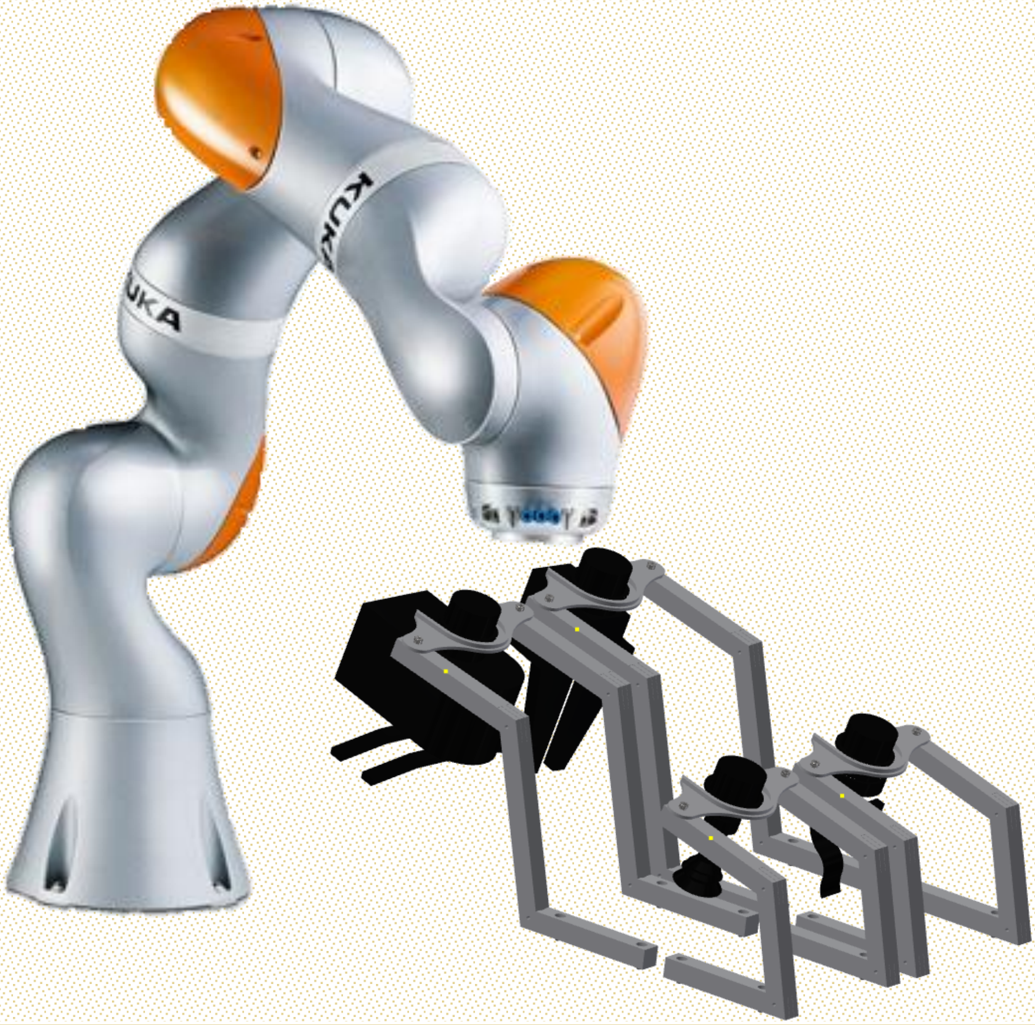

Mihail Babcinschi

Automatic Tool Changer on Collaborative Robots

Dissertação de Mestrado em Engenharia Mecânica
na Especialidade de Produção e Projeto

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Automatic Tool Changer on Collaborative Robots

Submitted in Partial Fulfilment of the Requirements for the Degree of Master in Mechanical Engineering in the speciality of Production and Project

Troca de Ferramentas Automática nos Robôs Colaborativos

Author
Mihail Babcinschi

Advisor
Professor Pedro Mariano Simões Neto

Jury

President	**Professor Doutor José Luís Ferreira Afonso** **Professor Auxiliar da Universidade de Coimbra**
Vowel[s]	**Professor Doutor Paulo Joaquim Antunes Vaz** **Professor Adjunto do Instituto Politécnico de Viseu**
Advisor	**Professor Doutor Pedro Mariano Simões Neto** **Professor Auxiliar da Universidade de Coimbra**

Coimbra, July, 2018

“The major value in life is not what you get. The major value in life is what you become”

Jim Rohn

Aos meus pais

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A great man once said, that what a person becomes is determined by the people around us and the experiences that we gather with them. Some of those people influence our lives consciously and other not, but ultimately all of them affect us in some way. By reaching this stage on my life and looking back in retrospective I can see the faces of so many extraordinary people to whom I owe a lot of appreciation.

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To my family and friends, for always being present over the years and for their constant support. I am honoured to have you in my life and a big thank you for helping me growing as a person every day.

And lastly, but I believe the most important one, to my parents. It is certain to say that without them I would not be here, and I am not sure if I will ever be able to thank them enough for their effort and dedication. Thank you.

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Abstract

Over the last few decades robots have been adding increasing value on the industry, with special focus on the robotic arms, allowing the implementation of a large number of repetitive tasks, with good reliability and speed.

Considering the vast spectrum of robots, this project focusses mainly on the collaborative robots, whose goal is to close the gap that exists between humans and robots, allowing them to work on a more interactive environment.

Depending on the desired goal, a robotic arm can execute one or more tasks for a specific job. In case the robot is performing only one task, it is possible to finish the job with only one tool, however, if the same robot is performing various tasks for the same job, there will be necessary to have a system that allows the tool changing before each new task.

This project consists on building an automatically tool changer for collaborative robots and it will be divided in two parts: The Tool Holder and the Automatic Tool Changer (ATC). The Tool Holder is a structure which will be positioned on robot's work table, and it is the place where all the tools will be placed. As for the ATC, it represents the mechanism which will allow to attach the tools to the robot.

Keywords Collaborative Robot, ATC, Tool Holder, Tools, Automatic.

Resumo

Ao longo das últimas décadas os robôs têm vindo a acrescentar cada vez mais valor na indústria, com especial destaque para os braços robóticos. Permitindo a realização de uma vasta gama de tarefas repetitivas, com grande rapidez e fiabilidade.

Dentro do grande espectro de robôs, este projeto encontra-se inclinado para os robôs colaborativos, cujo principal objetivo é aproximar o homem do robô de forma a que os dois trabalhem em conjunto de uma forma mais interativa.

Dependendo do objetivo pretendido, um braço robótico pode realizar uma ou várias tarefas para um determinado trabalho. Caso o robô esteja a efetuar só uma tarefa, é possível realizar a sua função apenas com uma ferramenta, no entanto, se o mesmo robô estiver a realizar diversas tarefas, será necessário trocar as ferramentas utilizadas por este cada vez que começar uma tarefa nova.

Este projeto consiste na construção de um sistema automático de troca de ferramentas nos robôs colaborativos, e será dividido em duas partes: O Suporte das Ferramentas e o *Automatic Tool Changer* (ATC). O Suporte de Ferramentas é uma estrutura que será colocada na mesa de trabalho do robô. Quanto ao ATC, este consiste no mecanismo que irá permitir acoplar as ferramentas ao robô.

Palavras-chave: Robô Colaborativo, ATC, Suporte, Ferramentas, Automático.

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ACRONYMS

3D- Three-Dimensional
CNC- Computer Numerical Control
ATC- Automatic Tool Changer
MTC- Manual Tool Changer
PLA- PolyLactic Acid

1. INTRODUCTION

Having a machine that could substitute the man on the work is not a new idea, it comes as far as ancient Greece when Aristotle speculated that in the future the man will build an Automata that will be able to help on our day-to-day jobs. Being troubled with the issues of Greece at that time, he also predicted that this Automata could abolish slavery and bring human equality. Fortunately, in the world in which we live slavery does not exist anymore like in Aristotle's time, but his speculation became a reality anyway and it changed the life of people for the better. Robotics allowed us to produce much more than we were able without it bringing to our lives abundance. In short, it allowed us to produce more and faster associating all of this with quality products.

One of the things that is happening already that robotics is contributing, and it is believed that will grow even more in the future, is the fact that robotics is taking action on more monotonous tasks and give much more opportunity and time for people to focus on the more exciting and fulfilling subjects. Because of that, there is this tendency to bring much closer the robots to humans, where the robots will do the most mechanical and monotonous jobs and the human will take care of the creative part.

The first robotic arm with a practical application was used in factory environment in 1961 (Figure 1). It was developed by George Devol and was used on an assembly line for General Motors. In the beginning the main task of this robot was to grab an object and move it from one point to another, but noticing that there was much more potential, factories started to implement them on more complexed assignments, such as welding.

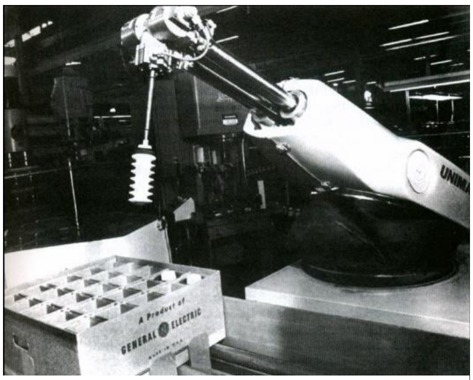


Figure 1- *Unimate*, first industrial robot

Normally, these robots have a defined work space and humans cannot enter there while they are in operation.

An evolution of the previous robots are Collaborative Robots, which allows us to enter on their work space and be more interactive with them and consequently improve productivity.

1.1. Problem and Motivation

On a production environment a product usually suffers many interventions, and that means that for each intervention, this is, for each operation on the product there should be a robot that would do a specific task. While for some cases we should have only one robot doing a single task in other cases it would be economically more viable to have a robot doing different tasks, and usually when changing the task it would be needed to change the tool that the robot is using.

Collaborative Robotics focuses mainly on a closer interaction between the human and the robot, where the robot would be a helper for the human. On this interaction, the human would "ask" the robot to perform a specific task and the robot will perform that task, and on a short moment the human will "ask" the robot to do another task and it will perform that other task. For a robot to be versatile and perform a wide range of assignments it would be needed to have the option to choose a different tool for each task to perform.

The most common tool change systems are applied to Computer Numerically Controlled machines (CNC) [1], and the goal is to bring a little bit of that reality to the collaborative robotics. The objective is to have at the robot disposition a set of tools.

1.2. Proposed Approach

The adopted approach to solve the problem above consists in two parts. The first is the design and production of a tool holder that will be installed on the work table near the robot, where all the tools will be located. The second, consists on applying a tool changer device, which will allow the robot to grab the desired tool.

For the tool holder it will be build a flexible tool support, this is, for the tool holder to not take too much space on the work table. It will be composed by independent cells, where for each cell there will be only one tool. For example, if we are doing a job were only 3 tools are needed for the robot, then it will be installed on the work table only 3 cells to hold the tools for the job. This will optimize the space used by the tools on the work table, making it a more practical and cleaner.

As to what matters for the second part, it will be implemented an automatic tool changer device. The automatic tool changer consists of two pieces, a Master-Side that is attached to the robot, and a Tool-side that is attached to the tool. In order to grab a tool, the robot will fit the Master-side with the Tool-side, and as a result the desired tool is grabbed.

1.3. Thesis Overview

This dissertation is composed of six chapters, starting on chapter one with the first ideas about the implementation of the ATC until its final implementation and installation on the collaborative robot's work table.

The first and second chapter are the introduction and the state of art. On introduction there is a short introduction about the collaborative robot's world, and its stated the problem and motivation of this work. On state of art is possible to encounter a range of the existing mechanism on tool changers that are applicable on robotic arms.

On chapter number three and number four, are described the construction and implementation of the ATC and the Tool Holder, respectively.

Finally, the chapter number six, represents the conclusion of this project.

2. STATE OF THE ART

2.1. Tool Changing Mechanisms

Nowadays robots are becoming more and more integrated on our productive systems and the massive growth that we are witnessing in this area is creating a need to develop and improve the things (tools, sensors, etc.) connected to them.

Collaborative robots make robotics even more versatile than it was previous to their existence. What differentiates these types of robots from the others is that they have a closer interaction with the operators on the workspace that they share [2], making all the operations more dynamic.

The number of tasks a robot can perform is directly influenced by the number of tools it has at disposal and is a key point to the versatility of the robot. Therefore, since few decades ago there were conducted investigations in tool changing mechanisms.

Robotic tool changers allow the exchange of end effectors during assembly or manufactory processes [3]. There are some robotic accessory manufacturers that offer a range of different types of tool changers, and they can be generally grouped into mechanical changers (MTC) and automatic changers (ATC).

As a robot is performing a task it is important to take in consideration the tool change frequency. If the changing frequency varies between, occasional to a few changes a day, then it is possible to use only MTC’s. But, when it increases beyond a certain limit, it becomes impractical to do it manually so in these cases is recommended to find a way and use ATC’s.

In addition to the locking mechanism that is inherent to tool changers there is also attached to them some useful utilities for power and signal transmission, Figure 2, where tool changers can be equipped with 8 to 50 electronic pins and several connectors. Some of the most common elements that is possible to transmit through these connectors and pins are: Gas, Liquid, Vacuum, Electric Power and Electrical Data Exchange [4]. All this helps to establish a “communication” between the tool and the robot, where the tool changer device works as an intermediary.

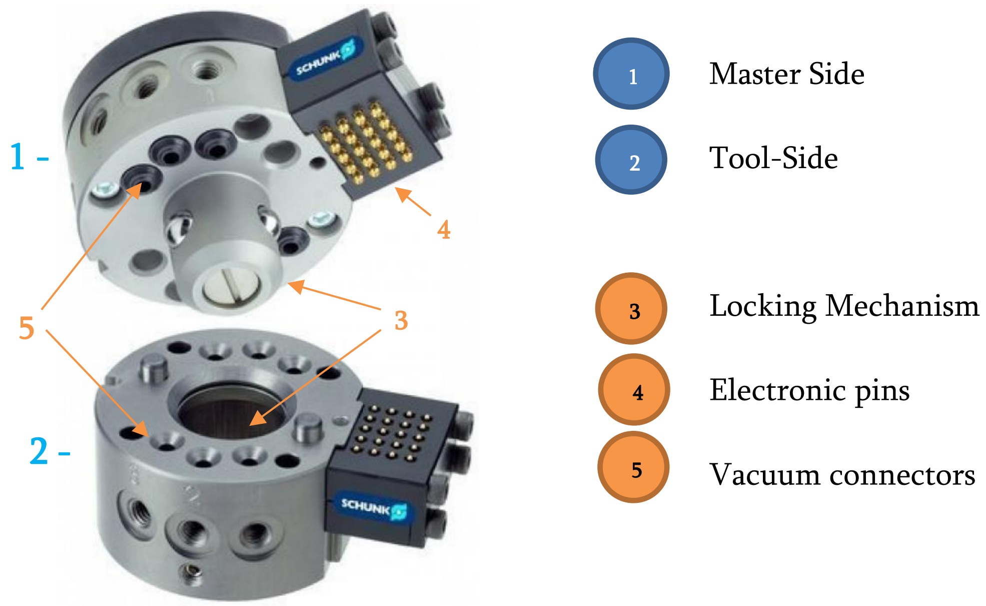


Figure 2- Tool Changer connectors

On Table1 are shown some of the market leading manufacturers on tool changers with small payloads.

Table 1- Examlples of Tool Changers

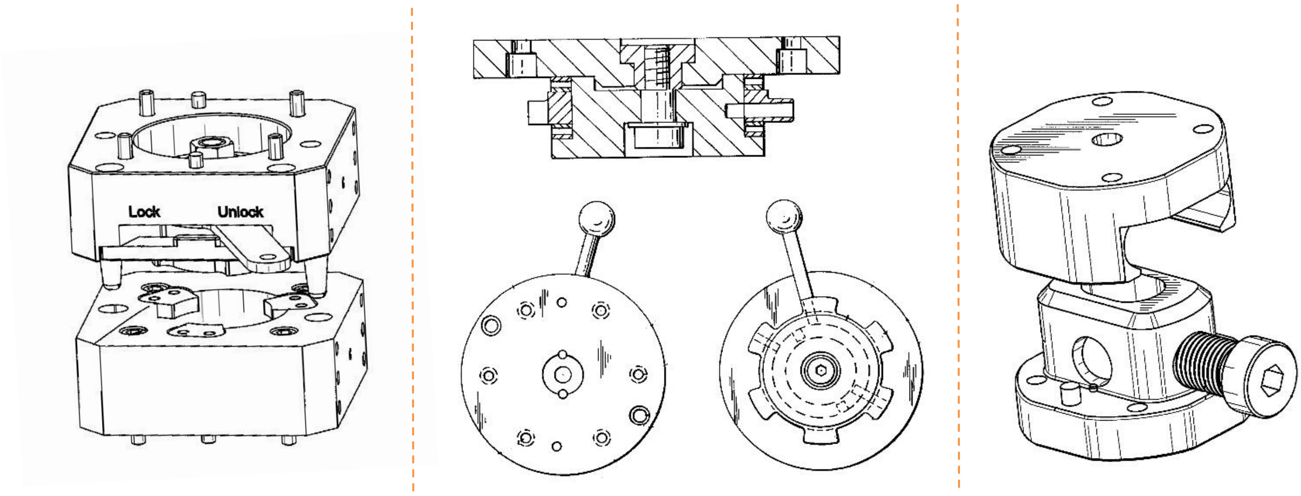
Model	Actuation	Clamping Principle	Payload (Kg)	Weight (Kg)	Diameter (mm)
Schunk SHS-040	Manual	Semi-cyl. Sh.	9	0.14	50
Schunk SWS-005	Pneumatic	Taper & balls	8	0.37	49
ATI MC-10	Manual	Taper & balls	10	0.26	50
ATI QC-5	Pneumatic	Taper & balls	8.2	0.36	49
ATI QC-11	Pneumatic	Taper & balls	16	0.245	49
RAD TC-11	Pneumatic	Taper & balls	16	0.21	50

2.1.1. Manual Tool Changers

MTC's are very useful when there is not available air pressure on the robot to enable the locking mechanism or when the tools are not changed with relatively big frequency.

The basic composition of a manual tool changer on robotic arms consists of a Master-side and a Tool-side. The first one is permanently affixed to the robotic arm, and the second one to the tool [5]. As the name indicates, the mating of the Master-side to the Tool-side is made manually by the operator.

There are a few models of MTC's each with some variations specially to what concerns to the locking mechanism. One of the models developed by ATI Industrial Automation Inc, is a tool changer with a rotating piston [6], where the mating of each side is made by a lever that is moved from an unlocked position to a locked one (Figure 3(a)). By moving the lever from one position to another it actuates a piston that rotates and consequently locks both sides of the tool changer. Other important models are the tool changer with rotatable sprocket (Figure 3 (b)), where the tool changer is locked through a series of teeth [7], and also the tool changer with rolling members (Figure 1(c)), where the locking operation is made by screwing a bolt [8].



(a) (b) (c)

Figure 3- Manual Tool Changers Mechanisms; (a) Tool Changer with Rotating Piston; (b) Tool Changer with Rotatable Sprocket; (c) Tool Changer with Rolling Members

The SHS-40 model developed by Schunk (Table1), is a manual tool changer with integrated air feed (Figure 4). Is used on flexible production environments were the locking mechanism is actuated by a lever, which can be pushed forward or pulled backwords, to respectively lock or unlock the tool changer [9]. Is a simple, quick and effective mechanism which can be the solution for many robots that do not have air pressure connected to them.

Figure 4- Schunk SHS-040 model

2.1.2. Automatic Tool Changers

ATC’s have mainly the same composition as an MTC, apart from the point that the mating of the two halves of the tool changer is made automatically by the robot.

Robotic ATC’s are generally divided into two classes: active and passive [9]. An active system functions with electrical or pneumatic actuators to establish the connection between the two halves of the tool changer. An example of this type of system is shown in U.S Pat. No.11374706, (Figure 5), developed by Michael L. Gloden et al., and entitled as “Robotic Tool Changer” [10].

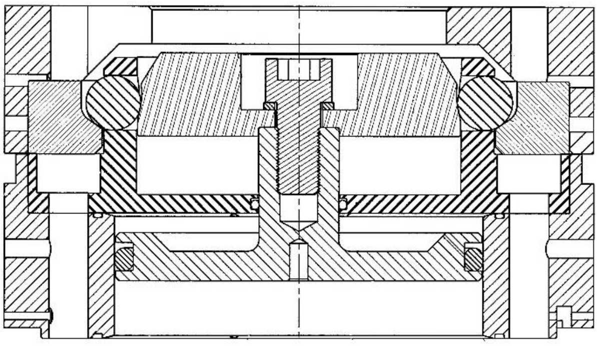


Figure 5 - Robotic ATC, U.S Pat. No.11374706

A passive system, on the other hand, uses the wrist motion of the robot to make the connection, and is possible to find an example of this type of mechanism in U.S Pat. No.06516972, (Figure 6), developed by D. M. Hennekes et al., and entitled as “Robot Toolchanger System” [11].

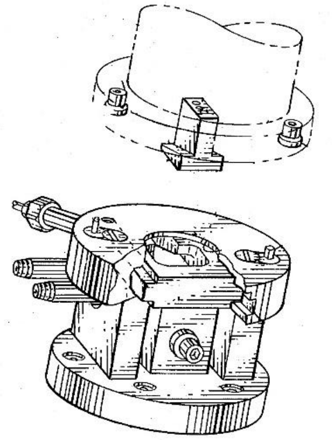


Figure 6- Robotic ATC U.S Pat. No.06516972

While for the most of ATC's the locking mechanism is made exclusively by pneumatic pistons, there are other physical methods available like: "Robot Pressed" and "Spring Retained Clamping Mechanism" which falls in the passive class. "Electro-Mechanical Pistons" and "Magnetic and Electro-Magnetic Actuator" are classified as active [12].

The ATC QC-11 model (Figure 7), developed by ATI Industrial Automation (Table 1) combines the lightweight with high strength locking mechanism. It is pneumatically actuated which makes it a good solution for environments were the frequency of tool change is high.

Figure 7- ATC QC-11, developed by ATI Industrial Automation

3. ROBOTIC AUTOMATIC TOOL CHANGER

The tool changing system was implemented on KUKA's Collaborative Robot LBR iiwa (Figure 8).

Figure 8- KUKA Collaborative Robot LBR iiwa

The selected tool changer mechanism was the QC-11 model from ATI Industrial Automation (Figure 9), which is classified as an active ATC and is pneumatically actuated.

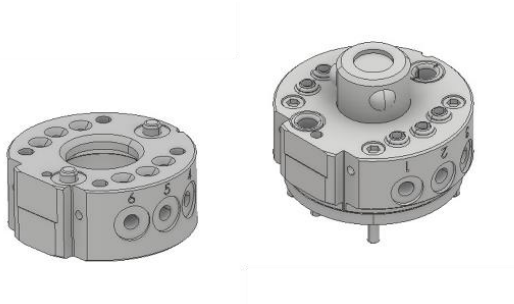


Figure 9- CAD drawing ATI QC-11

The ATI QC-11 is used for low payloads applications, and usually is made from steel. The challenge taken in this project, was trying to manufacture the tool changer in polymeric material using a 3-D Printer and see if it could handle the applied load and ability to retain pressurized air. If this would be found to be successful, it will have a big financial impact on the project, considering that producing the tool changer on polymeric material implies a much lower cost.

3.1. 3-D Printer

The 3-D printer used in this project was the Vertex K8400 from Valleman Company, Figure 10, which has a maximum build volume of 180 x 200 x 190 [mm].

Figure 10- Vertex K8400 3-D printer

The polymer used was a 1.75 mm PLA filament (Figure 11), which, when passes through the printer's extruder is transformed into an 0.35mm filament. The printing speed varies between 30 mm/s and 120 mm/s and the maximum operating temperature is 270 ºC. Although 270ºC is the maximum temperature, for PLA is recommended to print at 210 ºC [13].

Figure 11- PLA filament

In order to have a good printing quality there were considered some recommendations [14], such as covering the printing surface with painter's tape to ensure a good printing adhesion.

3.2. Construction Parameters

The parameters utilized on the 3-D Pinter, such as printing velocity, infill, etc., are decisive on the final quality of the printed parts. Therefore, they deserve some attention. The software used for the 3-D Printing was Vertex 3D Printer Repetier-Host, and on the Table 2 is possible to see the parameters used on the 3-D printer.

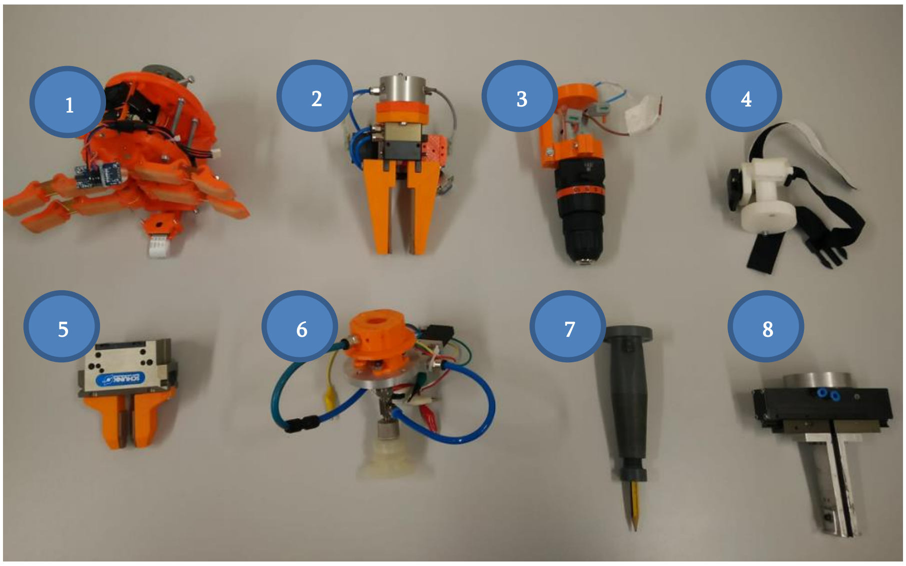
Table 2- Printing parameters used on 3-D printer Vertex K8400

Support		Everywhere
Adhesion Type		Brim
Quality [mm]		0.1
Speed [mm/s]	Print	45
	Outer Perimeter	43
	Infill	55
Infill Density [%]	Pressurized Parts	50
	Non- Pressurized Parts	30

3.3. 3-D Printed Parts

On this chapter the 3-D printed parts belong exclusively to the ATC, including also the structural parts that allow the attachment of the ATC to the tools.

The goal is to implement the ATC to a set of tools, Figure 12. In order to do that, it will be needed to print the ATC (Tool-Side) for each of the presented tools, and also find a way to attach the ATC to the respective tool. On this project was only printed the Tool-side because it has a much simpler structure, and also because independently of the number of tools utilised by the robot, its only needed one piece of the Master-Side, while for the Tool-Side, every tool needs to have it. For the Master-Side was utilised the original Tool Changer QC-11 from ATI Industrial Automation.



1 - Robot Grasping Tool
2 - Gripper nº1
3 - Drill
4 - Flexible Tool
5 - Gripper nº2 (Schunk)
6 - Vacuum Tool
7 - Writing Tool
8 - Gripper nº3 (Zaytran)

Figure 12- List of tools to implement the ATC mechanism

The printing time and the amount of PLA necessary is directly influenced by the volume and internal density of each part. All the components that link the ATC to the tool, are non-pressurized parts, and they will be mostly solicited at compression, therefore, the internal density selected for them was 30% (Figure 13). As for the ATC part, in some cases is required to establish the connection of pressurized air between the robot and the tool, because of that the selected internal density was 50%.

(a) (b) (c)

Figure 13- 3D Printed Parts: (a) Circular fitting part; (b) Tool-ATC connector; (c) ATC Tool-Side

The orientation of the printed parts was also an important factor that was taken under consideration. It was always tried to use the least amount of support structures and try to print the parts on the most natural way possible. As more structures for support we use, worst is the final quality of the parts.

Lastly, the vacuum connectors of the ATC (Tool-Side) were not completely impermeable to pressurised air. To solve that problem, the ATC was covered with a layer of urethane rubber [15] (Figure 13 (c)).

On ANEX A are represented the 3-D parts utilised to attach the ATC to the tools.

4. TOOL HOLDER

In order to have the tools near the robot its needed to build a tool holder. There are many types that could be designed, but the key points taken in consideration were that it should be easy to install on the robot's work table, easy to manufacture and have a low cost.

The design of the tool holder prototype was started having in mind the premises mentioned above and for simulation was utilised a CAD software (Autodesk Inventor).

Before finding which was the best version of the tool holder to be installed on the robot's work table a few design iterations have been made, that is, there were created a few different models and each time was tried to improve some aspect of the previous one.

4.1. First Model

The first model created, which can be visualised on, Figure 14, had two rows were the tools could be placed. In order to make the tool holder more compact and not taking too much linear space, the rows were built one in front of the other. Concerning the position were the tools are placed, it has a slight inclination toward the robot in order to make a little bit easier for it to reach and grab the desired tool. And lastly, the tool fit is made in a rectangular shape and has a cross like alignment.

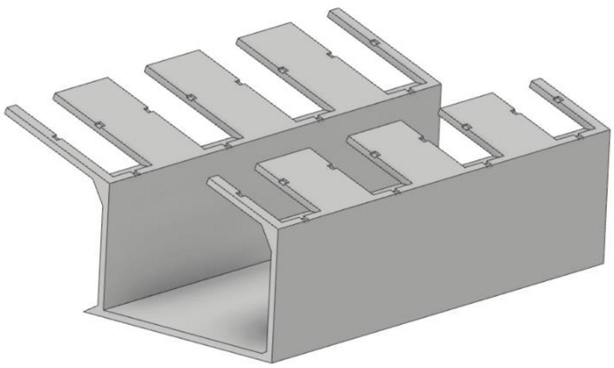


Figure 14- Tool Holder First Model

4.2. Second Model

After the completion of the first model it was intended to find some points that could be improved. The second model, Figure 15, has a round shape tool fit. That type of shape makes the tool placement much more reliable than the cross fit shape because it has a wider fitting surface. Therefore, it is easier for the robot to place a tool after finishing the job.

The second alteration made was the structure’s shape. It was made a bit curvier, and the reasons to that change is that for one side it improves the aesthetics of the tool holder and for the other it makes more space between the first row and the second row without changing the overall size of the tool holder. So, we have an improvement on space efficiency.

For last, and this taking in consideration the economic part, it was reduced the amount of used material for the building of the tool holder by making a grid type structure.

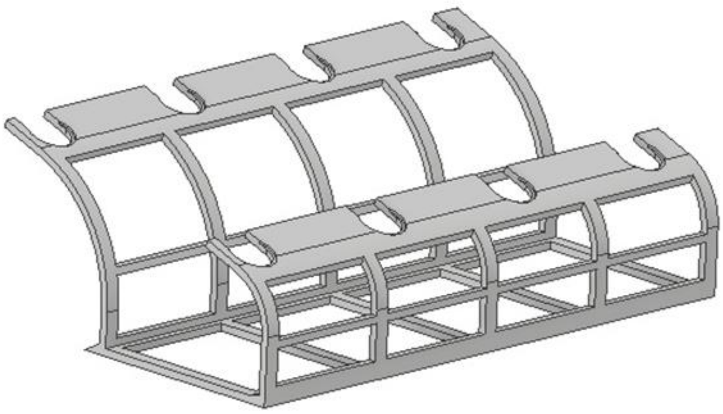


Figure 15- Tool Holder Second Model

4.3. Third Model

There have been other models made in between, but to make it more succinct, on this work are placed only the most meaningful changes that have been made on the tool holders. So, for the last prototype, Figure 16, surged the issue that a collaborative robot usually has different assignments along the time. By having different assignments, it means that for some type of work the robot may use a set number of tools and for a different one it may use a different number of tools. Because there is constantly present this variability, it was thought to build a tool holder divided in cells. That is, to build the tool holder in order that each cell holds only one tool, therefore, to create the cells independent from each other. In this way, there could be placed on the work table only the number of tools needed for the robot's present assignment. This change will have a big impact on the efficiency of the used space on the work table.

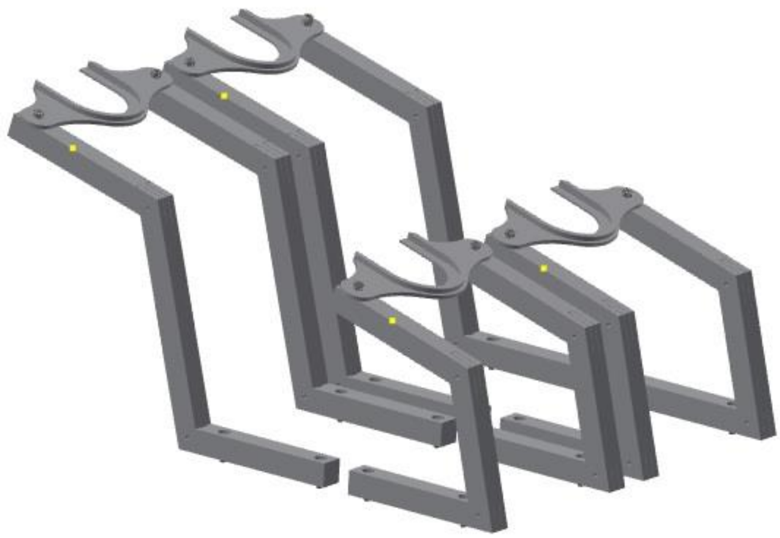


Figure 16- Tool Holder Final Result

4.4. Application

One of the best characteristics of this tool holder is its individual cells, which can be installed on the work table on the number that is needed.

Since the robot's work table is made of Rexroth Bosch profile, the installation of the tool holder is easily made by using a set of M5 bolts, Figure 17.

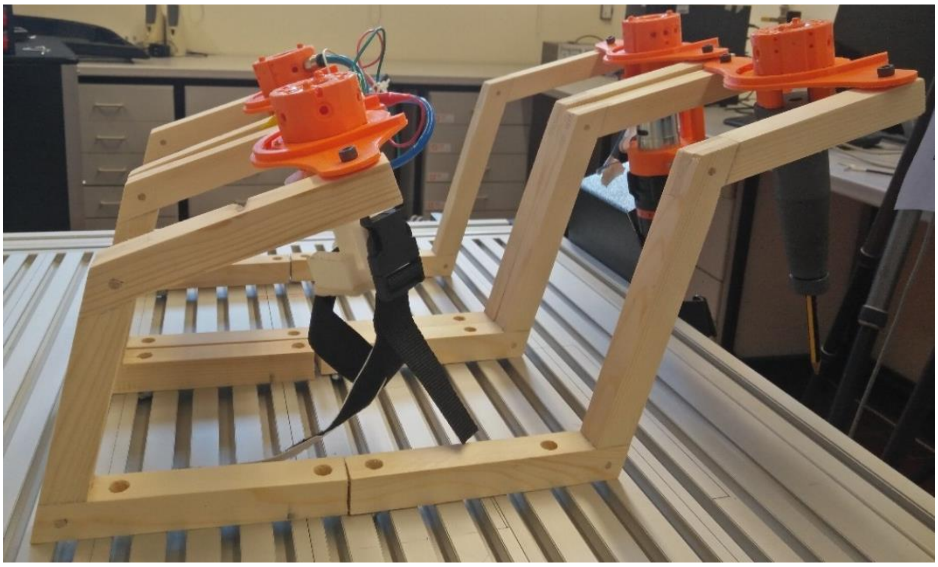
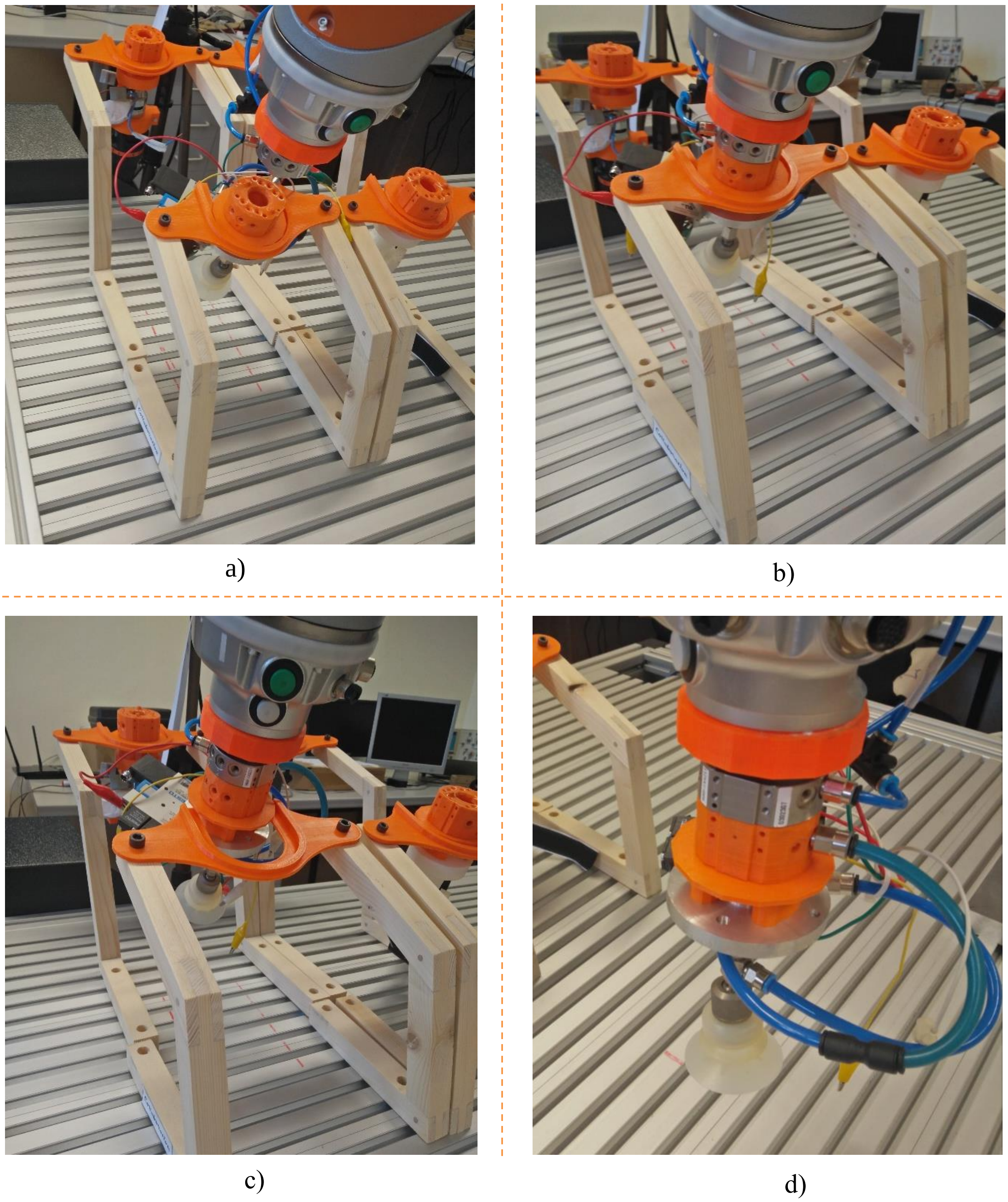


Figure 17- Tool Holder, Real model.

On Figure 18 is shown a sequence of steps made by the robot in order to grab a tool. First the robot receives an order to grab the tool and will make the path in direction to the desired tool, Figure 18 a). After receiving the order and having reached the position where the tool is located, it makes the connection between both sides of the ATC, which is actuated pneumatically, Figure 18 b). Having the tool attached to the robot, the next move consists on taking the tool out of the tool holder, which is made initially by sliding the tool diagonally and after that upward, Figure 18 c). Finally, after having the tool connected to the robot and out of the space of the tool holder, the robot can use the tool to accomplish the desired task, 18 d).

On ANEX B is possible to see the CAD files which led to the construction of the Tool Holder.



a) b) c) d)

Figure 18- Sequence of tool grabbing; a) The Robotic arm moves toward the tool; b) The connection between both sides of the ATC; c) Path made by the robot in order to take the tool out of the tool holder; d) The tool is ready for the task

5. CONCLUSIONS

The present dissertation consists on the implementation and production of a low-cost tool changing mechanism on collaborative robots.

Having a single robot which can utilise a variety of tools and being able to change them quickly between tasks, has a great influence on the productive systems, versatility, cost, modularity and space efficiency.

Some of the issues encountered during the development of this project were related with the production of the ATC's. One of the main problems, for example, was related to the ATC, which was losing pressure on the pressure connectors. A probable cause was the existence of some minimal free spaces between the printing filaments, which is normal since it was used 3-D printing to produce the ATC's. To solve this problem, it was applied a layer of urethane rubber which worked perfectly.

Another issue which occurred was more a structural one. It was related to the attachment of the ATC to the tool, were the parts which made the connection between the ATC and the tool was under too much stress and in some cases it broke. This problem was solved by using longer bolts and install them in a way to make them support all the stress instead of the printed parts. Anyhow, the occurred problems were not something which was unexpected.

In conclusion, the applied tool changing system works very well when considering small payloads. It is able to firmly connect both sides of the ATC and to establish a good vacuum connection without the loss of pressure.

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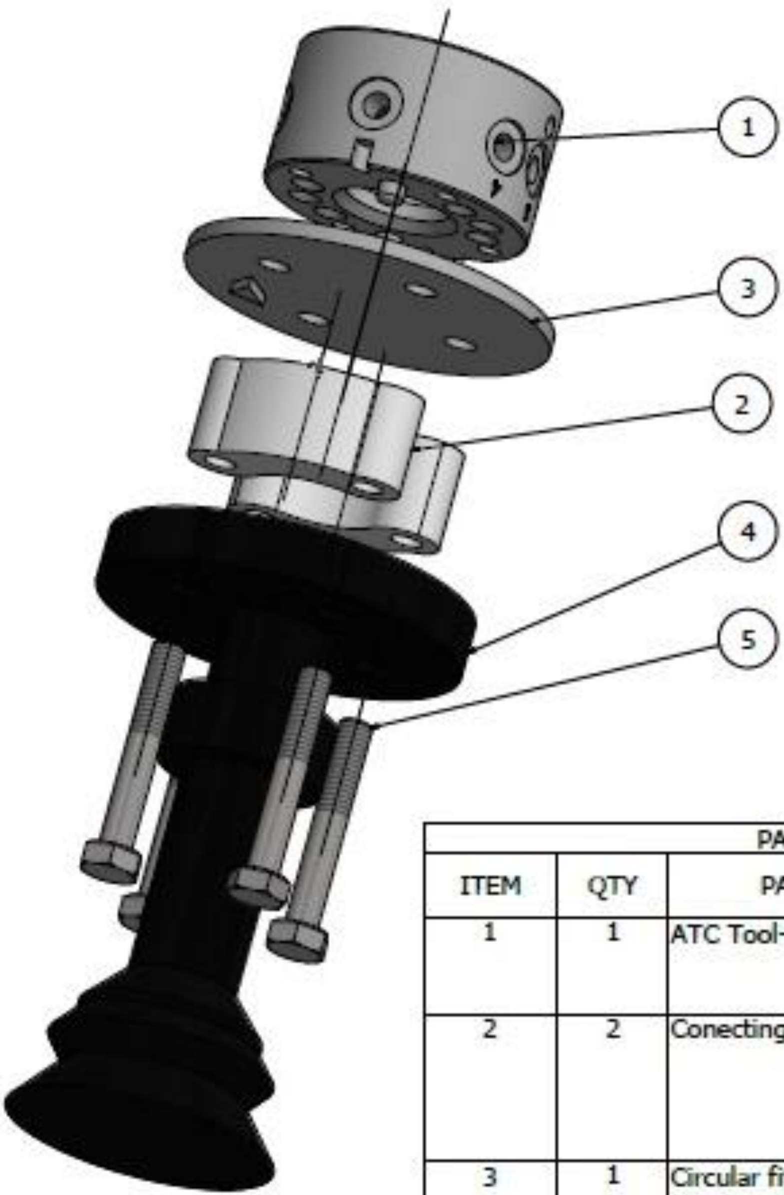
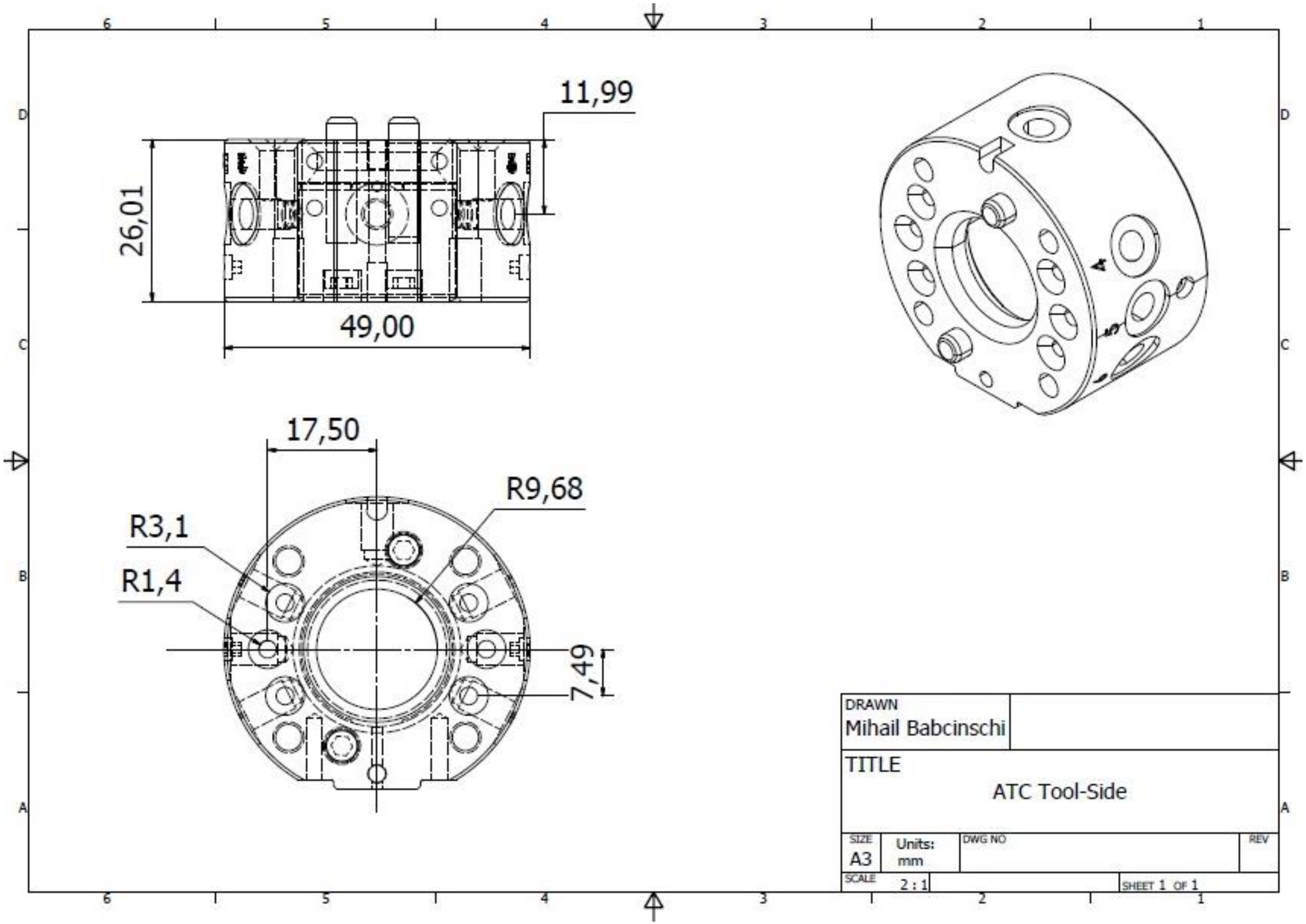
ANNEX A (ATC CAD FILES)



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	ATC Tool-Side
2	2	Conecting part
3	1	Circular fitting part
4	1	Vacuum Tool
5	4	AS 1111 - M6 x 40 (Bolt)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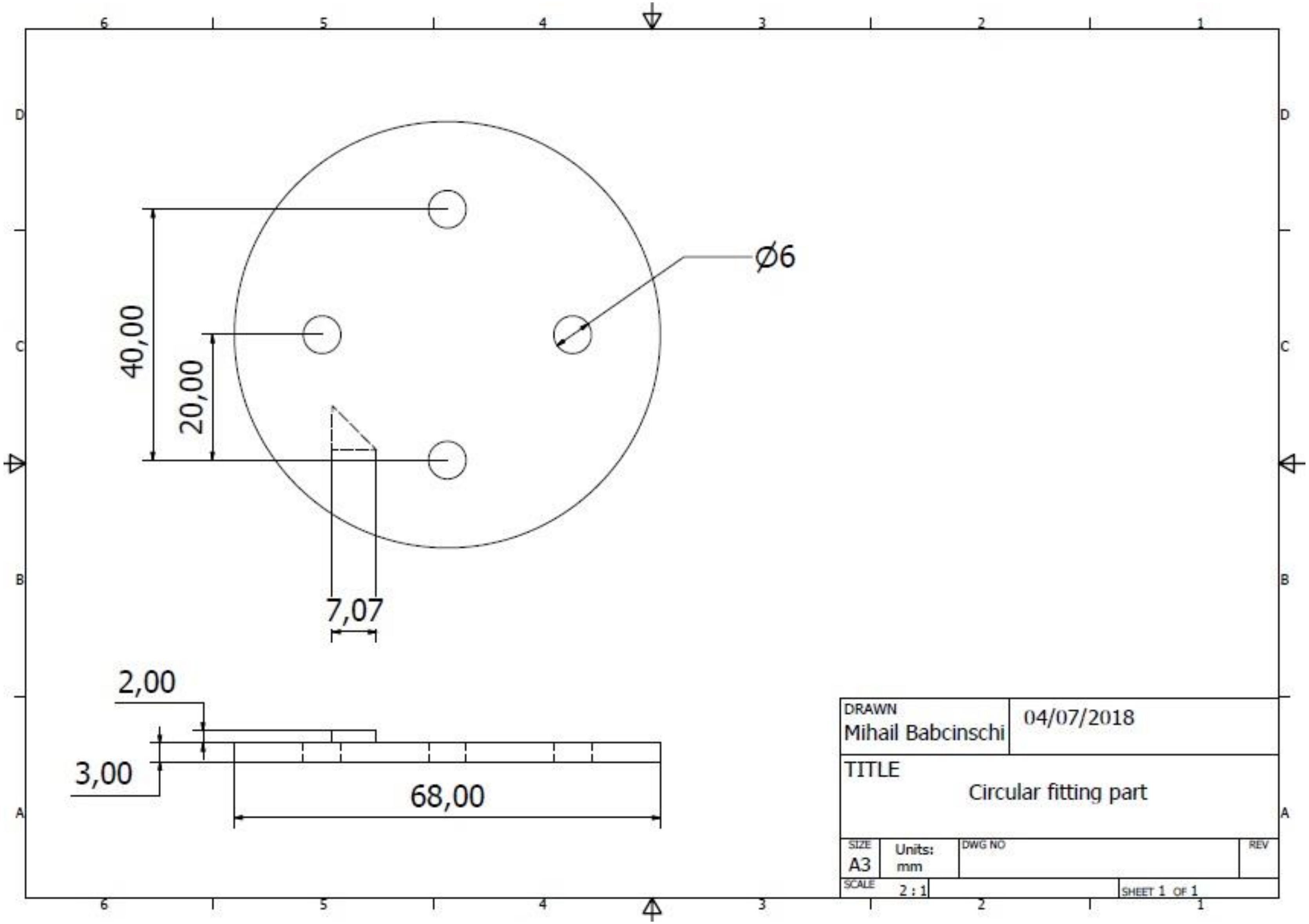
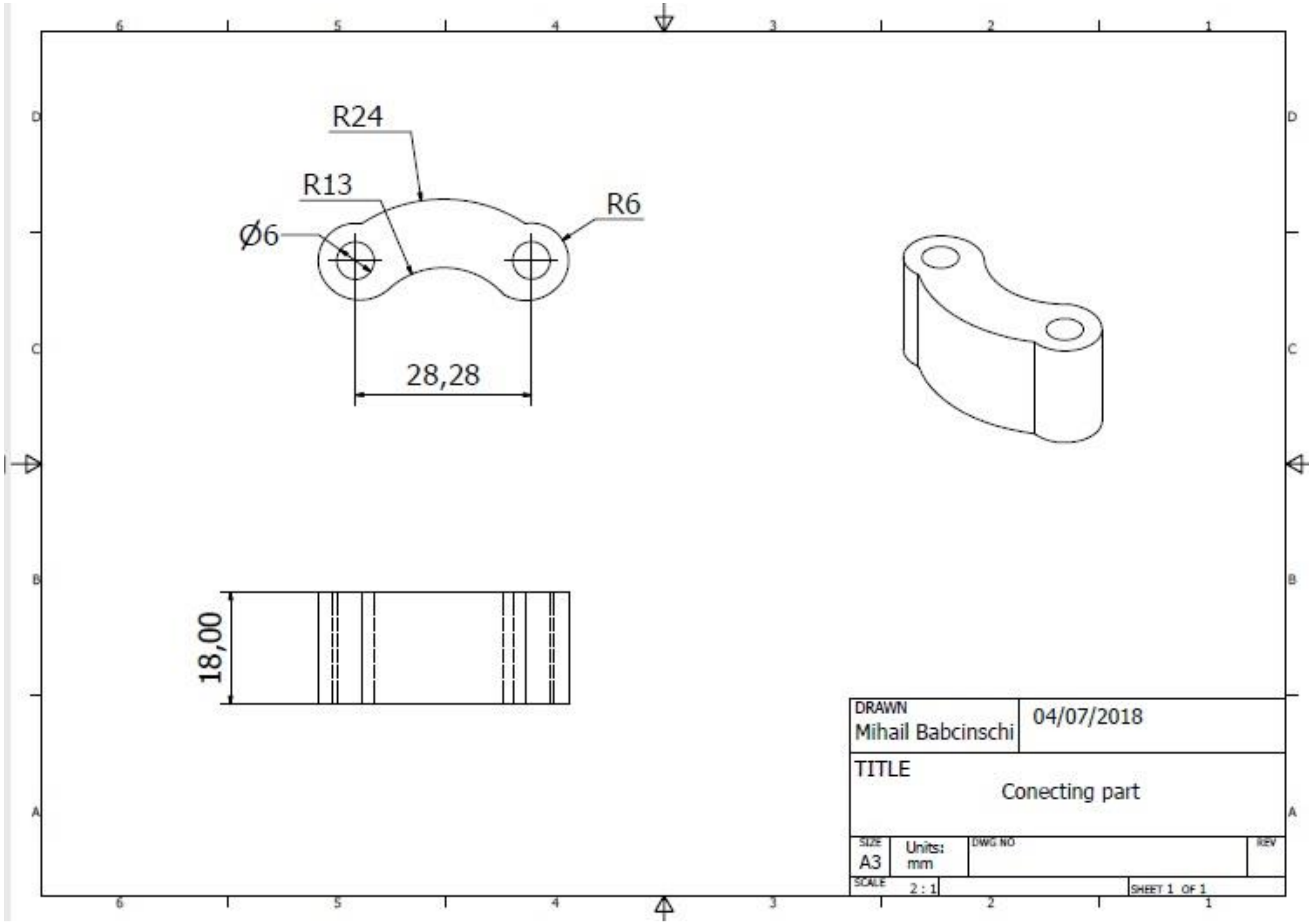
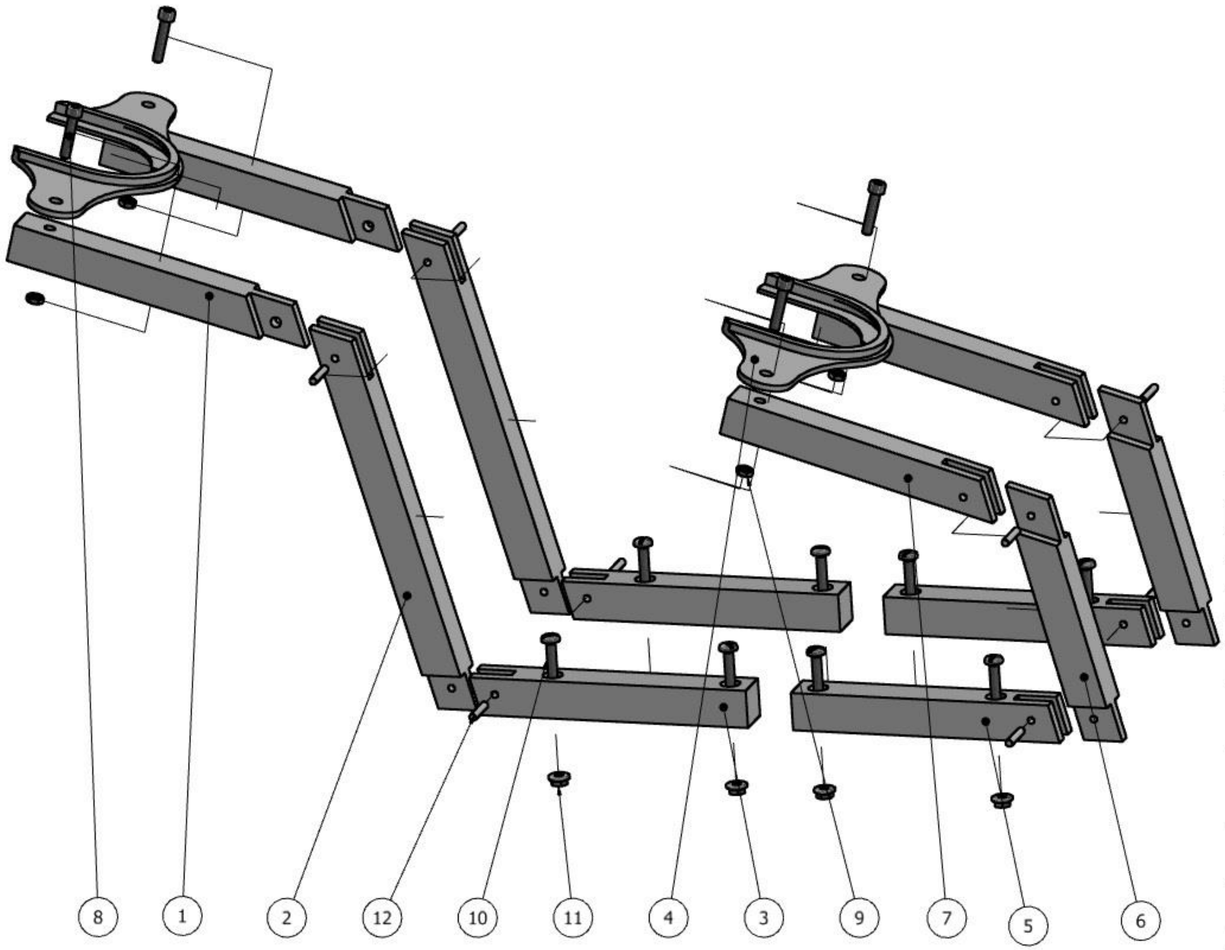
26,01
49,00
17,50
R9,68
R3,1
R1,4
7,49
DRAWN
Mihail Babcinschi
TITLE
ATC Tool-Side
SIZE
A3
Units:
mm
DWG NO
REV
SCALE
2 : 1
SHEET 1 OF 1

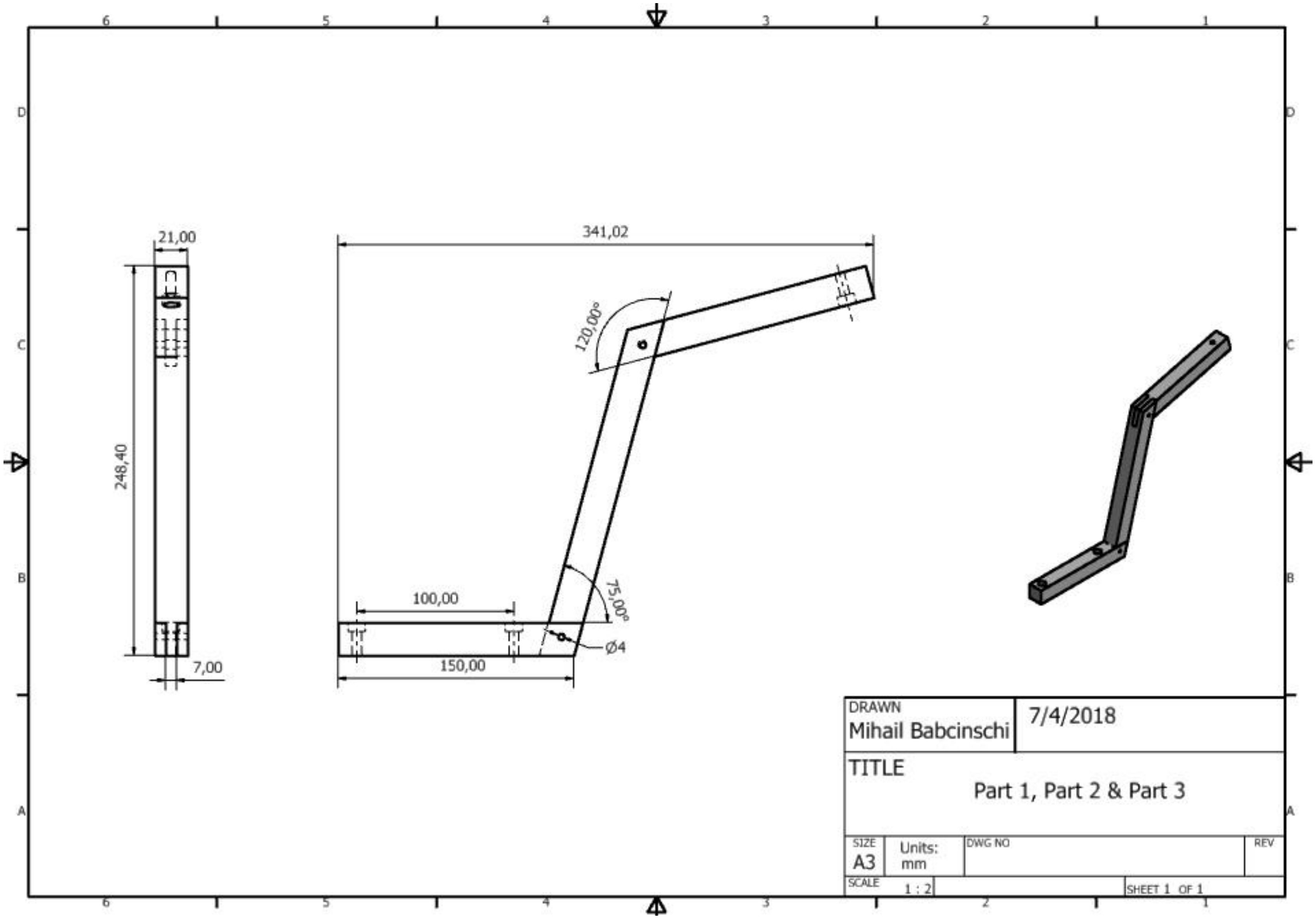

6
5
4
3
2
1
D
C
B
A
40,00
20,00
Ø6
7,07
2,00
3,00
68,00
DRAWN
Mihail Babcinschi
04/07/2018
TITLE
Circular fitting part
SIZE
A3
Units:
mm
DWG NO
REV
SCALE
2 : 1
SHEET 1 OF 1


R24
R13
Ø6
R6
28,28
18,00
DRAWN
Mihail Babcinschi
04/07/2018
TITLE
Conecting part
SIZE
A3
Units:
mm
DWG NO
REV
SCALE
2 : 1
SHEET 1 OF 1

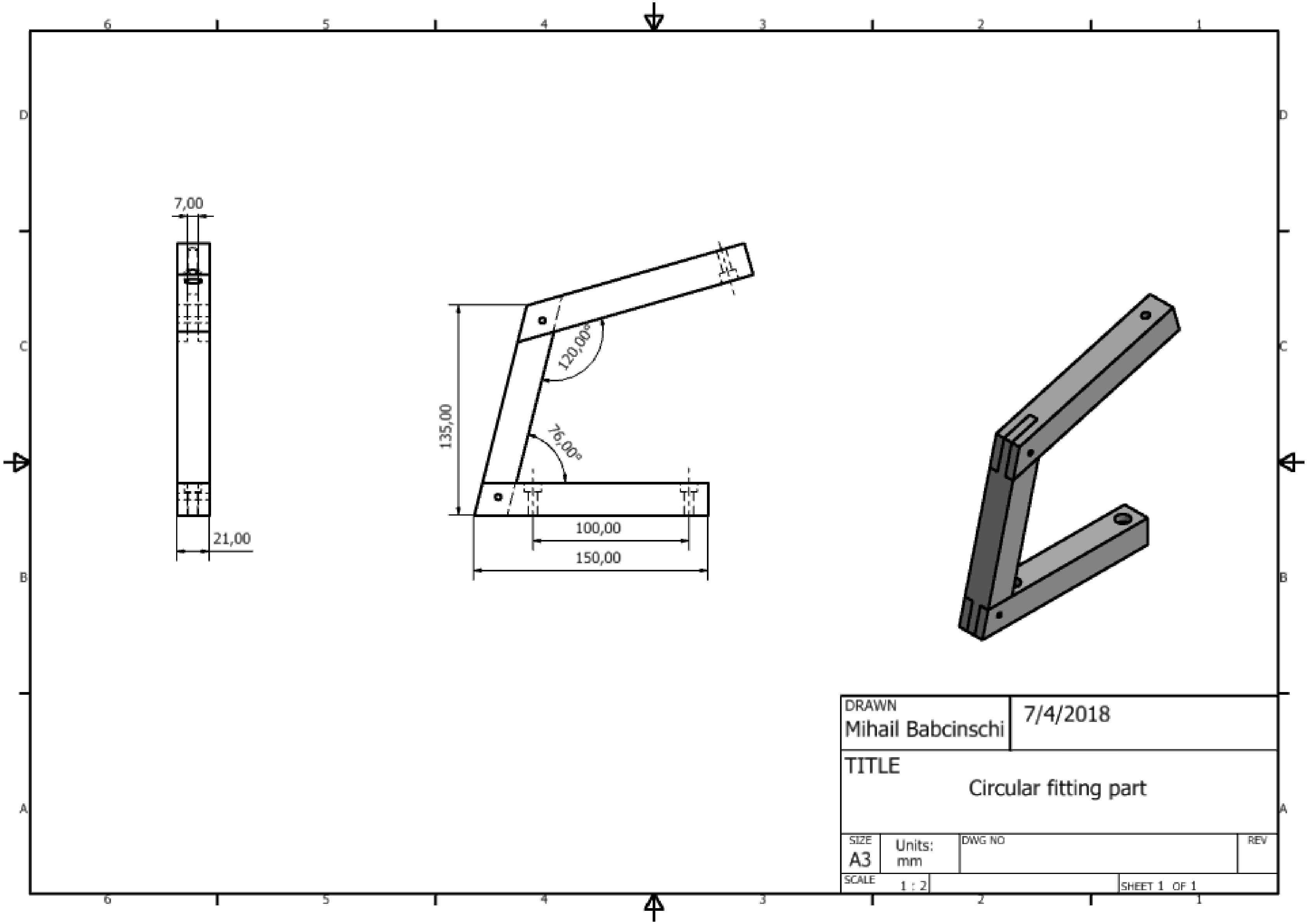
ANNEX B (TOOL HOLDER CAD FILES)



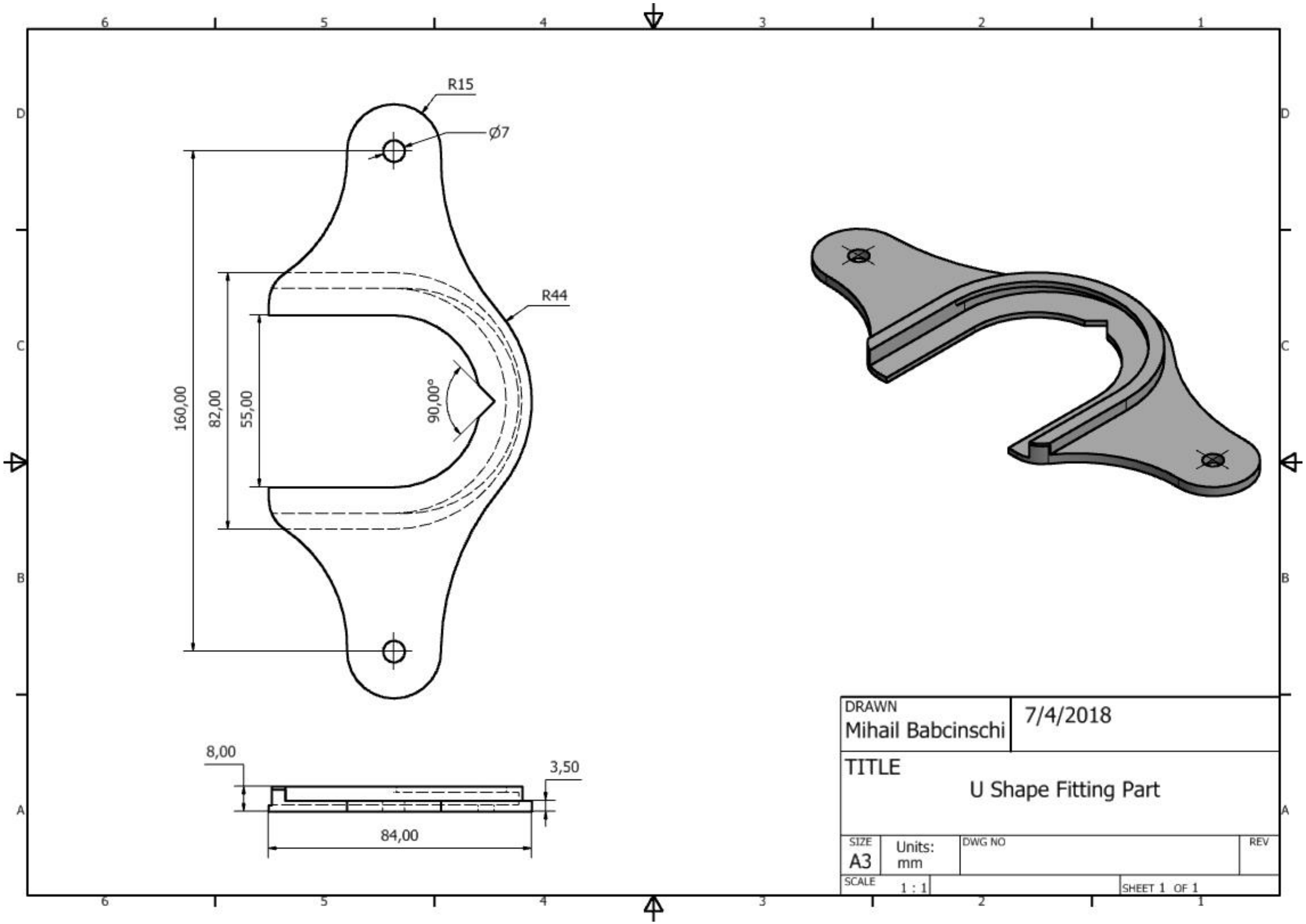
PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	4	Part1	
2	4	Part2	
3	4	Part3	
4	4	U Shape Fitting Part	
5	4	Part 4	
6	4	Part5	
7	4	Part6	
8	8	ANSI B18.3.1M - M5x0.8 x 25	Broached Socket Head Cap Screw - Metric
9	9	AS 1112 - M5	ISO metric hexagon nuts, including thin nuts, slotted nuts and castle nuts
10	16	AS 1427 - M5 x 30	ISO metric machine screws
11	16	DIN 6923 - M5	Hex Nut
12	16	Pin	



21,00
248,40
7,00
341,02
120,00°
75,00°
100,00
150,00
Ø4
DRAWN
Mihail Babcinschi
7/4/2018
TITLE
Part 1, Part 2 & Part 3
SIZE
A3
Units:
mm
DWG NO
REV
SCALE
1 : 2
SHEET 1 OF 1



DRAWN Mihail Babcinschi	7/4/2018
TITLE Circular fitting part	
SIZE A3 · Units: mm · DWG NO · REV	
SCALE 1 : 2	SHEET 1 OF 1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82,00
55,00
90,00°
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3,50
84,00
DRAWN
Mihail Babcinschi
7/4/2018
TITLE
U Shape Fitting Part
SIZE
A3
Units: mm
DWG NO
REV
SCALE
1 : 1
SHEET 1 OF 1