Tampere University of Applied Sciences

Utilizing Different Design Principles for Hard-Surface 3D Art

A study about achieving realistic 3D mechanical designs

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BACHELOR'S THESIS
March 2022

Degree Programme in Media and Arts
Interactive Media

ABSTRACT

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Tampere University of Applied Sciences
Media and Arts
Interactive Media

HAAPALA, KASIMIR:
Utilizing different design principles for hard-surface 3D art
A study about achieving realistic 3D mechanical designs

Bachelor's thesis 77 pages
March 2022

The purpose of this thesis was to research how 3D artists could utilize different design principles as part of their workflow, and to study the theory of realism in computer graphics to help 3D artists to achieve more realistic and believable mechanical designs.

The theory of realism in computer graphics was researched, and visual design principles were implemented with engineering and manufacturing principles to hard-surface 3D art. The implementation of those principles was demonstrated, by designing a realistic 3D humanoid robot. In addition, from a realism standpoint, a believable render for the humanoid robot was also created and documented.

As a conclusion, it was summarized and demonstrated, that it is beneficial for 3D artists to deepen their understanding and knowledge of the fundamentals in different design areas, to be able to design most realistic mechanical designs. A 3D artist should study the subject of their desired design area thoroughly and implement this as part of their workflow. Hard-surface 3D art should be always based on function, followed by the visual design, when creating mechanical designs.

Key words: 3D, realism, hard surface, robotics, mechanical design

CONTENTS

ABBREVIATIONS AND TERMS

3D	Three dimensional
CG	Computer graphics
Bevel	Smoothed edge in 3D software
Mesh	A 3D shape
Polygon	A surface made from at least 3 points
Blender	A 3D modeling software
Topology	3D model’s edge distribution and structure
Render	An image from 3D model
Photoshop	A photo editing software

1 INTRODUCTION

This thesis studies the importance for a 3D artist to understand the mechanical design principles from an engineering and manufacturing point of view, combined with visual design fundamentals to achieve the most believable mechanical 3D designs and photorealistic end results. Not every mechanical design area is the same, from practicality to visuals and this thesis aims to closely research key principles between different areas, from weapons to industrial robotics and what to take into consideration during the design process.

In the thesis is also included a practical project, where a mechanical 3D humanoid robot is designed, utilizing those principles and theory studied in the earlier parts of the thesis. The project follows the design process closely from 2D sketches to finished and textured photoreal final render.

The purpose of the thesis is to help 3D artists broaden their hard-surface 3D design skills, by utilizing fundamentals of different design processes and thoughts behind them, as a part of their regular workflow when designing mechanical designs for entertainment, such as video games or product visualization concepts. These same principles studied in the thesis can be applied to any hard-surface 3D design, from modern real-life objects to futuristic sci-fi objects.

This thesis doesn’t go deep into the technical side of 3D modeling and 3D software but focuses more on the theoretical and artistic side. Therefore, it is expected for the reader to understand the very basics of 3D modeling.

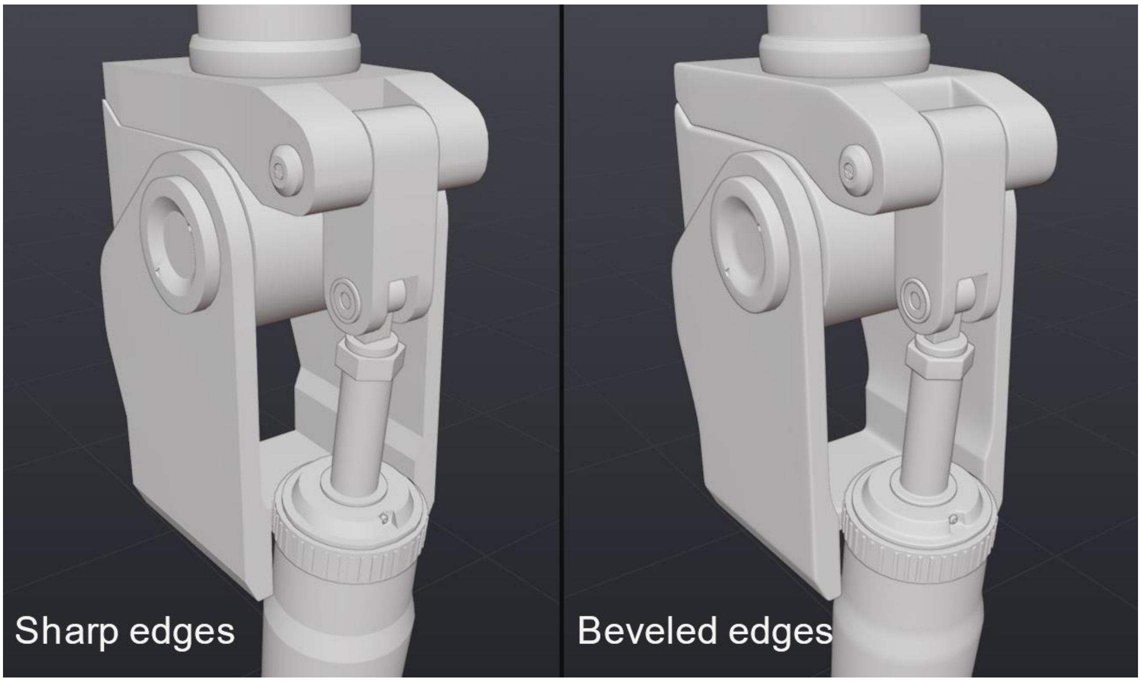
2 PHOTOREALISM IN COMPUTER GRAPHICS

According to Render4tomorrow Studio's article about using photorealistic renders to help you sell your project, photorealistic 3D rendering is when the final result is very difficult to distinguish from reality (render4tomorrow.com n.d.). By creating photorealistic renders, we are trying to create an illusion of something real, even though the end product we're looking for is only computer graphics displayed on a screen, whether it's a video game, animation or a product visualization.

Photorealistic 3D rendering cannot only rely to its technical aspect. Two other major aspects are understanding design principles and detail observation. A case study from 2007 concludes, that design fundamentals are very important to create a successful and outstanding photorealistic 3D rendering. Additionally, technical understanding of lighting and surfaces will help achieving more believable end results. (Joon, Yuen & Khong 2007.)

2.1 3D assets

One of the first aspects in the 3D design workflow to achieve the most believable results is focusing into the 3D meshes. In 3D modeling software, every edge of the mesh is sharp by default, and in the real world it's rare to see sharp edges in any other than thin objects, such as paper or in objects meant for cutting, like saws and blades. Therefore, you need to apply bevels to your models, so the light can interact with the edge in a realistic way (Picture 1). Every edge that is distinguishable by an eye should have some sort of beveling applied. Perfectly sharp edges do not exist in real life. Therefore, they should not be applied to 3D design (Curved Axis 2020).



PICTURE 1. Screen capture from Blender. Left image with sharp edges and right image with beveled edges

In my opinion, usually the most unrealistic 3D assets are easily distinguishable from the realistic ones, due to a lack of details and beveled edges. This is especially an amateur and beginner 3D artist's problem. This is mostly because understanding the complexity of 3D modeling workflow from the technical standpoint, is something a 3D artist will develop over time. One could argue, that to achieve photorealism in computer graphics, the artist should have good artistic skills and a capability to view and analyse real life forms, along with understanding the technicality of a 3D modeling software. To demonstrate this, I have combined two untextured 3D assets from TurboSquid.com, one having the most minimal amount of details and every edge being sharp, and the other having a maximum amount of details and the most distinguishable edges being beveled (Picture 2). This enables the lighting to interact with the model in the most photorealistic way, unveiling the true form of the weapon.

PICTURE 2. TurboSquid.com 3D model by ChrisJohnson22 from 2018 (left) and 3D model by Flewda from 2010 (right)

Another way to achieve realism in 3D assets is to get the proportions of the 3D mesh right. In an Ebal Studios' article about 3D (Geometrical) Modeling Fundamentals, Ali Ismail (2016) says "When working or training 3D artists who are just starting out, I notice that for the most part, they know quite a lot of tools, perhaps too much for the relative time they have been learning. But at the same time, some basic concepts like proportions seems to be lacking." (Ismail 2016). In 3D you must estimate your asset's depth, and how big something is in real life, and not simply, what it appears to be in a 2D drawing. Practicing 3D modeling with a conscious effort to improve and comparing your model to the reference images at every stage, in a similar way how traditional fine artists do, will improve your overall ability to understand proportions. (Ismail 2016.)

We can also use our 3D software of choice to measure things. One good way to measure objects, is to have something you know the actual size of, for example a human figure, and use it as a comparison of how your model looks with it (Ismail 2016). This technique can be implemented to anything you design, from small objects to big 3D scenes. For example, if you're designing a prosthetic leg and you're not sure about its proportions, one way would be to add a realistic model of a human leg next to it, and use it as a measurement tool, along with it being a reference for you of the shape of a human leg (Picture 3). By applying this technique as part of your 3D design workflow, you will avoid proportion mistakes in a same way as traditional fine artists avoid them by using a lot of reference photos, instead of drawing or painting everything from their head.

PICTURE 3. Screen capture from Blender. 3D modeled prosthetic leg with realistic 3D model of a human as a reference and measurement tool

Concept designer Alex Senechal (2019) points out in his YouTube tutorial, named Always Nailing Proportions, that he sees many 3D artists always failing to get the proportions right. He's using an AK47 assault rifle as an example. He continues to show a technique to calculate your reference image's proportions, by taking an existing part of the weapon you have already modeled, in this case the safety switch of the AK, by cutting, copying, and pasting it on top of the reference image in Photoshop (Picture 4). With this technique a 3D artist can easily measure proportions of the asset they're modeling. In this case, counting how many safety switches the receiver is by length. (Senechal 2019.)

PICTURE 4. Screen capture from Alex Senechal's YouTube video (2019)

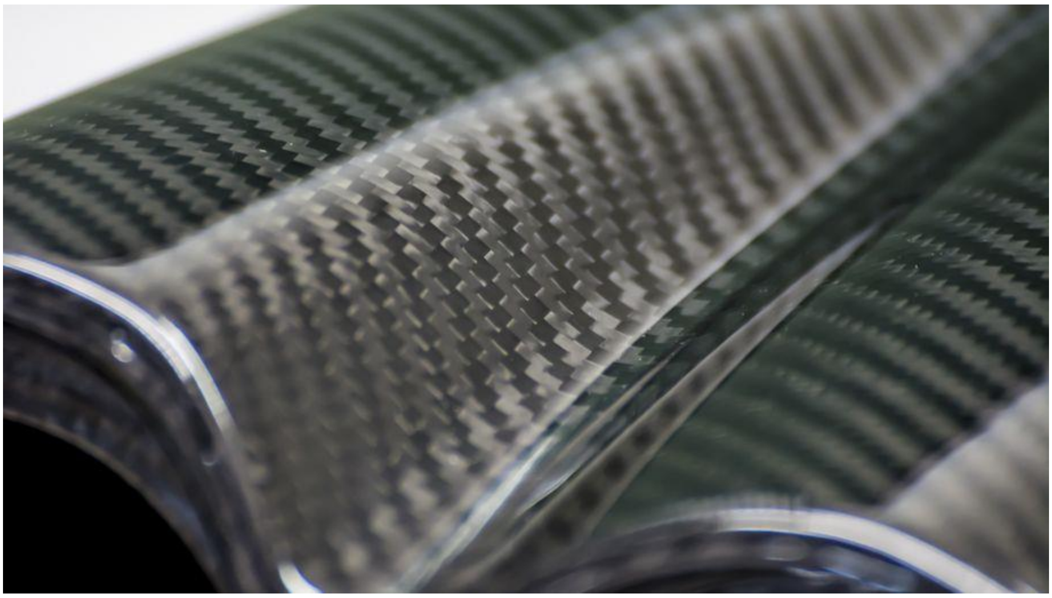
2.2 Textures, surfaces and materials

Textures are a thing that can really make or break how your final 3D work will look like, and to get the best possible results, it takes a lot of practice (Denham n.d). The most important aspect of believability is object recognition, therefore, the objects, including its surfaces must be believable. For the viewer to have something to solidify the realism of the image, the surface must be familiar. (The Principles of Photorealism n.d, 10.) Every object in real world has a surface texture, even the smooth ones. A common problem with the surfaces of 3D objects is that they are almost always too smooth, which is unnatural. Artist should keep in mind, that just because you can't feel the texture, it doesn't mean that it doesn't exist. The texture could be too subtle to feel, but it will still show up in the object's specularity. (The Principles of Photorealism n.d, 12.) So how a 3D artist can avoid making the mistake of creating unnatural textures? Like discussed above in the 3D assets -section, a 3D artist should use as much reference as possible to achieve photorealism in textures, and keep in mind that there is always a texture.

In the next paragraphs I am trying out multiple different options for carbon fiber material to see how it looks on a 3D modeled prosthetic leg. I will render them each and compare side by side. Since I am using a carbon fiber as an example, first we need to determine what is carbon fiber, and how it is used in our product, which in this case is, a prosthetic leg.

Carbon Fiber Reinforced Plastic or Carbon Fiber Reinforced Polymer (CFRP) is known for its resistance fatigue, its strength in comparison to how light it is and its excellent high-temperature characteristics. It has been substantially used in the manufacturing industries, especially in the weight-critical aerospace industry. It is also highly used in automotive, marine, and civil engineering industries. (helmut-fischer.com n.d). By looking at carbon fiber from a photograph reference, we can see how it looks in real life (Picture 5), and by looking at another reference, how it's applied to plastic as reinforcement (Picture 6) we can distinguish the difference, from its specularity of how it is applied to a product.

PICTURE 5. Carbon fiber from hiconsumption.com



PICTURE 6. Carbon fiber applied to hard plastic from helmut-fischer.com

Here are three different outcomes, which one of them, the third one is the most realistic (Picture 7). The test number one shows decent specular effects, but the sizes of the carbon fibers are too big. This gives an unrealistic look to it, because subconsciously we know, that that’s not what carbon fiber looks like in real world, therefore we need to compare our material more accurately to some references.

In the test number two we have achieved the right size, but there is still something off what makes it not look real enough. The carbon fiber looks sticky, rough, and bumpy, like in our first reference photo (Picture 4), before the fibers were applied to hard plastic. The reason what makes this look unrealistic is the fact that carbon fiber wouldn't be applied like that into a prosthetics, meaning without a cover, exposing them to detrition. We know that there is a layer of transparent, hard plastic on top of it, which covers the actual carbon fiber underneath (Picture 7).

In the test number three, the strength of the normal map and roughness of the texture was decreased, while specularity was increased. Now we finally have achieved desired illusion of realism in in our render, just by adjusting our textures, by comparing them to real world references.

PICTURE 7. Three screen captures from rendering tests, made with Blender, and compared each side by side

2.3 Lighting

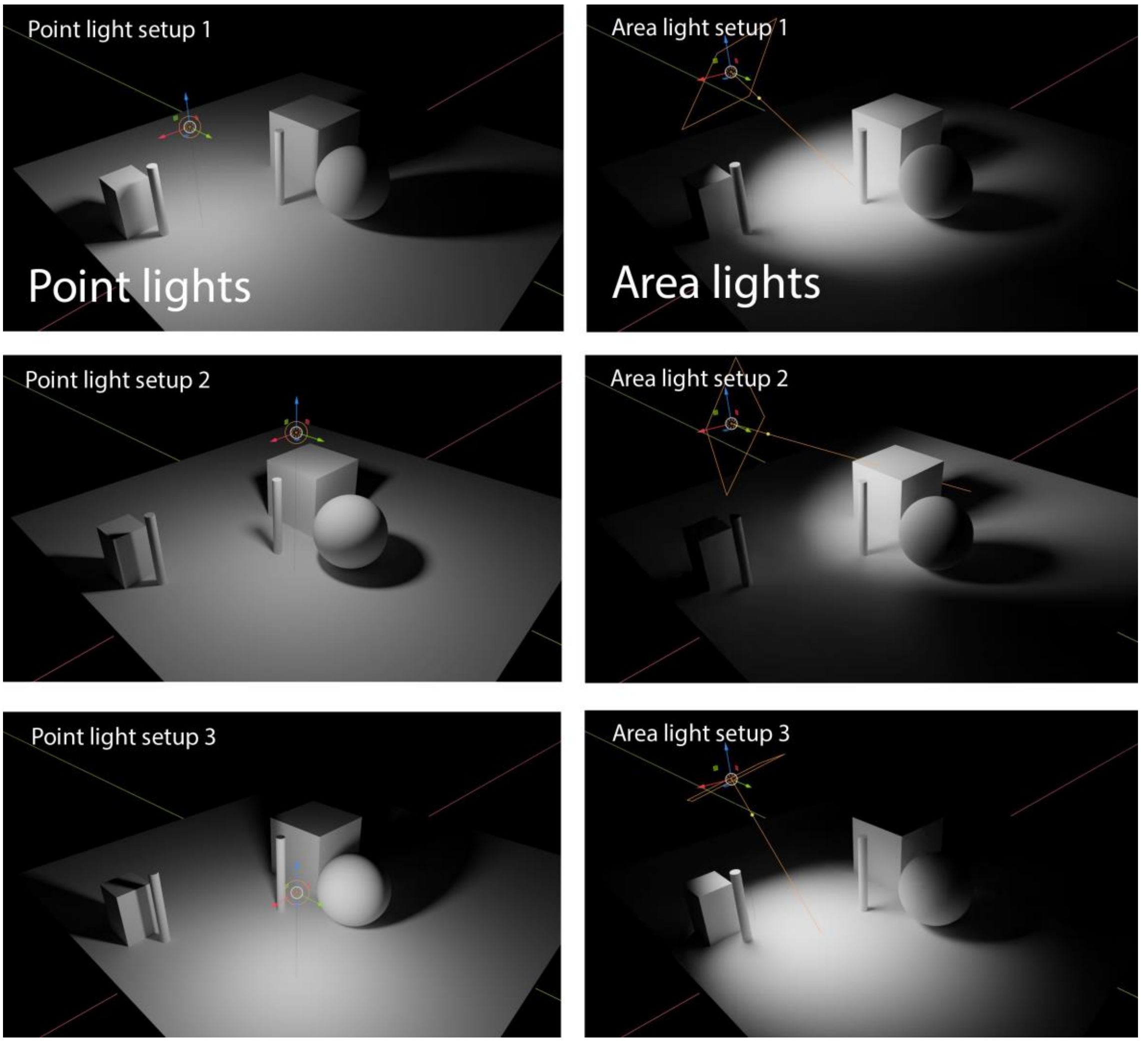
Ciro Sannino says the following in the description of his 2016 Lighting—the Key for Photorealistic Rendering online class for Autodesk University, "Lighting is often viewed as one of the most complex topics in 3D rendering. Lights are technically simple to use, but without the theory behind, one might feel lost." (Sannino 2016.) Lighting plays an important factor of how photoreal your end result will be, again, because light is a phenomena that happens in real life. In my opinion, a 3D artist should understand the theory of shadows and light, even though how light acts is predetermined by the 3D software, and not something we draw or paint manually, like traditional fine artists do. By setting up proper lighting, along with realistic materials, we can ultimately create a true photorealistic feel to our renders.

According to Darren Thomas (2019) 3D artists often ignore the shadows cast by the lighting, and specifically the edge qualities of them. Since there are so many different CG light options to choose from, it becomes easy to make a reality breaking choices. These principles apply to real-time and pre-rendered lighting both. However, real-time engines don’t have the same capabilities as in pre-rendering software. (Thomas 2019.)

Lights to avoid when aiming for realism in 3D are point lights and ambient lighting. Point lights emit light in every direction, from a non-physical source, meaning they are likely to produce unrealistic lighting effects and unconvincing shadows. Ambient lighting again lifts the darks and mid-tones of the scene. It is better to add more lights or increase the global illumination of a certain light, than add ambient lighting. (Thomas 2019.)

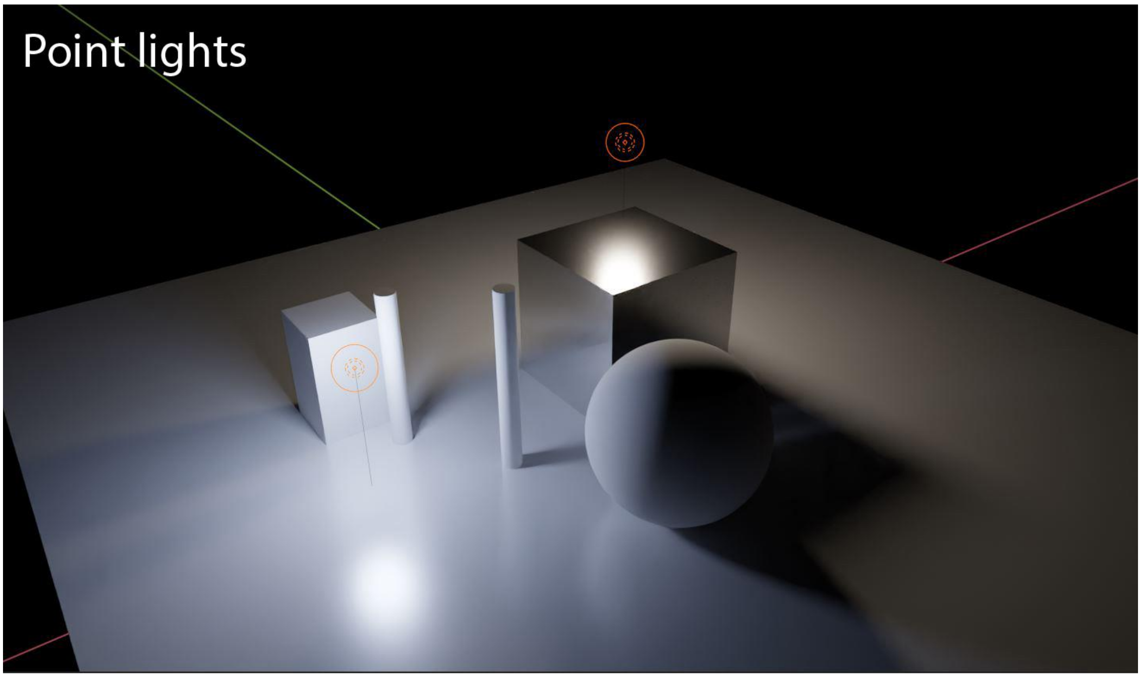
More believable lights, that represent the real world better are area lights, which are surfaces, that emit light, and skylights that simulate larger light sources, such as sun or sky. Area lights create more natural-looking shadows, as well as add soft edges to them and create more realistic fall-off. They are also visible on reflective surfaces. Both lights represent real world more than point lights or ambient lighting. (Thomas 2019.)

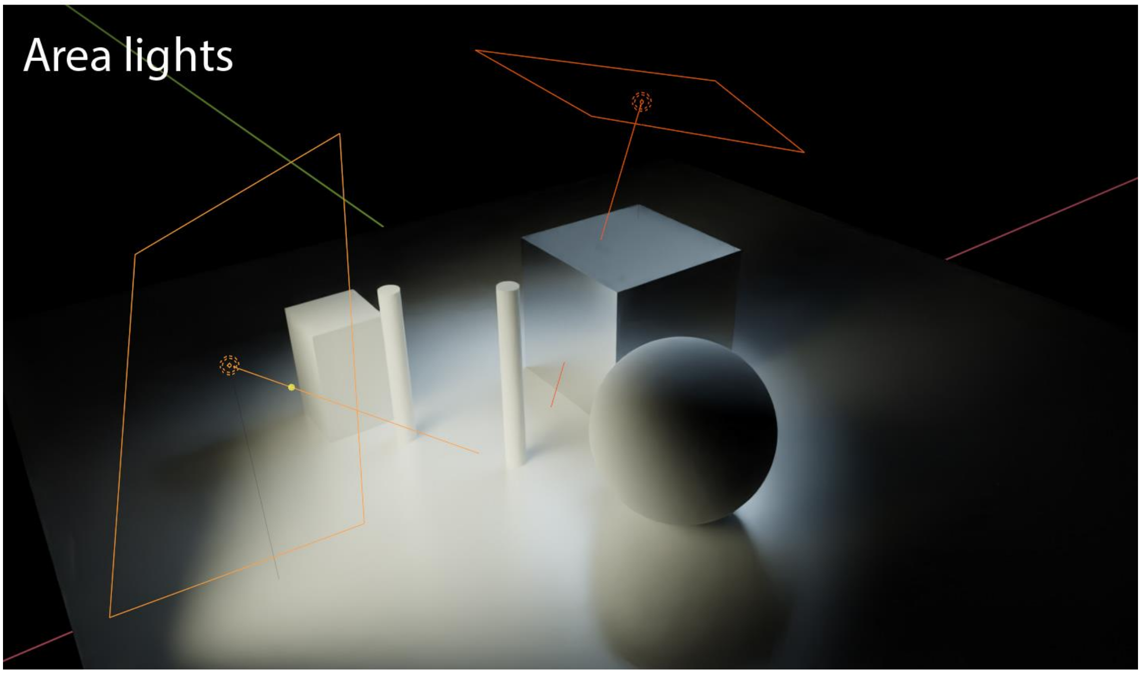
I made three different comparisons of point lights to area lights in Blender. The first example shows that you can change highlight of our desired focus area just by rotating the area light, by casting its rays to different direction, while keeping the light source itself in the same exact position. While with a point light, you must change the whole position of the light to even get different results. One could think of it as a moody scene, but this technique fails our desired goal of highlighting a certain area of a scene and is instead casting its light rays equally to every direction (Picture 8).



PICTURE 8. Screen captures from Blender. Comparing point lights and area lights, each from three different positions and rotations

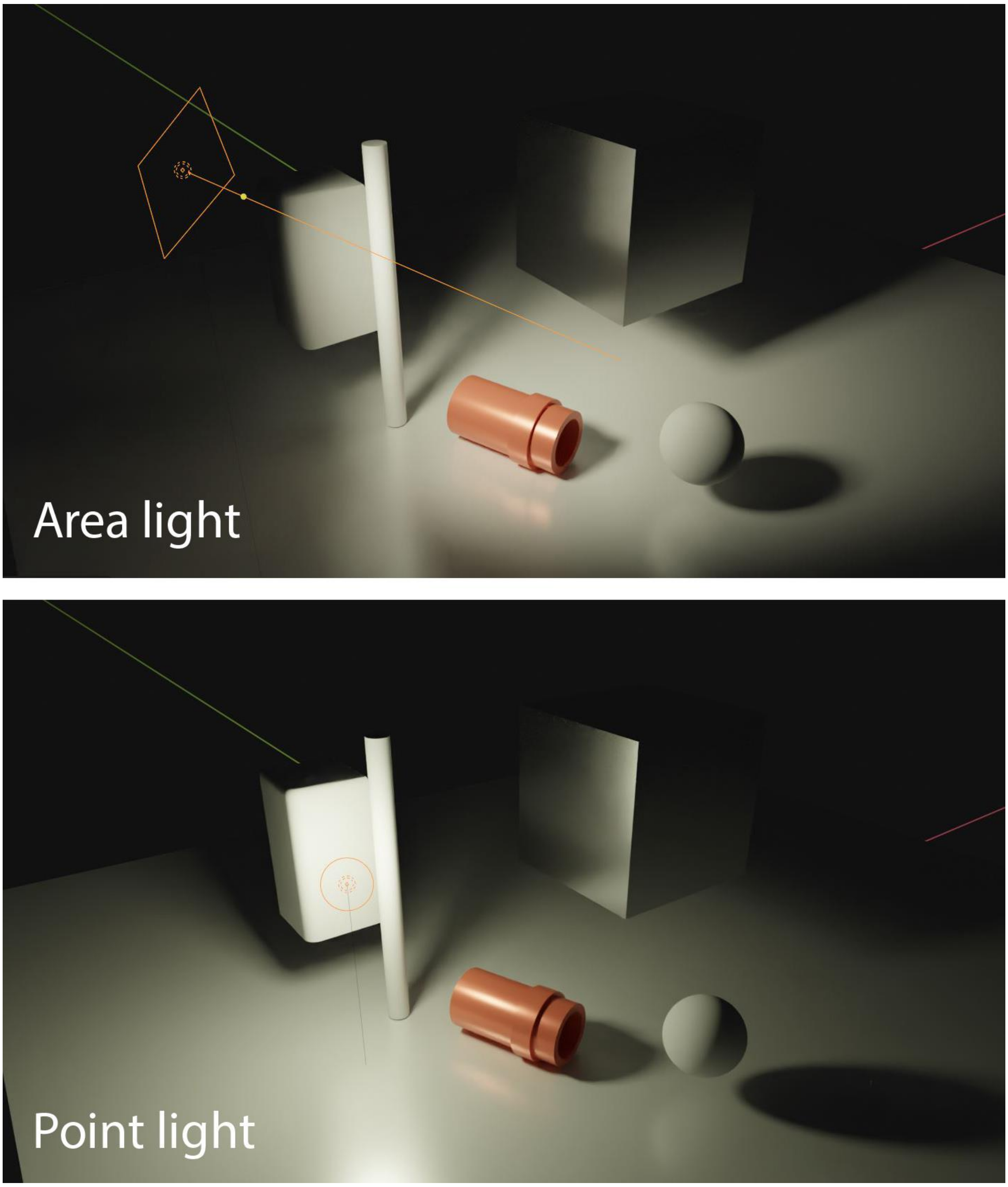
In the second example I compared how point lights and area lights act with reflective and metallic surfaces. Point lights create a clear, visible ball shaped reflection to surfaces. We also fail to highlight a certain area once again. With area lights we avoid unwanted clear reflections and can determine the highlight of our scene, by aiming our lights to a certain spot (Picture 9).





PICTURE 9. Screen captures from Blender. Comparing point lights and area lights with reflective, metallic surfaces

In the last example I tried to highlight the red cylinder-type object. With area light once again, we can determine our focus point from the scene easily, by aiming our area light towards the desired object. By using a point light, we light a far bigger area from the scene, and highlight unwanted objects, such as the white rectangle and the vertical white cylinder (Picture 10).



PICTURE 10. Screen captures from Blender. Comparing area light to point light with a desired focus point being on the red cylinder-type object

In my opinion, this light theory is vital to understand when creating your scenes. Not any real-life scene is lit up with point lights, but rather with multiple area lights. Though, usually one area light is not enough and using multiple light sources to set the scene is usually a standard. One of the most used techniques is by using a three different directional area lights.

3 DESIGN PRINCIPLES IN HARD-SURFACE DESIGN

3D modeling can be divided into two main categories, which are organic modeling and hard-surface modeling. Hard-surface models are usually everything man-made or manufactured. (Kochetov 2018.) Fundamentally, organic modeling consists of characters, animals, trees, plants, and other living objects. Hard-surface modeling then again consists of techniques, that are used to make machines, vehicles, robots, weapons, and generally anything non-living objects that have smooth, static surfaces (Fuentes 2021).

According to 3D artist Tomi Väisänen (2018), who has worked from the marketing of industrial robotics to advertisement industry and video game art, a good way to approach hard-surface designs is to understand and analyse how the model is assembled and disassembled. Väisänen also says, that when it comes to mechanical design, we can usually get realistic results just by giving an impression of something that works, and to be able to sell the design, the mechanics must at least give a hint of something real. (Tokarev 2018.)

Even though 3D art is just art presented on a digital screen, and not an actual physical manufactured product, in my opinion it still greatly helps to achieve more believable designs when we can understand how they would work in real life. According to 3D concept artist Edon Guraziu, for a 3D artist to create believable designs, they must respect the inherent boundaries of function if they want to design something that feels as it is manufactured in the real world, and that requirements such as movement must have priority over the artistic flair (Guraziu 2021). I interpret this that in your design process functionality should become before artistic decisions, since your visual, artistic choices can be later added to functionality, but functionality can't be applied to art. This means that a 3D artist should create their base design choices based on function, instead of artistic freedom.

The key is to find a balance between applying real world solutions based on research, to your own personal design choices and elevate their functionalities, details and ultimately, believability (Guraziu 2021). Therefore, a 3D artist who wants to create believable mechanical designs, should do great research of how the product they’re trying to design would work and be manufactured in real life, while at the same time add their own personal design choices and artistic touch to it.

In the next sub-chapters I am going to go more in depth into research of how these principles discussed above can be applied to hard-surface 3D art design process. I aim to go through fundamentals of different design processes, so they can be later utilized as a standard hard-surface 3D design workflow.

3.1 Mechanical engineering principles

In real world, mechanical machines are designed by engineers in the first place. This is due to a simple fact that for stuff to mechanically work, it needs engineering. If a 3D artist would design a mechanical machine for real world, the product would simply fall into pieces before it could even be assembled. 3D artists usually aren’t engineers, because in the end, they are not designing real mechanical machines, instead they are creating 3D art. I think that to be able to achieve the most realistic and believable CG art, it is good for 3D artists to understand some of the basic principles behind mechanical engineering design. I think that by applying basic knowledge of how mechanical machines are engineered, we can create more believable and realistic hard-surface 3D art.

According to robot engineer John V-Neun (robotwranglers148.com n.d) engineering is methodical process using available resources and experience to solve complex problems, therefore, to simply put it, engineering is problem solving. There is no single universally accepted engineering design process. The engineering design process in its simplest can be explained with a 3-step loop (Figure 1). (V-Neun n.d).

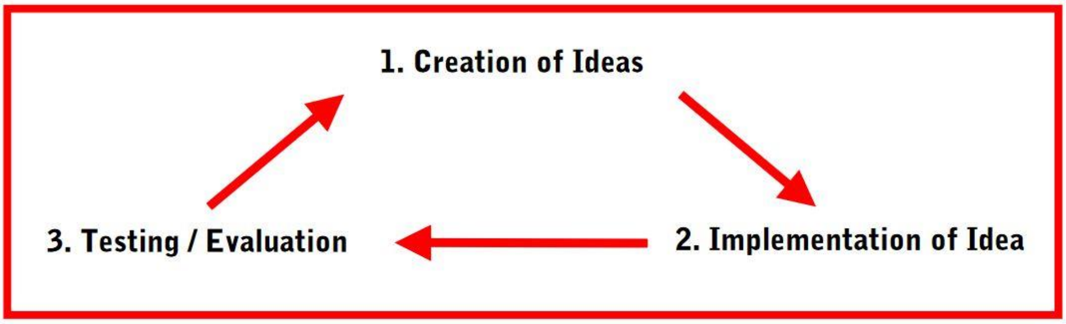


FIGURE 1. 3-step loop from robowranglers148.com (V-Neun n.d)

In my opinion, this 3-step loop can be applied to 3D hard-surface design very well. A 3D artist has an idea what they want to create, for example, designing an electronically functioning helmet for a character. They implement the idea, which in this case means 3D modeling it. They test the design by looking at it and notice if the design works or not. In this case I mean if the design looks realistic and believable or not. If the 3D artist thinks that it gives an impression of something real, the testing / evaluation phase is ready, therefore the design is finished. If the 3D artist is not happy with their design, they go to the phase one again, creation of ideas, which in this case means creating new or different ideas for the helmet design. Then they either change some of the 3D modeled parts or start the 3D modeling completely again with a fresh new design idea. The 3-step loop continues until the 3D artist is happy with their design.

Like discussed before, reference images and videos are the key. In my opinion, by looking at cross-section images of mechanical designs, we can get a better understanding of what is going on inside of them, while seeing the overall outside form at the same time. By understanding the insides of a mechanically designed and manufactured product, we can have more realistic design choices for the outer parts, which are the ones that are most visible for the viewer, and usually the biggest forms of the design. By looking at a cross-section image of a V engine, we can see that the inside of the engine is constructed from smaller mechanical parts. These smaller parts inside are the ones that make the engine function (Figure 2).

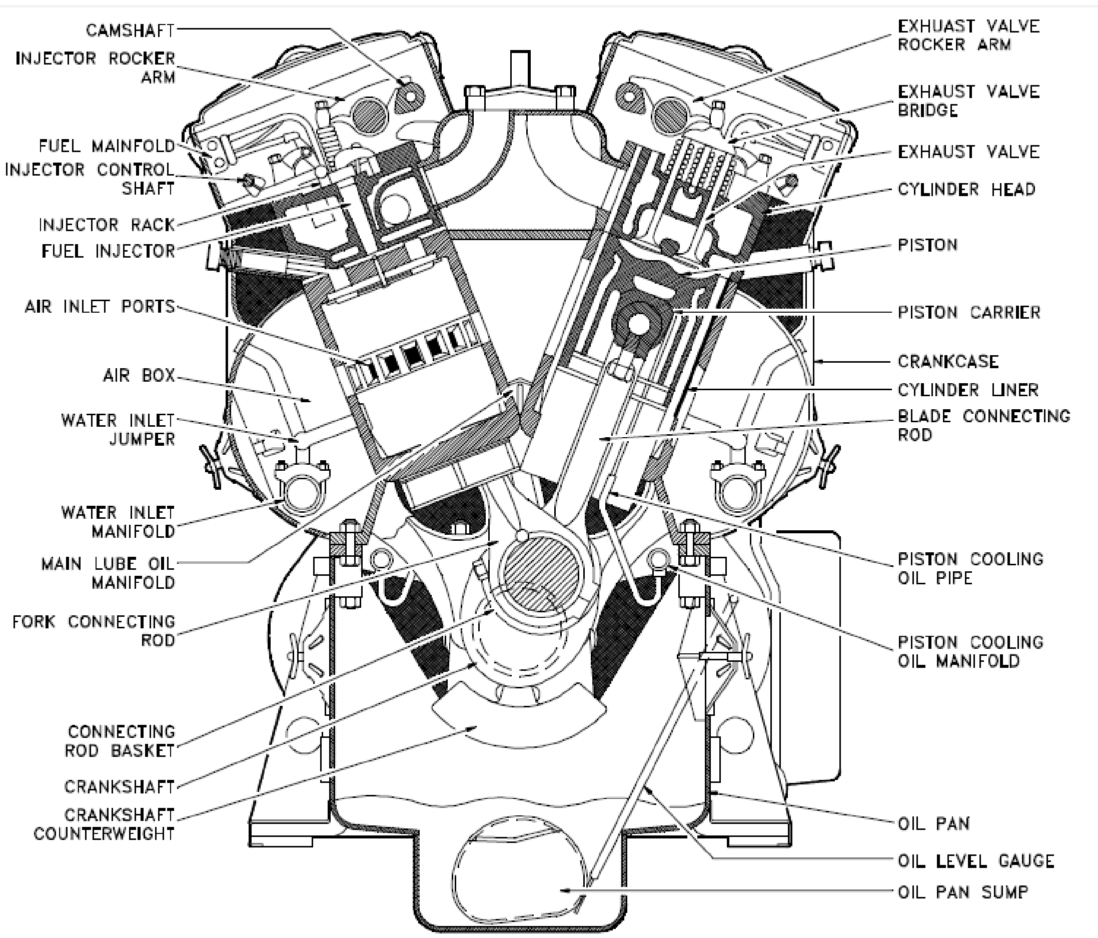


FIGURE 2. V engine cross-section from mechasource.blogspot.com (2019)

In my opinion, 3D artists don’t have to know what each inside part individually do but having an overall understanding of which parts the product is constructed from, and applying that knowledge to their designs, they can achieve more realistic results. For example, moving parts can’t rotate without proper joints, there can’t be electricity transferred from one part to another without wires or cables, and anything electronic can’t function without power supply. We also need to think about the placement for these parts. Anything electronic is usually protected from impact and water that could cause it to malfunction, as well as other important and sensitive inside parts.

These practices are not to be confused with industrial designers, even though many industrial designers are also 3D artists at the same time. Industrial designers develop concepts for manufactured products, such as cars, toys, and electronics, and combine engineering and business with art (careerexplorer.com n.d). Therefore, even though the workflow could be similar, their main goal is to design a real manufactured product, when a 3D artist's main goal is to create CG art for entertainment, even though 3D artists can still do concept designs for real life products as well. I think that in some cases, the difference between the two professions can be indeterminate.

In my opinion, every design choice should serve functionality. For example, cable placement and their colors, button placement, size of the objects in the design and used materials, along with overall details. By comparing two machine gun like designs from two different 3D artists from Artstation, we can analyse the realism between the designs (Picture 11).

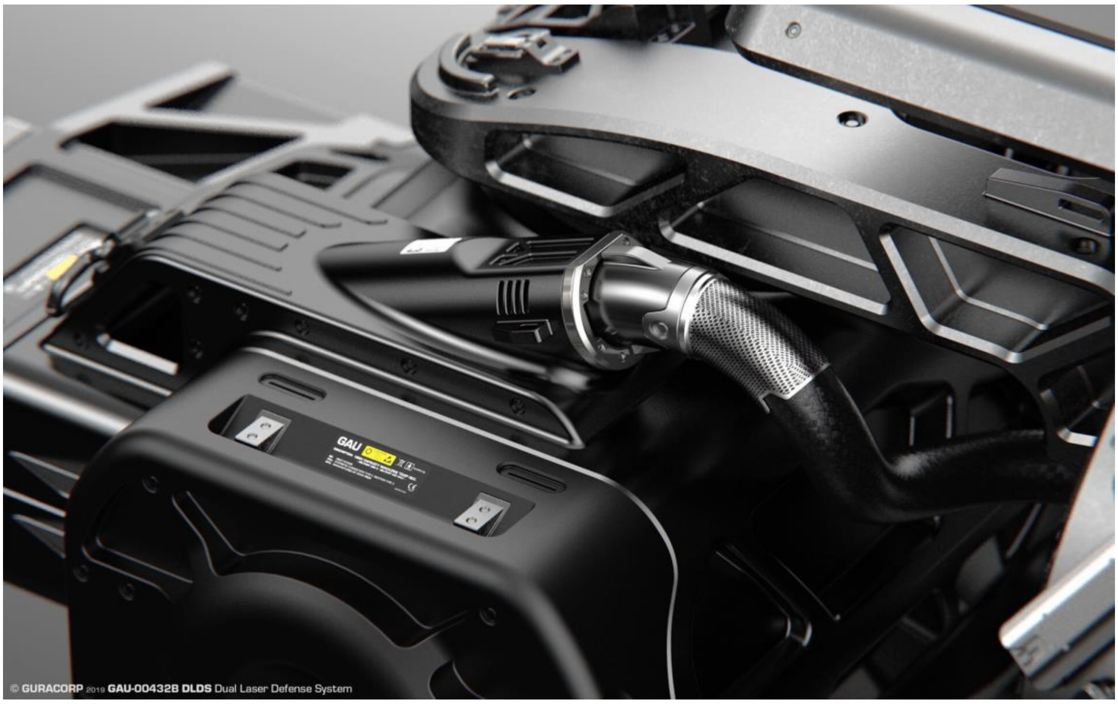
PICTURE 11. Artstation.com 3D designs by Marcelo Tozzo (2021) (left) and Edon Guraziu (2018) (right)

In the first example (left) we can see that the artist has designed the machine gun to be able to rotate to left and right, but at the same time it has a short cable attached from its bottom part to its upper part. The shortness of this cable would cause the gun not to be able to rotate more than a limited amount, before the cable would stop the rotation or it would snap off, breaking the machine. This instantly breaks the design and realism of it. It is supposed to be high tech weapon, yet it only has two small red buttons, with no instructions. Would a military machine gun operate from only two same-coloured circular buttons? I think not, and therefore it gives a toy like feeling to the design, because in my opinion we are more used to see simple big buttons on toys, rather than real mechanical machines.

Are the machine gun's only options to turn it on and off? How do you operate it? Does it have a computer inside of it? Where does the ammo go and where do the shells come out? Why does it have two different size camo patterns? In my opinion, the design leaves more unanswered questions than it gives an answer to, therefore, it fails to assure me that it is a real product and not a toy or unrealistic CG render. Without a more detailed engineering thought behind the design, it has not achieved the realism and believability that I am researching in this thesis, therefore it serves as a perfect example of how the design could be improved by applying these design principles and fundamentals.

The second example (right) is more detailed 3D design of a laser defence system. We can see that it is complex, and we would probably not know how to operate it, without throughout introduction, but does the design give us an impression of something that doesn’t make sense? I don’t know how to operate any real-world machine either, without proper introduction, so in my opinion, it increases the realism of the design. By looking at the design, I can see that it is a laser turret, like I could see in the first example as well that it is a machine gun, but I don’t doubt the believability of it. It doesn’t give me a toy like feeling. It gives the impression that it is something that could be real and manufactured product.

By looking a more detailed image of the second example (Picture 12), we can see that the author has put real thought behind the design. There are so many details, switches, nuts and bolts, and warning stickers, that we don’t easily question its believability. A cable is not just a random cable. It is well thought out and we can see how it is attached to the machine, and how it clearly serves a purpose, even though we might not understand it. Just the cable itself consists of different smaller parts and materials. It achieves believability well by giving an impression of something from the real world. In my opinion, this could not have been achieved by overlooking the importance of engineering details in the 3D art.



PICTURE 12. Artstation.com laser turret by Edon Guraziu (2018)

3.2 Visual design principles

In my opinion visual design in CG is as important as functionality and realism, and without visually pleasing design, we simply can’t create good art. I think that artistic choices can also either make or break the design’s believability in hard-surface 3D art, but like discussed earlier, visual design and artistic flair should come after functionality.

According to UX/UI designer Ville Tervo (2016), being a designer is about observing things considered beautiful and clever. Tervo says in Futurice’s blogpost about Visual design basics, “It might take years to study the history, nuances and techniques of visual design. However, there are a few basic rules that’ll guide you towards a visually coherent and understandable outcome”. (Tervo 2016). Even though Tervo is talking about more traditional 2D visual design, in my opinion all this still applies to 3D as well.

I believe that 3D artists who have prior experience in the field of visual design, will achieve more visually pleasing hard-surface 3D art faster, than those who are learning visual design basics at the same time they’re learning hard-surface 3D art. For example, it is easier to start creating your hard-surface 3D designs, if you have worked as a graphic designer before, because you already understand the basics of visual design, and how to construct visually informative and artistic designs. It comes to transferring that knowledge to a new area, which in this case is hard-surface 3D art. However, in my opinion prior experience from visual arts and design cannot automatically be transferred into a good hard-surface 3D art and there is still a learning curve to be done.

I think that someone could nail the design from an engineering point of view, have all the proportions right, realistic materials and excellent composition, but without the right visual design choices the design could turn out to be unappealing, flat, or too complicated. According to Ellen Mueller (2017), 3D design's element definitions are line, value, colour, texture, shape, form and space, and principal definitions are balance, unity/harmony, rhythm, emphasis, proportion, pattern, variety, and gradation (Mueller 2017.)

Lines are the edges of shapes and forms, or the direction followed by any motion. Value is shadows from lightness to darkness, and variation of it gives a sense of space and depth to an object. Colour is light reflected from a surface, which can create emphasis, emotions, unity, harmony, and movement. Shapes can create most of the elements and principles. Form encloses a volume of a 3D area, where light and dark values and space are used to emphasize form. (Mueller 2017.)

Space means illusion of depth and space. Couple ways to create space are overlapping shapes or forms in front of each other, and by creating holes and cavities. Balance refers to the equalization of elements in a work of art. There are three kinds of balance: symmetrical, asymmetrical, and radial (Figure 3). Unity/harmony relates to the sense of wholeness, oneness, or order in a work of art. Rhythm can be achieved by creating repeated objects. (Mueller 2017.)

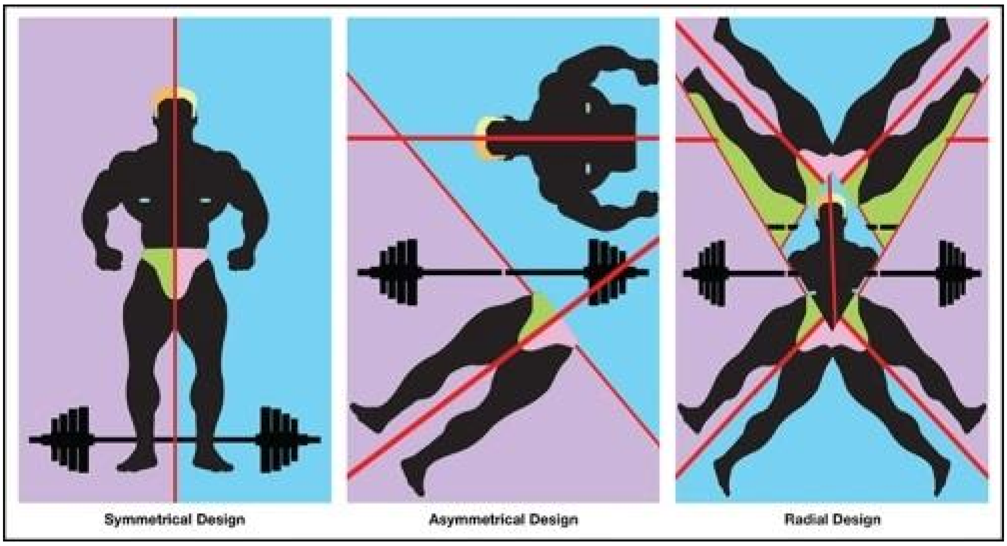


FIGURE 3. Symmetrical, asymmetrical, and radial design visualised from Annhjelle's blog (n.d)

Emphasis means placing attention to certain areas or objects. Proportion means the relationship of certain elements to the whole and to each other. Variety is achieved through change and diversity, by using different line types, colours, and shapes. Finally, gradation means a way of combining elements, by using a series of gradual changes, for example, gradually from small shapes to large shapes. (Mueller 2017.)

Based on these definitions, we can analyse an example of a hard-surface 3D design, that in my opinion, utilizes these definitions well. I have taken an example that has already achieved the realism and believability, by implementing engineering principles. I aim to analyse the design's visual design (Picture 13).

PICTURE 13. Artstation.com injection gun by A Guang_Ray (2021)

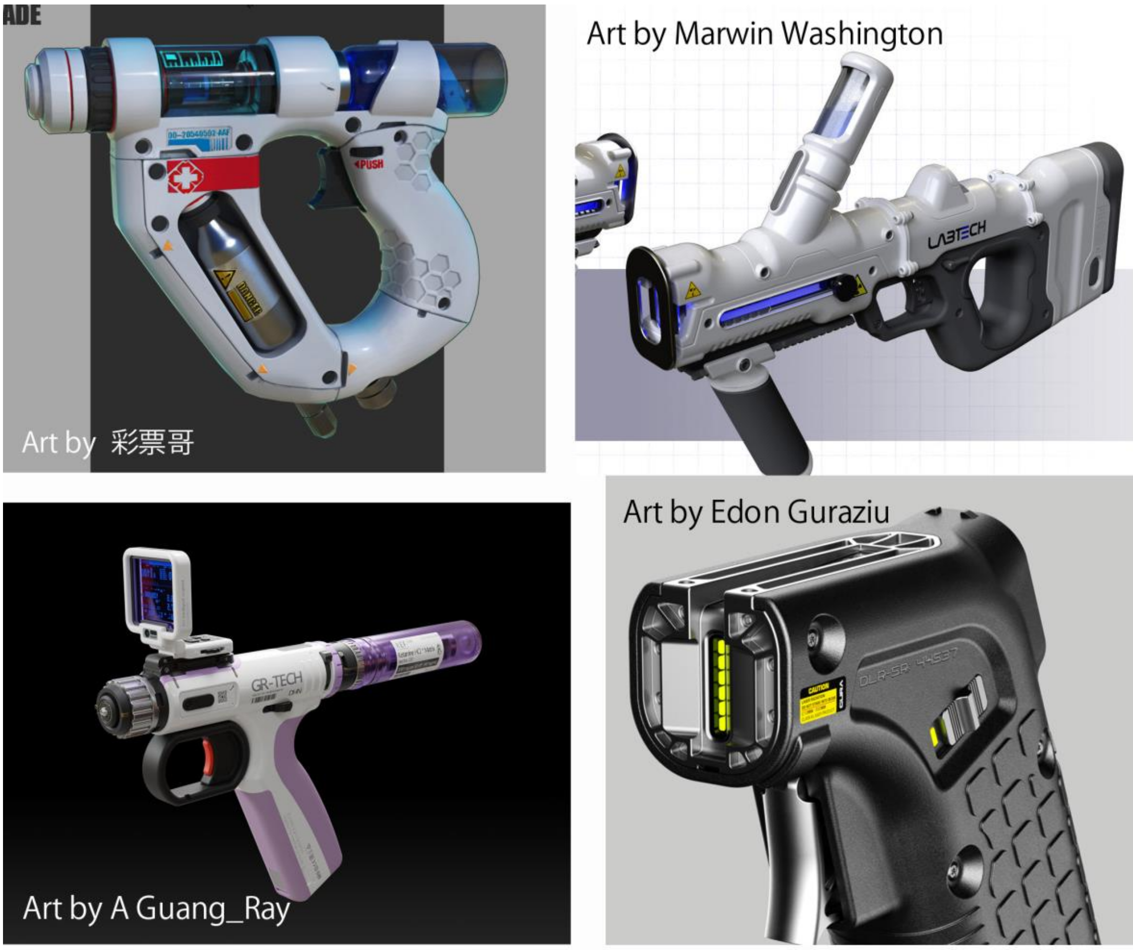
In the next example, we can see that the 3D artist has made three different colour variations, avoiding one too colourful design, which I think, would break the design's harmony visually. We can also see that the emphasis of the details has been put into the parts, where something is connected, like the ketamine chamber in the back, the syringe in the front, and the digital screen on the top, and by having more simpler forms on the bigger areas of the injection gun, such as the handle (Picture 14).

In my opinion, this also follows a logic of functionality, but how the 3D artist has left the visual design details mainly to the parts that are detachable, comes to a visual design choice. This choice follows the visual design principle of gradation.

PICTURE 14. Artstation.com injection gun by A Guang_Ray (2021)

I think that with a conscious visual design choices, we can affect the most of how the finished hard-surface 3D art will look like. Generally, visual design comes down to the artist's own artistic skills and a way of presenting their hard-surface 3D art, with their own visual style. Same product can be done visually pleasing, following the engineering principles and photorealism in CG with multiple different visual design ways (Picture 15).

Concept designer Alex Senechal explains in the CG Society's interview (n.d), that developing and learning a vocabulary as to why something is bad is important. He also explains that you can present an idea good or poorly, it's art and design fundamentals that make the difference. (Senechal n.d.)



PICTURE 15. Artstation.com injection guns by 彩票哥 (2018), Marwin Washington (2019), A Guang_Ray (2021) and Edon Guraziu (2019)

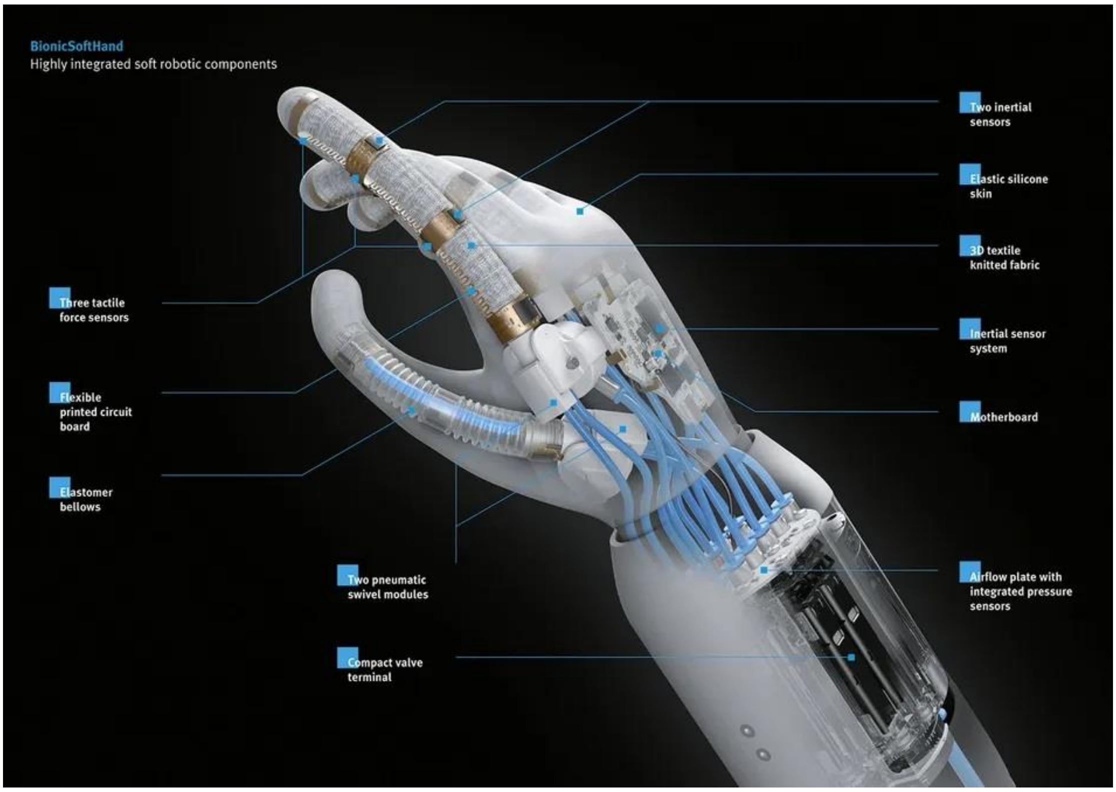
3.3 Mechanical design areas

In hard-surface mechanical design, each manufacturing area has different fundamentals that a 3D artist, in my opinion, should understand. These areas could be split into multiple different sub-categories, from different industries to different products. For example, military could include everything from weapons to military equipment, and machines could have everything from high tech robotics to construction cranes, and so on. In this thesis, I am going to focus on robotics, to keep the topic concordant.

3.4 Robotics

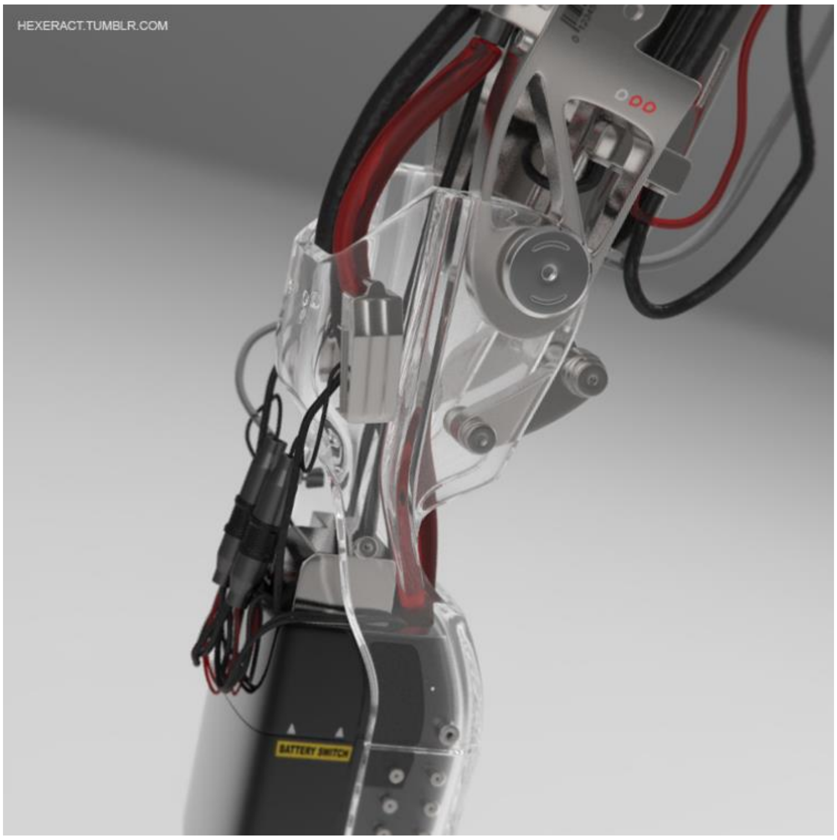
Katie Terrell Hanna (2021) explains robotics in a techtarget's article as a branch of engineering that involves the conception, manufacture, operation, and design of robots. The objective of the robotics field is to create intelligent machines that can assist humans in different ways. A robot may resemble a human, or it may be in the form of an application. (Terrell Hanna 2021).

I think that for 3D artists to be able to design realistic robotics, the key for a successful design process starts from understanding what is inside of the robot, and what makes it function. Like discussed earlier, cross-section images are an excellent way of looking into the inside of the design, while seeing the overall form at the same time. For example, by looking at a cross-section image of a BionicSoftHand by FESTO we can analyse it more detailly (Picture 16).



PICTURE 16. BionicSoftHand developed by FESTO (2019)

We can see that every part is connected to another with wires or mechanical joints, and that there are lots of circuit boards and other electronic devices inside. This is also vital to understand, if a 3D artist wants to design a robot with less protective covers, exposing more of the insides, such as the example of a robotic leg below (Picture 17). We can see that it has a battery in the calf part of the design and transparent plastic giving only cover for the joints, while exposing other parts. I think it is up to the 3D artist to decide, which direction they want to take their design, but the overall visual design choices should be in harmony with each other. By this I mean, that a 3D artist should not leave some parts of the design mostly exposed and other parts mostly covered. For example, if the shoulders' wires, cables, and electronic devices are exposed, there is no reason to cover them from legs, and same for the other way around. This would break the coherent visual design.



PICTURE 17. 3D concept art by Gavriil Klimov (2015)

3.4.1 Human anatomy in robotics

As early as mid-90's study about the anatomy of a humanoid robot (Seward, Bradshaw & Margrave 1995) has researched the possibilities to create a humanoid robot and made the following conclusion, "The principal properties and capabilities of the human body have been quantified in engineering terms and as a result of this the basic requirements for a humanoid robot have been defined.

Existing technology has been reviewed to see if it can match the requirements and in general it seems to be capable of doing so." (Seward, Bradshaw & Margrave 1995, 442.) I think that based on this information, we can assume that humanoid robots can be real, therefore we can create believable robotics 3D art that relies on realism, especially considering the more advanced technical and scientific possibilities of mechanical designs of a present day.

Humans exist in a wide range of shapes and sizes, and generally most of them can function adequately. This suggests that functional performance is not too sensitive to variations in physical stature. (Seward, Bradshaw & Margrave 1995, 438.) I interpret this that an engineer, as well as a 3D artist can create a human-like robot, but with many freedoms in the design process. It doesn't have to follow human anatomy precisely to be able to have a successful human-like functions and form. Therefore, a 3D artist can exaggerate the overall design, or some parts of it, but should have the basic mass and centre of gravity as close to human anatomy as possible, like explained in the 1995 study (Figure 4).

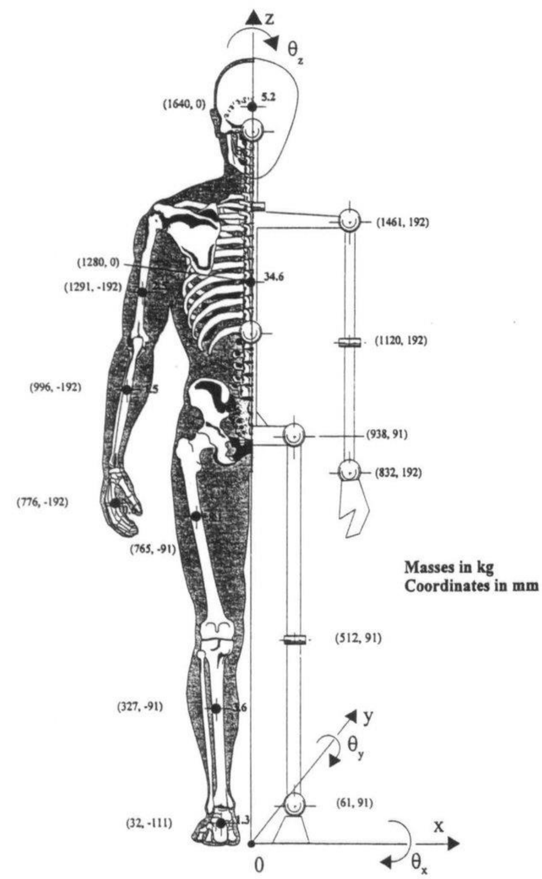
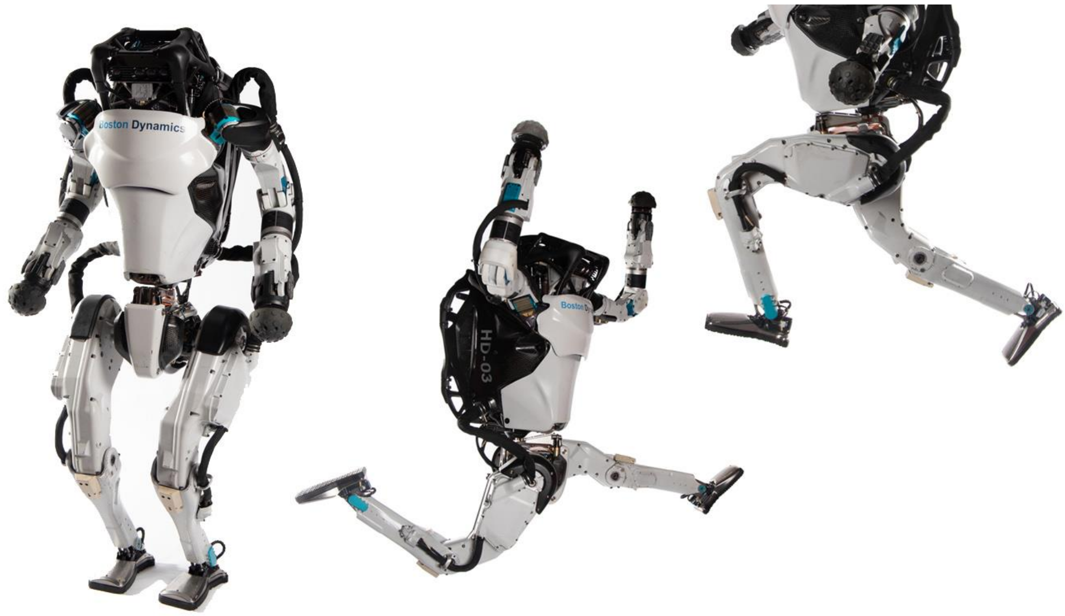


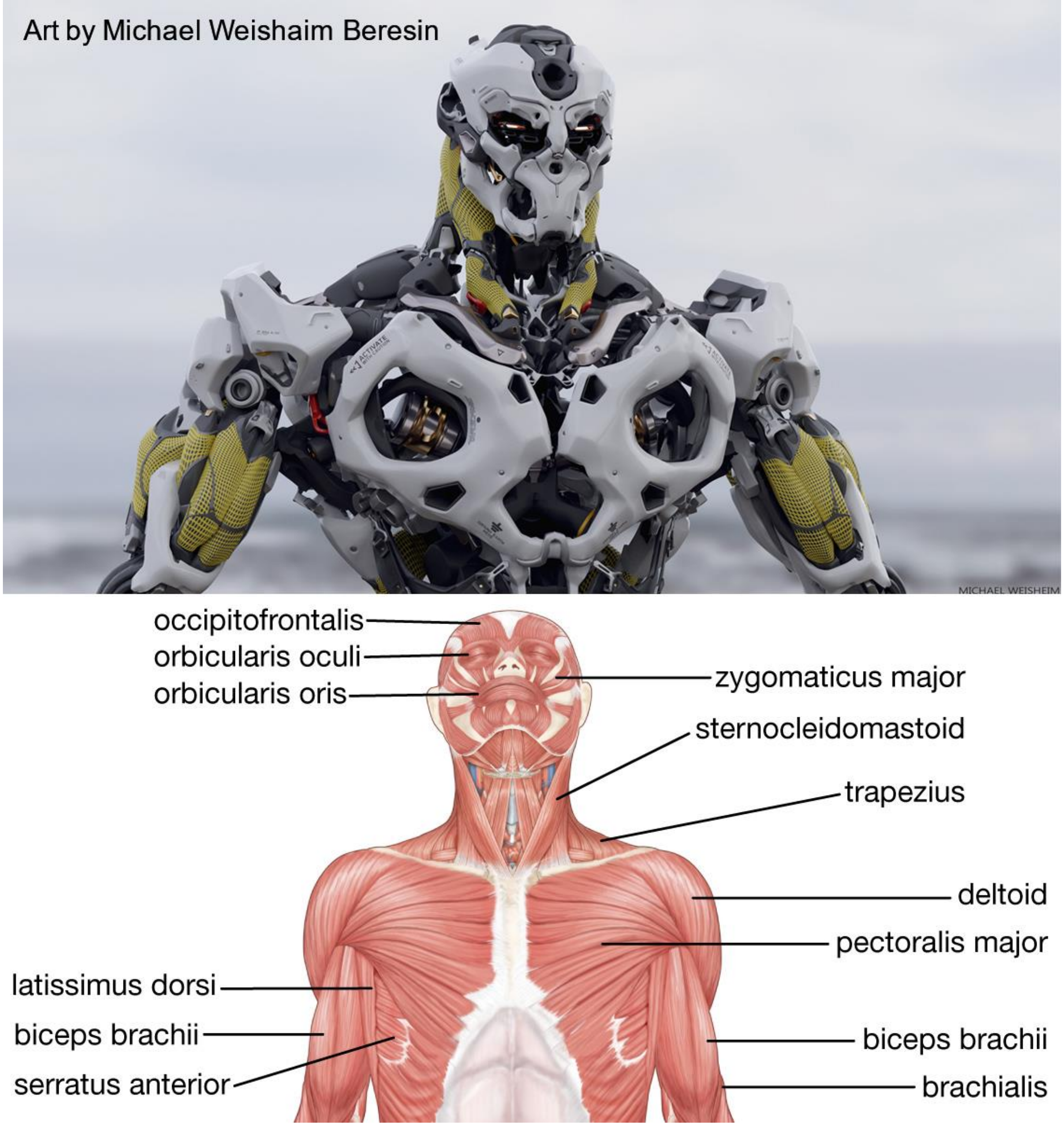
FIGURE 4. Mass and centre of gravity of limbs and joint coordinates (1995)

By looking at a Boston Dynamics robot Atlas (Picture 18), it’s safe to say that it has been designed to be human-like, based on its proportions, limbs, and form. According to bostondynamics.com, Atlas is a robot with advanced control system and hardware, that give the robot the power and balance to demonstrate human-level agility (Boston Dynamics n.d).



PICTURE 18. Boston Dynamics robot Atlas

We can see that Atlas generally functions like humans, even though it’s missing many human-like visual features, such as muscles, human-like head, fingers and so on. However, in my opinion, if the robot is meant to have more precise human-like movements, it should follow the science of human anatomy even more precisely. To achieve this, applying more detailed human anatomy to a hard-surface 3D robotics design is greatly recommended. By comparing the Encyclopædia Britannica, Inc. (2013) illustration of a human anatomy, to Michael Weisheim Beresin’s (2021) robot character 3D art, we can analyse how the 3D artist has followed the human muscular system anatomy in their hard-surface design choices to achieve realistic and believable robotic design (Picture 19).



PICTURE 19. 3D art by Michael Weishaim Beresin (2021) compared to illustration of a human muscular system (2013)

We can see that the 3D artist has enabled a human-like neck movement for the robot, by including artificial pneumatic muscles, based on humans' neck muscles, called sternocleidomastoids. Biceps and triceps are also made from the same pneumatic mechanism. Even though the robot is CG and not real, in my opinion it has perfectly captured realism, by utilizing this design principle as part of the workflow. It's safe to assume that the 3D artist has studied human muscle anatomy to achieve this result. I think that the artist has implemented other hard-surface design choices as well to the robot, by using a human muscular system anatomy as a reference.

3.4.2 Futuristic and science-fiction design principles

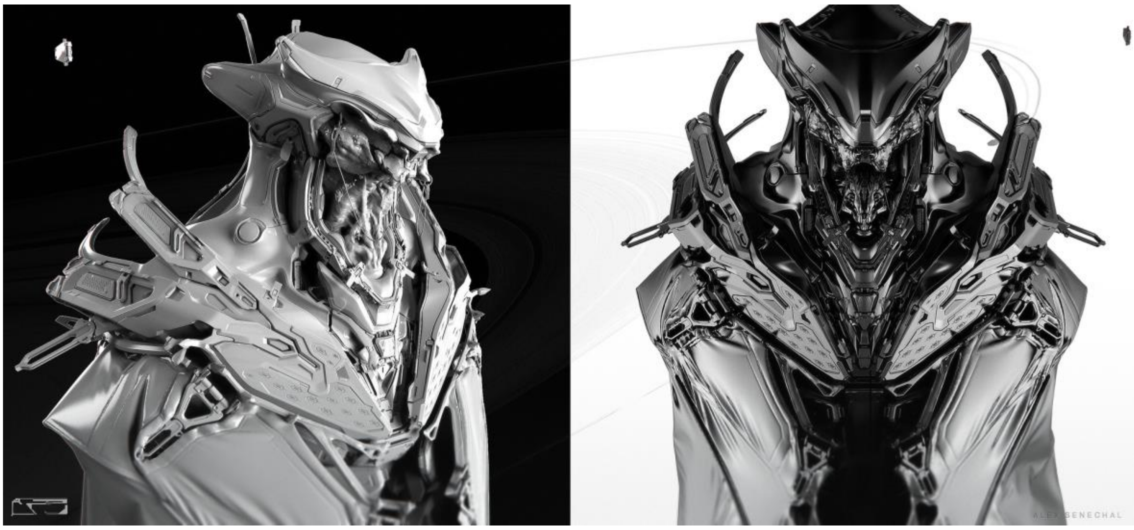
In my opinion, creating a hard-surface 3D art is more flexible than a real mechanical engineering, in a sense that CG allows 3D artists to create something that is not real or would be too difficult or expensive to manufacture and have functioning in real world, because after all 3D artists are creating art and concepts, rather than manufactured industrial design. There are no budgets or time specific scientific limitations, therefore, a 3D artist can create whatever they want, including futuristic and science-fiction based designs.

According to 3D concept artist Alex Senechal (2017), sci-fi requires an underlying idea like everything else, but has a different execution. Applying design theory and exploring continually new ways to apply those fundamentals is important. In sci-fi artistic principals are as important as in any artistic endeavour and it makes the difference between sci-fi that stands out and that doesn't. You can have the best ideas, but without a good execution it won't matter. Artistic fundamentals and theory are how you make sci-fi work. (Tokarev 2017.)

Senechal also explains, that one of the reasons why a lot of sci-fi feels generic is the boxy look of it. He says in the 80 Level interview the following, "I think sci-fi environments are really important to give context to and apply artistic theory too. It is no different than making any other type of art. I see a lot of sci-fi with random 45-degree angles, beveled boxes and retro ovular forms, and random details. I think it's important to try and find unique visual languages, instead of falling back on generic sci-fi looks. Pushing for more compound shapes aka breaking the box is important I think." (Tokarev 2017.)

I interpret this as, that for a 3D artist to achieve a successful, believable, and visually pleasing sci-fi look, one of the most important factors is to avoid making general design choices, such as boxy and general forms, as quoted above. So how to apply these fundamentals to robotics design? I believe that the key is to combine the previously discussed principles of mechanical engineering and visual design and apply them to robotics design.

By looking and analysing some of Alex Senechal's sci-fi based 3D art we can get a better understanding what he meant by avoiding boxy shapes and doing general forms. Alex Senechal has an original style, and, in my opinion, it is well presented on his art (Picture 20; Picture 21).



PICTURE 20. Exiled 15 – The King's Emissary by Alex Senechal (2018)

PICTURE 21. Planetary repair suit by Alex Senechal (2019)

Boxy shapes and forms are almost non-existent in his sci-fi designs. The first example is taken to an extreme, when it comes to sci-fi, and it seems more alien than human technology. In my opinion, it still looks real and believable, but nothing that would exist in present day. Therefore, the 3D artist has achieved an extremely beautiful sci-fi look, by avoiding general design choices.

4 PIPELINES FOR PRESENTING PHOTOREALISTIC CG

4.1 Real-time rendering

According to Chaos' article, real-time is explained as the process of a computer generating a series of images fast enough to allow for interaction. The goal with real-time rendering is to match the monitor refresh rate to make visuals smooth. (Winchester 2019.) I believe that real-time rendering is mostly used in the process to create video games. Although, there are many other ways to utilize real-time graphics too. The most common game engines are Unreal and Unity.

To produce 3D art for video games the pipeline is more precise. Henry Winchester (2019) explains real-time graphics for artists as the following, "An artist working on a video game, for example, has to understand how to make the game assets fit certain polycounts and how to optimize textures without compromising how they look. A VFX or arch-viz artist has to make sure everything looks photorealistic and physically correct. Working photorealistically is easier by comparison since the results relate to the real world, and so this workflow is beneficial to all designers and artists. "(Winchester 2019.) In conclusion, to present a real-time graphics properly, there are many more rules and limitations for artist, whereas in the offline rendering 3D artists can cut some corners from the perspective of technicality.

4.2 Offline rendering

Offline rendering refers to anything where the frames are rendered to an image format, such as still images or videos (Teo 2010). Therefore, offline rendering cannot be interactive the same way as real-time rendering. In my opinion, offline rendering is best for product visualization and concept art, because the 3D artist doesn't have to worry about the poly count and other technical limitations. Only the visual outcome matters, and I think this gives more freedom to create more believable results. For this thesis' practical project, I am going to use the offline rendering pipeline, because I am trying to design a concept of a manufactured product.

5 MAKING A 3D ROBOT

5.1 Creating a concept

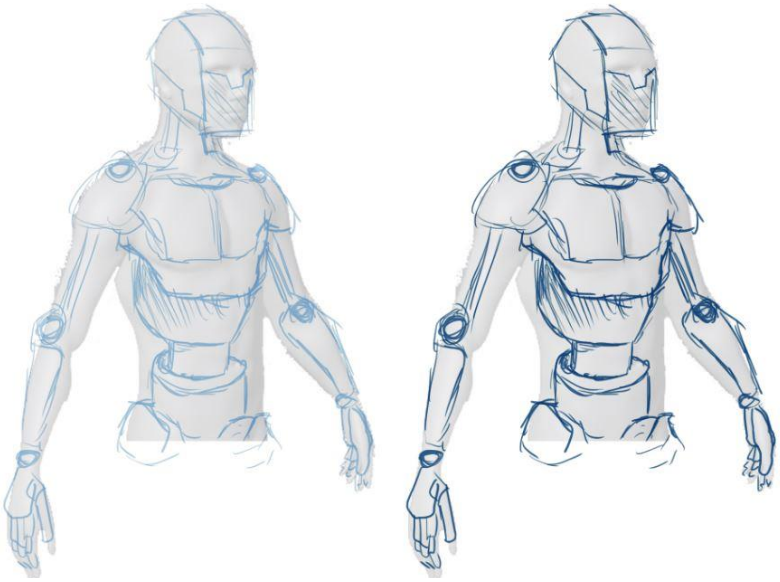
To demonstrate the researched topic in the most profound way, I am going to make an upper body of a humanoid robot. I believe that good way to start the design process is to start putting the concept idea in some sort of basic medium, such as sketching it digitally or on paper, before going to the 3D modeling. However, it's not a necessity and some professional 3D artists don't even do it. Some people can visualize the design in their head and start straight from the 3D modeling process. Even I do this some of the time, but for demonstrative purposes, I am going to start from the 2D sketch, continue to a 3D blockout in Blender, and then start the final 3D modeling process.

5.1.1 Gathering reference materials

Like discussed multiple times in the thesis, reference is one of the most important key principles of achieving realism in CG. I gathered some reference images, so I had a better visual perception what I wanted to design. I wanted the robot to look believable and realistic, with minor sci-fi elements, but at the same time rely on present day possibilities and avoid creating alien looking technology. Therefore, I decided to use some real-life machines as a reference, along with some existing CG robots. I gathered all the references on same artboard using a software called PureRef.

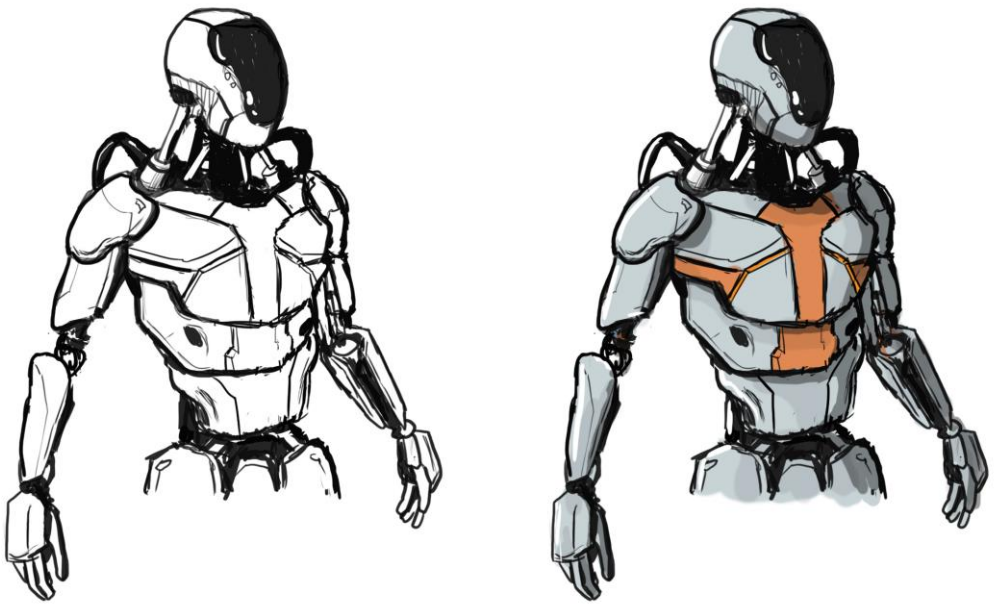
5.1.2 Making a 2D sketch

2D sketches aren't necessity in 3D art, but they can help a 3D artist to pre-visualise what they want to create, therefore having a more straightforward workflow towards the final result. I took a screenshot of a 3D human model from Blender to help me to start the sketching in Photoshop. After importing the screenshot to Photoshop, I drew some basic primitive forms over it, to get the proportions and perspective somewhat right and help me to visualise of what I want to design (Picture 22).



PICTURE 22. A screenshot of the first primitive sketch in Photoshop

After drawing the basic blocky shapes, I started experimenting with more detailed, but still a rough sketch of what kind of overall forms and shapes I wanted to achieve. I made one sketch, where I tried to achieve general idea for my robot (Picture 23).



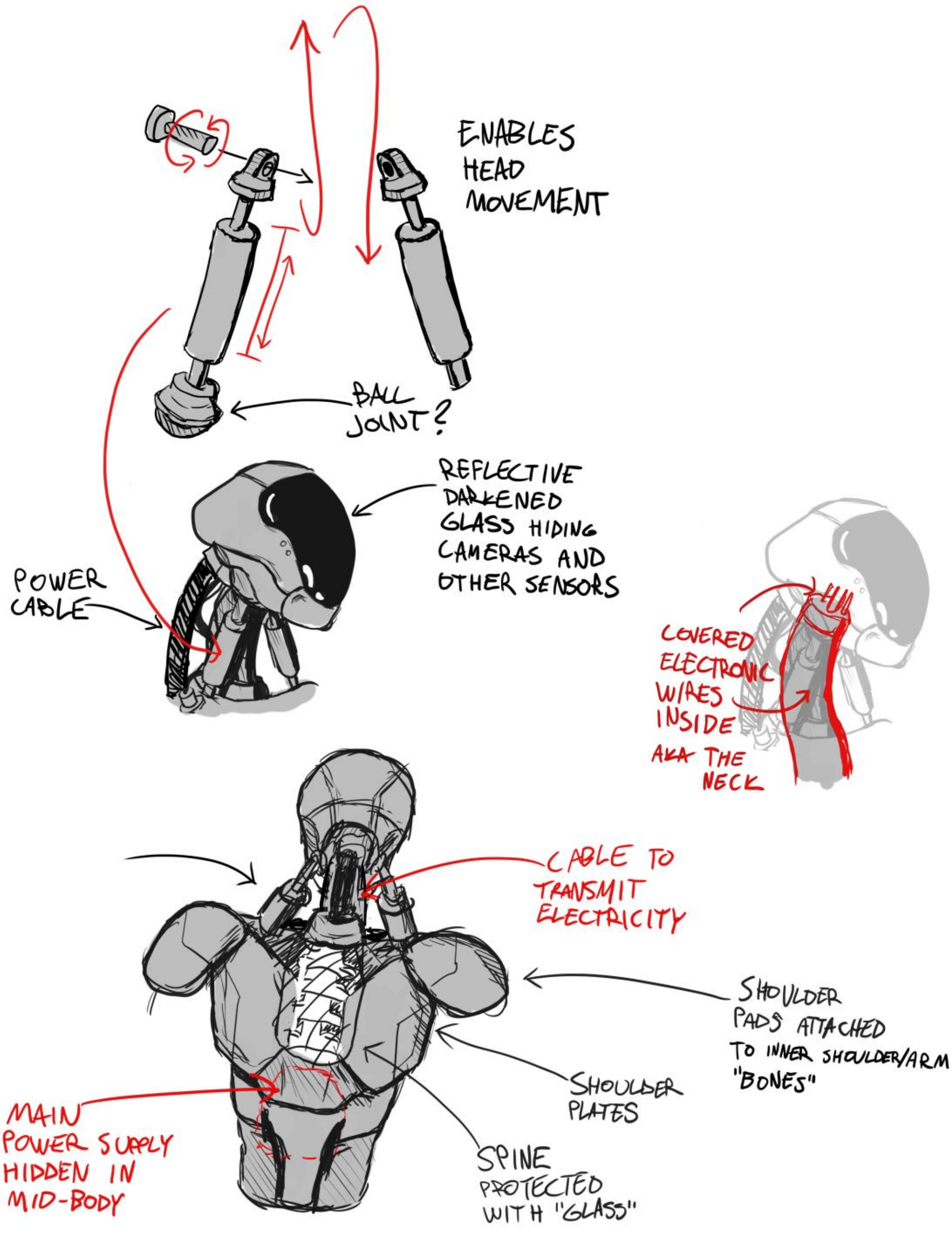
PICTURE 23. Overall design sketch

After I was somewhat happy with the sketch, I made different variations for the head. I experimented with the shapes to get something more interesting, avoiding simple forms, and was most happy with the third option (Picture 24).

PICTURE 24. 2D sketches for different head variations

Like discussed earlier, a 3D artist should create their base design choices based on function, instead of artistic freedom, and since this is the earliest concept base, it is good to include functionalities in the design process. Therefore, trying to avoid possible unrealistic results.

Since the front of the torso is probably going to be just plates covering the insides, I sketched the back of the torso to my 2D concept document (Picture 25). In my opinion, so far everything in my concept has followed the principles of functionality. I applied human anatomy to my robot design as well, including a human-like artificial spine to it. I thought that the main power supply of the robot should be inside of the torso, same way as humans have the most vital organs protected by rib cage and muscles around them. Cables, motors, power supplies, circuit boards, batteries and other vital parts that make the robot work are hidden inside of the torso. For the head movement I added hydraulic cylinders, that are commonly used in mechanical designs. The hydraulic cylinders have another rotating cylinder attached to the head part, and ball joints attached to collarbone part, allowing mobile neck and head movement. I wanted to make the design more interesting and sci-fi, by showing the artificial spine underneath a transparent plastic cover.

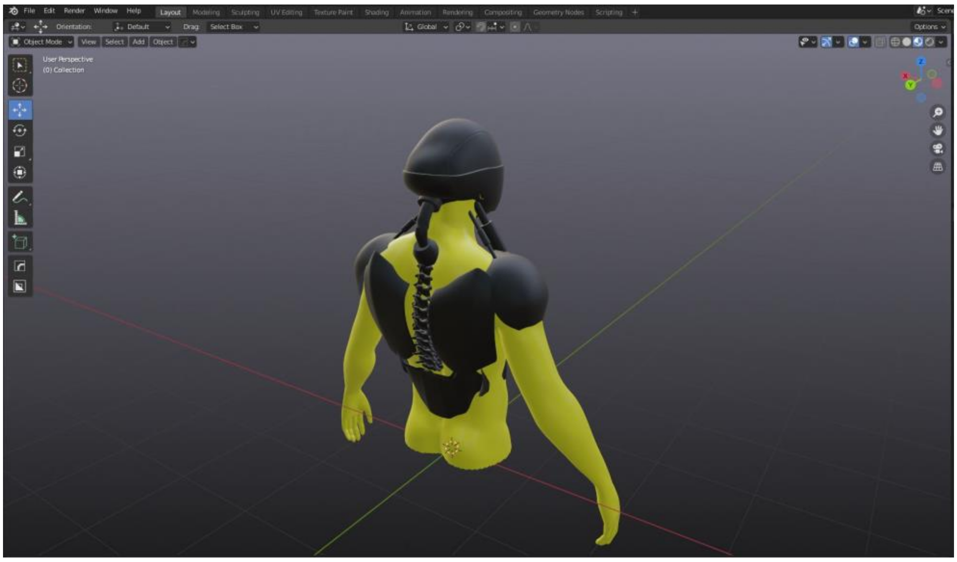


PICTURE 25. 2D concept art for function and design

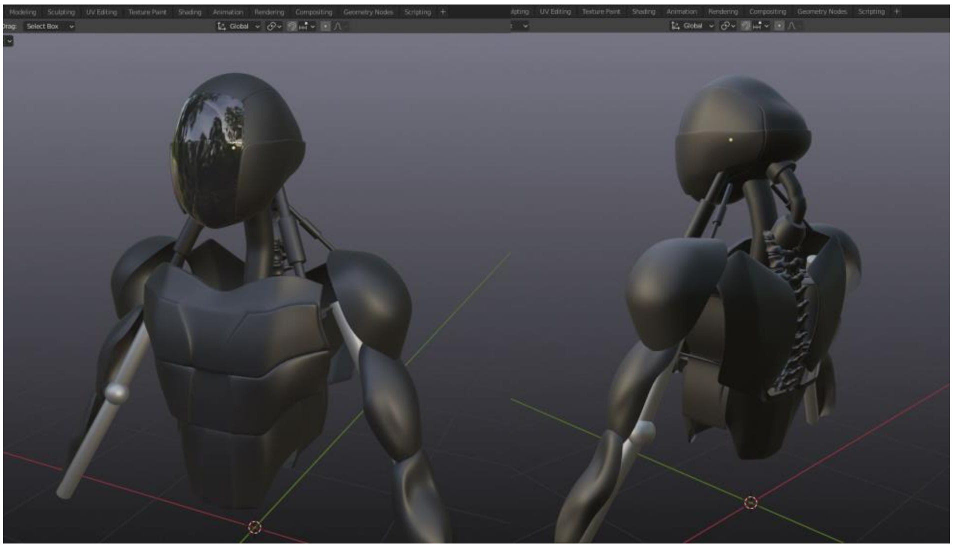
It was more than probable, that the design would change during the 3D modeling process. This is due to a fact, that after all, I am creating a CG art piece, rather than engineering a real robot. The goal was to make the viewer believe it could be something real, therefore I saved some of the possible artistic and visual decisions for the 3D modeling process, as long as I followed functionality.

5.1.3 Making a 3D blockout

A 3D blockout is a process where a 3D artist can use the most primitive shapes to create the base for their design. This can help to visualise of what they are creating in the end and unveil some problems that weren't so obvious in the ideation or in the 2D sketching phase. For this project I imported a human male 3D model for reference for my blockout, and started building shapes around it, to get the proportions and position somewhat right (Picture 26). After that I hid the reference human body from the 3D viewport and re-positioned the meshes to look correct, without the human reference underneath (Picture 27).



PICTURE 26. A screen capture from Blender of the 3D blockout with the human body reference

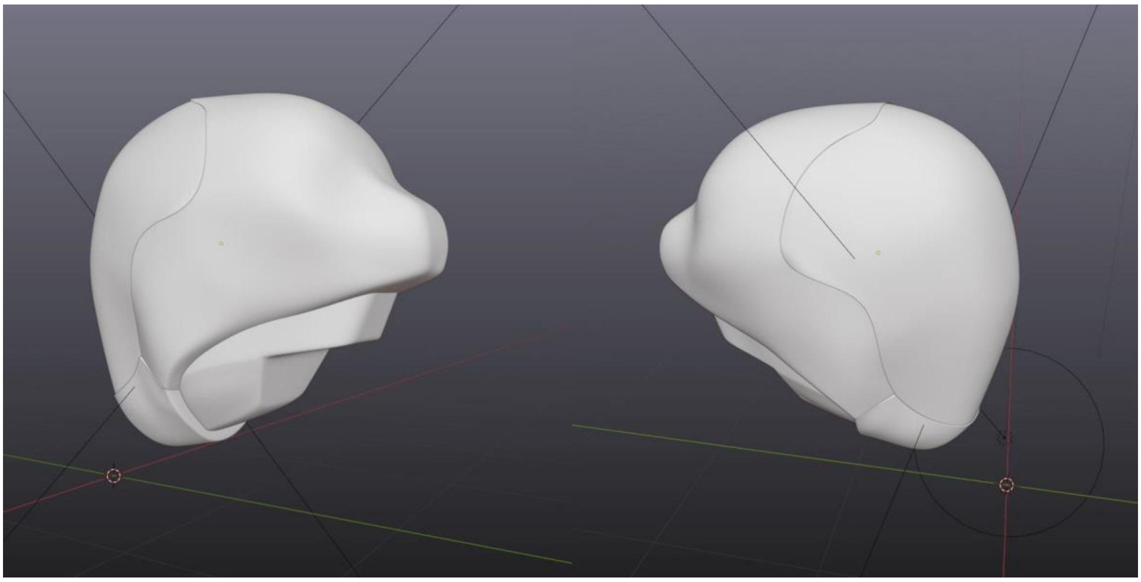


PICTURE 27. Screen captures from Blender of the 3D blockout

Since I didn't encounter any problematic design choices so far, I felt confident to continue to the actual final 3D modeling process. A 3D blockout is not a necessary part of the workflow, but in my opinion, it can only give advantages for a 3D artist. All this concepting was done for me to have a better understanding of what I was going to do, and it was almost certain that the design would greatly change from the original 2D sketch and from the 3D blockout. Again, this was only for me to design the function, and some artistic and visual design choices will follow afterwards. It is a different scenario when a 3D artist is following someone else's concept design.

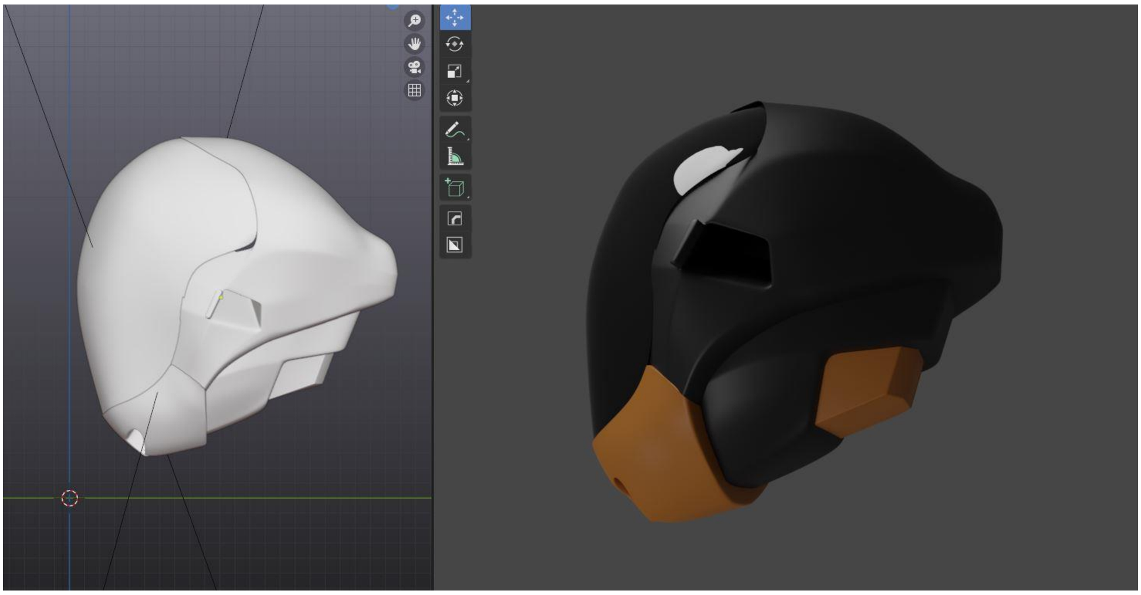
5.2 3D modeling

For the 3D modeling process, I am going to focus on the theoretical aspects of the workflow, instead of the technicalities of Blender and 3D modeling, and aim to document how to achieve the desired finald product, from the design standpoint, that was researched for the thesis. I started the 3D modeling by making the base mesh for the head (Picture 28). I had a side- and front view 2D sketches as a reference to guide me.



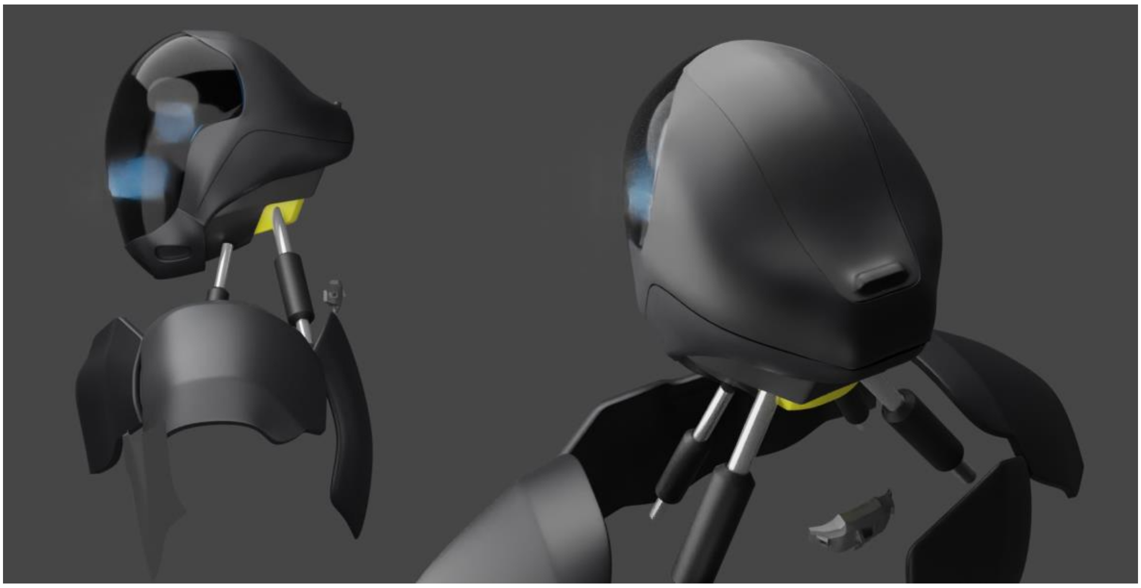
PICTURE 28. Screen captures from Blender of the base mesh of the head

When I was happy with the basic form of the head, I started experimenting with different shapes and colors already (Picture 29). In my opinion, this is a good way to see what you want to create. If there's not a detailed concept what the 3D artist is going for, best way to try different possibilities is to experiment, until something visually pleasing is found. This can also be done in the blockout phase.



PICTURE 29. Screen captures from Blender of the base mesh of the head

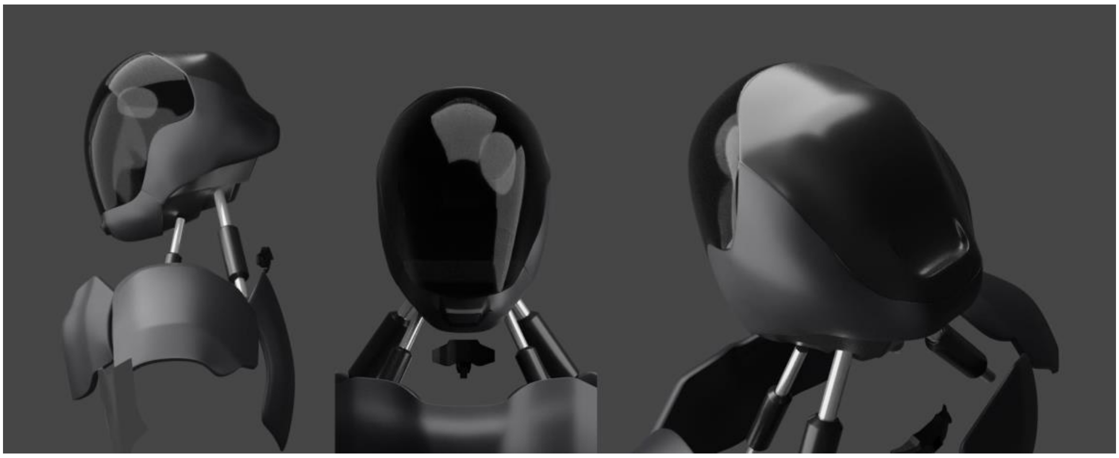
I continued the modeling by creating base shapes for shoulder- and chest pads and adding some primitive hydraulic joints for reference (Picture 30). It is good to keep in mind, that I'm not yet at this point creating final shapes, I am just experimenting with them, and going back and adjusting them to my liking.



PICTURE 30. Screen captures from Blender of the base meshes of the upper body

I think that this is a good phase to also experiment with panel lines and other details, but it is important to keep a copy of all your 3D meshes and preferably an older save file, and to not save your progress yet, as I'm only experimenting and don't want to commit to any final decisions yet. Again, it is also vital to remember that every design choice should be based on function. Therefore, if there is a panel line somewhere, it needs to have a reason to be there. We could ask ourselves questions like what is underneath the panel? Is it important that what is underneath is accessible? Would the cover panels be built like that in that specific area? There is no reason to have illogical panels, just as they don't exist in real life either, because in the end, everything that is manufactured in real life serves a purpose for function. Since the head was so round, it made sense that it would have been built from more than one uniform hard-surface shape, because it must be assembled and have an option for disassembly. Therefore, I kept the upper panel line on top of the head, in a same way I had it in my 2D sketch.

After some redesigning, I got more detailed and final look for the head. I added more curve to the top of the head to give it more interesting visual design, and at the same time implicating that there are some important parts inside of it. Therefore, it has a panel line around it, and the lower part works as a hatch at the same time by making a shape that helps a person to get a grip of it and open it, even though it needed more details to give the impression that it could be opened. I also made the chin part lower and gave it some details that, in my opinion, improved the design's believability from the functional standpoint. Finally, I removed the panel line in the middle since it was breaking the harmony of the visual design and didn't seem to serve any kind of functional purpose (Picture 31).

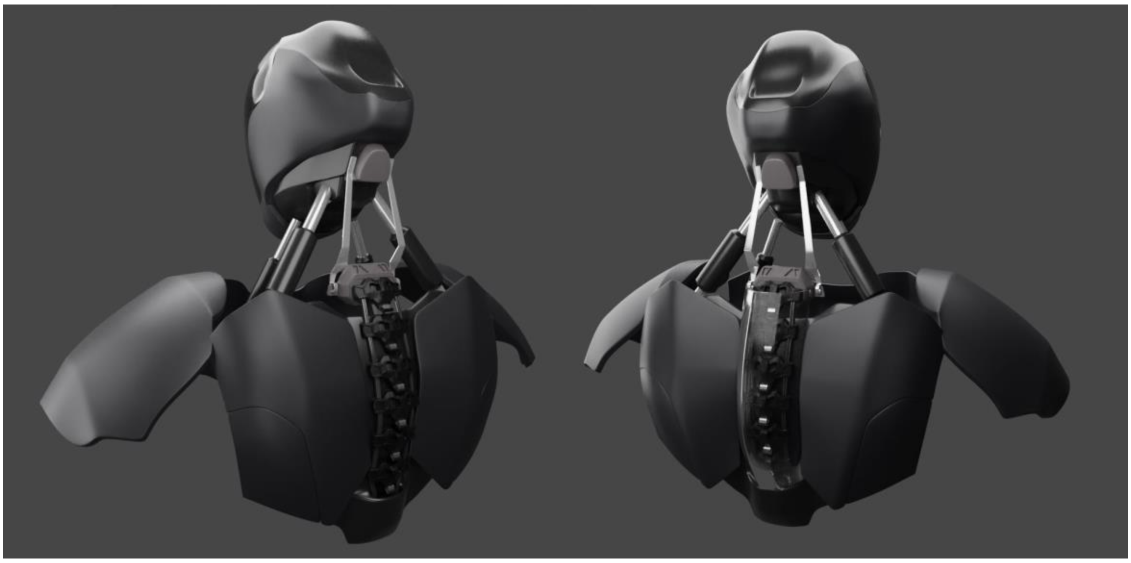


PICTURE 31. Screen captures from Blender of the head design

After that I continued to create the base for the spine (Picture 32). I used CG robots with spine and a human anatomy as a reference. The spine only had one kind of vertebras at this point, but I would add more underneath to make it seem more functional, after I've made the overall design further. It is possible that the spine's design would change completely in the later design process.

PICTURE 32. Screen captures from Blender of the spine

When I was somewhat happy with the spine, I continued to experiment with panel lines of the shoulder plates and designing functional attachments from spine to the neck (Picture 33). Having some basic materials during the thinking process helps me to visualize the outcome I want to achieve better.

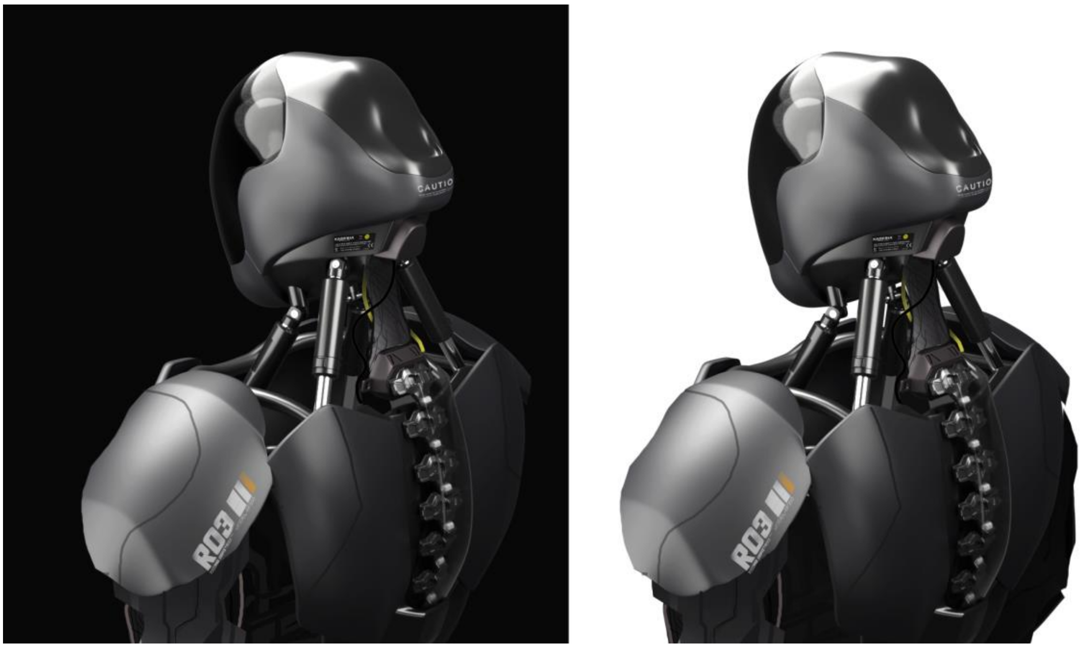


PICTURE 33. Screen captures from Blender of the spine

I removed the slim metal attachments from the neck, since they were breaking the harmony of the visual design and didn't seem to serve any functional purpose. I also removed the wires from the spine, since they were giving a toy like impression for the design, build a metal cage for the shoulder and neck area to hold everything together, reinforced the hydraulic cylinders and thought out the mechanical joints on how to attach them to the head in realistic way (Picture 34).

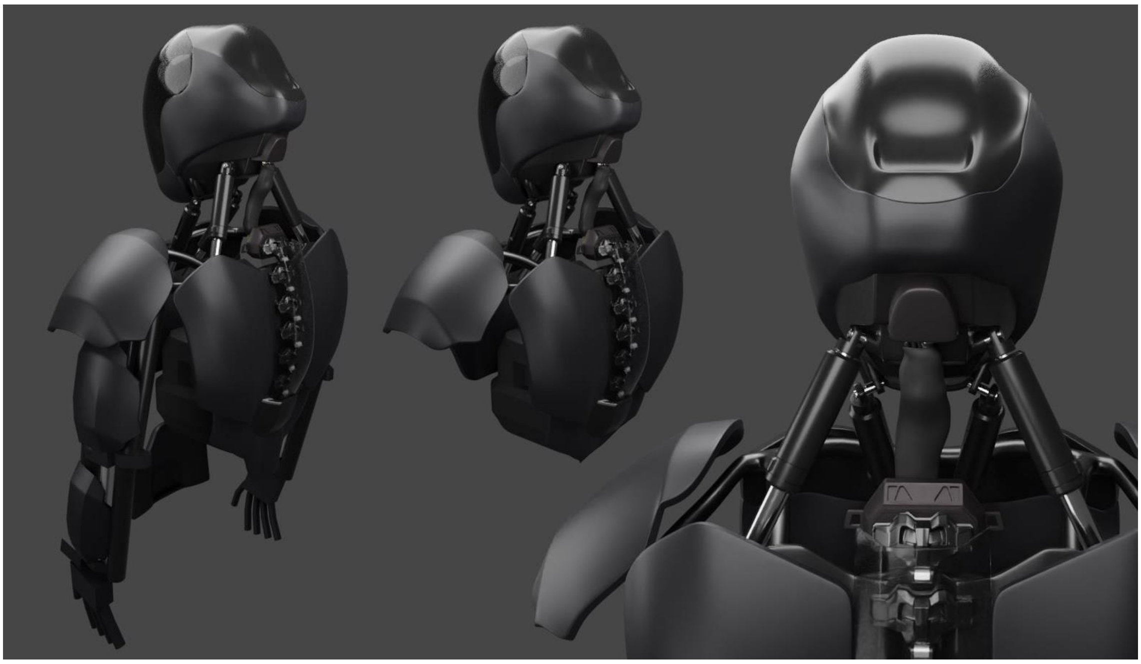
PICTURE 34. Screenshots from Blender of the neck and shoulder area

I then took the first test render with Blender's Cycles renderer and imported it into Photoshop, where I adjusted the lighting, added some decals for reference, and painted over the rendered image, by adding arms, panel lines, some wires, and removing volume from the shoulder pads (Picture 35). This helps me to experiment with minimal effort and instantly see how the design would look in the 3D software, without doing actual 3D modeling. I now knew that smaller shoulder pads looked better on the robot and that the wires in the neck would add more realism to it. After all, I needed some way to have the electricity transferred to the head from the lower area of the robot.



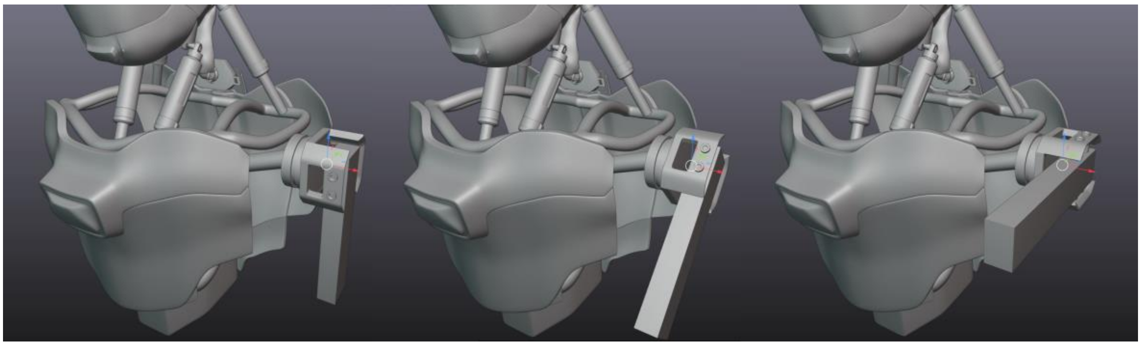
PICTURE 35. First test render with Photoshop pass

Following the photoshop pass, I resized the shoulder pads, 3D modeled some wires to the neck and blocked out simple arms for a reference. The blockout process can be continuous throughout the 3D modeling process if it helps the 3D artist to design. In my case, this is a vital part of the workflow, where I can think about function at the same time as the visual design. I also changed the rotation of the hydraulic cylinders in the front (Picture 36).



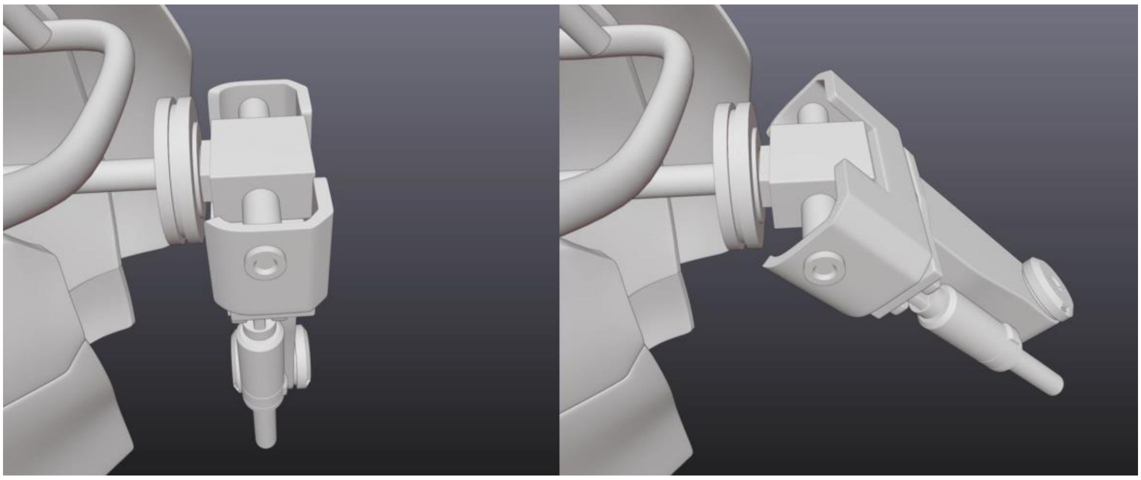
PICTURE 36. Screen captures from Blender of the upper body and blocked out arms

When designing the arm, I needed to make sure that it could function adequately, before committing to any final design choices, that could later turn out to be unpractical, therefore breaking the illusion of realism. Good way to test this is to build the base joints for the shoulders. Now, by rotating the shoulder from X-axis I can see that it functions and doesn't overlap with anything else. There's a cylinder-shaped joint allowing the rotation, but I also needed to think the Y-axis rotation for the shoulder as well (Picture 37).



PICTURE 37. Screen captures from Blender of the X-axis rotation of the shoulder

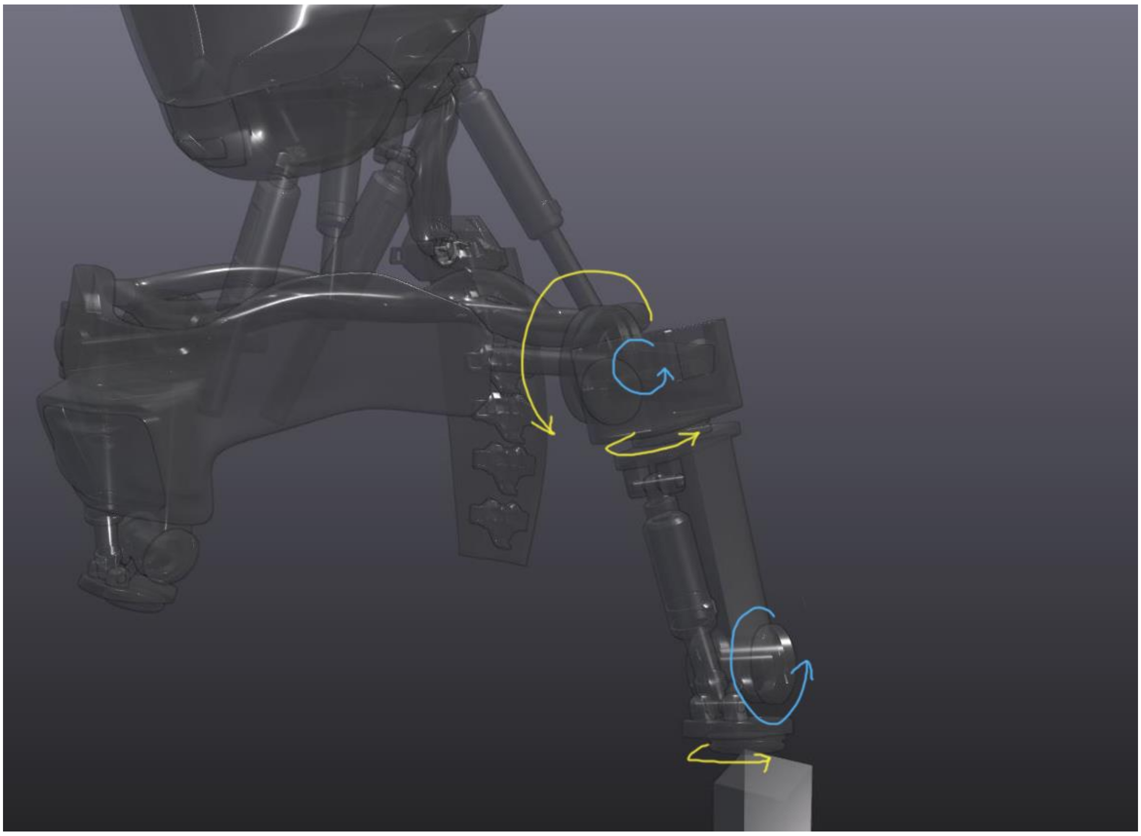
I had to look a lot of references of real-life robots to get a proper understanding of how their joints work. After watching a lot of videos about humanoid robots, I got to this solution for the Y-axis rotation, so any of the meshes wouldn't have any clipping (Picture 38).



PICTURE 38. Screen captures from Blender of the Y-axis rotation of the shoulder

In the end it doesn't matter too much because most of the joints would be hidden from the viewer with cover plates, and since I am only creating CG art, and not a real robot. Like discussed earlier, the key is to sell the realism for the viewer.

When I finally designed all the rotational axis for the arms, I could begin to design the covers for them. I know that the arms function properly now, based on real life physics and give realistic rotation for everything, therefore I am following the design principle: function before design (Picture 39).

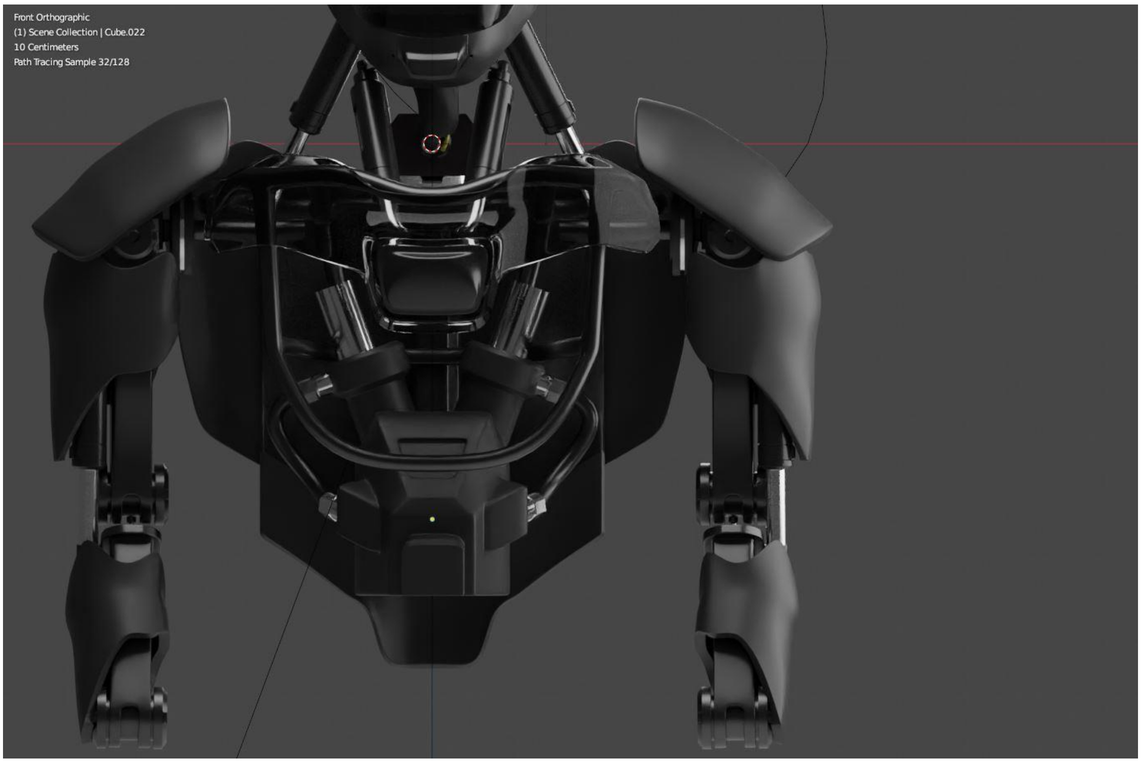


PICTURE 39. Screen capture from Blender of the arm joint rotations

When designing cover plates for the arms, I made the first design test relatively fast to get the basic visual idea (Picture 40). This helps me to visualize if they are even needed. Do they serve any function? Will there be something important that they are covering? These are the questions to ask myself at this point, because after all, the arms that already are done, are in fact covers of some sort, that are hiding many vital parts, like studied in the thesis earlier. So, it would basically be extra cover, and not the cover for the electronics and mechanics inside, that has already been done, but more for a visual cover.

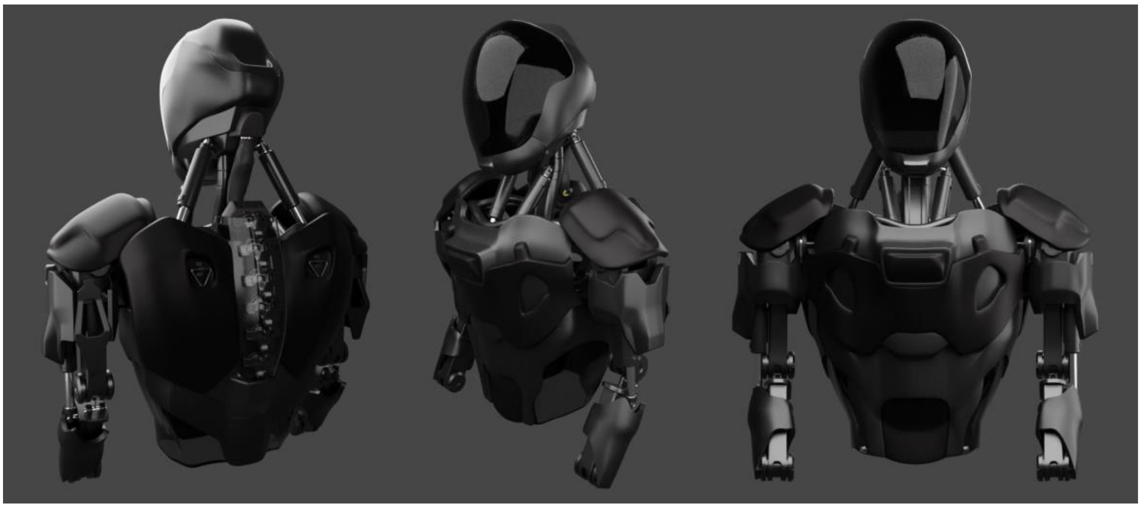
PICTURE 40. Screen captures from Blender of the first arm cover designs

I decided to have some cover on the arms, because in my case, I think the robot will need some extra cover that protects the insides from impacts and harsh weather conditions. Since it is a robot that can be utilized by military, I think the extra cover is needed. At least it won't do any harm from the standpoint of function. After that I thought it was good to design the motor, because I needed to start building the insides, so I could construct the upper torso overall and think about how everything is attached, and how the motor transfers electricity to other parts (Picture 41).



PICTURE 41. Screen capture from Blender of the motor

Since I had most of the functions thought out for the outer, most visible parts and the inner parts on place I could start designing the outer panels and more detailed look for them (Picture 42).

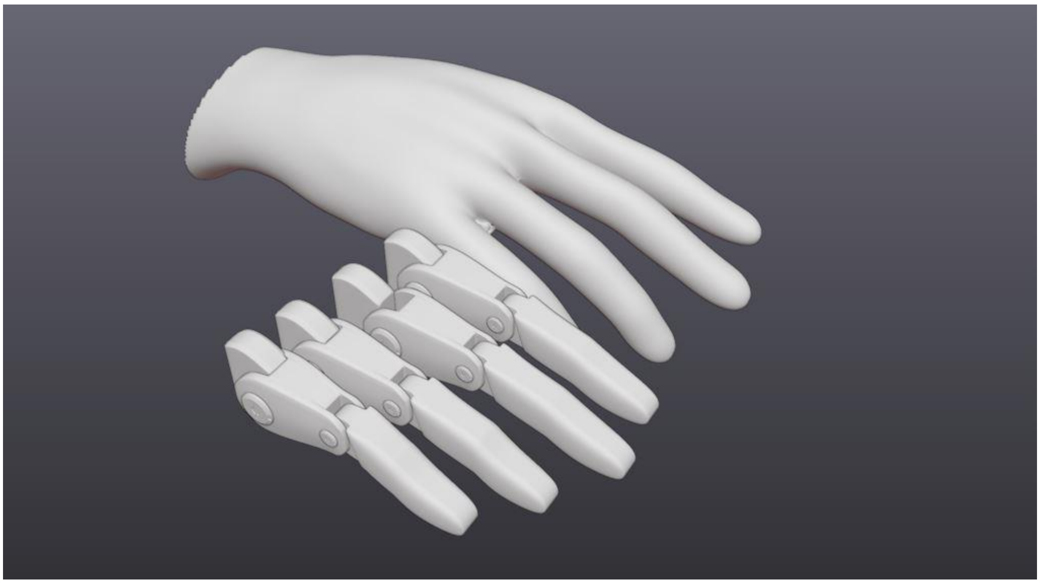


PICTURE 42. Screen captures from Blender of the almost finished outer parts

Because the head could not be supported by the hydraulic cylinders alone and it needs a stronger support from the upper body, while at the same time it would make sense that there are lots of cables, wires, microchips, and other electronic parts hidden, I made the neck almost three times as thick as it was before. I also took a second test render and made some fake details to it in Photoshop, such as panel lines, screws, surface imperfections and decals (Picture 43). This helps me once again to visualize what and how I will continue my design in the 3D software.

PICTURE 43. Second test render with Photoshop pass

Finally, I started to design the hands and fingers. For this I used a human hand as a reference again, to get the proportions and joints right. Since the robot doesn’t need to have full human anatomy in its fingers, I simplified the tip of the fingers, because they don’t need to bend in the same way as in real human hands (Picture 44).

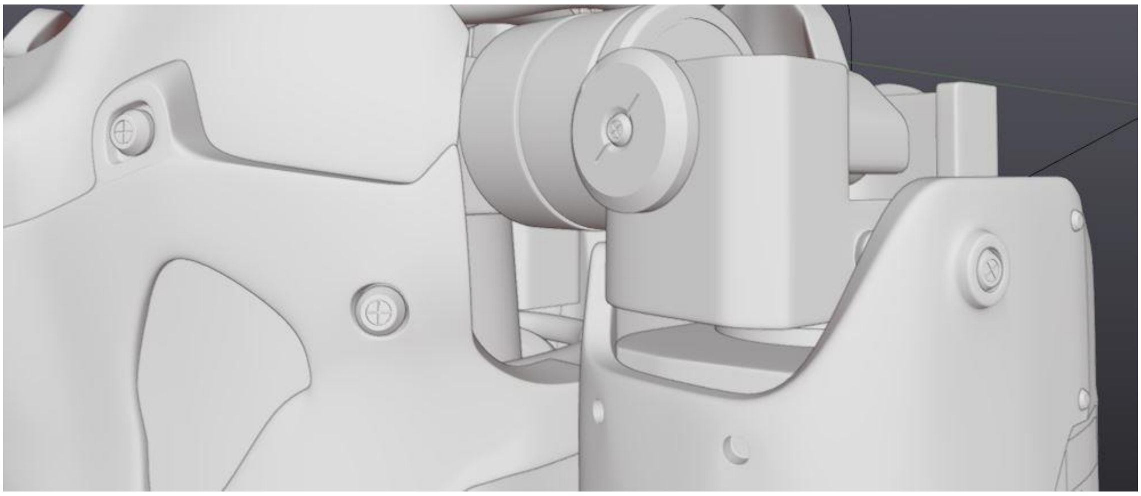


PICTURE 44. Screen capture from Blender of the fingers

After the fingers I designed the hand and thumb (Picture 45). It is not necessary to have the thumb as flexible movement as a real human would have, because again, the robot I am designing doesn’t have to be able to use its hand and fingers the same way as a real human. Its only purpose is to be able to do basic human-like movements, such as grabbing and pulling. Now I just needed to design the attachment for the wrist part, and after that I could start creating the details.

PICTURE 45. Screen captures from Blender of the finished hand design

Creating details into 3D meshes is the phase where you commit to your design choices, unless there are backup meshes or files, which in my opinion are always good to have. I created screw holes and screws for the outer parts that are attached to each other (Picture 46). These small details add up to the realism, but it is good to keep in mind that too much could break the illusion of realism. I added these details to almost every outer part of the robot, where it would make sense to have them. Again, they need to serve a purpose.

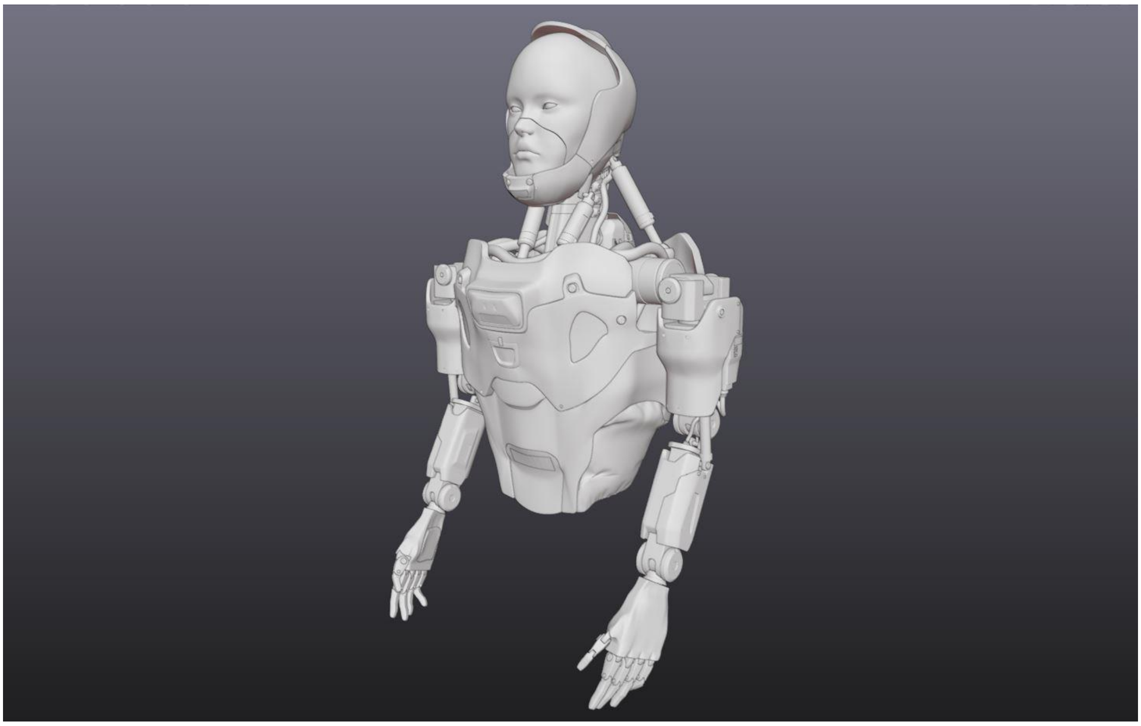


PICTURE 46. Screen capture from Blender of screw holes and screws

Another important detail was the panel lines (Picture 47). Some of the panel lines already came automatically when I was modeling the outer parts and detaching them from each other. I think that this is also a vital part to think about the visual design principles.

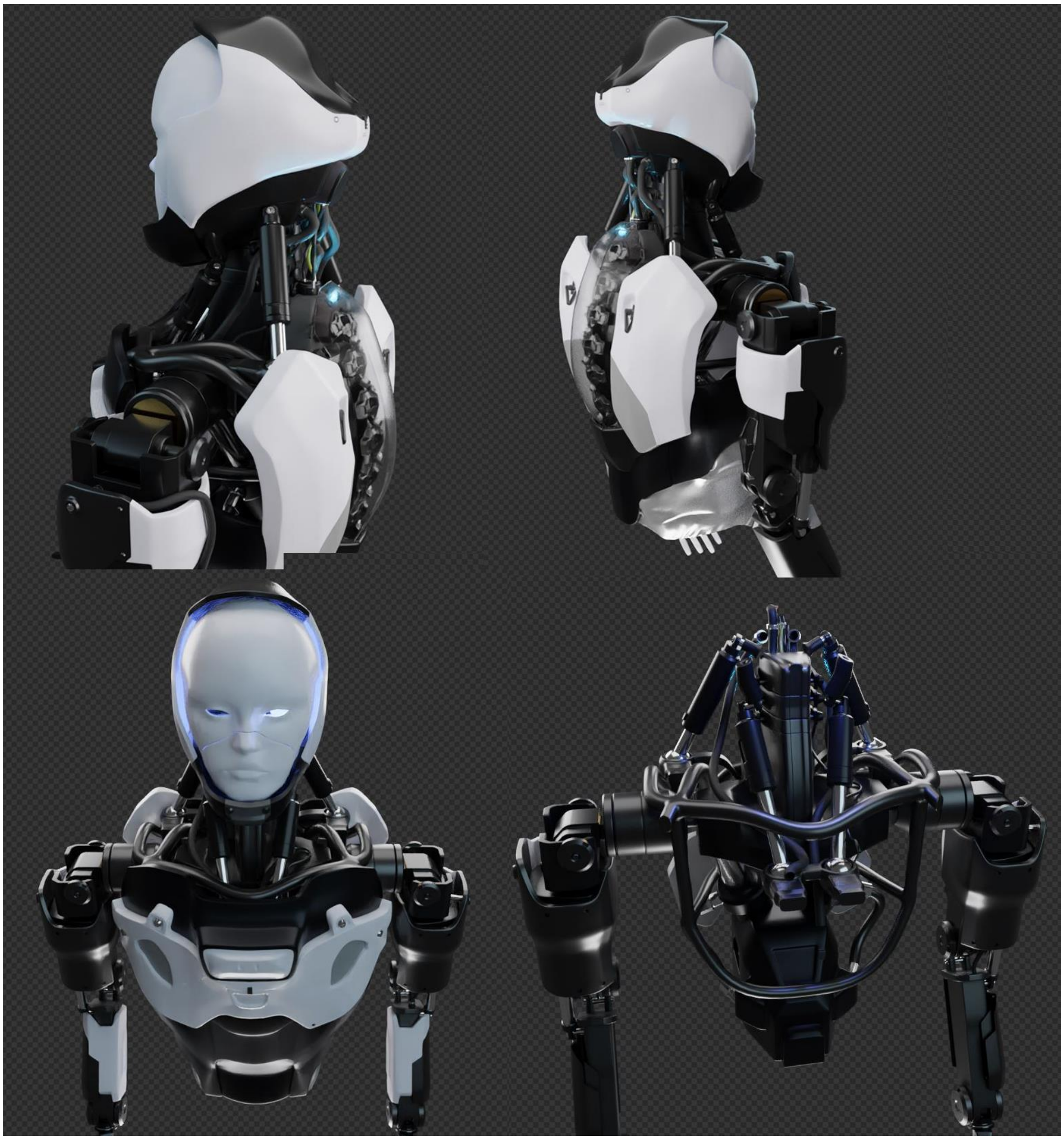
PICTURE 47. Screen capture from Blender of the panel lines

In the very end I added the robot a human-like female face to make the design more interesting (Picture 48). There's also a possibility to keep the visor in front of the face, which gives more possible variations for the design. In my opinion, I had now reached the design that gives an impression of something that works and functions properly, while at the same time maintaining harmony in the visual design.



PICTURE 48. Screen capture from Blender of the final design

Each joint was properly connected and enabled real life like movement, the electronic parts and their wires were well thought out, and there weren’t any unrealistic attachments or other parts. I decided to leave the shoulder pads off the robot, because I felt that they broke too much harmony of the design and when testing the movement of the arms and shoulders, it seemed that the shoulder pads made the arms’ rotation and functionality difficult. I also noticed that the visual design of the robot is more pleasing without them. The 3D modeling process was now done, and I was ready to move on to the texturing process (Picture 49).

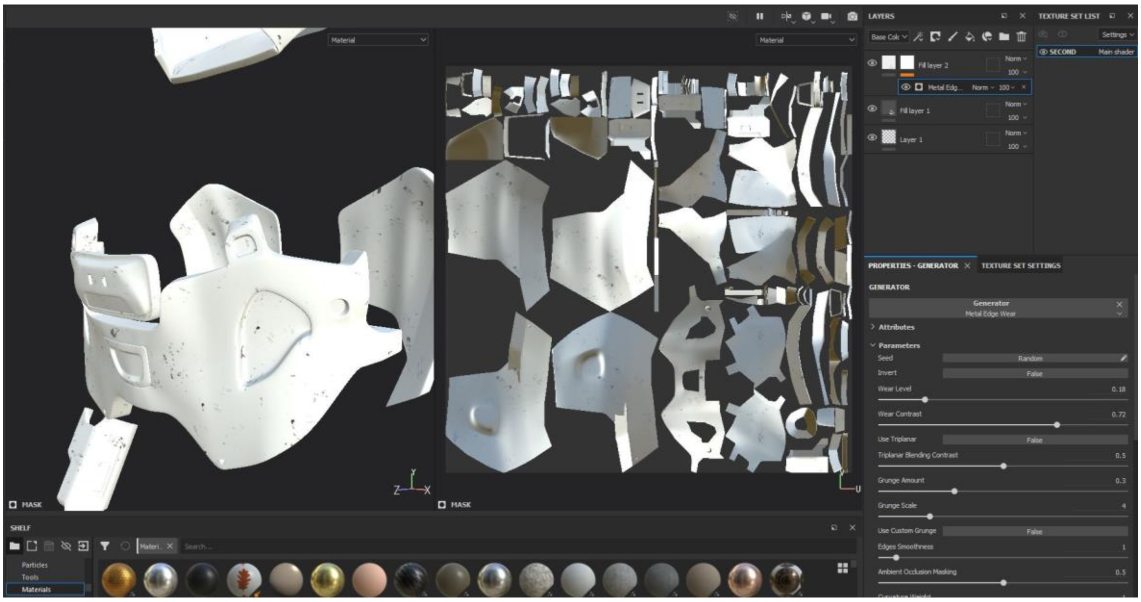


PICTURE 49. Screen captures from Blender of the final 3D modelled design

5.3 Texturing

I had already added some basic materials throughout the 3D modeling process, which have helped me to visualize the 3D modeling workflow better. However, to get the most photorealistic render, basic materials aren’t enough. I think they can serve a purpose of a simple, clean plastic or metal, but anything more than that needs more detailed texturing. For this process I used ready-made, downloaded textures as well as Substance Painter to create my own.

Since I wanted the robot to look like it has already been in some use, either manufactured and used, or a prototype which had been tested out, after UV-unwrapping the white cover plates of the robot, I imported them to Substance Painter and created some edge wear for them (Picture 50). This gives the impression that the robot has taken some minor surface damage. Unless something is straight from the box, they usually have edge wear and it's difficult to find anything metal or plastic from the real world that doesn't have any surface imperfections.



PICTURE 50. Screen capture from Substance Painter of the edge wearied plastic

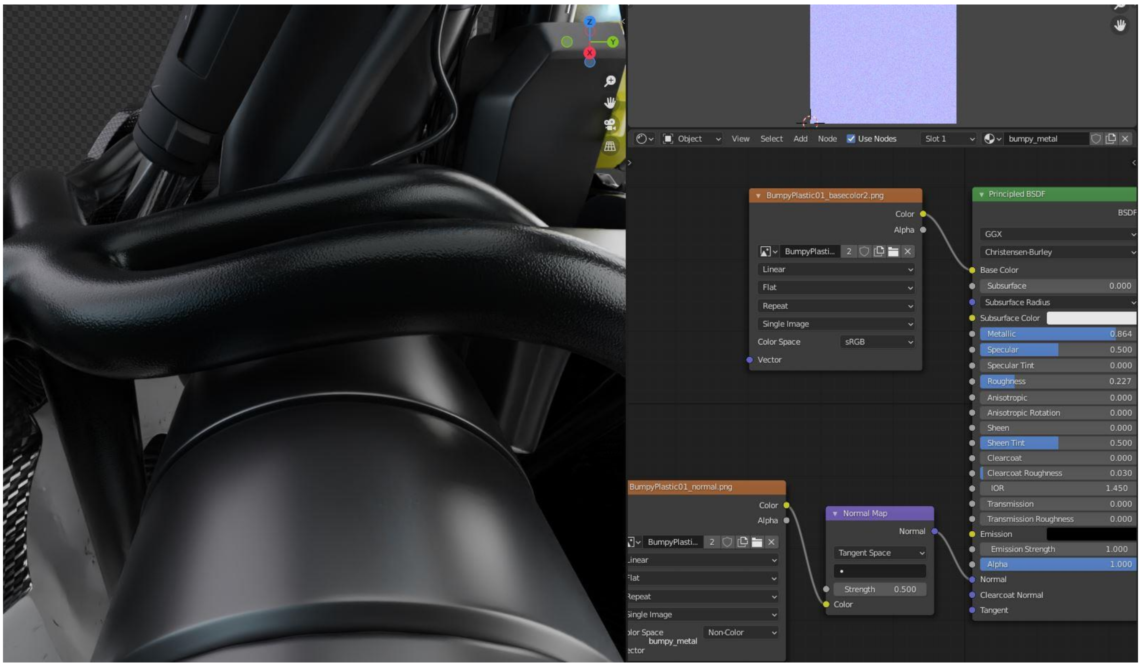
Like in real life, many of the products that are made to be durable are made from carbon fiber. Therefore, I wanted to have some of the panels made from it. For this I chose the thinner panels, since they need more durability, because they are not as thick as the big chest plate that is made from regular hard plastic (Picture 51).

PICTURE 51. Screen capture from Blender of the carbon fiber parts

For the hydraulic pumps in the neck, I also created edge wear in Substance Painter. Since they are in a place that would most likely take some sort of damage, I also painted some scratches to them. They are painted with black paint, but underneath the scratches, the clear metal is exposed (Picture 52).

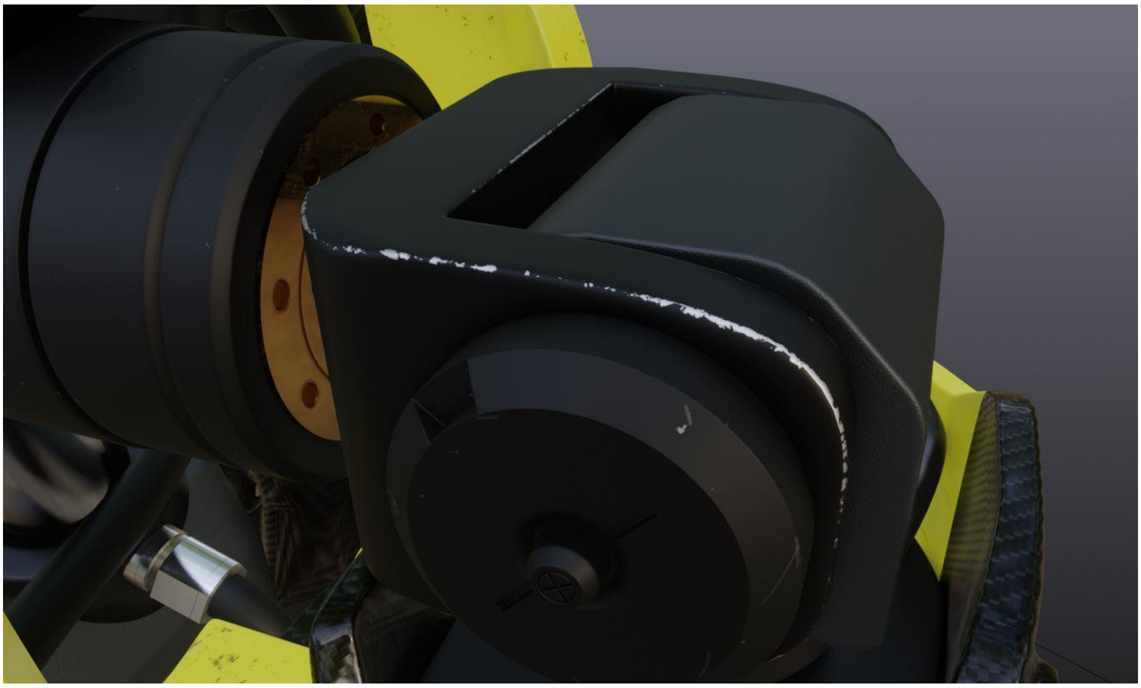
PICTURE 52. Screen capture from Blender of the hydraulic pumps

For the roll cage inside, that should be the most durable of all, because it is the part that holds everything together and covers the most vital parts in the inside, I created this black painted steel material. I used a bumpy plastic texture in Blender for it, but I changed the metallic value to 0.9, giving it an almost metallic look. This gives an impression of a steel like material, with heavy black paint texture (Picture 53). In my opinion, the roll cage doesn’t need any surface imperfections, because this sort of steel doesn't usually have any big visible scratches, due to its protective thick black paint.



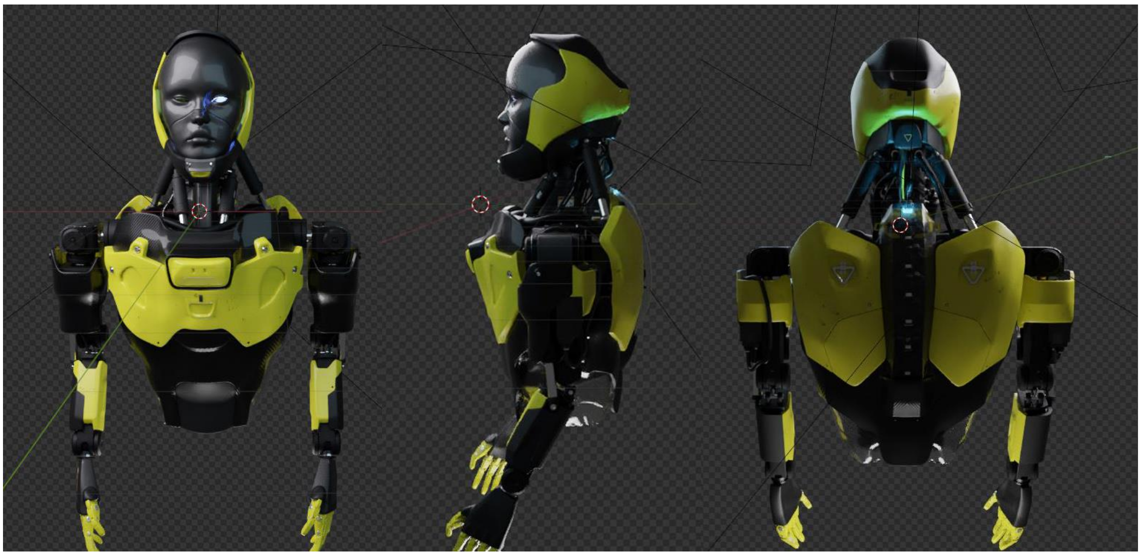
PICTURE 53. Screen capture from Blender of the black painted steel roll cage

For the rest of the parts I added some edge wear and scratches, that mostly reveal the metal underneath the paint or some bumpy plastic surface. Every material has some sort of surface imperfections, whether it's the overall texture or some sort of surface damage, such as edge wear or scratches. Even the brass material has some dusty fingerprints and dirt on it (Picture 54).



PICTURE 54. Screen capture from Blender of the shoulder area

Finally, I tested the primary color as yellow to give some variation to a basic white or black design, after I had created all the textures and materials (Picture 55). In my opinion, the model looked real enough for me to continue to final details of the project before final rendering, though I decided to take the final renders with the white as the primary color, instead of yellow.



PICTURE 55. Screen captures from Blender of the textured robot

5.4 Adding decals

Decals can be, for example, stickers or logos that give that final realistic feel to a 3D model. As always, references from real life give the best idea of how they should be applied. Too big or badly placed decals could break the design's harmony or give that toy-like look, therefore, the placement of them should be carefully thought out. Another important thing is to make them serve some sort of purpose. A 3D artist should think why there would be a sticker in the first place. After all, just like in real life, those stickers serve a purpose. Usually, they give some sort of information, such as a warning of some sort or an instruction.

Since my model is a robot, which runs with electricity, therefore it has lots of batteries and other electronic parts, it will make the most sense if the stickers give some sort of warning for the user about the electricity. In real life these sorts of parts usually have some sort of information, whether it's some small, printed text or instructions for recycling, in my opinion it is good to include those as well (Picture 56).

PICTURE 56. Screen captures from Blender of the warning stickers

Before I applied these warning stickers to the actual 3D model, I created some scratches and edge wear to them in Photoshop, to give that extra realism (Picture 57). In my opinion, it doesn't matter too much what is written to them, if it makes an impression of something real.

PICTURE 57. A high voltage warning sticker with some scratches

For the logos and other decals, I also created my own designs. Like in real life, manufacturers want to include their logos to their product, and I need to keep in mind that maybe some of the parts aren't made by the robot manufacturer itself but bought from another company. Therefore, I designed a different logo for the hydraulic pumps (Picture 58).

PICTURE 58. Screen captures from Blender of the logos and model number

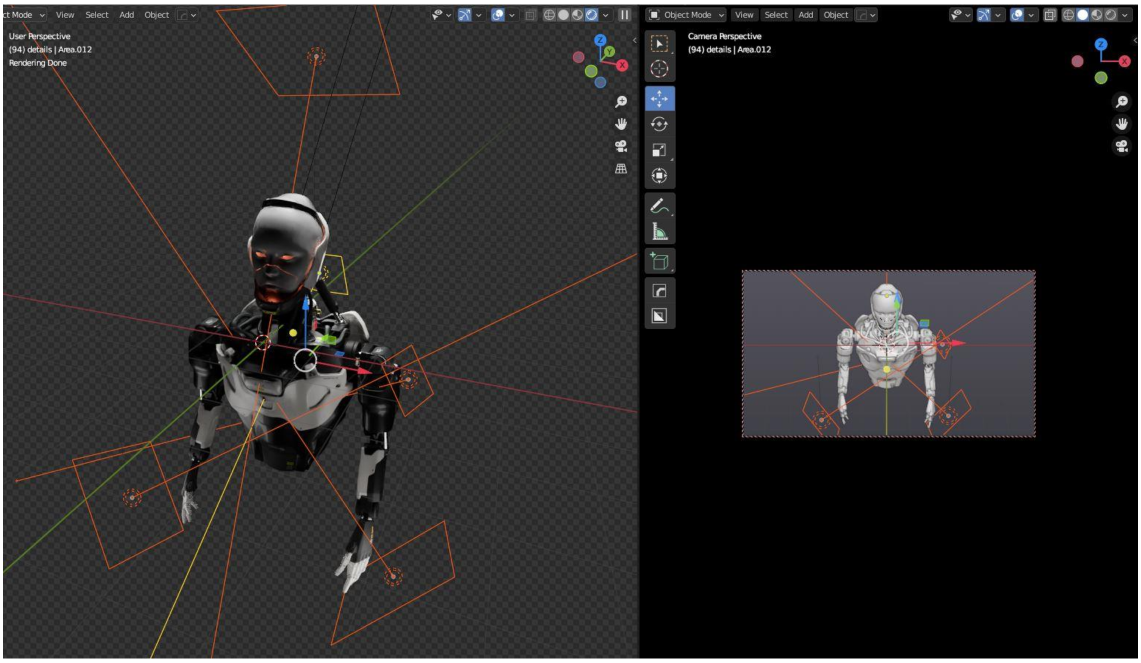
Finally, I scattered some small instructional decals about operating the robot, such as “press here to open” texts and minor visual symbols. In my opinion, the robot looked realistic enough for me to continue to the final rendering process.

5.5 Creating the final render

I wanted to create a product visualization type of final render. Therefore, it was important that the renders looked professional, and even commercial. I think it creates more believability and realism to the final render if it’s presented in a realistic way.

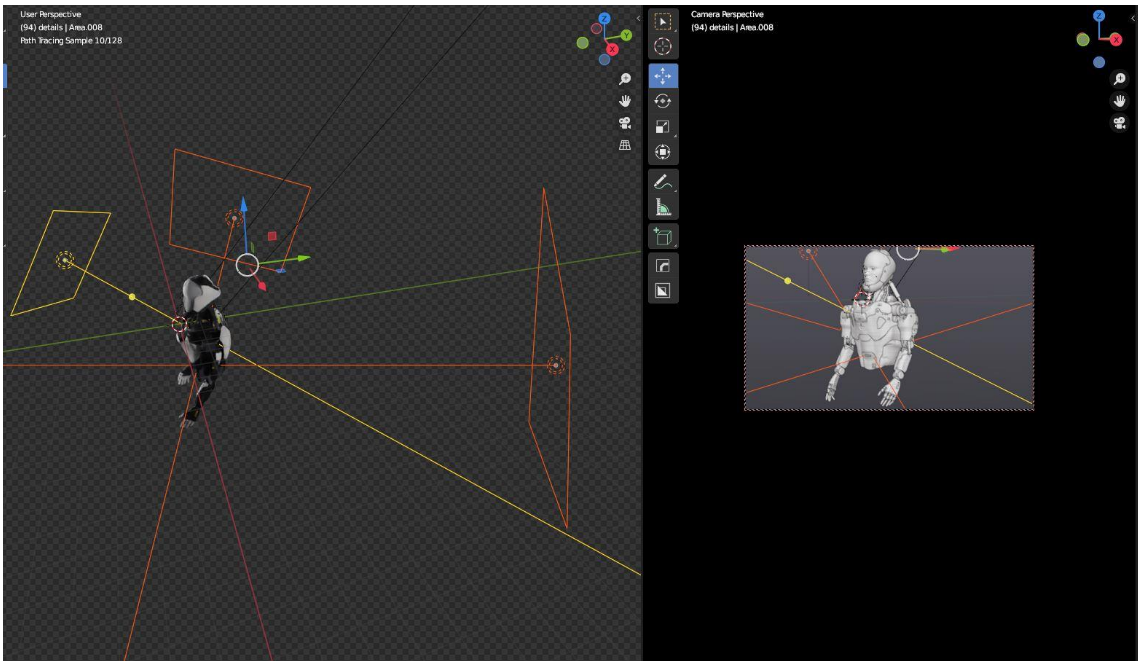
5.5.1 Lighting and composition

For the first render I wanted the composition to be even threatening looking, because I wanted to add some dark futuristic vibe for it. In my opinion, great way to achieve this is to take the render from the front and have the camera angle slightly from above the product. Since there is red light glowing inside the face of the robot, I wanted the actual face to be more in the dark, while highlighting the top of the head and the chest area. For this I had the brightest of the lights at the behind, creating a rim light effect, while having the front lights much dimmer, but having enough light to highlight the chest area. This creates an interesting lighting and shadows to it, that direct the concentration to the face and neck area (Picture 59). I aimed for a cinematic and product visualization look, keeping the dark and futuristic atmosphere present. I used a 140 mm focal length for the renders. The higher the focal length is, the less distortion it creates.



PICTURE 59. Screen capture from Blender of the lighting and camera view

Since I wanted to present the robot as a professionally manufactured product as well, and not only as a cinematic futuristic render I created another more basic lighting setup, as one could see in a real studio. I added studio HDR for the scene and had only three, bigger lights around the robot. Here my goal was to present the robot, in a more realistic and photographed way (Picture 60).



PICTURE 60. Screen capture from Blender of the second lighting and camera view

I took more renders with this lighting setup, including closeups and a wireframe view. Wireframe render is something I can combine with a realistic render to show the topology in my portfolio.

5.5.2 Post-processing in Photoshop

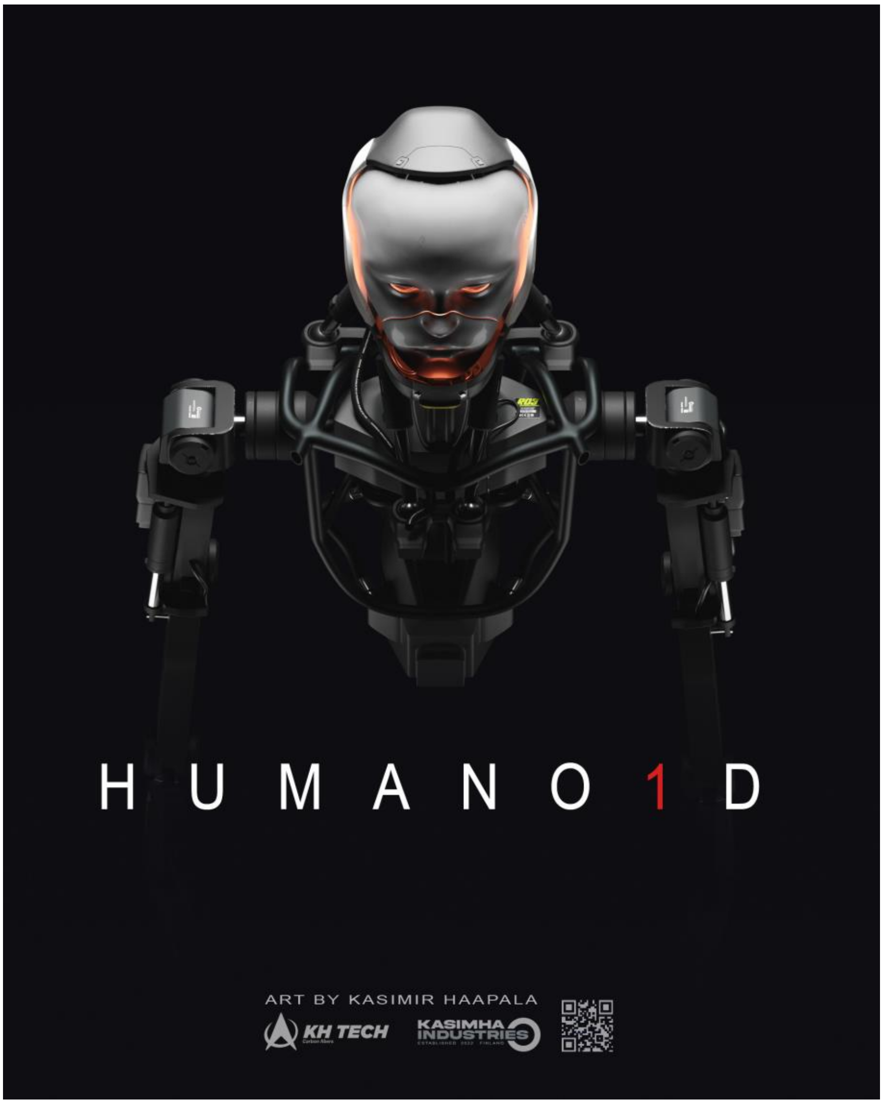
In my opinion, post-processing is a vital part of the workflow to achieve the realism. Since we can't see the final renders so clearly in our 3D software, even with the render view on, it is important to color correct them manually. For the more atmospheric and cinematic renders I created a dark blue background with a slight gradient, I then placed different render views next to each other and designed a cinematic project title for it. I made the lighting more natural looking with curves, amping up the white areas and making the darks even darker. With this technique I avoid creating a faded look for the design. Finally, I added some logos and my own name to the image (Picture 61). I used the same post processing technique for every render, but with minor changes depending on the lighting of the render.

PICTURE 61. Screen capture from Photoshop of the edited renders

5.5.3 Presenting the final product

For the final renders I created three different categories. The first one being where I showcase a more cinematic, futuristic, and atmospheric feel (Picture 62; Picture 63; Picture 64).

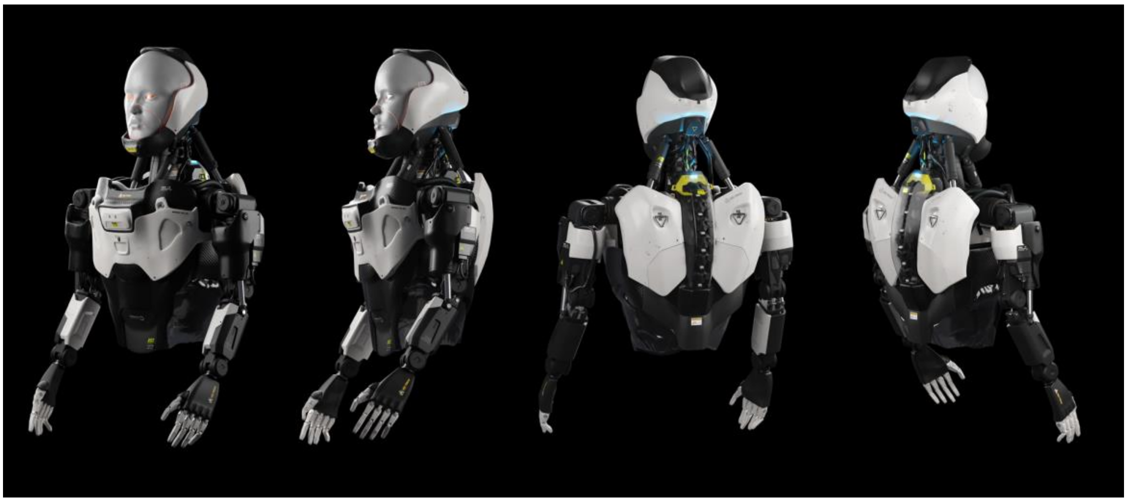
PICTURE 62. Final cinematic render



PICTURE 63. Final cinematic render

PICTURE 64. Final cinematic render

The second category was a presentation of a manufactured product, where I included closeup shots as well (Picture 65; Picture 66; Picture 67).

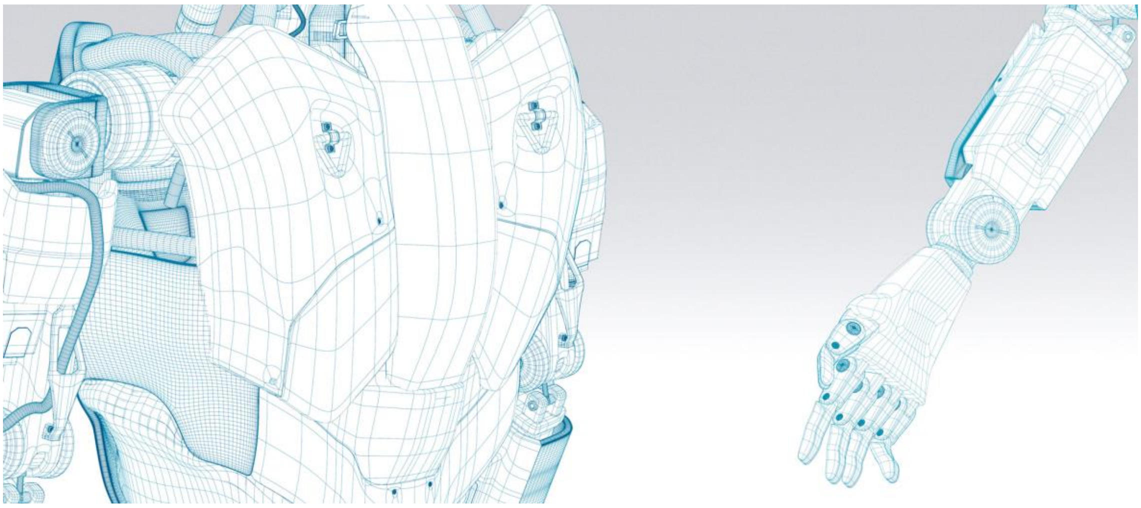


PICTURE 65. Final product visualization render

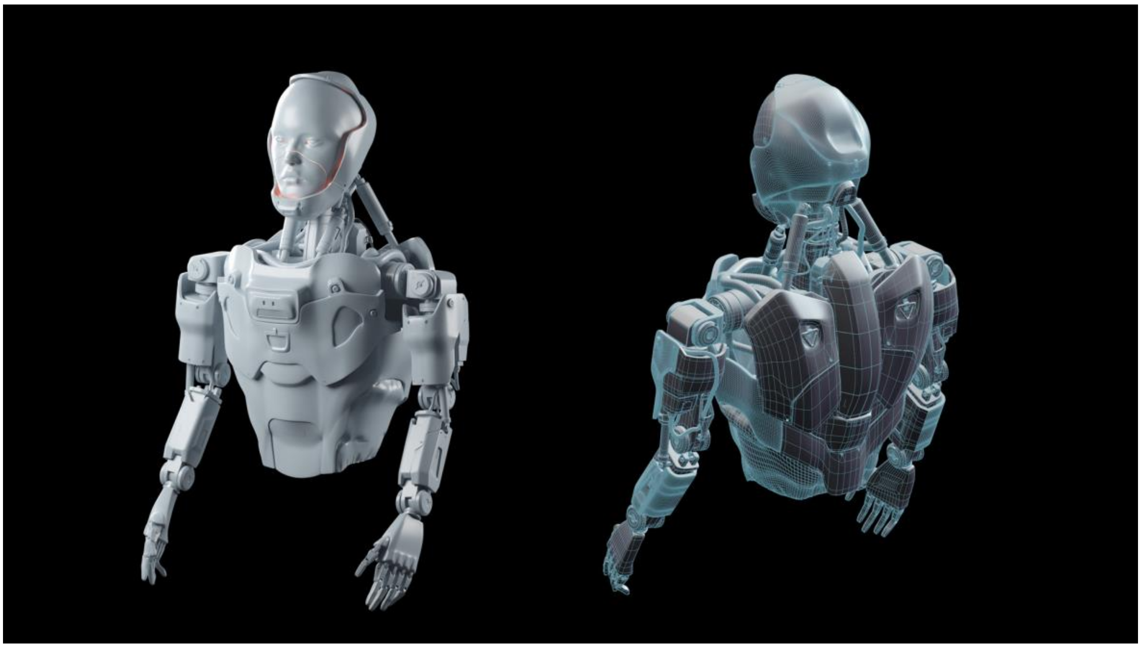
PICTURE 66. Final product visualization render

PICTURE 67. Final product visualization render

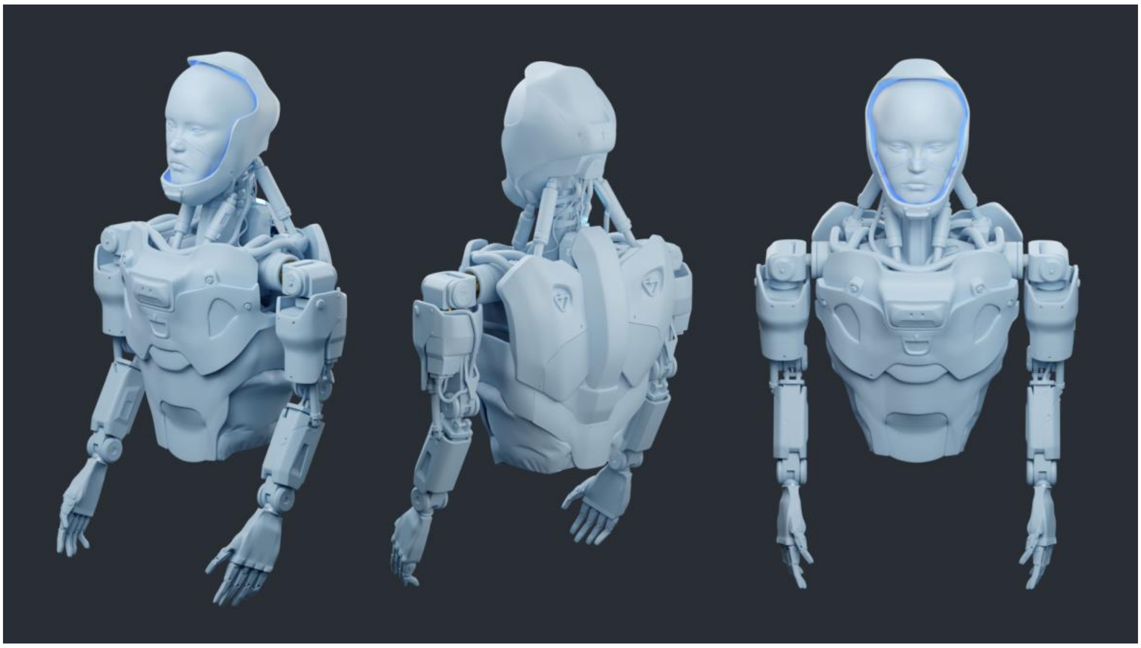
The last category was a portfolio category, where I can show the wireframe of the topology and to present the robot with just one texture in every mesh, displaying matcap of the 3D model, without any textures (Picture 68; Picture 69; Picture 70).



PICTURE 68. Final product in wireframe view



PICTURE 69. Final product in wireframe and matcap view



PICTURE 70. Final product in matcap view

6 CONCLUSIONS AND DISCUSSION

It is extremely beneficial for a 3D artist to understand the fundamental ideas behind engineering when designing mechanical 3D art. Understanding visual design and its theoretical sub-categories will also greatly improve the outcome of the design, but it is important to keep in mind that form should always follow function, and not the other way around. In hard-surface 3D art functionality is where the base for a realism and believability is built. It is presumable that each mechanical design area has its own theory behind it, that a 3D artist should always research and understand, to be able to create the most realistic hard-surface 3D art. Though this all requires the technical skill of using a 3D software and moderate artistic skills. It is arguable, that no doubt a wide visual library will also improve how you design, and it can only be built over time. Good way is to focus on references and other artists' 3D art by analysing and studying them.

During the practical project, the importance of a 3D blockout, or alternatively, a really detailed 2D sketch turned out to be more important than thought before. Having these two, or at least one of them as the basis of 3D artist's concept will greatly fasten and make the actual 3D modeling process easier. It all comes down to building a broad base for the concept and understanding the function of the product the 3D artist is trying to create. The actual design and thinking process is more time consuming than the 3D modeling process, which is beneficial to understand before starting the project. Another thing that was learned, was the fact that designing takes time, therefore, it is better to do smaller projects before going for a bigger one. It is probable that too big of a project could tire a 3D artist quickly, if they're only learning the fundamentals at the same time and have no prior experience of the subject they're designing, because understanding function and design theory is as time consuming as the practical work.

The practical project was successful in a sense, that it achieved what it was supposed to achieve, to create a humanoid robot. Even though it came out to be a realistic looking, it wasn't photorealistic. This is mostly due to a fact, that for a 3D artist to be able to produce photorealistic 3D art, they need a lot of experience and learning from mistakes, which can only be achieved over time.

Utilizing different design principles is an important factor in hard-surface 3D art and should be taken seriously by every 3D artist. A 3D artist must know more than one area of design fundamentals. Mastering only one design principle isn't simply enough, because in the field of CG art, a 3D artist is arguably doing the work of what is usually in real life done by different individual professionals, that combine their skills as a team to produce something that works and looks visually pleasing at the same time. Understanding the basics doesn't take too much time, but getting good at those fundamentals and understanding them thoroughly is something that a 3D artist must do, if they want to create amazing 3D art. The basics can be learned fairly quickly but becoming a professional takes years of practice.

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