56 |
| built by workshop machines | 13,15 | 4 | 52,6 | 2 | 26,3 | 3 | 39,45 | 4 | 52,6 | 3 | 39,45 |
| intuitive way to prove | 7,89 | 5 | 39,45 | 4 | 31,6 | 3 | 23,67 | 3 | 23,67 | 3 | 23,67 |
| correct attached to other components | 10,52 | 5 | | 5 | | 5 | | 5 | | 5 | |
| permit an addition of components | 7,89 | 5 | | 5 | | 5 | | 5 | | 5 | |
| Net score | *99,94* | 339,64 | | 205,15 | | 339,27 | | 297,19 | | 255,11 | |
| Rank | | 1 | | 5 | | 2 | | 3 | | 4 | |

# Appendix 4. Pros and cons evaluation table

| **Concepts** / **Selection criteria** | **A Blue plunger**  | **B Ball-and-socket joint**  | **C Concave plate with screw**  |  **D Black plunger** |
|---|---|---|---|---|
| EASY TO ASSEMBLE AND CONSTRUCT | | | | |
| The construction of extra pieces lengthens the construction period | - | - | - | + |
| Easy to attach to the board | - | + | + | + |
| Easy to attach to the table support | + | - | - | + |
| Do not need extra pieces to adapt the movement | + | - | - | + |
| The mechanism does not limit the board thickness | + | + | - | + |
| Do I need help to construct the system? | + | - | + | + |
| PROVIDE GOOD MOVEMENT (resistant to weight & stress) | | | | |
| The mechanism has any problem to support the weight tested | - | + | + | + |
| Different parts stop the movement<br>- handles<br>- table support<br>- mechanism<br>- frame<br>- other accessory (spring) | -<br>The mechanism A needs to be stop by the handles, a frame or another accessory | -<br>The mechanism B itself the supports the slope but it is necessary to stop the turn | -<br>The mechanism C needs to be stop the turn by the handles, the frame, or other accessory | +<br>The mechanism D itself has a good slope and any turn when moving the heavy board on top. |
| It provides the two direction movement | + | - | - | + |
| It has a good inclination ( measurable) | - | + (20º) | + (12º) | + (~12º) |
| The board weight does not affect | - | + | + | - |
| An stable system can be easily reached in the support point | - | - | + | + |
| The weight of the handles permit a board zero position | - | + | - | + |
| Handles can be any shape and position | + | - | - | + |
| OTHER CONSIDERATIONS | | | | |
| Long live material mechanism | + | + | + | - |
| Need maintenance | + | - | - | + |
| Easy materials to buy for the pieces needed | + | + | - | + |
| Net score | 11 | 10 | 9 | 16 |

Appendix 5. Obstacle path sketches.



Appendix 6. Sensing distance vs. size and material of sensing of the E2A-M30LN30-WP-B1 2M sensor.