MENDEL UNIVERSITY IN BRNO

Faculty of Forestry and Wood Technology

Department of Furniture, Design and Habitat

Design process and manufacturing with CNC routers – case studies

DIPLOMA THESIS

2017 Bc. Kateřina Plšková

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Thesis: Design process and manufacturing with CNC routers – case studies

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Abstract

The thesis investigates possibilities of practical application of CNC routing by designing and manufacturing its own product and describing the development process with focus on wood based materials with application of luminous resin. The first theoretical part of the thesis aims to describe CNC routing principle and to analyze manufacturing possibilities, applications and potentials of the CNC routing, also to compare is with competitive technologies. The second theoretical part of the thesis aims to describe usage luminous resin and applications with focus on CNC design. The practical part presents manufacturing process of real product (from the proposal to the final piece).

Keywords: CNC routers, design, light, luminous resin, materials, product, technology

Diplomová práce: Designový proces a výroba pomocí CNC stroje – případové studie

Autor: Bc. Kateřina Plšková

Abstrakt

Diplomová práce se zabývá možnostmi praktického využití CNC frézování prostřednictvím vlastního návrhu a popisuje vývoj tohoto produktu za využití CNC technologií a využití materiálů na bázi dřeva s aplikací luminiscenční pryskyřice. První teoretická část práce vysvětluje princip CNC frézování, analyzuje výrobní možnosti, využití a také jej srovnává s konkurenčními technologiemi. Druhá teoretická část práce vysvětluje princip použití luminiscenční pryskyřice se zaměřením na CNC design. Praktická část práce prezentuje proces tvorby skutečného objektu (od počátečního návrhu po konečný výrobek).

Klíčová slova: CNC stoje, návrh, světlo, luminiscenční pryskyřice, materiály, výrobek, technologie

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1 INTRODUCTION

“There are stars whose radiance is visible on Earth though they have long been extinct. There are people whose brilliance continues to light the world even though they are no longer among the living. These lights are particularly bright when the night is dark. They light the way for humankind.” (Hannah Senesh)

From the very beginning of mankind light was source of human interest. Whether it was represented by the shining stars or lightning crossing the sky, or perhaps fireflies flitting summer evenings. The need for light is given by the innate human needs. It allows safe movement in space and creates a feeling of safety, which positively affects the human psyche, especially at night. Human genius is constantly looking for new ways to create, preserve and adapt those “stars” to own needs. Before 790,000 years ago, prehistoric people conquered the fire. The electricity was discovered with the development of human intelligence, science and technology by the beginning of the 19th century.

Currently, electricity is a common and integral part of people's lives. Thanks to electricity, the handmade production has been largely replaced by machine production. Electricity allowed to push the boundaries of human creation. On the design field there are many opportunities how to create designed products. The design-process is no longer just paper and pencil. We use modern computer technologies. Thanks to these technologies we can manufacture our products faster, better and cheaper. We use technologies from the proposal to the final piece.

The most commonly used modern technology for manufacturing products from wood based materials are CNC routers. CNC routers are cheaper than competitive technologies and they are not that difficult for using machine. CAD–CAM technology achieves new creative and innovative way with a wide range of applications. Thanks to that we can experiment with shapes and using unusual materials. The modern trend is using original natural materials with new advanced synthetic materials.

The thesis is focused on possibilities of the CNC routing design with application of luminescent resin. The aim was to create an intimate lighting. It was inspired by the self-adhesive plastic shining stars which perhaps every child had on the ceiling. They were glowing into the night. This thesis is dedicated to all of those, who as children were afraid of darkness in their rooms.

2 PURPOSE OF THESIS

The purpose of the thesis is to gain knowledge and experience with CNC routing. The purpose of the theoretical part is making research of CNC technology and making research of luminescent resin. The main part of thesis is practical part. The main aim is to develop and produce object with using CNC technology with application of luminous resin. Specifically, it is the idea of creating a light element in the interior, with low light intensity to not disturb the sleeping person and yet which allows safe movement around the room during the night. The secondary aim is to create something like a manual for inspiration to produce a similar object using the combination of CNC routing and luminescent resin. Discussion part of the thesis deals with evaluation of the product itself and finding benefits of the thesis for industry.

3 METODOLOGY

The thesis is mostly interested in applying the gained knowledge on designed object. The basis of the thesis is a literature review, compilation form created on the theme of CNC routers.

The theoretical part of thesis deals with the introduction to CNC technology, tools and using materials and also integration of CNC routing in the design process. The secondary research deals with luminescent resin and its application.

Rather than on a theoretical research, the thesis is focused on creating a real practical model. The practical part is focused on creating own design product with using CNC routing. In the introduction this part contains research of real design products created by CNC routers and products including luminescent resin. The final product is recorded and described during the whole process of designing (from the proposal to the final piece). It is a created portfolio with a sort of mind map with which it is possible to produce the product.

The project is produced in the workshop of family firm PETR PLŠEK – INET in Jesenice city. All of the design models are made using the CNC router Tech z5.

The discussion part of the thesis introduces advantages and disadvantages of using CNC technologies for design production and also mentions advantages and disadvantages of application of luminescent resin.

4 THEORY

4.1 CNC technology

CNC designation means “Computer Numerical Control”. Numerically controlled machine tools are machines which machine components with one of available machining technology (e.g. companies turning, drilling, milling, tapping, etc.) and operation is being automatically controlled by entering commands in numeric (value-based) form of a computer program. (Řasa, 2005, P.16)

CNC machine industry is a highly complex science. It involves physics, electronics, pneumatics, mathematics and a bunch of other disciplines. The best way how to design and use CNC machines is not scientifically proven. It is all about practice and skills of workers. CNC technology should help the business become more successful and improve the bottom line. The one common fact that has been experienced by countless manufacturers of wood products around the world is that a taste of CNC technology will change a business forever. (Albert, 2006, p. 10–23)

The skill of the manufacturing industry is to create a quality part that meets the consumer’s specifications for the least amount of money. The progression and advances in manufacturing continue to decrease the cost of production and further decrease the overall cost of goods which, in turn, affects the national economy (Collins, P. et al, 2011, 15 p.)

4.1.1 History

History of CNC machines started in United States. The importance of manufacturing and having skilled manufacturers in the United States industry has been apparent since the industrial revolution in the 1800’s. The economic change that took place when production went from skilled craftsman to machines and factories has helped to transform the U.S. into superpower nation as it is today. Since the modern industrial revolution took place in 1973 all areas of industry from technologies, politics, and the economy have all been influenced and changed dramatically. (Albert, 2006, p. 6)

The aim of mechanization is to facilitate and eliminate strenuous human labor. The goal of mechanization is to get rid of repeating monotonous tasks, and in its highest degree exclude entire human influence from the machine operators and let them just for inspection, maintenance and adjustment of the machine. The NC (Numerical control) program is a detailed set of step by step instructions that tell the machine which path to follow and which operations to perform.

It is during 1940 at the Massachusetts Institute of Technology that Gordon Brown establishes the Servomechanisms Laboratory. It is in 1949 that the Servomechanisms Lab is awarded a contract to develop a numerically controlled milling machine for Parsons Company. Numerical code is entered via "punch tape" (typical encoding medium of the time) and deciphered by the machine controller. Each punch corresponds to a predetermined value and allows the machine to move independently of the human operator. This system is successfully demonstrated in 1952. The Servomechanisms Laboratory continues work writing a machine code language (among other things) in addition to promoting numerical control for industrial use. (Collins, P. et al, 2011, 15–16 p.). By the mid 1960s, NC technology was playing a dominant role in the industry. End of the 1970s was invented the first 5 axis CNC in woodworking. Most machine programs were recorded on a punched paper or aluminum tape until about 1980.

In the 1970s and 80s, the growth of microprocessor technology, made it possible for computers to be connected directly to NC machines using cables, hence the term CNC. Fundamentally, numerical control is a technique for controlling machinery rather than a specific type of machine. CNC machines were originally built for machining metal. They were subsequently adapted for other industries such as wood, fabric, foam, and plastics. All these machines have some features in common which are a program (instructions), a controller and a machine tool.

Wood routers differ from their metalworking cousins in the fact that they are not subjected to the same forces of load and vibration. They spin faster and have larger work tables. They use smaller tools and tool holders and work at faster machining speeds. These routers, unlike other technologies, use also similar tools like manual production.

Todays CNC machines are ubiquitous part of the manufacturing process. New functionality and improved performance is being developed every day which will give CNC an ever increasing role in the success of our industry. (Albert, 2006, p. 6–11)

4.1.2 Benefits of CNC technology

The first benefit offered by all forms of CNC machine tools is the improved automation. Many CNC machines can run unattended during their entire machining cycle, freeing the operator to do other tasks. This gives the CNC user several side benefits including reduced operator fatigue, fewer mistakes caused by human error, and consistent and predictable machining time for each work piece.

The second major benefit of CNC technology is consistent and accurate work pieces. Todays CNC machines feature a typical accuracy rate in the range of 2 to 4 thousandths of an inch or 0.05 to 0.10 mm and repeatability near or better than 8 ten-thousandths of an inch or 0.02 mm. This means that once a program is verified, two, ten, or one thousand identical work pieces can be easily produced with the same precision and consistency.

A third benefit offered by most forms of CNC machine tools is flexibility. Since these machines are run from computer programs, running a different work piece is as easy as loading a different program. This leads to yet another benefit, quick changeover. Since these machines are very easy to set up and run, and given the ease with which programs can be loaded, they allow for a very short set up time. The resulting reduction in the number of machines needed in a wood manufacturing shop is yet another benefit worthy of noting. In the past, a great number of dedicated machines was needed to produce furniture or cabinets. With the advent of CNC technology, this reality has changed drastically. Less time spent between work centers means faster production time. Less Work-in-Progress (WIP) also translates into lower inventory and less investment in non value-added resources. As a result, machinery requirements decrease, employee workloads are simplified, and waste is minimized while production is maximized.

Limitations Machines are made to optimally perform a set of functions and they don’t inherently have the same mobility and versatility as humans. Newer machines have evolved to become multitasking and more versatile and although there are still some limitations with CNC software technology, manufacturers are constantly improving their machines and creative users are finding new ways of using them beyond their limitations.

Space is the one commodity that is often lacking (along with time). These machines not only take up a large footprint but one has to take into consideration other space uses such as raw material, finished parts, jigs and fixtures, and tooling. (Albert, 2006, p. 12–13)

4.1.3 Software

Software is at the heart of any NC machine. Even the most advanced piece of machinery cannot perform to its full potential without the proper software to make it happen. It is also the area that will require the highest skill set on the path toward CNC success. There are many levels of software needed to run a CNC router: from the technical drawings to the sales requirements and scheduling, to the actual NC code that makes the axes move.

CAD - the acronym for Computer Aided Design (CAD) originally meant Computer Aided Drafting because of its use as a replacement for traditional drafting. CAD is used to design, develop and optimize products which includes goods used by end consumers or intermediate goods used in other products. CAD enables designers to lay out and develop work on screen, print it and save it for future editing, saving time on their drawings.

CAM - Computer Aided Manufacturing (CAM) takes the CAD drawings and helps translate them into manufactured parts by adding tool sequences, machining parameters, cutting speeds, etc. CAM refers to a wide range of computer-based software tools that assist engineers, tool and die makers and CNC machinists in the manufacture or prototyping of product components. (Albert, 2006, p. 76–95)

4.1.4 Machining operations and tools

CNC machine offers a wide array of machining modes and there is also an incredible amount of different types of cutting tools used in CNC machining. The basic and most used types of machining includes milling, turning, sawing and drilling. Each machining operation requires special tooling. CNC tooling is designed specifically for use with CNC machines and is made with incredible precision so that the performed operations are also precise. In general, CNC tooling can withstand higher temperatures and cutting pressures than regular machine tooling. They are also more wear resistant. They are normally made of high-speed steel, carbides, ceramics and diamonds.

4.1.4.1 Milling

Milling is the process of cutting and shaping materials into a desired part. The actual shaping of the part is done with a cutting tool attached to a spindle, delivering rotational forces. In complex operations it is far more effective to use a CNC machine. Milling operations are usually classified as face milling, end milling, and slotting. (Collins, P. et al, 2011, 23–21 p.) Milling cutters are usually made of high-speed steel and are available in a great variety of shapes and sizes for various purposes.

End mills are used for milling applications. Though they look similar to twist drills, their geometry is way more different and they are used for different operations. End mills are used to mill in all directions, but some cannot cut in the axial direction due to their short length. End mills are used for pocketing, profile milling, face milling (not to create a smooth finish), and other small operations such as tapping.

Face mills usually have three cutting edges and are used to take a small amount of material off of a face of a work piece. The blades are very sharp and create a good finish on the surface of the work piece, unlike using an end mill. The most common type of face mill for CNC machining is the 3 inch version. They are normally used for facing aluminum and nonferrous materials. These metals are considered soft and are easier to machine a smooth surface finish.

Slotting is used to cut grooves and slots in shapes and holes while additionally smoothing the worked surface. Because it is more economical at high production rates due to reproducibility and consistency, slotters are generally used in high volume operations. (U.S. Army, 1996, 46 p.)

4.1.4.2 Drilling

While milling is performed in all directions and can create unique parts, drilling is performed only in the axial direction. Drilling can be described as a process in which a cutting tool of fixed diameter is fed into a work piece. It is a very simple operation and the resulting holes share a diameter with the size of the cutting tool.

There are many categories of CNC drills that are used. Drill bits are cutting tools used to remove material to create holes – nearly without exception – of circular cross-section. Drill bits come in many sizes and shape and can create different kinds of holes in many different materials. In order to create holes drill bits are attached to a drill, which powers them to cut through the workpiece, typically by rotation. Twist drills are used for cutting the hardest of materials. They are also used to drill deep holes in softer materials.

4.1.4.3 Turning

Turning is a process that can be done on a machine called lathe. It allows a machinist to create parts with features that are axially symmetrical. A lathe spins the work piece while the cutting tool removes stock in the radial or axial direction. Turning is used to create concentric features on the outside, inside, or face of a part. Lathes are useful to machinists in many ways. They are often used to create circumferential grooves, screw threads, as well as stepped, tapered, and rounded shafts. (Collins, P. et al, 2011, 23–21 p.)

4.1.4.4 Sawing

The sawing machine is a machine tool designed to cut material to a desired length or contour. It functions by drawing a blade containing cutting teeth through the workpiece. The sawing machine is faster and easier than hand sawing and is used principally to produce an accurate square or mitered cut on the workpiece. Devices for cutting are the saw blades. (U.S. Army, 1996, 47 p.)

4.1.5 Using materials

CNC machines provide processing of a wide range of materials. The selection of a certain material depends on which type of product it should be, the chosen technology which we are to use and it depends also on the selected tools. Solid wood, plywood and MDF are among the basic types of materials which are used in CNC machining. It is also possible to use some of the non-wooden materials, mostly it is extruded polystyrene. Other non-wooden materials are: polyurethane, carbon plate, PVC, PEXIGLAS and soft aluminum.

Solid wood. Solid wood materials come in a wide range of hardnesses with varying grain qualities. The advantages are that solid wood looks nice and it will withstand wear and tear**.** The disadvantages of solid wood are: higher price, low dimensional stability and limited sizes. Wood with higher density may require more complex milling strategies and can slower the process.

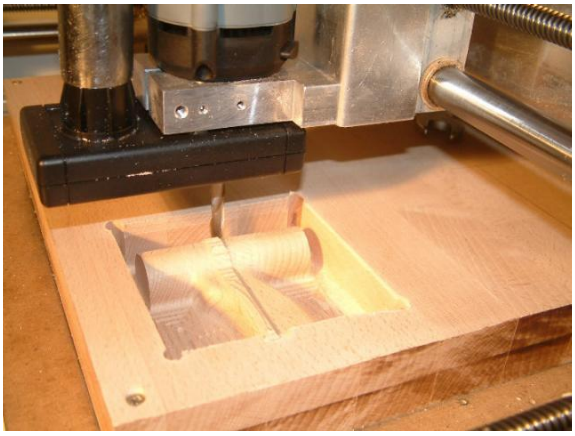


Fig. 1: *Model of solid wood (wiki.imal.org)*

Plywood. The advantages of plywood are: withstanding wear and tear, layers creating interesting effects (but often distracting) and dimensional stability. The disadvantages of plywood are: the potential to be expensive, the possibility of requiring specialized cutting tools, the fact that layers are of different quality and may contain knots.

Fig. 2: *12 mm plywood with a 3mm cutter (wiki.imal.org)*

MDF (medium density fiberboard). The advantages are: the dimensional stability of MDF, uniform color, homogenous material. The disadvantages of MDF are: it requires expensive cutting tools, it creates hazardous dust (flammable and explosive).

Fig. 3: *Model of table from MDF material*

Extruded polystyrene (Blue Foam). Recommended for people new to milling, for the milling of surface. This material is convenient for first work models before using the final material. The advantages are: low price, lightweight and transportability, quick milling without expensive tools, ability to be painted with gesso and water-based paints. The disadvantages are: dimensional instability, the need of a more rigid backing, material may require painting, inability to withstand significant wear and tear.

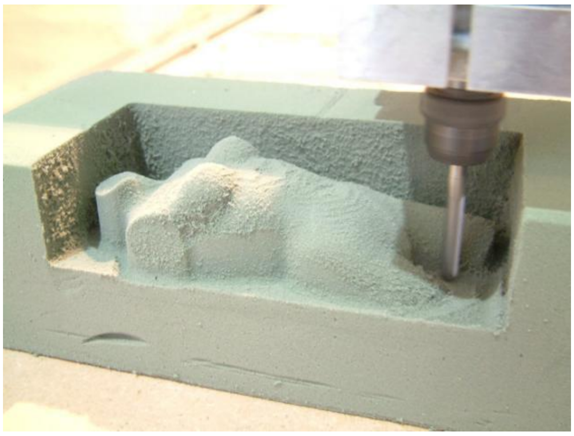


Fig. 4: *Polystyrene foam with a 3mm radial router (wiki.imal.org)*

But there is an amazing array of new materials available to manufacturers today. The days of knotty pine and red oak as the only two choices are long gone. Lightweight panels, reconstituted veneers, sustainable and low VOC particleboard are only a few of the items that are readily available today.

On design field we can find new products from wood with combination of plastic, stone or synthetic leather. One can buy metal laminates and reconstituted stone that can be cut with a CNC router. The combinations are limitless and are bound only by the limits of the imagination. (Albert, 2006, p. 94–95)

4.1.6 Tech z5

CNC machine called "Tech z5" was used to manufacture the model of lightning described in this thesis. This machine allows to use the "top" of flexibility offered by a 5-axis machine.

Fig. 5: *Tech z5* (*scmgroup.com)*

Tech z5 is a drilling-milling device with CNC control used to process wood and other materials with similar attributes. The construction is formed by two basic elements – supporting base (A) and shoulder (B) which moves along the axis X. The drilling head (C) is assembled on "sledges" (D) with displacement on movable arm (B) along axis Y and in the axis Z.

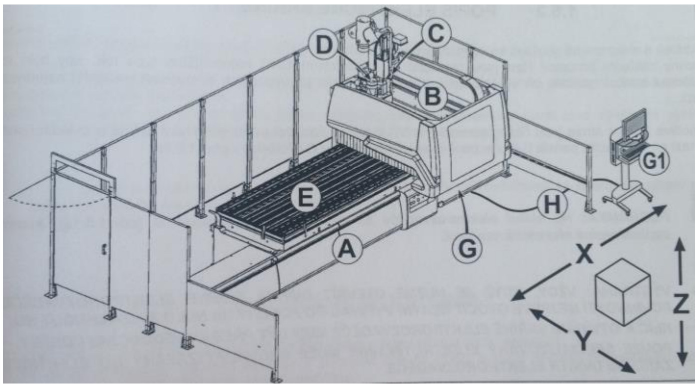


Fig. 6: *Tech z5- description of the machine* (*scmgroup.com)*

All movements involve sliding on prism guides with recirculating ball screws. “Y” – “Z” -axis movements are made possible using top quality recirculating ball screws. X-axis movements are made with a very high quality rack and pinion. The base (A) is fitted with the worktables (E) and the reference stops for workpiece positioning. The worktables consist of extruded aluminium alloy bars mounted on supports containing recirculating ball bushings and pneumatic locking devices. The worktables move along the X-axis on round, ground steel bars.

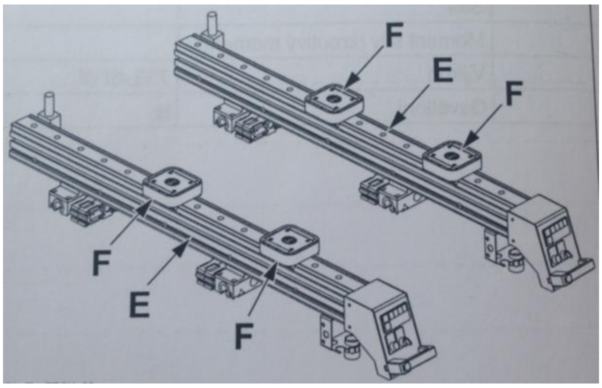


Fig. 7: *Tech z5 – description of the fastening device* (*scmgroup.com)*

The suction (cups F) are fitted in the worktables, to secure the workpieces by means of the vacuum. These suction cups are positioned by sliding them on the table along the Y-axis. The control unit of the machine is installed on the electrical cabinet (G) and a console (G1) is connected by sheaths (H), these have a sufficient length for an easy positioning (maintaining the minimum distances of the machine).

This machine is a CNC machining centre designed especially for drilling and routing operations. This device can be used only for working on wood and wood-related materials. Coated parts of wood and similar material are also considered as workable materials. The way of working/milling and chip removal can’t be changed. The device was designed for exclusive use of tools which correspond with standard EN 847-1:2005a, EN847-2:2000/AC2003.

4.1.7 Types of CNC production

Depending on the type of machining operations and tools we generally divide CNC production into planar (2D) and spatial (3D) machining.

4.1.7.1 2D routering

2D milling is the most common and versatile technology for the processing of sheet materials from plastics to wood. 2D milling is intended to generate both simple and complex tool paths. It is about drilling and production holes. Types of operations are drilling, front cutting, pocket machining, adaptive machining, contouring, slotting and chamfering. (1cpro.cz, 2015)

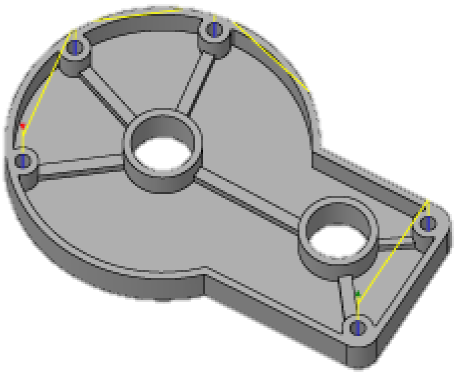


Fig. 8: *Drilling (1cpro.cz)*

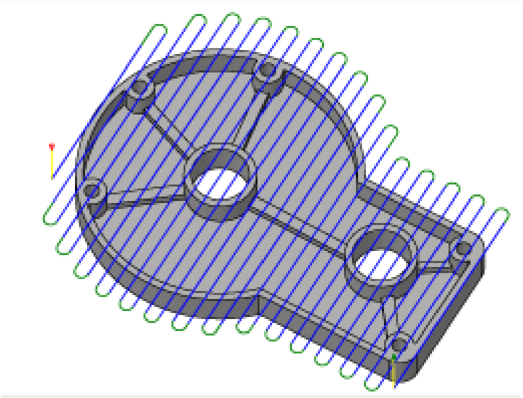


Fig. 9: *Front cutting (1cpro.cz)*

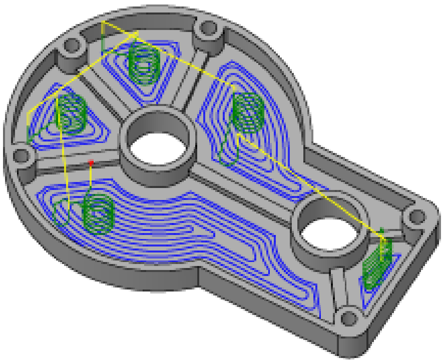


Fig. 10: *2D pocket machining (1cpro.cz)*

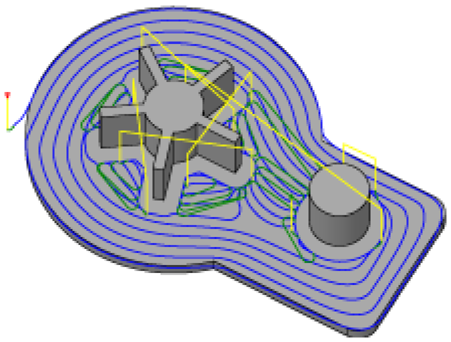
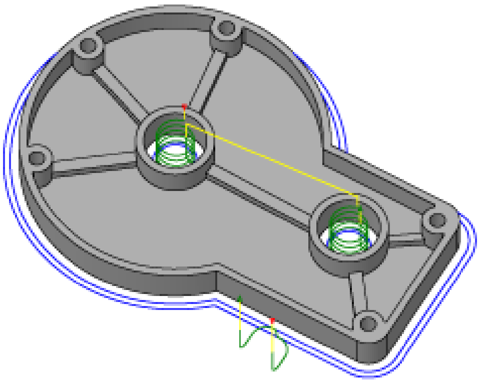


Fig. 11: *Adaptive machining (1cpro.cz)*



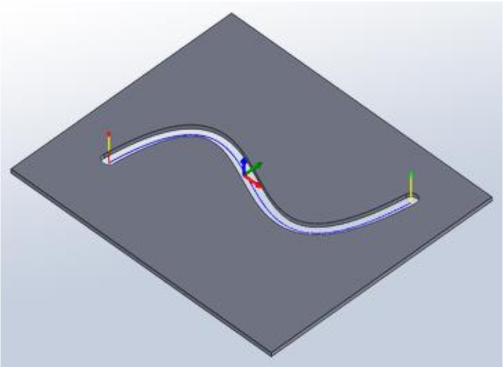
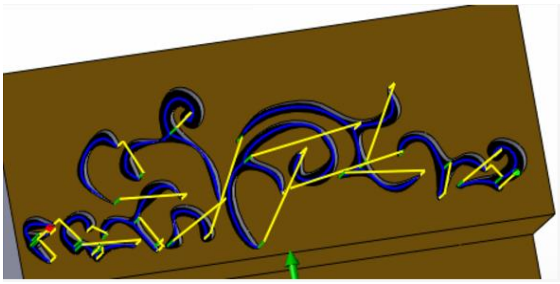


Fig. 12: *2D Contouring (1cpro.cz)* **Fig. 13:** Slotting (*1cpro.cz)*



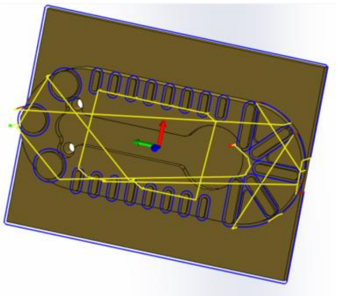


Fig. 14: *Engraving (1cpro.cz)* **Fig. 15:** *chamfering (1cpro.cz)*

4.1.7.2 Examples of 2D design

4.1.7.2.1 Set of jewelry REPUBLIC

Fig. 16: *Earrings Republic 1* (*plskova.cz)* **Fig. 17:** *Earrings Republic 2* (*plskova.cz)*

This set of jewelry is inspired by the outline of the state of the Czech Republic. Heart milled into rings and earrings is a symbol of home, which we carry in our hearts. Jewelry made of precious metal components light and thin plywood, machined on CNC router. There are used 2D contouring and engraving for the processing. Dimensions of beech plywood are 35 × 20 × 1.5 mm.

4.1.7.2.2 BOOKMARK

Fig. 18: *Bookmark – two types (plskova.cz)*

Fig. 19: *Bookmark (plskova.cz)*

This bookmark named BOOKMARK is designed as elegant and simple promotional item for Mendel university of Brno (MENDELU). This object is made of beech plywood, milled on CNC router with combination of adhesive green plastic foil. There are used drilling and slotting for the processing. Dimensions of bookmark are 35 × 35 × 1.5 mm.

4.1.7.2.3 HYBRID

Prototype of seating Hybrid consists of two interlocking molded ribs with flexible seating surface. Shaped ribs forming the backbone of the product are made of plywood thickness 40 mm, surface-finished oil wax. The seating surface is made of textile fabrics and glass fiber networks. For the outdoor use option there is a possibility of replacing the technical fabric by the textile fabric. Shaped ribs are milled by CNC router. There are used 2D contouring, engraving and chamfering for the processing. (plskova.cz, 2016)

Fig. 20: *Hybrid – two types* (*plskova.cz*)

Fig. 21: *Hybrid - detail* (*plskova.cz*)

4.1.7.2.4 Another examples

There are many ways to create a design element using 2D machining. Material may be removed gradually, at different depths in the material. It is thus creating the impression of 3D objects (sacral windows) or the impression of photograph (BMW car). For windows is used plywood with 2D pocket machining. For impression of photography is used black laminate with engraving.

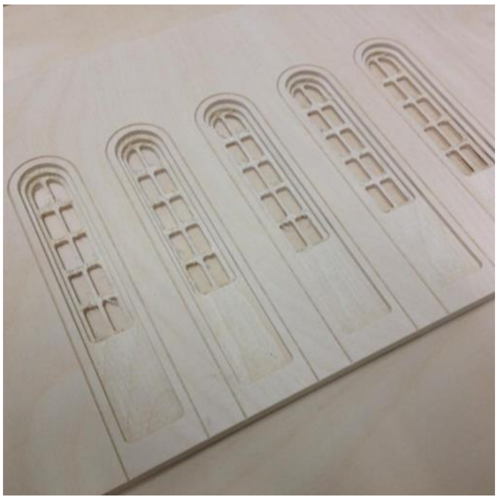


Fig. 22: *Model of windows* (*cnc-zakazky.cz*)

Fig. 23: *Photography of car* (*cnc-zakazky.cz*)

4.1.7.3 3D routering

3D routering is about milling complex 3D parts, sculptures, models, forms, different tools and hollows. In this case of machining, the object is routered in different axis which creates complex shapes and patterns. There are more types of 3D routering depending on the way of movement of the milling machine and depending also on the type of milled object. Primarily pocket machining, machine contouring and ramp finishing can be counted among the basic types of 3D routering. And there are some other types (fig. 24–31) like: parallel machining, pencil milling, beam milling, spiral and projected machining. (1cpro.cz)

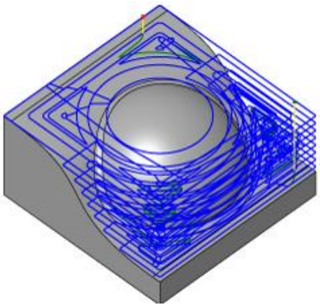


Fig. 24: *Pocket machining*

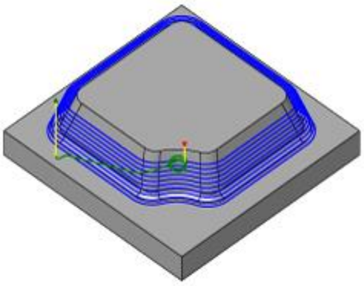


Fig. 25: *Contouring*

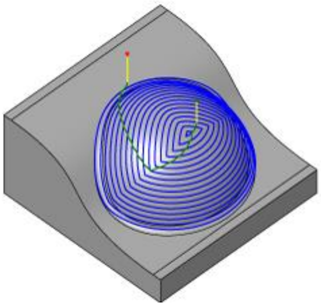


Fig. 26: *Ramp finishing*

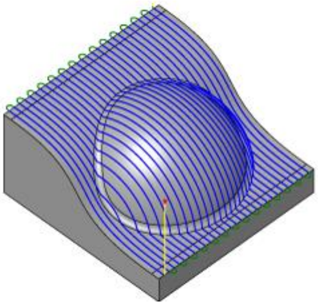


Fig. 27: *Parallel machining*

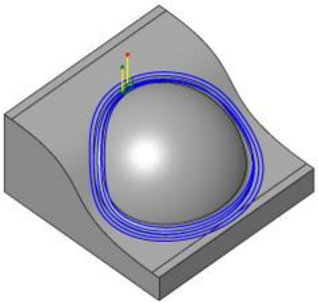


Fig. 28: *Pencil milling*

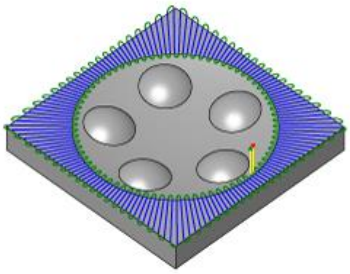


Fig. 29: *Beam milling*

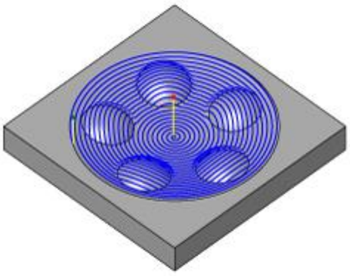


Fig. 30: *Spiral machining*

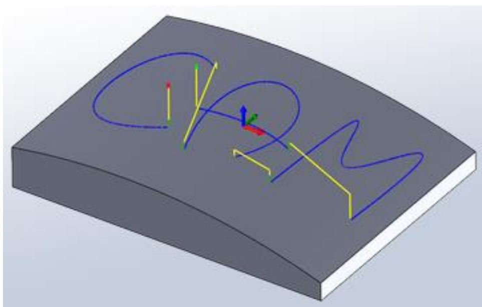


Fig. 31: *Projected machining*

4.2 Related technologies

In addition to CNC machines, other related technologies are used at design. These are mainly machining technologies based on the use of physical or chemical principle of material removal. It is mostly force-free machining tools material without the formation of conventional chips that arise during machining cutting tools.

According to the principle of machining there are defined some individual groups. It is electrical discharge machining (electric spark, electric arc), chemical machining (electro chemical machining), the machining beam of concentrated energy (laser, electron beam, ion beam, plasma) and mechanic processes - machining by ultrasonic, water jet). Last but not least the punching and cutting. Cutting also belongs to the chipless machining.

These technologies were introduced into industry primarily because of increasing number of difficult materials in mechanical engineering (composite materials, etc.), the need of complex processing and highly irregular shapes (external and internal), miniaturization and suitability of use in automated operations (CAD CAM system utilization). A general lack of some physical machining technology is less productivity. (Řasa, 2005, p. 87–89)

4.2.1 Laser cutting

It is a machining method, which is broadly equivalent to the CNC machining. Laser machining is based on the conversion of light energy into heat energy. This is done in contact (interaction) of the laser beam with the workpiece material. The material of workpiece heats, melts and evaporates by high temperature. Laser stands for Light Amplification by stimulated emission of radiation. The laser operates by induced emission, i.e. forced radiation. The laser technology is used for describing components, cutting, welding, drilling, turning, milling and engraving. The ability to machine the material depends on the material properties (light absorption, thermal conductivity, and reflectance). Machinability of material for laser machining is the better the higher is the absorption of the material, the smaller thermal conductivity, and the smaller reflectivity of the surface of the workpiece. (Řasa, 2005, p. 152–176)

4.2.2 Water jet

Water jet is an alternative technology to laser cutting. It uses a high pressure stream of water that cuts a wide range of thick and thin materials. Beam of working fluid flows at high pressures (200 to 600 MPa) from the nozzle at up to four times higher than the speed of sound. Water jet is able to cut almost any material including stone, ceramics and metals of greater thickness. However the first water jets were developed in 1970s to cut wood, very little wood is manufactured this way nowadays. Pure liquid jet (water, oil) is used for cutting materials, as well as abrasive fluid jet with added grains of abrasive material (sand, olivine, garnet in size from 0.2 to 0.5 mm). With additional abrasives, it is possible to cut harder materials such as concrete and steel. Water jet produces precise cuts, it has no problems with intricate details, there is a minimal material loss, it is a noncontact operation with no deformations due to the blade. The protective wear is necessary when machining. Water jet produces a high level of noise, there is an amount of cutting waste due to mixing water with abrasives and high machine cleaning requirements. There are no tooling cost but qualified skilled workforce is required. (Žáková, 2012, p. 47) It is possible to cut complex shapes and perform drilling, deburring, chamfering, blasting, turning and milling. Water jet can machine all kinds of metal (steel, titanium alloys, etc.), even non-metallic materials (plastics, laminates, fiberglass materials, etc.). The disadvantage of this low machining is the accuracy of machining (only 0.1 mm–1 mm). Squareness of cut is 0.3 to 6.4 °, because the kerf is downwardly extending. (Řasa, 2005, p. 178–186)

4.2.3 Plasma cutting

Plasma cutting is based on heating or melting the material at extremely high temperatures (above 10 000 °C). Plasma is electrically conductive state of gas, an ionized gas. Gas passing through the nozzle to the surface is ionized by an electrical arc which turns some of the gas to plasma. The temperature of the plasma is able to melt metal. The gas flow removes the melted material from the kerf. Plasma is able to cut metals of greater thickness and is mainly effective for cutting shapes with less intricate details. The workpiece have rougher edges when cutting material of greater thickness. It is able to cut highly reflective metals, which is problematic for CNC routers.

4.2.4 Punching, blanking and die cutting

Punching, blanking and die cutting are shearing processes. Punching is cutting an internal shape, the removal of material from the workpiece, blanking is the opposite process of cutting out an external shape. Punching and blanking are processes used in metal work for thin sheets up to 5 mm. Die cutting is a blanking process in flat thin sheet non-metal materials, such as paper, plastic or foam, typically used in packaging industry. Complex patterns, shapes and intricate details are limited by the dies and blades. Shearing is a contact process, the workpiece is stressed, deformations or fractures might occur. Dies are expensive to be made and stored and they must be replaced frequently since they wear out quickly. The process is efficient just for very large quantities of simple shapes, they are not suitable for prototypes or smaller batches because design changes cannot be easily handled. (Žáková, 2012, p. 84–86)

4.3 Luminous resin

"The light shines in the darkness, and the darkness has not overcome it."

(John 1:5, The Bible)

The design concept of this thesis also includes luminescent resin. Luminescent resin is a combination of a resin with a luminescent pigment. The combination of these two substances is great for creating a design of a subdued light on the nightstand. This light should lightly illuminate even after turning off the light source.

4.3.1 Luminescence

4.3.1.1 History

Light may be generated in different ways. One of the most common way is heating the object to a sufficiently high temperature. Example is the Sun (which is on the surface of several thousand degrees Celsius), fiber of ordinary light bulb or candle flame. Along with the light, large amounts of heat is also released. But there is another way – luminescence. (prirodovedci.cz, 2015, p. 8)

News about luminescence was detected since ancient Rome. There are mentions of the fact that soldiers in ancient times marked the path with fluorescent rotting wood from the trees. In the middle ages, they were discovered natural luminescent objects e.g. rotting mud or fireflies. The first experiment with artificially prepared luminescent materials is dating back to the beginning of the 17th century. There was a substantial development of chemistry as a science, and especially the development of alchemy. One of the most famous alchemists was a Bolognese shoemaker Vincenzo Gasciarolo that tried to produce gold and find the elixir of life. However, his greatest discovery was the first artificially produced luminescent substance called phosphor.

The actual physical systematic research on these substances dates back to the turn of the 19th and 20th centuries. It was associated with the names of prominent physicists like Henri Becquerel and George Gabriel Stokes. These scientists used luminescence properties of substances, mainly to improve the visibility of ultraviolet and X-rays. (Bradová, 2011, p. 9–17)

Definition of luminescence was formulated in 1889 by physicist Eilhard Wiedemann (1852–1928). Then physicist Sergey Ivanovich Vavilov (1891–1951) explained it. He divided all cases in which was radiation into three types: spontaneous, forced and recombination. The word luminescence, derived from the Latin (lumen), means light. (Pelant, 2014, p. 12–15)

The definition of luminescence is: “The emission of light that does not derive energy from the temperature of the emitting body. Luminescence is caused by chemical, biochemical, or crystallographic changes, the motions of subatomic particles, or radiation-induced excitation of an atomic system.”

In case of luminescence, the source of heating light is not essential in contrast with bulbs or candle. Light is emitted even at low temperatures and there is almost no heat. Important is in particular that the luminescent radiation (and sometimes even very strong) may be transmitted substances which does not need to be hot. In most cases, luminescence intensity increases with decreasing temperature and the strongest intensity may be near absolute zero 0 K (–273 °C). Therefore, the luminescence is called as a cold light. Other important difference is that hot objects emit a yellow-orange or white light. (The bulb on the Christmas tree has glowing stained glass fibre, which gives them the coveted light color.) But luminescent dyes may glow virtually any color.

Two things are needed to induce luminescence. First thing is that there must be so-called phosphors - substances that may shine under certain conditions. The second thing is the need of energy. The essence of the phenomenon is supply of the energy of phosphor, which converts it into visible light.

Luminescence can be simply explained by quantum physics. When energy is provided to the phosphor, electrons inside “jump” to a higher energy level (technically “excites”). However, at this level they cannot remain and therefore they return to the initial, baseline. When the electron returns, it releases energy in the form of photons, a piece of light having a certain color. This process is not perfect - the energy of the emitted light is always less than the energy that is delivered to the phosphor. (prirodovedci.cz, 2015, p. 8–11)

Ability of luminescence is not inherent to all substances. There is not even a criterion that would be able to unequivocally predict whether a given substance (e.g. newly prepared chemical substances) will appear luminesce or not. However, there exist a sort of general rules and that is somehow paradoxical, because these rules are based on the electrical traits of the substances, although luminescence clearly belongs among the optical properties.

This rule says that only substances which are not conducting electric current well can have luminescence, thus are insulators (dielectrics) and semiconductors (For example, metals do not have the property of luminescence because they are generally good conductors of electricity). Because the conduction of electricity is a result of electron transport, we can infer that luminescence is primarily a matter of electrons in the substance. Specifically, it is a matter of electron orbits of which the substance is composed. It has nothing to do with the dangerous “radioactivity”, with high-energy radiation emitted by nuclei of some elements, as sometimes people mistakenly believe: it is an ordinary light. It implies that for example copper (Cu), silver (Ag), gold (Au), aluminum (Al), are not luminescent materials. But they are very simple compounds (particularly oxides Cu_2O, Al_2O_3, but also others, such as CuCl, AgCl) which are insulators or semiconductors. Likewise the complex substances of organic (e.g. polymers “plastics”) and a variety of so-called organic pigments (and especially their solutions) can be luminescent. (Pelant, 2014, p. 12–15)

Application of luminescence can be found in art and also in many industrial sectors. Significant luminescence phenomena can be found particularly in electrical engineering. The most important representative is certainly “LEDs” (in televisions, screens, lamps, etc.). The biggest advantage is the existence of diodes exhibiting ultraviolet radiation which can, in some cases of visual art with fluorescent properties, replace fluorescent source of ultraviolet light.

The explored area of luminescence is relatively stable at these days. This phenomenon is based on physical laws, which are already sufficiently explored and settled in all exact sciences. That means that most of literary publications, dealing with this phenomenon, are outdated. The documents but also electronic resources that would reconcile the concept of luminescence with art are not sufficiently elaborated. (Bradová, 2011, p. 9–17)

4.3.1.2 Types of luminescence

The light that emanates from plants and animals is not only a mystery appearing in films as James Cameron's Avatar. Luminosity objects and living organisms are also found on our planet. This thesis was inspired just by the luminescent rotten wood. But this kind of luminescence is just one of many known species. It is necessary to know the difference between these types of luminescence for suitable use. Mainly, the difference in distribution according to physical principles and time duration.

4.3.1.2.1 Physical principles

Bioluminescence. Special type of chemiluminescence. It accompanies certain exothermic chemical reactions occurring in living organisms. These include fungi, protozoa, fireflies, jellyfish, deep sea fish, starfish, crabs, shrimp and etc. The rotting wood is probably luminescent bacteria.

Photoluminescence. Excitation is happening from irradiation with light, generally electromagnetic waves. Excitation of light is probably the most common way to induce luminescence, and often we are its witnesses without realizing it. General regularities in the photoluminescence are defined by so-called Stokes law, which expresses the law of conservation of energy.

Elektroluminescence. It arises due to application of voltage and electric current passing through the substance. Excitation is thus electric, i.e. the electrical energy is converted to light energy. Currently electroluminescence is perhaps most widely used of all luminescent phenomena, especially in the electronics and optical communications, but also in daily life. They are mainly so-called LEDs, which operate on the principle of electroluminescent and are offered in a wide range in each store with electronics and lighting equipment today.

Chemiluminescence. This type of luminescence does not require irradiation by extreme light source or application of an electric field. It is the nonequilibrium light radiation, which accompanies certain exothermic chemical reactions. The energy released in the reaction, instead of warm reacting (which happens normally) is radiated in the form of light – luminescence.

Cathodoluminescence. This type of luminescence is due to excitation of the material impact of accelerated electrons moving bags or jars with highly diluted gas.

A typical example of cathodoluminesce is light of the TV screen, but the “fat” classic rather than trendy flat or plasma. On the inner side of the screen, there is coated substance – phosphor.

Rentgenoluminescence and Radioluminescence. In case of rentgenoluminescence, the excitation takes place by irradiating the substance with X-rays (i.e. electromagnetic radiation with high energy photons compared to visible or ultraviolet radiation). In the case of radioluminecence, the excitation carries into effect with high energy particles (electro, alpha particles, gamma photons with energy of 100 keV to 10 MeV), denoted sometimes as ionizing radiation. An example is a screen capture X-ray images e.g. the human body during visual observation by a doctor in real time.

Thermoluminescence. This is not thermal radiation as it might seem. For the excitation, cooling the substance to a sufficiently low temperature is needed. Second step, substance is usually excited by visible or ultraviolet radiation. If the substance includes suitable places, usually impurities or defects, there can be supplied pieces of the excitation energy capture, “freeze”. Finally, the third step is about gradual warming of the substance after the excitations. During the increase of temperature to the level of freeze, accumulated energy is released in the form of light, and that results into thermoluminescent radiation.

Mechanoluminescence. Excitation energy comes from mechanical action on solid.

Triboluminescence. It is the emission of light from a substance caused by rubbing, scratching, or similar frictional contact.

Crystalloluminescence. Excitation comes from the energy released during crystallization from the solution.

Sonoluminescence. Luminescence excited in a substance by the passage of sound waves through it. (Pelant, 2014, p. 15–32)

4.3.1.3 Photoluminescence

Photoluminescence is a particularly important type for this work. Photoluminescence is divided into fluorescence and phosphorescence by the duration. While fluorescence stops practically at the same moment when supply of power is stopped, phosphorescence may persist even tens of minutes after turning off the light source. (geologie.vsb.cz)

4.3.1.3.1 Types according to time duration

Fluoroluminescence. This is a very brief phenomenon that usually takes only units in the hundreds of nanoseconds up to hundreds of milliseconds with no external excitation. When an external excitation is used (heat, radiation, pressure, sound, etc.), this phenomenon may take longer. It depends on the particular case. Without the fluorescence, fluorescent tube even unlit - include a phosphor, converting UV radiation generated in the lamp into visible white light. Fluorescent security features also protect banknotes, tickets for public transport or personal documents from counterfeiting. Fluorescence is also very common among natural substances. Known natural phosphors includes green chlorophyll of plants (glows red), some proteins (elastin, collagen), curcumin in curry powder, berberine in celandine, vitamins (A, B, D) and many others. This trait is known for a number of minerals (scheelite, willemite etc.).

Phosphoroluminescence. Unlike fluoroluminescence, phosphoroluminescent substance does not release all of its energy to area all at once. Substance is able to release this energy gradually and illuminates quite a long time without any charging and utilization of external resources. The phosphorescence is commonly indicating labels of emergency exits. If a label is shortly lighted by UV radiation we can observe, by type, several dozen minutes long luminescence. Phosphorescence is also used for commercially available “glow in the dark” objects. (prirodovedci.cz, 2015, p. 8–11)

4.3.2 Luminous pigments

While photoluminescence, the excitation is done by irradiating the substance with light having a shorter wavelength than the luminescence itself. Photoluminescence is frequently excited by ultraviolet or blue radiation. Photoluminescence can be elicited by huge amounts of organic matter. Typical compounds are organic dyes, i.e. colored compounds which find many practical applications, inter alia with that they impart color to other substances.

The dye must meet several important conditions. Firstly, their photoluminescence must be sufficiently intense. Second and that is perhaps more important, dyes must be excited by daylight. The third condition is equally important to others, colors of their photoluminescence should be as close as possible to peak of spectral sensitivity of the human eye. (Pelant, 2014, p. 58)

Pigment is the material which changes the color of the reflected light, which is caused by selective absorption of certain wavelengths. The resulting color is determined by the spectrum of reflected wavelengths of light (Fig. 32).

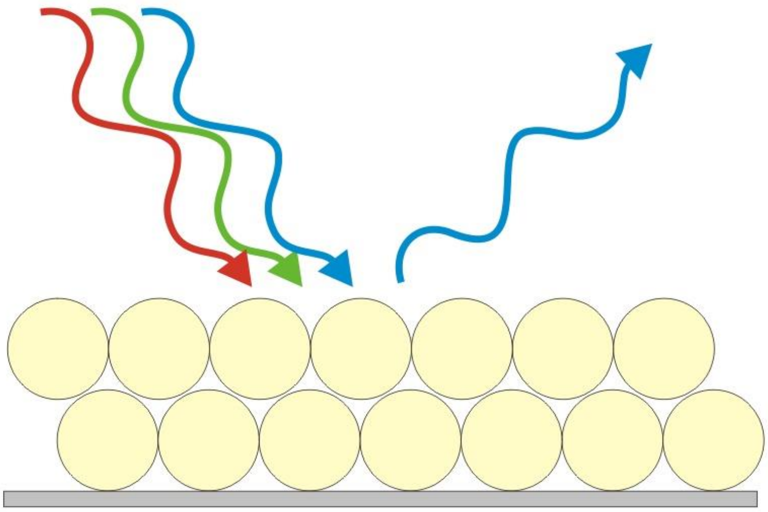


Fig. 32: *Color is developed by reflecting specific wavelengths of light. (geologie.vsb.cz)*

Pigments may be inorganic or organic and natural and synthetic materials may be in these two groups. They are usually very fine-grained materials with particle sizes of 0.2 to 10 μm.

The pigment is generally insoluble in the binder, while the colorant is either a liquid or is soluble in the binder. The dye is defined as cohesive colored material adhering to the substrate on which to deposit. Colorant consists of pigment, binder (varnish, epoxy resin, etc.) and a solvent (alcohols, toluene, esters, water, etc.).

There are two kinds of pigments, the synthetic and biological. Biological pigments are natural organic substances, derived from bodies of animals or plants. Typical examples are purple from the marine snail (*Hexaplex trunculus*) or karmin recovered from mealybugs (*Dactylopius*). Synthetic pigments are pigments produced directly or after chemical modification of the material occurring in nature. Interest in them has been going on for several centuries because natural pigments do not cover all color shades, plus their price is too high and uses are sometimes limited. Most of synthetic pigments are derivatives of complex organic compounds.

Phosphorescence is glowing characterized by long duration – a substance emits visible rays for some time after the end of its radiation. Phosphorescent pigments usually consist of a luminescent basis (sulphides Ba, Ca, Sr, Zn, Mg CD) and from activator, which is usually trace admixture of some metals, for example Cu, Co, Zn, Bi, Mn, Au and Ag. Every base has a different luminescent characteristic color of their radiation. However, the color of fluorescence varies according to the activator.

Special cases are self-lighting pigments. Long was used ZnS with very little admixture of salts from radioactive metals. These pigments glows pale green without prior irradiation. (geologie.vsb.cz)

4.4 Resin

Main goal was to discover the easiest product to use, without the need for industrial equipment, vacuums, or scales. There are several types of resin that are used in art. Resin can be used in a variety of techniques and incorporated into mixed-media designs. Resin is a multi-faced craft. Contemporary resin designs are very sophisticated, and resin is used for many innovative applications. Ranging from crystal clear to translucent glowing hues, resin has a wonderful appeal for its glass-like properties. It can be used to simulate other materials or as an element in mixed-media designs. (Haab, 2006, p. 9–20)

Resin, any natural or synthetic organic compound consisting of a noncrystalline or viscous liquid substance.

Natural resins are typically fusible and flammable organic substances that are transparent or translucent and are yellowish to brown in color. They are formed in plant secretions and are soluble in various organic liquids but not in water. Most natural resins are exuded from trees, especially pines and firs. Resin formation occurs as a result of injury to the bark from wind, fire, lightning, or other cause. The fluid secretion ordinarily loses some of its more volatile components by evaporation, leaving a soft residue at first readily soluble but becoming insoluble as it ages. The ancient Chinese, Japanese, Egyptians, and others used resins in preparation of lacquers and varnishes. Natural resins may be classified as spirit-soluble and oil-soluble. Among the former ones, there are balsams, long popular as a healing agent; turpentines used as solvents; and mastics, dragon's blood, dammar, sandarac, and the lacs, all used as components of varnishes. The oil-soluble resins include rosin, derived along with turpentine from the long-leaf pine and long used for a variety of applications, including soapmaking; copals, used in varnishes; amber, the hardest natural resin, fabricated into jewelry; Oriental lacquer, derived from a tree native to China; and cashew-nutshell oil, derived from cashew nuts.

Fig. 33: *Insect trapped in tree resin. (britannica.com)*

In modern industry natural resins have been almost entirely replaced by synthetic resins, which are divided into two classes, thermoplastic resins, which remain plastic after heat treatment, and thermosetting resins, which become insoluble and infusible on heating. Synthetic resins comprise a large class of synthetic products that have some of the physical properties of natural resins but are different chemically. Synthetic resins are not clearly differentiated from plastics. (britannica.com, 2015)

Resin is a liquid plastic that becomes a solid following a chemical exothermic reaction. Heat is generated when a hardener or catalyst is introduced to a base resin, causing polymerization (linking of the polymers) of the plastic. The resin goes from a liquid state to a solid rigid form in this process, and remains as such.

New resin formulas, including low-odor products, are easy to mix and measure. There are a number of resin products on the market today, offering more options than were available in the past, making this an exciting craft for the first time. (Haab, 2006, p. 9–20)

4.4.1 Resin Types

The resins that are used in fibre reinforced composites can also be referred to as "polymers". All polymers exhibit an important common property in the fact that they are composed of long chain-like molecules consisting of many simple repeating units. Man-made polymers are generally called "synthetic resins" or simply "resins". Polymers can be classified under two types, "thermoplastic" and "thermosetting", according to the effect of heat on their properties.

Thermoplastics, like metals, soften with heating and eventually melt, hardening again with cooling. This process of crossing the softening or melting point on the temperature scale can be repeated as often as desired without any appreciable effect on the material properties in either state. Typical thermoplastics include nylon, polypropylene and ABS, and these can be reinforced, although usually only with short, chopped fibres such as glass.

Thermosetting materials, or "thermosets", are formed from a chemical reaction in situ, where the resin and hardener or resin and catalyst are mixed and then undergo a non-reversible chemical reaction to form a hard, infusible product. In some thermosets, such as phenolic resins, volatile substances are produced as by-products (a "condensation" reaction). Other thermosetting resins such as polyester and epoxy cure by mechanisms that do not produce any volatile by products and thus are much easier to process ("addition" reactions). Once cured, thermosets will not become liquid again if heated, although above a certain temperature their mechanical properties will change significantly.

Although there are many different types of resin in use in the composite industry, the majority of structural parts are made with three main types, namely polyester, vinylester and epoxy. Besides polyesters, vinylesters and epoxies there are is number of other thermosetting resin systems that are used in where their unique properties are required. We have about 15 another commonly used types of resins.

4.4.2 Epoxy Resins

Epoxy resin is widely available and has a variety of applications. The large family of epoxy resins represents some of the highest performance resins of those available at this time. Epoxies generally out-perform most other resin types in terms of mechanical properties and resistance to environmental degradation, which leads to their almost exclusive use in aircraft components. As a laminating resin their increased adhesive properties and resistance to water degradation make these resins ideal for use in applications such as boat building. Epoxy resins are used in art and craft for their visual effect of glass.

The term “epoxy” refers to a chemical group consisting of an oxygen atom bonded to two carbon atoms that are already bonded in some way. The most simple epoxy is the three-member ring structure known by the term “alpha-epoxy” or “1,2-epoxy”. The ideal chemical structure is shown in the figure below and it is the most easily identified characteristic of any more complex epoxy molecule.

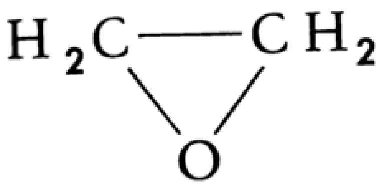


Fig. 34: *Idealised chemical structure of a simple epoxy - ethylene oxide (merriam-webster.com)*

Epoxy resins are formed from a long chain molecular structure similar to vinylester with reactive sites at either end. In the epoxy resin, however, these reactive sites are formed by epoxy groups instead of ester groups. The absence of ester groups means that the epoxy resin has particularly good water resistance. The epoxy molecule also contains two ring groups at its center which are able to absorb both mechanical and thermal stresses better than linear groups and therefore give the epoxy resin very good stiffness, toughness and heat resistant properties.

Usually identifiable by their characteristic amber or brown colouring, epoxy resins have a number of useful properties. Both, the liquid resin and the curing agents, form low viscosity easily processed systems. Consistency of liquids to hard, brittle materials. Under normal conditions, they are virtually unlimitedly storable.

Epoxy resins are easily and quickly cured at any temperature from 5 °C to 150 °C, depending on the choice of curing agent. At this type of resin types, it is possible to accelerate the cure by the application of heat, so that the higher the temperature is the faster the final hardening will occur. Curing at temperatures of 100 °C to 200 °C for several hours. (Ducháček, 2006, p. 104) This can be most useful when the cure would otherwise take several hours or even days at room temperature. One of the most advantageous properties of epoxies is their low shrinkage during cure which minimises fabric "print-through" and internal stresses. Epoxies differ from polyester resins in that they are cured by a "hardener" rather than a catalyst. The hardener, often an amine, is used to cure the epoxy by an "addition reaction" where both materials take place in the chemical reaction. The chemistry of this reaction means that there are usually two epoxy sites binding to each amine site. This forms a complex three-dimensional molecular structure.

High adhesive between resin and reinforcement fibres is necessary for any resin system. The adhesion of the resin matrix are important to the fibre reinforcement or to a core material in a sandwich construction. Vinylester resin shows improved adhesive properties over polyester but epoxy systems offer the best performance of all, and are therefore frequently found in many high-strength adhesives. High adhesive strength and high mechanical properties are also enhanced by high electrical insulation and good chemical resistance. Epoxies find uses as adhesives, caulking compounds, casting compounds, sealants, varnishes and paints, as well as laminating resins for a variety of industrial applications. The adhesive properties of epoxy are especially useful in the construction of honeycomb-cored laminates where the small bonding surface area means that maximum adhesion is required. (britannica.com, 2015)

5 PRACTICE

The main aim of this thesis is designing product for CNC routers with application of luminous resin. After the research of CNC designs and introduction sources of inspiration were determined requirements for real designed object. Last but not least, the design process of this object was described there.

5.1 Sources of inspiration

Research relates to the use of the combination of resin or luminescent glow-in-the-dark resin and wood material together. There are jewels design inspirations and lights design inspirations in this research too. Every one of these products was the inspiration for the design of this resultant diploma thesis project.

5.1.1 DIY Glowing Inlaid Resin Shelve

Back in August 2014, industrial designer Mat Brown shared a method for creating wood shelves inlaid with glow-in-the-dark resin.

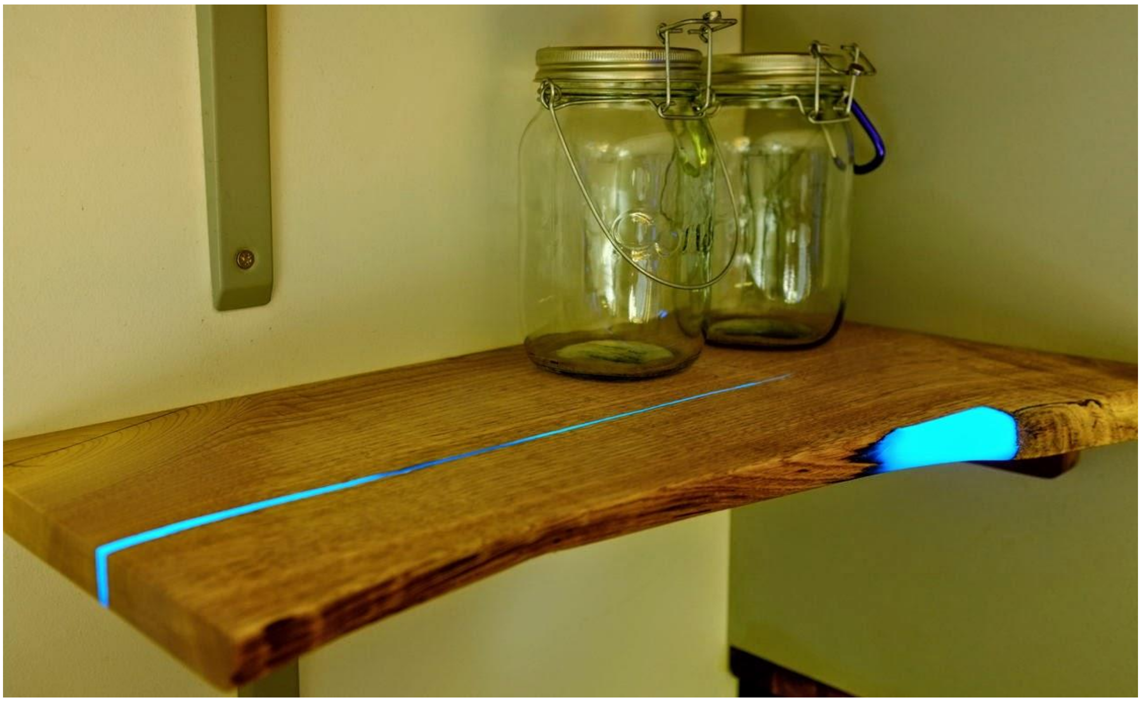


Fig. 35: *DIY Glowing Inlaid Resin Shelve (thisiscolossal.com)*

5.1.2 Wood tables embedded with photoluminescent resin

Not to be outdone, Mike Warren just released a tutorial of how to fill the naturally formed voids in pecky cypress with photoluminescent powder mixed with clear casting resin. The effect is pretty amazing. (thisiscolossal.com, 2014)

Fig. 36: *Glow table (instructables.com)*

Fig. 37: *Glow table – detail (instructables.com)*

Photoluminescent (glow) powder mixed with clear casting resin fills the naturally formed voids in Pecky Cypress hardwood, creating a unique and stunning table. The glow powder charges up in sunlight and emits a cool blue glow when in partial or complete darkness. Placing this table near a window will allow it to collect rays from the setting sun and then set off a pleasant glow from the transition from twilight to evening. The type of wood Mike Warren used for this table is known as "pecky cypress", which is regular cypress that has been naturally damaged with a fungal growth inside causing sections to rot. These damaged pockets can be easily removed and create cavities in the wood which are perfect for filling with resin and glow powder. The pockets of damaged (rotten) cypress are soft and can easily be removed with compressed air and some light digging with a hand tool. (instructables.com, 2015)

5.1.3 World map on the tabletop

This table with World map contour on desktop was made by CNC router. Birch plywood was used for few hexagons glued together and embedded by resin, combined with blue glow in the dark pigments.

Fig. 38: *World map on the tabletop (imgur.com)*

Fig. 39: *Milling the contour (imgur.com)*

Fig. 40: *Hexagons with contour (imgur.com)*

5.1.4 Simple desk with built in LED and glow in the dark stripes.

This simple glow in the dark stripes was made by CNC milling on massive desktop (140 × 70 cm). LED strips were used there and embedded by blue resin. It was coated with clear varnish three times. (imgur.com, 2015)

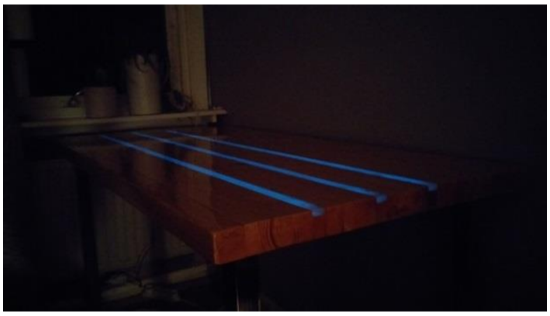


Fig. 41: *Desk with LED – ON (imgur.com)*

Fig. 42: *Desk with LED – OFF (imgur.com)*

5.1.5 The front door

The front door was made for special tiny house in Toronto by CNC router. There was used cedar wood with epoxy resin combined with blue glow in the dark pigment. Powder is from Glow Inc brand and should last forever. The door was made in Frank Lloyd Wright design. (ywwg.com, 2015)

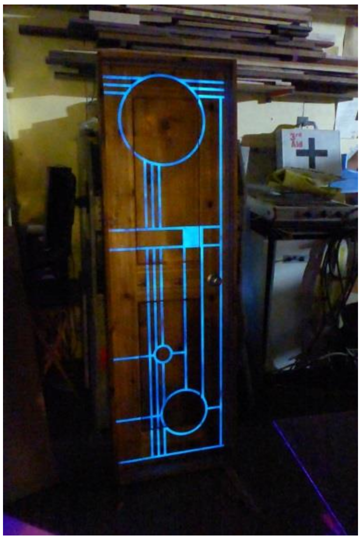


Fig. 43: *The front door – milling (ywwg.com)* **Fig. R44:** *The front door – with resin (imgur.com)*

5.1.6 Glow in the dark pattern

A crochet pattern was milled on a big slab of wood at this project. For the luminescent pigment to be more powerful and long-lasting, one should mix it with a transparent material. Polyester resin was used there (very smelly and eco-unfriendly filler). Luminescent pigment was added to the resin and it immediately turned into a deep coral blue.

Fig. 45: *Glow in the dark pattern – workflow (fabacademy.org)*

The smaller wood pockets were filled directly with the mixing stick, to avoid overspill. Then the surface was covered with a dark plastic (polyester does not like air and light while curing). After curing it was laid by the window for a couple of hours and then brought to a dark room. The pigments showed a pretty powerful and long-lasting glow-in-the-dark capacity. (fabacademy.org, 2015)

5.1.7 Luxury Led Backlit Wood Furniture

Like an enchanted forest of trees that light up at night, this fascinating luxury LED backlit wood furniture and ethnic collection of tables, seats and lamps, designed by Giancarlo Zema for Luxyde, uses natural materials like wood scratched by several resin rings that lighten at sunset. They are ideal for the most exclusive interior decoration, from hotels to nautical furnishing. (giancarlozema.com, 2010)

Fig. 46: *Furniture with resin (giancarlozema.com)* **Fig. 47:** *Glowing resin (giancarlozema.com)*

5.1.8 Wood Jewelry

British artisan, Mat Brown is an accomplished metal smith as well as a wood worker – an unusual combination of skills. He made inlaid glow-in-the-dark epoxy and wood contemporary jewelry collection.

Fig. 48: *Atom pattern (beadinggem.com)* **Fig. 49:** *Zigzag pattern (beadinggem.com)*

Mat uses a variety of sustainably sourced woods for his line. The hollowed out areas are simple given his modern design approach. These are filled with blue glow-in-the-dark epoxy. (beadinggem.com, 2014)

Fig. 50: *Spotted pattern (beadinggem.com)* **Fig. 51:** *Sunshine pattern (beadinggem.com)*

5.1.9 Plexiglass lamp

This plexiglass and wood, unique lamp was designed by Eduard Locota. It is a fusion of massive spruce wood, translucent acrylic glass and LED light. (eduardlocota.com, 2015)

Fig. 52: *Plexiglass lamps (eduardlocota.com)*

5.1.10 Water bright lamp

Water Bright is a fragment, a synthesis of the millennial relationship between wood and water. It´s the story of the profound and romantic rapport, that develops between these two elements in Venice. The light of variable intensity reveals the poetry of this union and referts to the Lagoon atmosphere. Alcarol has patented an elaborate craftsmanship capable of filling only the empty spaces of the wood with a transparent resin capturing the underwater air bubbles that bring the wood back to the original look and conditions in the depths of the Venetian canals.

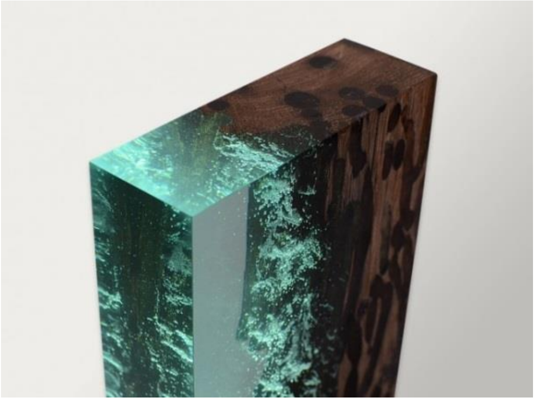


Fig. 53: *Water bright lamp (alcarol.com)* **Fig. 54:** *Detail of lamp (alcarol.com)*

Dimensions of this lamp are 11 × 4 × 25 cm. This lamp is made from solid oak wood, extra clear polished resin (colorless or aquamarine), burnished steel base, integrated led system, dimmer metal touch, natural wood surface not covered by resin on the section planes. Selective wood coating is with matt natural effect. (alcarol.com)

5.1.11 Wood Brecce Lamps

Marco Stefanelli's handsome collection of Brecce lamps combine high-tech LED lights and scraps of wood to make a beautiful way to accent a space. The pieces are made from salvaged wood scraps sourced from a lumber mill, a local river, and even the firewood pile. The magic comes with the addition of low-energy LEDs embedded behind a layer of resin.

Fig. 55: *Brecce Lamp (inhabitat.com)* **Fig. 56:** "*The boxer design" of Brecce collection (inhabitat.com)*

The log lamps come in a variety of sizes and can be used as stools or simply as bookshelf lamps. The process required to realize every log lamp is quite work-intensive, requiring a section of the log to be sliced out and then for a silicone cast of the slice to be made. The light is then set in the cast. All the components of the lamp are assembled with screws or by locking the parts together. The lamps are sometimes finished with natural wax or with linseed oil. (inhabitat.com, 2012)

5.1.12 Interior light Moon

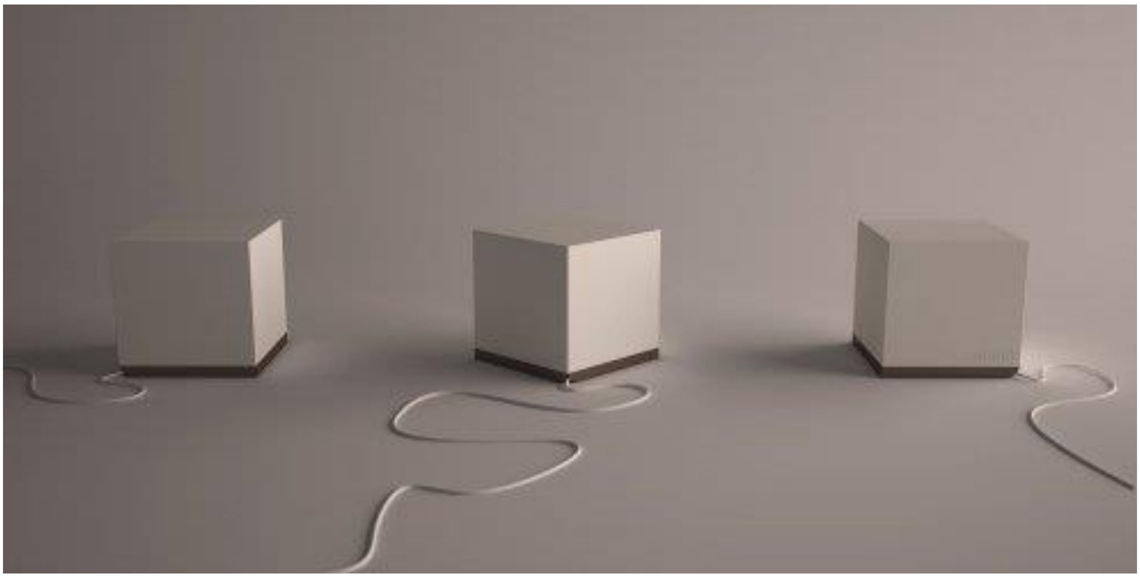


Fig. 57: *Interior light Moon (bvv.cz)*

This stool lamp is inspired by starry night sky. The luminance of the light source is comparable to the pair of candles. Cubic lamp with edge of 200 mm is made of hard decorative wood (prototype - oak) and modeler gypsum, interwoven with optical fibers. This interior light Moon was designed by Jan Černý. Dimensions of this lamp are 20 × 20 × 20 cm. (bvv.cz, 2016)

5.2 Analysis of requirements

Product requirements were determined based on searches of inspirational sources. The main requirement was to use luminescent resin in an interesting decor, or shape, which would be milled by CNC routers. Material for its manufacture has to be a wood or a wood-based material. It should be a machinable material, which is not prone to chipping and whose edges do not break. Also, it has to be material which adheres well to the resin. Last but not least it must have an attractive appearance. The product should serve as a mood lighting on the nightstand. The main aim is that the luminescent resin will glow after nightfall or after turning off the lights built inside the object. The object will therefore serve as a lamp and decoration simultaneously. Design of the lamp should be modern and should be easily producible.

5.3 Case studies

At this chapter, there is the description of work methodology of design of object FOTON. Case studies which led to the creation of the product's final version are descripted in the text regarding development of this project. Experiments with shapes, materials, pigments and resins are presented there. Noted mind maps during design process are there and all design process is documented with photos.

5.3.1 First case study

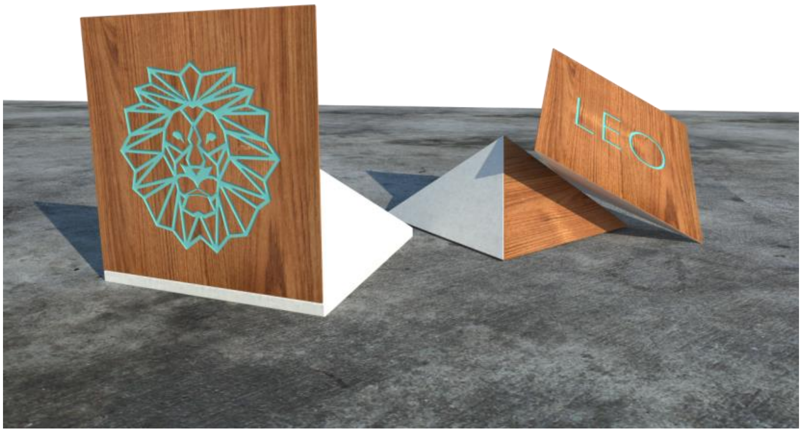


Fig. 58: *LEO lamp – pyramids with luminescent resin*

The object with the working title "LEO" was the first case study. The main idea of this project was to create an element that would be variable and which would glow in the dark without using electricity. This object was created from five separate identical pyramids. Pyramids folded together would form an incomplete cube. Each pyramid would have an milled ornament on its square base. This ornament would be sealed with luminescent resin. There were two types of ornaments. First was the inscription "LEO" and second was a geometric portrait of a lion.

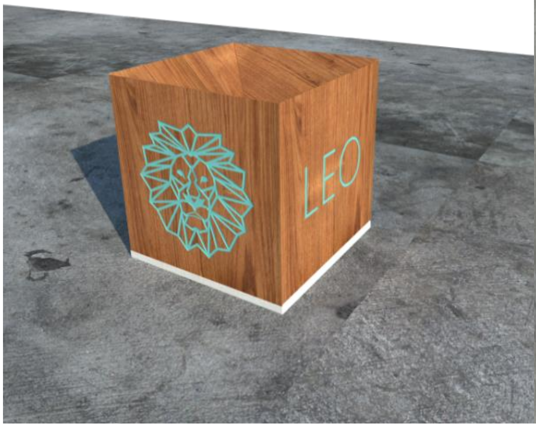


Fig. 59: *LEO lamp – standing on board* **Fig. 60:** *LEO lamp – hanging on wall*

A working model wasmade on CNC router according to the graphic design. This model was made of one peace MDF (medium-density fiberboard) with measures 20 × 20 × 15 cm. This material is ordinarily used for milling, but during production, there was a problem with this material. During milling, the top of MDF pyramid was torn off. This problem was repeated even after the adjustment of tool movement. This problem could be solved by choosing a harder material (e.g. harder MDF, plywood or solid wood).

Fig. 61: *Cube of MFD material* **Fig. 62:** *Milling of MDF pyramid*

All pieces were put together and visually evaluated. Visual part of the cube did not meet expectations and therefore new shape for the object was searched. It was discovered by combination of two pyramids, connected to each other on square base. This new visual was approved and subsequently elaborated.

Fig. 63: *Visual variations with pyramid model*

The new shape offered new use and processing of the object. New design sketches were drawn up and the light source was incorporated to the project. 3D graphic visuals with variations of this shape were created gradually.

The product's design was also focused on the use of light and its combination with the luminescent resin. The technological procedure was also reassessed. Construction from five pieces was changed to construction from two identical segments. These segments will be joined together. The product will be hollow and thus also lighter. There will be a place for light that will shine through luminescent resin. Thanks to this direct light, luminescence will have more intensity.

5.3.2 Second case study

Second case study, with new shape, was designed with predominance of luminescent resin. Here, however, the light intensity was too intensive for mood lighting. Furthermore, there should be probably a problem with the adhesion of resin to wood in that size. There would have to be some reinforcement (e.g. steel wire, reinforcing nylon network).

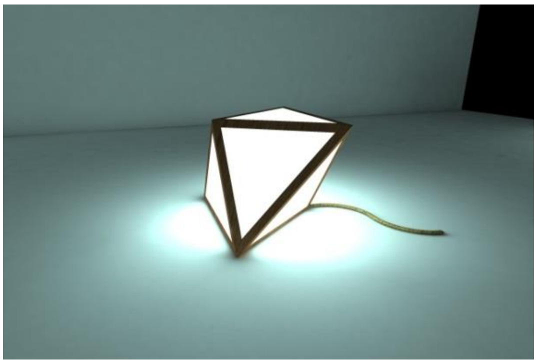


Fig. 64: *Second graphic case study*

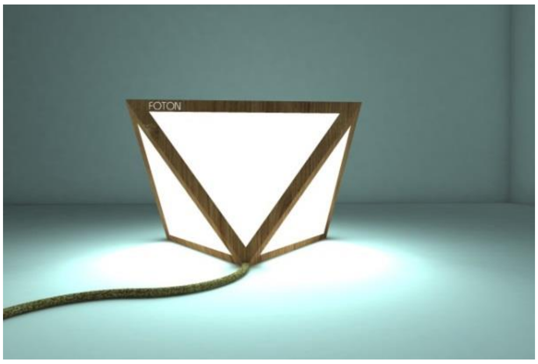


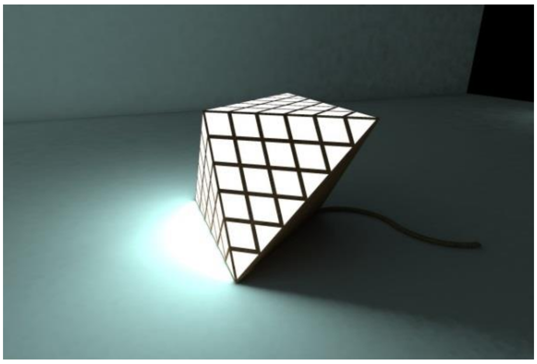
Fig. 65: *Rear view*

5.3.3 Third case study

Third case study was inspired by The Louvre Pyramid (by architect Ieoh Ming Pei) which is the modern glass entrance of the Louvre Museum in Paris.

Fig. 66: *The Louvre Pyramid in Paris – inspirational photo (aviewoncities.com)*

One of two pyramids surface is divided into small triangles at this graphic variant. The second one is without milled pattern, just wood construction. Also, there are small pieces of material that could cause a problem when CNC milling.



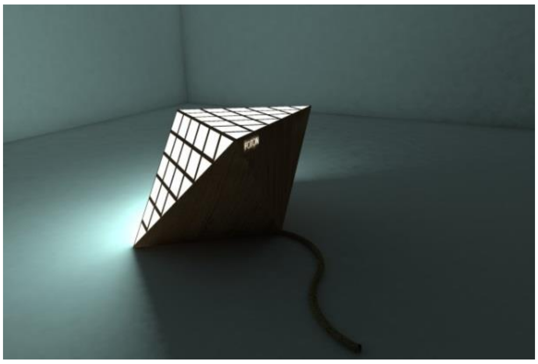


Fig. 67: *Third variant with „Louvre“ pattern* **Fig. 68:** *Third variant - rear view*

5.3.4 Fourth case study

The fourth graphic version already qualifies for mood lighting. At the edge, there were used rectangular sections placed in the point of connection of the two pyramids' bases. The design is minimalist and has a bit cosmic impression.

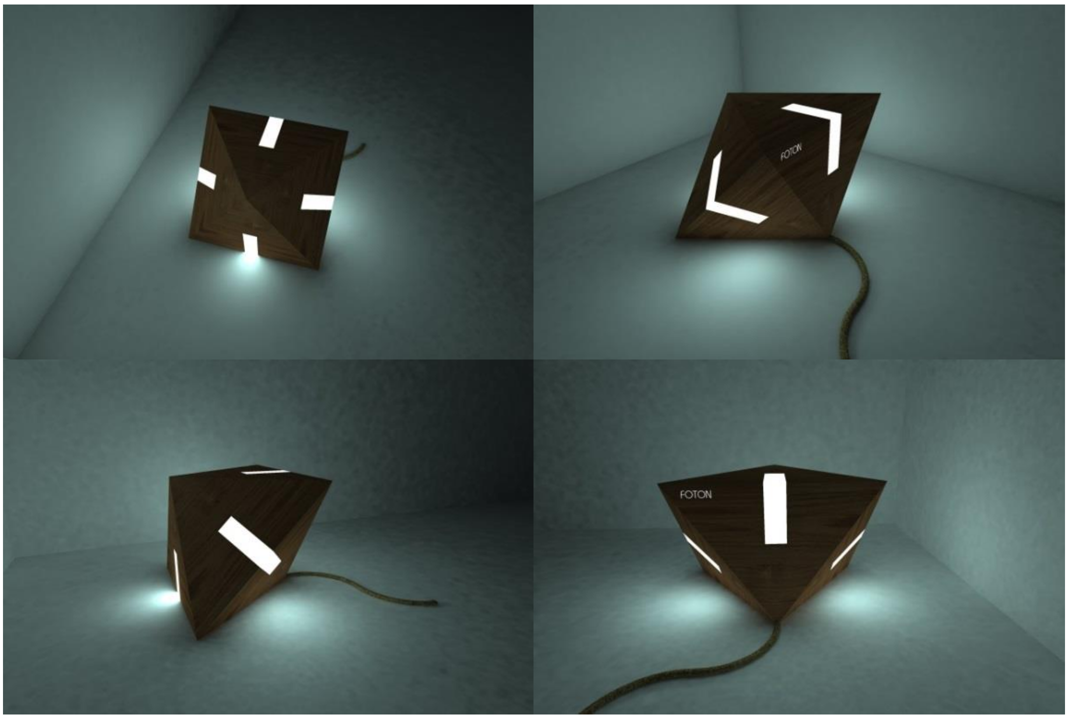


Fig. 69: *Fourth variant with minimalistic pattern*

5.3.5 Fifth case study

The fifth design of lamp is formed from large number of holes. These holes are milled in different sizes and they are arranged randomly. These holes are located in two vertices of both pyramids. Thanks to the effect of small diffused parts of light, project was named "FOTON" It means "photon" in Czech, the smallest particle of light.

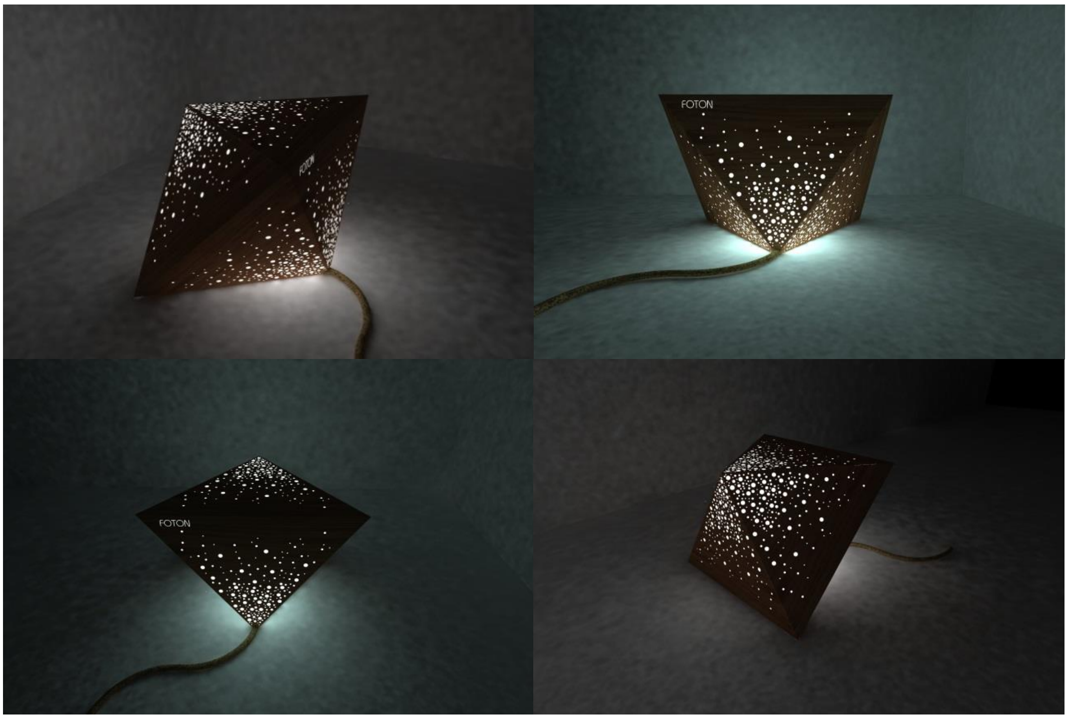


Fig. 70: *Fourth variant with minimalistic pattern*

Graphic visualizations of FOTON lamp were made in four views. Small holes create pattern on the wall, reminding starry night sky.

Experiment with resin was next. Pattern from the fourth and fifth case studies was selected for this experiment. To evaluate luminescent resin's luminosity through the holes, there were used two thicknesses of MDF material, 8 mm and 18 mm.

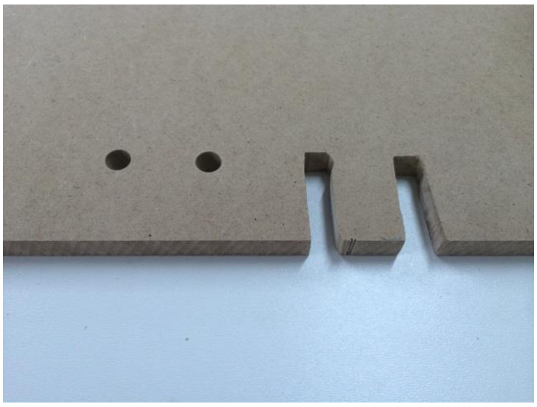


Fig. 71: *Variants of holes*

Fig. 72: *Variants of thickness of the material*

For this experiment, there was used epoxy resin EPOLEX (resin suitable for bonding) in combination with luminescent pigments. There were used two types of pigments colors for comparison of luminosity. These pigments were mixed with a resin and applied on milled holes.

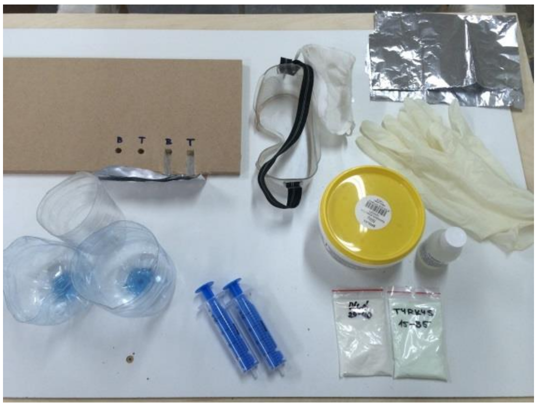


Fig. 73: *Workspace for experiment*

Fig. 74: *Epoxy resin EPOLEX*

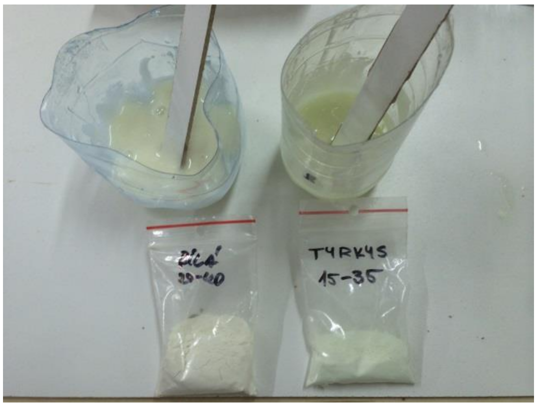


Fig. 75: *White and turquoise pigments*

Fig. 76: *Pigments glows in dark*

StardustColors pigments were used for this product. These pigments are photoluminescent, based on rare oxides of alkaline soil. The product is non-toxic, harmless and it is not radioactive. Pigments have a lifespan from 10 to 20 years. Pigments have high physical and chemical stability (temperature > 1300 °C, good resistance to UV radiation). These pigments are in accordance with the safety standards for toys (EN 71–5/A1, EN 71–3:1994 and A1:2000). White pigments (grain size of 20–40 μ), and turquoise pigments (about 15–35μ) were chosen for this experiment. Both types of pigments were illuminated by light. The result was that turquoise pigments glowed much more than a white pigments in the dark.

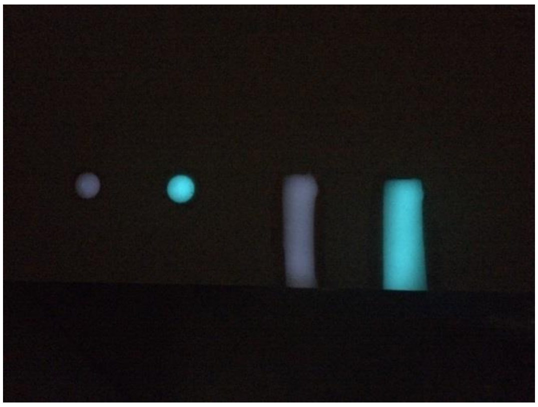
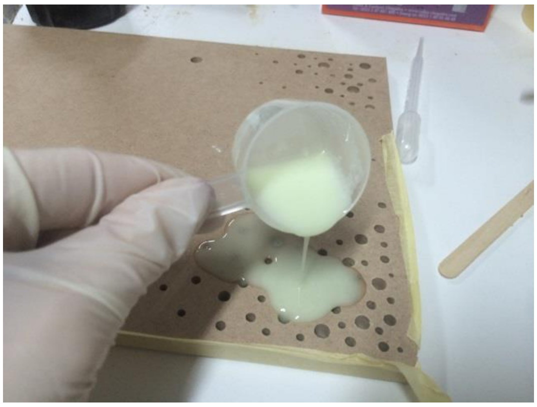


Fig. 77: *First experiment with EPOLEX resin* **Fig. 78:** *Luminous resin glows in dark*

The requirement was that the resin fills the holes. This requirement was met but it was difficult, because the consistency of resin was too dense. Cléopátre epoxy resin was selected for the second experiment. The resin is used for forming jewelry. It is "casting crystal resin".

Fig. 79: *Second experiment with Cléopátre resine* **Fig. 80:** *Resin with turquoise pigments*



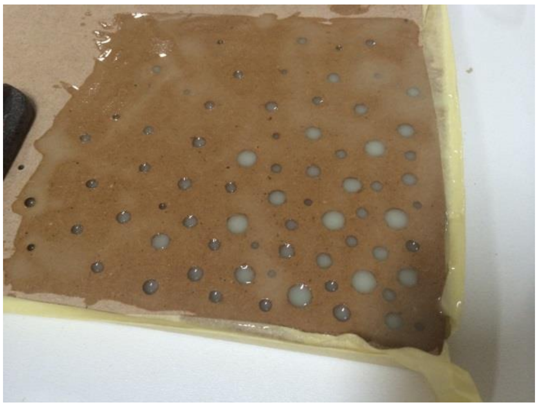


Fig. 81: *Better consistency of resin* **Fig. 82:** *Resin in holes*

The consistency of this resin was sparse. Pigment was better mixed into the resin. There was created a test pattern of holes of the desired diameter. This resin seamlessly filled all holes.

The next step was to choose the material. MDF material used for debugging the prototype was replaced by solid wood. Mahogany was used for the final product. Mahogany has better strength and it is a less absorbent wood. There was selected plank, which was dried for 10 years, with thickness of 55 mm. This plank was equalized and formatted by CNC machine Tech Z5 to the desired dimension. The material was glued together to required thickness by dispersion adhesive. Finally the material was sawed into three identical prisms with dimensions 101 × 210 × 210 mm.

Fig. 83: *Glued material together*

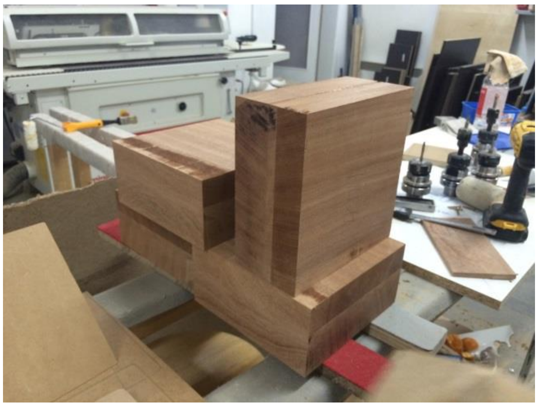


Fig. 84: *Identical prisms*

3D model of the pyramid was developed in the computer program T-flex. This pyramid is one of the half of the model. This model was subsequently transferred to the program Xilog Maestro as an IGES file. It is one of the files, suitable for CAM programming. Any program that is used to produce this model of the light is composed of three basic parts - roughing, finishing of the workpiece surface and supplementary operations (drilling, grooving of locks, etc.).

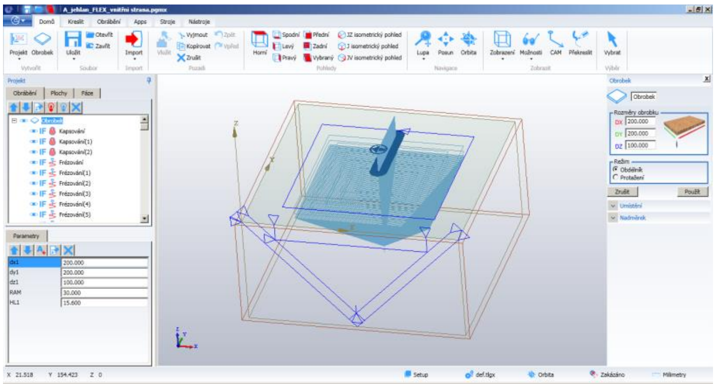


Fig. 85: *3D model in program Xilog Maestro*

First convex portion of each of the pyramids was milled by CNC machine Tech 5. This hole in the shape of an inverted pyramid was milled by using two tools. Tool “Roughing spiral cutter - positive (D16×120 L170 S16)” was used for roughing. “Groove spiral cutter - positive (D16×120 L170 S16)” was used as the finishing tool. The time required for the milling of this part was about 55 minutes (one part).

Fig. 86: *Spiral roughing cutter - positive (igm.cz)* **Fig. 87:** *Groove spiral cutter - positive (igm.cz)*

Fig. 88: *Mahogany prism on CNC* **Fig. 89:** *Milled shape of an inverted pyramid*

Special hole was programmed for the lock system. Two screws, half round head of size 4 × 16 mm, were used as a counterpart for those holes. This makes the model's opening and closing invisible and simple. These holes were made through the "Cutter for cylindrical groove (S8 D9,5×11 d4,8 HM)". The time required for milling hole was about 30 seconds.

Fig. 90: *Cutter for cylindrical groove (igm.cz)*

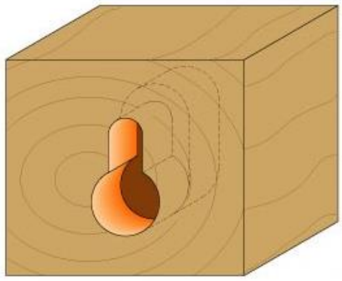


Fig. 91: *Special hole for lock system (igm.cz)*

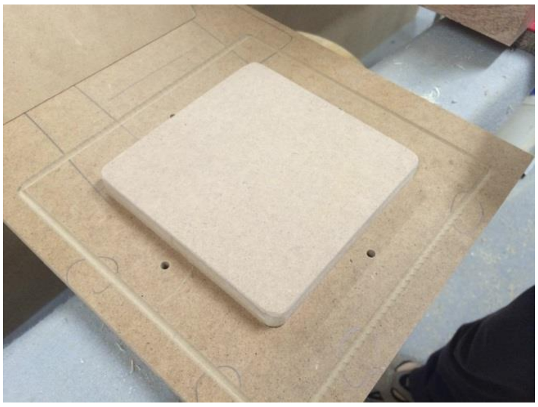


Fig. 92: *Stand from MDF material*

Very precise stand from MDF material was made for milling of the outer face of the pyramid. This stand was calibrated to zero point of the machine and of the workpiece. Stand was made for repeated fixing the workpiece (already partially machined) back to the CNC machine. It ensures stabilization of the product on the desired location. It guarantees maximum of precision machining and control over the course of return operations. The time required for milling the outer surface of the pyramid was 2 hours.

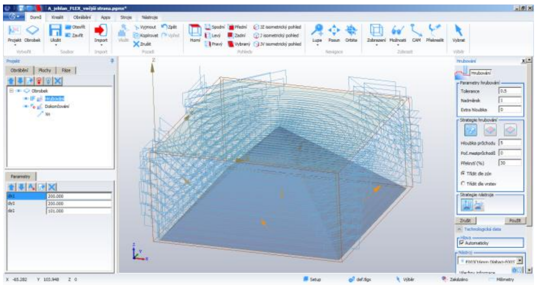


Fig. 93: *Roughing*

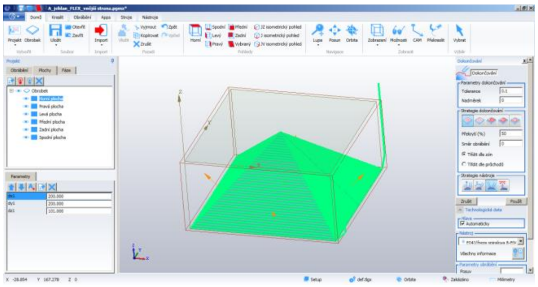


Fig. 94: *Finishing of the workpiece surface*

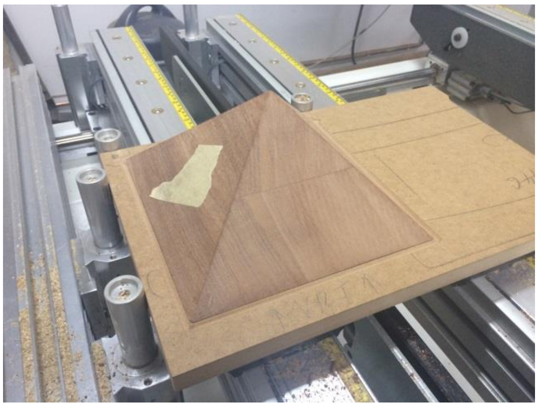


Fig. 95: *The outer surface of the pyramid*

Location for holes on the pyramid's surface was created in the computer program AutoCAD 2017. It was created DXF file. This file was loaded again to semifinished project in program Xilog Maestro. Parameters of each holes were defined and projected on inclined planes of machined surfaces pyramid. Dimensions of one pyramid are 150 × 200 × 200 mm.

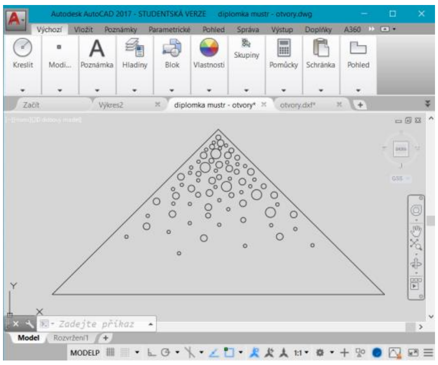


Fig. 96: *Created holes in program AutoCAD 2017*

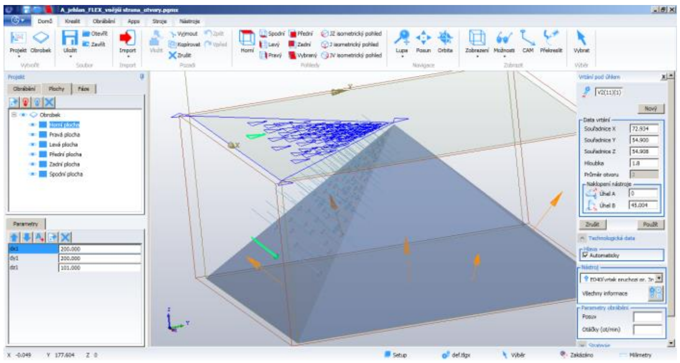


Fig. 97: *Projected holes in program Xilog Maestro*

Holes were defined on diameters of 2, 3, 4, 6 mm. "Through-hole dowel drills (S8 HW D2×30 L56, L56 HW D3×30 S8, S8 HW D4×30 L56, L56 HW S8 D6×3)" were used as tools.

Fig. 98: *Through-hole dowel drill (igm.cz)*

Fig. 99: *Drilling holes on CNC machine*

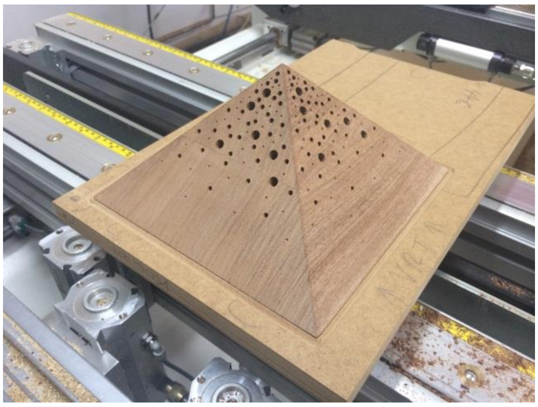


Fig. 100: *Drilled holes*

Fig. 101: *Both parts of the model*

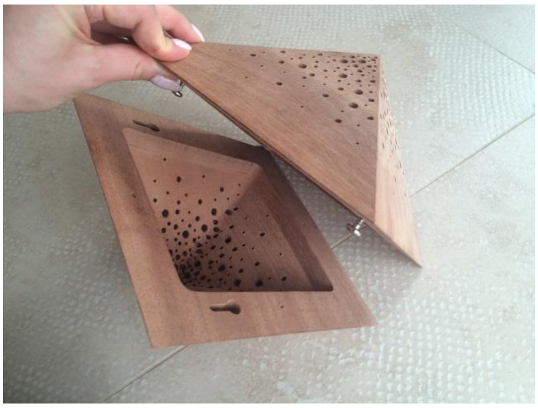


Fig. 102: *Detail of join*

Surface was manually sanded by sandpaper with grit 80, 120 and 400. The milled holes were cleaned, to have better throughput for resin. Screws were mounted and fixed to serve as joint of the two parts of model. Standing combined model has dimension of 145 × 145 × 200 mm.

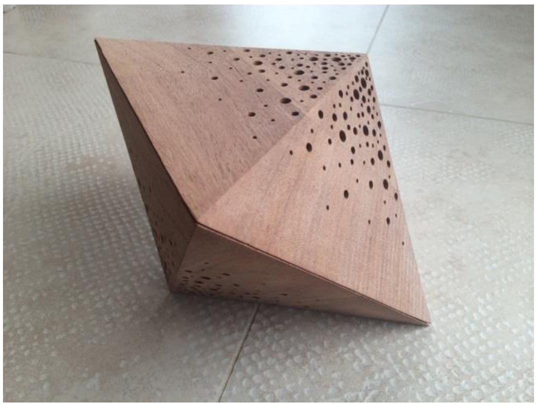


Fig. 103: *Locked model*

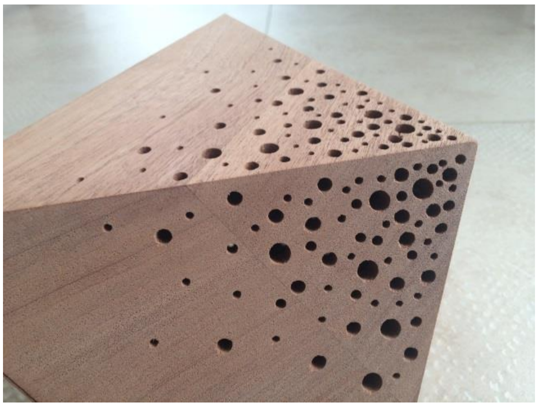


Fig. 104: *Detail of holes*

Subsequently, the model was wrapped with metallized insulating adhesive tape (paper tape could flow through). It was blended mixture of epoxy resin Cléopátre (100 ml) and turquoise pigments (10 g). Model was laid with tip down, and all of those holes were poured by resin. Because the top of the pyramid was milled through with lot of holes, the resin was left there in greater thickness for higher rigidity.

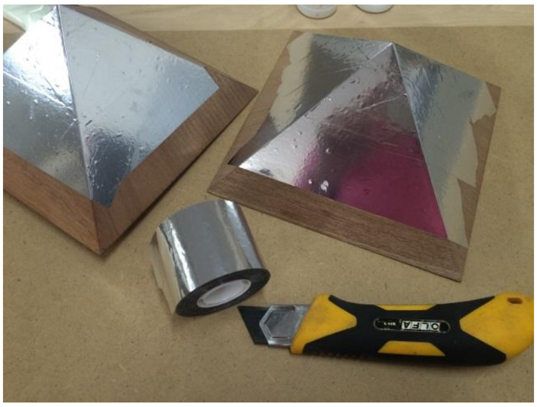


Fig. 105: *Model wrapped with tape*

Fig. 106: *Holes poured by resin*

Overmold model was left in this position at room temperature. After 16 hours the resin has been at the stage of gelation. After 48 hours the resin has been cured.

Fig. 107: *Resin in tip of the model*

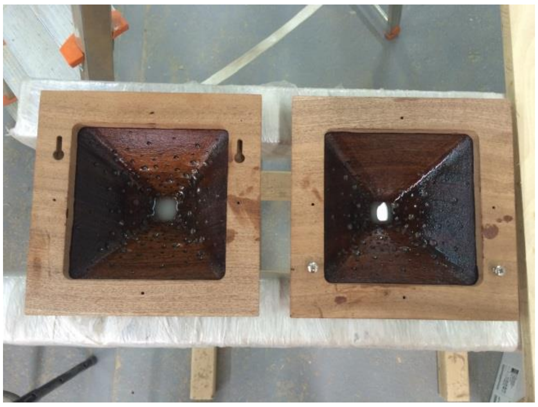


Fig. 108: *Both parts of the model with the resin*

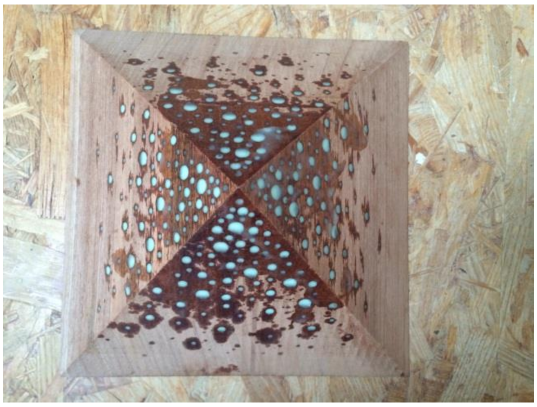


Fig. 109: *Model with cured resin in holes*

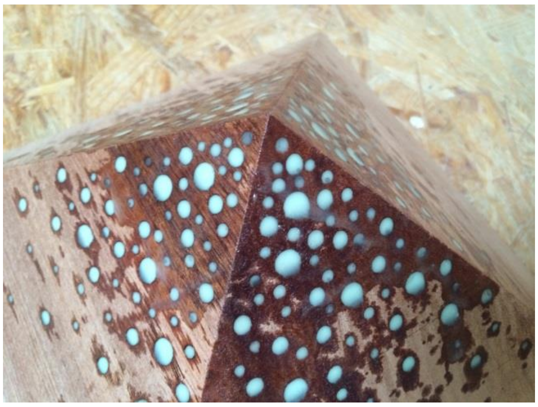


Fig. 110: *Detail of holes with cured resin*

The resin was cleaned from a model by CNC machine. Tilted surfaces was milled with an accuracy of 0.1 mm. The last step was creating a hole for the supply cable and vents for transformer, which is located inside of the lighting. Finally, the cover for wall light was made of HDF, also vented. Three “Silicone stop dampers (selfadhesive, transparent, 3 × 10 mm)” were glued on the model. It ensures ventilation for light and it is easier to lift the model from a desk.

Fig. 111: *Transparent wax oil (floorwood.cz)* **Fig. 112:** *Surface finish*

Fig. 113: *Cover for wall light* **Fig. 114:** *Silicone stop damper*

Fig. 115: *Through hole for the cable* **Fig. 116:** *Vents in model*

“Transparent wax oil OSMO” was used for the surface’s finishing.

Adhesive “LED strip 12V EPISTAR IP20 60 - warm white” of length of 50 cm was used for illumination. This LED strip has been connected to the transformer “Panlux DRT006/12 LED DRIVER 6W 12V DC”. “Power cable to movable inlets 2 × 0,75 mm^2, transparent PVC.” was used as the power cable.

“Flat plugs network 230V/10A” from Bohemia design was used. This company is a Czech manufacturer of design lighting fixtures and accessories. Plugs has been selected transparent, as well as cable. This combination does not attract attention.

Fig. 117: Transparent cable and plugs

Fig. 118: *LED driver*

Touch sensor “switch TS01 Touch 12V/8A DC” was used for switching the light. This sensor is used specially to control LED lighting. Its sensitivity is 20–30 mm depending on the type (A, B, C). Its dimensions are 43 × 48 × 9 mm. This touch sensor is connected between the transformer and lighting. Touch switch is located inside of the model. This sensor automatically switches when the hand approaches to the surface of the model. This sensor eliminates the need of switch on cable.

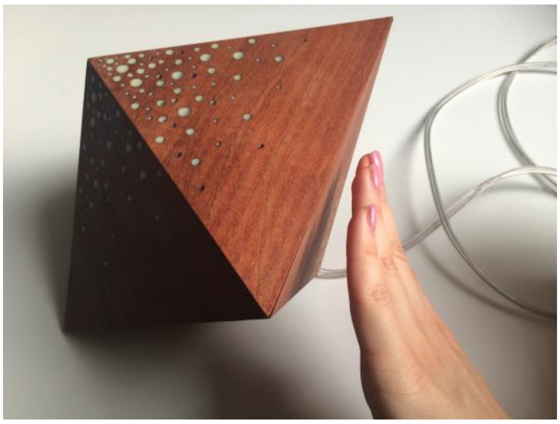


Fig. 119: *Touch switch (dvirka-kovani-kuchyne.cz)*

Fig. 120: *Touch switch – position on/off*

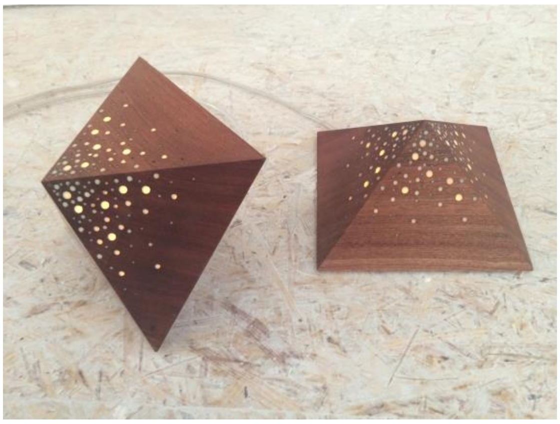
All electrical installations were placed directly into the body of the model. This placement was anticipated and the model was adapted for this function.

Fig. 121: *Electrical installations*

Fig. 122: *LED*

Fig. 123: *Finished model of light FOTON*

Fig. 124: *FOTON – background*



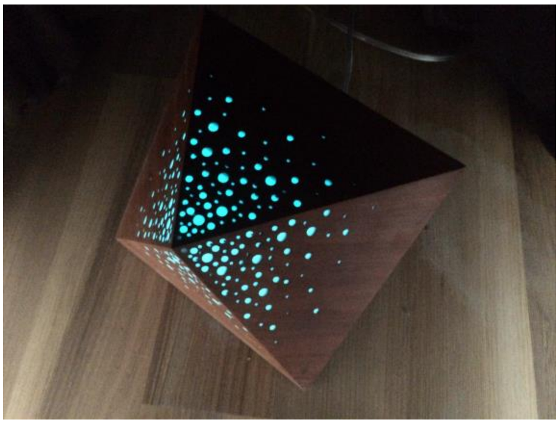


Fig. 125: *Lamps FOTON – two variants*

Fig. 126: *Lamp FOTON – glow-in-the-dark*

Fig. 127: *Lamp FOTON – on the nightstand*

Fig. 128: *Lamp FOTON*

6 DISCUSSION AND RESULTS

Currently, there are a lot of modern technologies, which can be used to produce design products. All these technologies require large expertise, there are expensive and space consuming. These technologies include CNC machining. CNC machining is affordable from the competing technologies (such as laser cutting, water jet, plasma cutting etc.) and its operation is derived from the classic craft, which can make the work with these technologies easier. The advantages of this treatment are the use of many materials and its high quality processing. The disadvantages could be demands for programming, frequency of the required machining tools, a lot of noise and dust generated during machining. Also, machining range is limited for example in small pieces and rectangular patterns. Unlike laser cutting, at CNC machining has to be taken of the average machine tool. CNC machine Tech Z5 was used for the production of the own model of the lighting FOTON.

The theoretical part brings the concept of the luminescent resin. The resin itself does not emit light. It ensures pigments, which are mixed into the resin. The mass from pigments and resin is suitable for pouring molds and holes. This mass is very solid after curing and it illuminates after excitation. There are many types of luminescence. This part explains the physical principles of each species and describes in detail the photoluminescence. Luminescent pigments illuminate on this principle. This type of luminescence is often encountered in real life e.g. with escape signs, or clock hands. Use of pigments with resins can offer new applications, especially in lighting design, when pigments light for several hours after excitation. It may be appropriate for the dim lighting of corridors and children's rooms, where there is no need of intense light during the night.

The benefit of the practical part was to use the acquired knowledge and verify its truthfulness. Options of CNC technology have been tried by creating the real model. The model was made of only two identical parts. This allowed the programming of various kinds of processing of different difficulty – both 2D and 3D machining. There were used different tools for the primary roughing and for final finishing. The difference was evident in the quality of surface. While the roughing made rough and uneven surface, finishing program made smooth and flat surface. It depends on the programs and on machine tools as well. In the production of the prototype, there were used two types of material – MDF material (which is a wood-based material) and the solid wood (mahogany). Solid wood was proved as better choice for the final model. Wood is stronger and therefore better workable for this kind of model. Surface of mahogany was smooth after machining and quality, while the surface of the model of MDF was rough and shaggy. MDF material also failed during milling of the tip of the pyramid, when the tip was broken off, because of low strength of material.

Thanks to the experiment with two kinds of resins, there could be evaluated which type of resin was better for pouring into small holes in combination with powdered pigments. These pigments make denser resin, which complicates its pouring into molds and holes. The resin used for the bonding was dense, which resulted in a very bad handling with mixture and watering holes after addition of the pigment. Therefore second type of resin was selected and used specially for pouring into small forms and jewelry. A disadvantage of this resin was the cure time – 48 hours.

As the light sources, there were selected LED strips that were inserted into the model. Construction of model is hollow and it also includes a transformer. Because the transformer is located inside of the model, there has been milled the vents into the bottom of the model. Light is not hermetically sealed and ensures safe ventilation. Turning the lights was resolved by touch switch, which is also located inside of the construction of light. Thanks to this, switches are not outside of the model, only cable for power supply is. The light is easily switched on by placing a hand on the backside model surface.

FOTON light was made in two versions. In addition to the original version of table lamp, there was made wall lighting. Both models offer two kinds of lighting. When using electric lighting, the model has a greater light intensity and individual holes create the impression of a glowing night sky on the walls. Luminescent resin glows after switching off the lights, and creates warm and intimate atmosphere suitable for sleeping.

7 SUMMARY

This thesis brings possibilities of contemporary CNC machines and their innovative use on design field in combination with luminescent resin.

The theoretical part contains an introduction to the topic of CNC machines. It brings a brief history of CNC machines and their contribution to the industry. This part describes software for CNC machine. There is a created research of the most commonly used manufacturing operations, tools and materials suitable for CNC machining. This section also contains examples of already made products that were designed during the study. CNC machines are also compared with competing technologies. Another part is focused on the luminescent resin. This section provides an introduction to the topic of synthetic resins, mainly with epoxy resin, which was used for own product of light FOTON.

Another part of the work contains a theoretical introduction to the luminescence, its history and different types of luminescence. Type of the luminescence, which is used in this work is called photoluminescence and is excited by light. There are luminescent pigments what emits this light after excitation. The result of mixing this pigments and resin is luminous resin.

The creation of broader view in CNC machines, including using of luminescent resin, is the main contribution to the theoretical part. The combination of these two themes was not yet so elaborated at domestic design field, so this information was primarily drawn from foreign sources.

The practical part of this work focuses on the design and manufacturing of own lighting model. This model is produced using CNC technology in combination with luminescent resin. This section includes a search of design, not only in the field of lighting. This research was an inspiration to create own design, intimate lighting. The entire manufacturing processes of the model of light FOTON, from the first draft to the final product is described and photographed. There are also experiments with pigments and resins. CNC machine Tech Z5 was used for manufacture this product.

The benefit of the practical part was to use the gained knowledge and verify their veracity in the production of own product. Original design element for indirect lighting of corridors and rooms was created by combining CNC technology and luminescent resin. This lighting offers dual – illuminated using electricity (internal LED illumination) or natural sunlight (radiation of luminescent resin lasts 5 hours without electricity after excitation by daylight or another external light).

8 ZÁVĚR

Diplomová práce přibližuje možnosti současných CNC strojů a jejich inovativní využití na poli designu v kombinaci s luminiscenční pryskyřicí.

Teoretická část práce obsahuje úvod do problematiky CNC strojů. Přibližuje krátkou historii CNC strojů a jejich přínos pro průmysl. Je zde popsáno řízení CNC strojů a je vytvořena rešerše nejčastěji používaných výrobních operací, nástrojů a materiálů vhodných pro CNC obrábění. Tato část obsahuje i ukázky již zhotovených výrobků, které byly navrženy v průběhu studia. CNC stroje jsou také porovnávány s konkurenčními technologiemi.

Další část práce se zaměřuje na problematiku luminiscenční pryskyřice. Tato část obsahuje úvod do problematiky syntetických pryskyřic. Kapitola se zabývá především epoxydovou pryskyřicí, která je použita pro výrobu modelu. Další část teoretické práce obsahuje úvod do problematiky luminiscence, její historii a rešerši jednotlivých druhů luminiscence. Luminiscence, jež je využita v této práci se nazývá fotoluminiscence a je vybuzena světlem. Tuto luminiscenci vytváří pigmenty, které po nasvícení vyzařují světlo. Smícháním pryskyřice a luminiscenčních pigmentů pak vzniká ona luminiscenční pryskyřice.

Hlavním přínosem teoretické části práce je vytvoření širšího přehledu v oblasti CNC strojů s využitím luminiscenční pryskyřice. Kombinace těchto dvou témat nebyla na tuzemském poli designu ještě tolik propracována, proto byly informace čerpány především ze zahraničních zdrojů.

Praktická část této práce se zaměřuje na návrh a výrobu vlastního modelu osvětlení s využitím CNC technologie a luminiscenční pryskyřice. Tato část obsahuje rešerši designu, nejen v oblasti osvětlení. Tato rešerše byla inspirací pro vytvoření vlastního designu intimního osvětlení. Dále je zde zaznamenán vývoj vlastního produktu osvětlení FOTON, od prvních návrhů po finální výrobek. Je zde popsán a vyfocen celý procesy výroby, použité materiály a nástroje. K výrobě tohoto výrobku byl použit CNC stroj Tech z5. Dále jsou zde uvedeny i experimenty s různými druhy pryskyřic a pigmentů.

Přínosem praktické části bylo použití získaných poznatků a ověření jejich pravdivosti při výrobě vlastního výrobku. Kombinací CNC technologie a luminiscenční pryskyřice vznikl originální designový prvek pro nepřímé osvětlení chodeb a místností. Toto osvětlení nabízí duální použití – osvětlení pomocí elektrické energie (vnitřní led osvětlení) a osvětlení využívající přirozené sluneční světlo (luminiscenční pryskyřice po excitaci vydrží svítit až 5 hodin bez elektrické energie).

9 REFERENCES

Publications:

ALBERT, A. (2006): *Understanding CNC Routers*, FP Innovations, Forintek, p. 105. Available at: http://www.solutionsforwood.ca/_docs/reports/UnderstandingCNCRouters.pdf

BRADOVÁ, B. *Luminiscence in art education* [online]. České Budějovice, 2011 [Accessed. 2017-03-02]. Available at: http://theses.cz/id/9pr8l8/Luminiscence_ve_VV-DP_s_plohami.pdf. Diploma thesis. University of South Bohemia in České Budějovice. Vedoucí práce Mgr. Aleš Pospíšil.

COLLINS, P., CUMMINGS C., DITTRICH W., JONES P.and SEALEY A. *CNC Application and Design* [online]. England, 2011 [Accessed. 2017-02-23]. Available at: https://web.wpi.edu/Pubs/E-project/Available/E-project-042811-010443/unrestricted/CNC_MQP_Final_Edited.pdf. Bachelor thesis. WORCESTER POLYTECHNIC INSTITUTE. Major Advisor Professor M. S. Fofana.

DUCHÁČEK, V. *Polymery - výroba, vlastnosti, zpracování, použití.* 2. vyd. Vysoká škola chemicko-technologická v Praze, Praha 2006. Str. 104. ISBN 80-7080-617-6.

HAAB, Sherri. *The art of resin jewelry: layering, casting, and mixed media techniques for creating vintage to contemporary designs*. New York: Watson-Guptill Publications, c2006. ISBN 9780823003440.

SCM GROUP S.p.A - Instruction manual. *https://www.scmgroup.com* [online]. ITALY, 2013 [Accessed. 2017-03-31]. https://www.scmgroup.com/en/products/machining-centres.c874/cnc-machining-centres.877/tech-z5.732

PELANT, I. a VALENTA J. *Luminiscence doma, v přírodě a v laboratoři*. Praha: Academia, 2014. Průhledy (Academia). ISBN 978-80-200-2394-0

ŘASA, J., POKORNÝ P. a GABRIEL V. *Strojírenská technologie 3*. (2), Praha: Scientia, 2005. ISBN 8071833363.

U.S. Army. *Fundamentals of Machine Tools* [online]. U.S.A.: U.S. Army www.woodworkslibrary.com/, 1996 [Accessed. 2017-02-27]. ISBN ASIN:

B0018FA9AM. Available at: http://www.woodworkslibrary.com/repository/fundamentals_of_machine_tools.pdf

ŽÁKOVÁ, L. *Analysis of the Design Process and Manufacturing with laser Cutters* [online]. Brno, 2012 [Accessed. 2017-03-10]. Available at: https://is.mendelu.cz/auth/lide/clovek.pl?id=22211;zalozka=7;studium=42179;zp=27329. Diploma Thesis. Mendel University in Brno. Thesis supervisor Ing. Milan Šimek, Ph.D.

Internet sources:

Bright Woods Collection: Luxury Led Backlit Wood Furniture. *Www.giancarlozema.com* [online]. ITALY, 2010 [Accessed. 2017-02-21]. Available at: http://www.giancarlozema.com/bright-woods-collection/

CNC Milling: materials. Wikimal: a hub to share projects and know-how exchanged at iMAL [online]. 2013 [cit. 2017-03-05]. Dostupné z: http://wiki.imal.org/howto/cnc-milling-materials

DIY Glowing Inlaid Resin Shelves by Mat Brown. *www.thisiscolossal.com: Colossal - Art, design, and visual culture.* [online]. 2014 [Accessed. 2017-02-21]. Available at: http://www.thisiscolossal.com/2014/08/diy-glowing-inlaid-resin-shelves-by-mat-brown/

First CNC project. *Www.thisiscolossal.com* [online]. 2015 [Accessed. 2017-02-21]. Available at: http://imgur.com/gallery/peVtd

Glow table. *www.instructables.com* [online]. 2015 [Accessed. 2017-02-21]. Available at: http://www.instructables.com/id/Glow-table/

HYBRID. *Http://www.plskova.cz* [online]. PRAHA, 2016 [Accessed. 2017-02-27]. Available at: http://www.plskova.cz/tvorba/hybrid/

Inlaid Glow in the Dark Epoxy and Wood Jewelry by Shinium. *Www.beadinggem.com* [online]. 2014 [Accessed. 2017-02-21]. Available at: http://www.beadinggem.com/2014/10/inlaid-glow-in-dark-epoxy-and-wood.html

Jan Černý / Dřevěné brýle, Interiérové svítidlo Moon: Interiérové svítidlo Moon. *Www.bvv.cz: Design For a Better World!* [online]. Brno, 2016 [Accessed. 2017-

02-21]. Available at: http://www.bvv.cz/mobitex/mobitex-2016/grand-prix-mobitex-2016-sekce-student/mendelova-univerzita-v-brne2/03-jan-cerny-drevene-bryle-interierove-svitidlo-mo/

John 1,5: The Word Became Flesh. *Www.BibleServer.com: The Bible for All* [online]. 2016 [Accessed. 2017-02-27]. Available at: https://www.bibleserver.com/text/ESV/John1

Louvre Pyramid: Pyramide du Louvre. *Http://www.aviewoncities.com: A View On Cities - Sights and attractions in some of the world's greatest cities.* [online]. [Accessed. 2017-02-24]. Available at: http://www.aviewoncities.com/paris/louvrepyramid.htm

Lumiere Collection. *Http://eduardlocota.com: design studio* [online]. 2015 [Accessed. 2017-02-21]. Available at: http://eduardlocota.com/product-category/lumiere_collection/?v=f5b15f58caba

Marco Stefanelli's Salvaged Wood Brecce Lamps are Embedded With LED Lights. *Http://inhabitat.com: Design For a Better World!* [online]. 2012 [Accessed. 2017-02-21]. Available at: http://inhabitat.com/marco-stefanelli-salvaged-wood-breece-lamps-are-embedded-with-led-lights/

MINERÁLNÍ PIGMENTY A BARVIVA. *Www.geologie.vsb.cz* [online]. [Accessed. 2017-03-05]. Available at: http://webcache.googleusercontent.com/search?q=cache:im9Pn3DYk3cJ:geologie.vsb.cz/Loziska/suroviny/pigmenty_barviva.html+&cd=1&hl=cs&ct=clnk&gl=cz

Pračlověk uměl rozdělávat oheň už před 790 000 lety, tvrdí vědci. *Www.idnes.cz: s námi víte víc* [online]. Czech republic, 2008 [Accessed. 2017-03-05]. Available at: Zdroj: http://zpravy.idnes.cz/praclovek-umel-rozdelavat-ohen-uz-pred-790-000-lety-tvrdi-vedci-pq8-/zahranicni.aspx?c=A081028_023526_vedatech_lf

PROPAGAČNÍ PŘEDMĚT BOOKMARK. *Http://www.plskova.cz* [online]. PRAHA, 2016 [Accessed. 2017-02-27]. Available at: http://www.plskova.cz/tvorba/propagacni-predmet-bookmark/

Přehled operací: 2D Frézování. *Http://www.1cpro.cz* [online]. 2015 [Accessed. 2017-02-27]. Available at: http://www.1cpro.cz/hsmworks_2d.php

Přírodovědci.cz: Světlo [online]. Faculty of Charles University in Prague, 2015, (1.) [Accessed. 2017-03-02]. Available at: https://www.prirodovedci.cz/templates/modules/magazin/pc/index.php?uuid=bb67cdec-c805-11e4-ab77-0025900e353a

Resin: CHEMICAL COMPOUND. *Www.britannica.com* [online]. The Editors of Encyclopædia Britannica, 2015 [Accessed. 2017-03-05]. Available at: https://www.britannica.com/science/resin#ref258632

Resin Systems. *NetComposites Now* [online]. England [Accessed. 2017-03-05]. Available at: http://netcomposites.com/guide-tools/guide/resin-systems/

Shut The Front Door. *Http://ywwg.com* [online]. 2015 [Accessed. 2017-02-21]. Available at: http://ywwg.com/wordpress/?p=1725

Simple desk with built in LED and glow in the dark stripes. *Http://imgur.com/* [online]. 2015 [Accessed. 2017-02-21]. Available at: http://imgur.com/gallery/J47cp

So I made a pretty thing.. *Http://imgur.com/* [online]. 2015 [Accessed. 2017-02-21]. Available at: http://imgur.com/gallery/K7Yuo

ŠPERKY REPUBLIKA. *Http://www.plskova.cz* [online]. PRAHA, 2016 [Accessed. 2017-02-27]. Available at: http://www.plskova.cz/tvorba/sperky-republika/

Water Bright Lamp: Bricola Collection. *Www.alcarol.com: design studio* [online]. Italy [Accessed. 2017-02-21]. Available at: http://www.alcarol.com/products/bricola-collection/water-bright-resin-lamp/

Week 8: computer-controlled machining: Glow-in-the-dark table. *Http://fabacademy.org* [online]. LISBON, 2015 [Accessed. 2017-02-21]. Available at: http://fabacademy.org/archives/2015/eu/students/boavida.maria/week8.html

Wood Tables Embedded with Photoluminescent Resin by Mike Warren. *Www.thisiscolossal.com* [online]. 2014 [Accessed. 2017-02-21]. Available at: http://www.thisiscolossal.com/2014/12/glow-tables-by-mike-warren/

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http://www.bvv.cz/mobitex/mobitex-2016/grand-prix-mobitex-2016-sekce-student/mendelova-univerzita-v-brne2/03-jan-cerny-drevene-bryle-interierove-svitidlo-mo/

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Fig. 86: *Spiral roughing cutter - positive*

http://www.igm.cz/igm-195-hrubovaci-spiralova-freza-pozitivni-hwm-z3r--d12x42-l90-s-12/

Fig. 87: *Groove spiral cutter - positive*

http://www.igm.cz/igm-193-drazkovaci-spiralova-freza-pozitivni-hwm-z3--d8x32-l80-s-8/

Fig. 88: *Mahogany prism on CNC*

Fig. 89: *Milled shape of an inverted pyramid*

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Fig. 90: *Cutter for cylindrical groove*

Fig. 91: Special hole *for lock system*

http://www.igm.cz/cmt-c950-freza-na-cylindricke-drazky--d9-5x11-d4-8-s-8-hm/

Fig. 92: *Stand from MDF material*

https://www.dvirka-kovani-kuchyne.cz/dotykovy-senzor-pro-ovladani-zejmena-led-osvetleni-prepinaci-funkce-zapnutovypnuto-p-17223.html

Fig. 120: *Touch switch – position on/off*

Fig. 121: *Electrical installations*

Fig. 122: *LED*

Fig. 123: *Finished model of light FOTON*

Fig. 124: *FOTON – background*

Fig. 125: *Lamps FOTON – two variants*

Fig. 126: *Lamp FOTON – glow-in-the-dark*

Fig. 127: *Lamp FOTON – on the nightstand*

Fig. 128: *Lamp FOTON*

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