

Web tehnologije za prikaz 3D grafike

Trajkov, Aleksandar

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UNIVERSITY OF ZAGREB
FACULTY OF ORGANISATION AND INFORMATICS
VARAŽDIN

Aleksandar Trajkov

**WEB TECHNOLOGIES FOR
REPRESENTATION OF 3D GRAPHICS**
MASTERS THESIS

Varaždin, 2019.
UNIVERSITY OF ZAGREB

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**WEB TECHNOLOGIES FOR REPRESENTATION
OF 3D GRAPHICS**
MASTERS THESIS

Mentor:

Doc. dr. sc. Konecki Mario

Varaždin, august 2019.
UNIVERSITY OF ZAGREB

Izjava o izvornosti

Izjavljujem da je moj diplomski rad izvorni rezultat mojeg rada te da se u izradi istoga nisam koristio drugim izvorima osim onima koji su u njemu navedeni. Za izradu rada su korištene etički prikladne i prihvatljive metode i tehnike rada.

Autor potvrdio prihvatanjem odredbi u sustavu FOI-radovi

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Summary

The subject of this master's thesis is a research of 3D's potential and the impact it already has and possibly could have on a greater scale. With the use of a 3D tool called Maya, two models of buildings were created for the purpose of testing several online 3D platforms and their features, and then comparing them side by side.

The research contains a survey on younger people regarding their knowledge and familiarity with the practical use of 3D technology as the potential it possesses. Some important historic milestones of 3D are mentioned, as are the big innovations of today like house 3D printing, organ 3D printing, virtual walks, etc. The practical part of the master's thesis involved the 3D models abovementioned being subjected to several platforms in order to identify the level of service they offer and the potential they bring, leading the research towards the practical use the technology could be subjected to over the upcoming years.

Key words: 3D, model, web technologies, rendering, virtual environment, potential, exploration, availability, evolution, progress

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1. Introduction

Being (un)willingly surrounded by dozens of breakthroughs in numerous fields every day brings a lot of new ideas to the table constantly. One of the fastest progressing fields is definitely IT and as the technology around us keeps evolving, new ideas shine through and interconnect areas to create something new and unique that gives a whole new world of possibilities. One of those innovations is 3D modeling. The opportunity of creating an exact digital Xerox of the designated object (or objects) contains a lot of potential in a wide range of areas – medicine and physiotherapy, architecture, movie and gaming industry, etc.

The need of exploration of the 3D world grows daily for numerous reasons – one of them being the plastic waste we produce, so we owe it to us to find a new way of producing goods with less by-products, something like 3D printing – technique where materials and objects are made out of “greener” materials after being re-created in a 3D world. It could also be worth mentioning that re-creating/modeling (and even 3D printing) human organs could come to a greater use in the fields of medicinal research and could someday even make a human donor obsolete – the possibilities are endless.

The subject and purpose of this thesis is to bring closer the available technology that is 3D modeling with the benefits it can bring over a vast number of fields which are necessary to progress in order for life on earth to be sustainable. It is also worth mentioning that getting familiar with the potential of 3D environments to the greater crowd is only to bring benefits and upgrades. The idea is to commercialize and cheapen the everyday usage of 3D in every aspect of our lives because it has absolutely more than enough features that are only waiting to be properly utilized.

The motivation behind this thesis is based on 3 fields that had been noticed to lack general support in evolving – architecture (3D printing is cutting the costs of building a home or a shelter to the maximum while still getting incredibly good service and material but still is not commercialized and in production *en masse* [1]), physiotherapy & medicine (it has been shown that physiotherapy via VR/AR helps the patient with effectiveness of the treatment [2]; there are indications that organ printing is something very achievable within the upcoming years; 3D mapping of organs is already in use - Magnetic Resonance Imaging – for the use of research and treatment estimation) and last, navigation (e.g. a scenario where someone is

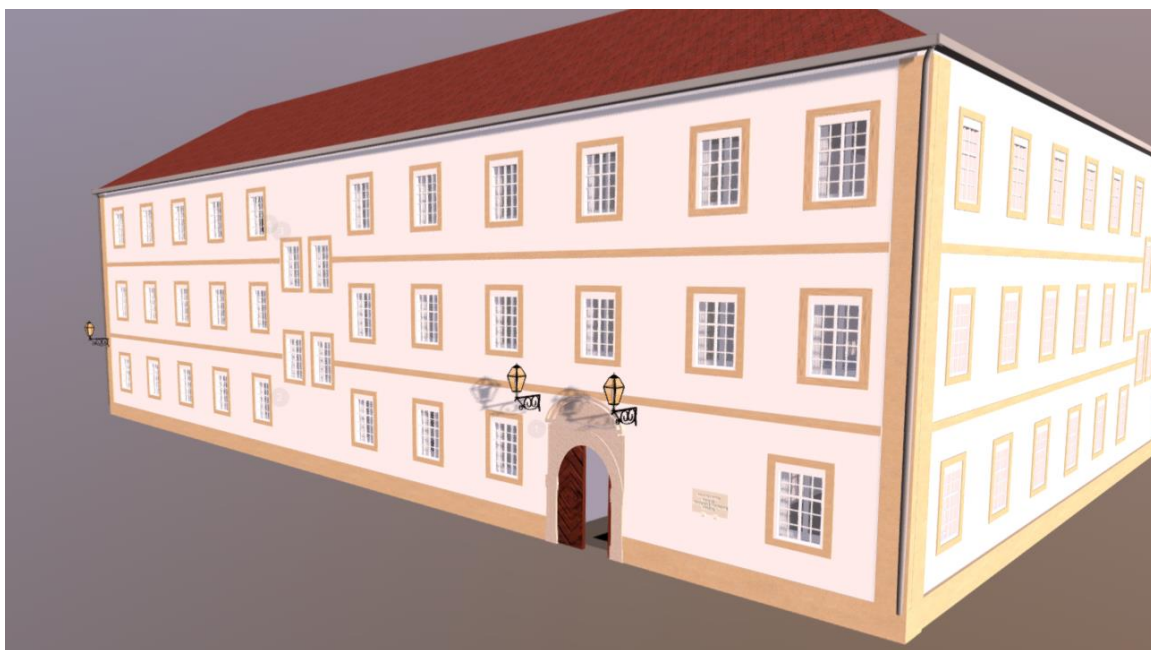
visiting a new building, it is easily discovered where the most visited places are with the use of “3D pins” of various places).



Picture 1. 3D model, Escuela Politécnica Superior, Alcalá de Henares, Spain

In relation to those three fields, and especially the last one, two models have been created for the purposes of testing several online 3D platforms and their features. First model is the atrium building of Escuela Politécnica Superior (picture 1) in Alcalá de Henares, Spain (because of platform memory limitations, only the first floor was used), and the second model is the building of Faculty of Organisation and Informatics in Varaždin, Croatia (a lab room D5 was used for testing purposes). The goal was to explore the features that platforms support and their useful practice in terms of engineering, architecture, medicine, etc.

Even though the models are colossal, the technology is still usable and approachable on a smaller scale. Even if the designated model was not a building, but a tissue or an organ, the technology to explore the model would still be incredibly useful and richer with information than the common methods of exploration.



Picture 2. 3D model of the Faculty of Organisation and Informatics, Varaždin, Croatia

2. About 3D modeling

For a question of “What actually is 3D modeling?” there are several answers that differ, but still explain the core of the technology. 3D modeling is the process of creating a 3D representation of any surface or object by manipulating polygons, edges, and vertices in simulated 3D space [3]. This kind of modeling is somewhat of a digital playground for creative individuals whose understanding of space and material is greatly established. According to Carey Wodehouse, “The world of 3D graphics is a complex field, fueling industries from gaming and film to architecture and engineering. 3D artists and designers use specific techniques and processes like 3D graphic design, rendering, visualization, and animation to bring a vision to life onscreen. But when it comes to taking those 3D images and turning them into physical objects—specifically with 3D printing—the science behind it is called 3D modeling” [4]. 3-D modeling software generates a model through a variety of tools and approaches including simple polygons, 3-D primitives - simple polygon-based shapes, (pyramids, cubes, spheres, cylinders and cones), spline curves and NURBS (non-uniform rational b-spline- smooth shapes defined by bezier curves).



Picture 3. 3D modeling environment - Maya 2018 (Source : [5])

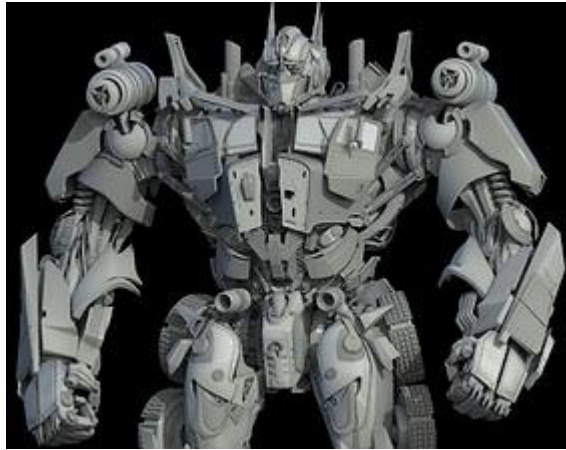
Although the breakthrough for 3D came in the last decade, the beginnings of the technology date all the way back into to the 1960s, but this will be explained more in detail in the following paragraphs.

2.1. The history of 3D

With the momentum gained in computer graphics (the spotlight was on anti-aliased lines, circles/curve drawings, etc.), Pierre Bézier really had an impact on the technology and its roots with his work on parametric curves and surfaces that were basically predecessors of ray tracing. During the 70s which were more eventful, rendering was discovered (Gouraud & Phong, University of Utah), key frame-based animation for 3D graphics emerged, the Z-buffer algorithm was introduced by Ed Catmull and T.Whitted introduced the recursive ray tracing, the foundation for photorealism. Next in the line of breakthroughs was binary space partitioning as a data structure that did not get the attention needed when introduced because BSP was not immediately understood as a great foundation for 3D. J.Blinn discovered blobby models and texture mapping concept during the 80s and set the standard for most of the 3D work almost 30 years before the big 3D boom. In the meantime, Adobe presented the Photoshop software, video games were extremely popular and the momentum they gained was enough to create a new demand on the market for graphics evolution. The biggest impact on the technology was definitely set in the 90s when OpenGL was introduced and immediately became the standard for graphics APIs and animation with collisions, friction, gravity and effects were presented, showing the way to great introduction of graphic effects usage in movies like Jurassic Park and Terminator 2 that were considered as masterpieces at the time for their groundbreaking changes in the industry. [6]

2.2. The present and the future of 3D

While the history of 3D was stretched through about 40 years of development, the present is full of commotions. Even with all the ideas where 3D can be implemented (and even sometimes – forced in) such as in video games (Pokémon mobile game – Augmented Reality), mobile apps (Snapchat filters, Facebook, Furniture & interior design apps, etc.) or movies (Ted, Transformers, etc.), there is still a feeling that the technology has not fulfilled its full potential.



Picture 4. Movie franchise "Transformers" is based on CGI and 3D modeling (Source : [7])

Construction sites have definitely seen the better side of 3D modeling. "Printable homes" are the new big thing in architecture as the expenses for such house is dropped almost to 4,000\$ (around 3,605€) and is done in time around 24 hours which puts things in perspective regarding the traditional way of building homes. As Aria Bendix states:

At 350 square feet, the house was far cheaper than the average tiny home, which has a price tag hovering at around \$25,000, but can often reach six figures. Before using 3D-printing technology, it took New Story eight months to build 100 homes, each costing about \$6,000. While the prototype was being developed, Icon's printer, known as the Vulcan, was running at only 25% speed. That gave the companies confidence that they could build a 600- to 800-square-foot home in just 24 hours for \$4,000 or less.[1]

Besides the architectural benefits, an increase of interest also emerges in medicinal spheres where 3D technology has found more than a few useful purposes:

- Using the Microsoft "HoloLens" MR headset, surgeons can overlay 3D images of the liver on the surgical site and exactly locate the position of the ventricles or metastases for example. In dermatology, physicians can project a 3D SPECT-CT onto the patient to locate the sentinel lymph nodes. When used in traumatology, doctors can view broken bones and fractures from all angles. Based on experience, all fields can benefit from this technology: doctors who try VSI immediately come up with great ideas on where and how they can use it. [8]

- When talking about organ transplants, a potential solution to this problem is to grow or fabricate organs using biomaterial scaffolds and a person's own cells. Even though the realization of this process is currently limited by the technology we have and the knowledge we possess, the development of new bio fabrication approaches will make it more achievable. This method provides an overview of natural and synthetic biomaterials that have been used for organ/tissue development with the new methods that are still getting finalized and refined. From organ/tissue development to drug discovery/screening to development of complex in vitro models of human diseases, options are wide open with the latest technological advances.[9]
- Expert demonstrations with the possibility of enhancing 3D views from multiple angles for students and/or interns who would definitely benefit from a richer source of information. Anatomy would also get on the upper side of this – providing a personal exploration of any organism, organ or tissue to any student would definitely enhance consummation of knowledge and would lead to bigger interest resulting in more satisfied students. [2]
- Rehabilitation and treatment – VR based therapy could actually bring joy and delight to its patients while still delivering results when undergoing therapy, thus maximizing the effort and results. Intelligently encouraged exercise progression could lead to maximizing neuro-plastic development. It is also worth mentioning that it has been proven that the VR environment and effect it has on human brain assists in overcoming chronic pain in general, e.g. issues of pain in burns patients when undergoing therapy. [10] [2]
- Not only is it possible to replace organs, new 3D printing techniques involving bio inks which contain stem cells provide the opportunity to replace worn out cartilages between joints which weaken down over time to cause arthritis. As part of a project called 3-D-JOINT, Professor Jos Malda and his team from the Medical Centre of Utrecht, Netherlands are working to make bio printed tissues that can be implanted into a living joint to replace the damaged part. These would eventually mature into a tissue that is the same as the original healthy cartilage.[11], [12]



Picture 5. Therapy with 3D mapping device –Kinect (Source : [13])

With the unfortunate event of a devastating fire that recently took place in Paris, the great Notre Dame Cathedral was ravaged into pieces. If there is anything good to focus on in this cultural tragedy, it is that a recent video game could actually be the key to the salvation of the immensely famous cultural center of Western Europe. Assassin's Creed, a game well known for its open-world beauty and the exterior that can be seen in-game, might contain the information crucial for reparation of the Notre Dame. Although each sequel is set in another part of the world as in different point of time, sequel of the name "Unity" was set in Paris, and the maestro who orchestrated the creation of Notre Dame in-game, Caroline Miousse, worked on the cathedrals appearance for over two years in order to have everything perfectly set literally down to the last brick. With the support of a historian to research and build every section of the building faithfully, they managed to sculpt the structure in the perfect 1:1 ratio, and even paid attention to each and every painting to be the same at the correct spot on the walls.[14]

In the meantime, and it needs to be said – pretty fortunately - a work of art emerged after the disastrous catastrophe. Andrew Tallon is the name of the historian who used laser scanners to create an immaculately accurate model of the cathedral. [14]



Picture 6. Assassin's Creed Unity - Notre Dame Cathedral (Source : [14])

Needless to say, 3D also had a big impact in the engineering industry. Whether it is the case of a car parts production line or the tiniest screw of some simple student project, CAD systems have changed the game on all levels. Being able to focus on the slightest of details, but still being robust enough to endure some applied physics on the whole model. The collaboration between 3D printing and CAD systems has advanced so much that companies such as Rolls Royce, BMW and Porsche have certain car parts 3D printed inside of the car factory instead of having them manually made. There are numerous benefits as to why to do so - reduction in weight, reduction in material loss, creation of customizable parts and easy replacement of spare parts. [15]

Picture 7. Customizable Car parts available through 3D printing (Source : [15])



When talking about engineering, it is also important to highlight that without the use of some 3D tool, it would be impossible to get familiar with how construction is going to behave at a certain type of ground and in conditions that might harm the foundations or create some other hazardous situation. Statistical analysis of firmness is absolutely crucial for this kind of operations. It is also easier to replicate same parts that are important for the forming of the structure. The margin for error also gets minimalized because the process is automated, and the best part is – everything is more economical, faster and healthier for the environment.



Picture 8. World's first 3D printed bridge - Madrid (Source : [16])

With the use of a good simulation system, it is important to put an emphasis on trainings that both military and commercial pilots undertake often while getting their education at their domestic institution. It is even getting common nowadays for truck drivers and bus drivers to undergo this kind of practice as it gets the closest to the real life experience as it gets, minus the real danger on the roads or air. Pilots and drivers are often stress-tested to see how they perform under extreme pressure and to train them to be as calm as possible if an emergency breaks out. Those kinds of trainings really yield higher results as the equipment evolves to give the realest of sensations to its clients.

The future is bright when it comes to technology and 3D. Whether it is bio fabrication of organs and tissues, automation of car parts production with greener and lighter materials or 3D studying materials for medicinal, military or other purposes, the next 10 to 20 years will definitely be under impact of this technology and the features it brings to the table. It would be pointless to ignore the scope and effect 3D could make in the world, especially now when the climate is getting to the point of no return because of the populations carbon emissions, the planet is getting overpopulated and resources are getting exhausted year by year. It is up to the younger generations to yield the best of what 3D has to offer because its potential is unquestionable. How it is going to be exercised is up to the population.

In a survey conducted on over 80 people of younger age (under 30 years old), interesting results emerged when talking about the 3D technology. 70% of the people were sure that 3D technology could improve and advance their field of interest when talking about jobs.

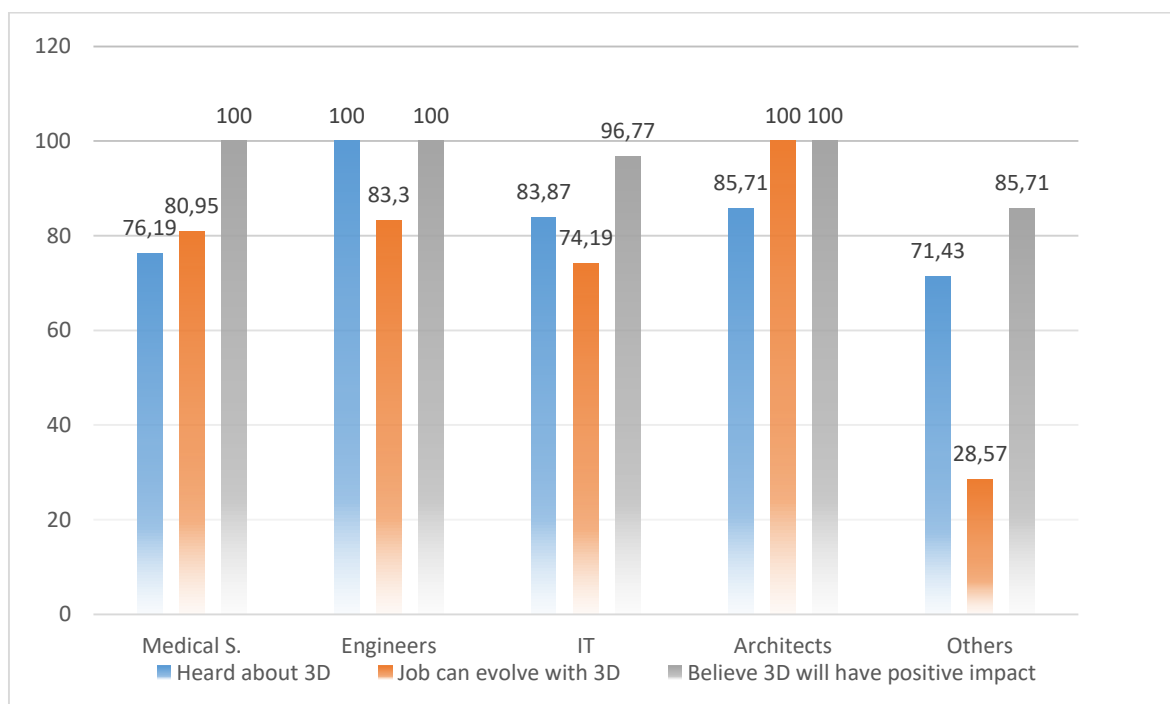


Figure 1. Data from the survey participants

If the people that took the survey are parted into groups by their profession, the results get thought-provoking (figure 1). It seems that the IT students, even though they are well informed on the technology, do not really believe in the improvements 3D can bring to the IT world. Although the least informed group of participants (relatively, still high percentage of informed people) are from the medical domain,

they are still highly optimistic about the improvements the new technology can bring and the benefits it involved, but it is no wonder figuring all the breakthroughs 3D has had in the last decade.

When it comes to participants related to engineering, their awareness about 3D goes as high as it gets, and even though they have the biggest gap to believing in development inside the area with the given technology, they still have a positive stance regarding the general impact 3D can have. Participants associated with architecture and construction, on the other hand, while still having a decent level of awareness about the technology, are the most optimistic group of participants that expressed their opinions.

While analyzing the participants linked with “other” such as entertainment, arts academy, etc., it is noticeable that not so many people believe in improvement of their work domains and that is a valid number because not everything is subjectable to advancements 3D provides. Regardless of that, the group is still well informed with the number of 71.45% of people who clicked affirmatively that they have encountered 3D technology somewhere in their life, but when the groups of the survey are gone, the results vary in some cases.

Znate li išta o 3D tehnologiji i njenim mogućim upotrebama?

81 responses

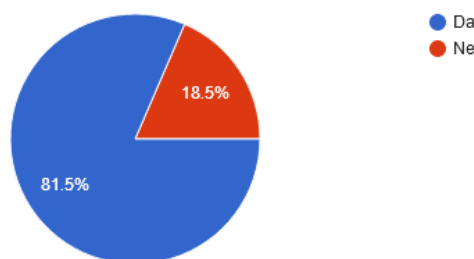


Figure 2. Percentage of people familiar with 3D and its possible practice

In this group of people, around 81.5% of people (figure 2) are familiar with the benefits 3D can provide and that number is forecasted only to go higher over time because of the connection the younger generations have with technology.

Smatrate li da, s obzirom na Vaše zanimanje, 3D ima potencijal unaprijediti određene aspekte spomenutog područja?

81 responses

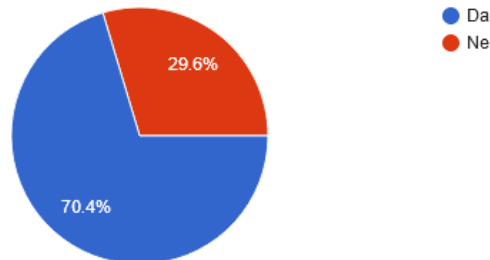


Figure 3. Percentage of people believing in 3D technology improving their profession

Vjerujete li u 3D tehnologiju kao tehnologiju budućnosti koja će donijeti pozitivne promjene?

81 responses

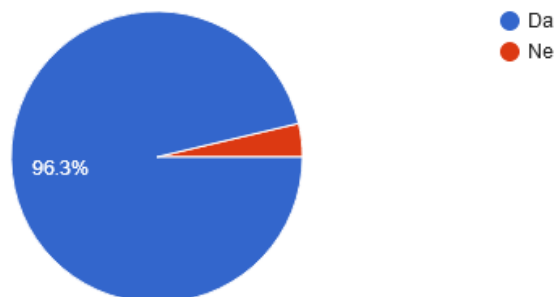


Figure 4. Percentage of people praising 3D as positive impact in the future

Seeing the positivity in both of these charts (figure 3 and 4) , it is noticeable that people are generally well informed and optimistic about this, yet, 1/3 of the people surveyed do not believe 3D could actually improve their profession in any possible way (figure 3). When asked about their familiarity with specializations of 3D technology in particular, the answers were not exactly predictable.

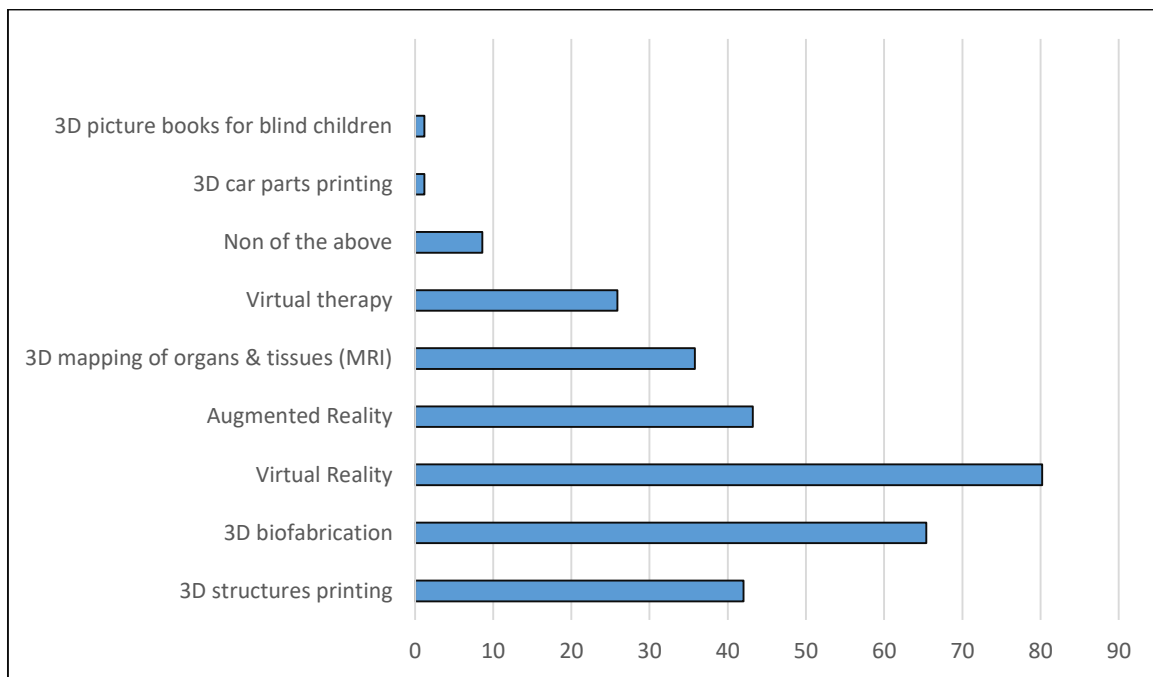


Figure 5. Data visualization - percentage of people familiar with any of the use of 3D technology

The most familiar technology was VR and it does not surprise that almost 80% of people had experiences with this exact product of/for the entertainment industry. Surprisingly enough, 3D bio fabrication came second in familiarity and had surpassed augmented reality by almost 20%. 3D home printing was at solid 42% just like augmented reality, right in front of 3D mapping (MRI) and virtual therapy. Regardless, around 7 out of 80 people have yet to meet or use any of these inventions.

The forecast is definitely something to look forward to. With almost 82% of young people having experience with this kind of technology, the future is brighter, even for a bit because if humans would make the transition from concrete and cement to thermo-materials made for 3D printing of homes, ditch disposable plastics again for the same materials, develop to perfection bio fabrication for treatments and make organ transplant an everyday thing and minimize waiting lists from years to days, humanity will definitely hit its golden age pretty soon with even more promising future and everything that comes with it.

3. 3D online platforms

3D online platforms are still a rare thing to experience these days. Memory is still expensive, rendering power on the server side is still something that gets experimented with and with the constant progress of technology, the real breakthrough is yet to be made. In a brief time, it is possible to find some of the most popular and accessible ones: Sketchfab, Cl3ver, Poly by Google, p3D.in, Sketchup, etc. , but not every one of them is compatible with Maya files and scenes, and Maya 2018 was the environment used to build the 3D models of the aforementioned buildings. To test and get familiar with these (free) platforms, those created models will be imported to see what features do they really provide and in what way they can be used.

3.1. Models

Each building was created and modeled over a period of 4 months. It was a decision to take up a challenge so big so several issues could be tested – how will the platforms behave with such a hefty model, what will their performance be like and how can the model be lighten up online to make it more usable and the experience smoother.

3.1.1. Model of Escuela Politecnica Superior

First came the building of Escuela Politecnica Superior at University of Alcala de Henares in Alcala de Henares, Spain. Because of the complexity of the building and with the help of Professor Luis de Marcos Ortega from the University of Alcala de Henares, only the first atrium building was created, and due to memory limitation on some platforms, there will be only a partial rendering available.

3D modeling and programming share a lot of concepts and one of them is the concept of inheritance. Due to memory limitations on most of the platforms (e.g. 50 MB for free license on Sketchfab and Google Poly), it was a necessity to build the model as light as possible and to fit as many objects as possible.



Picture 9. Textures with bump maps to make the model lighter

Before this revelation, the first version of the model was about 1.6 GB big, but only because the principle of multiplying objects was duplicating instead of instancing. The duplication makes the same object twice – so 2 objects of 1 MB result in 2MB increase of memory after duplication, but with instancing, it is a different outcome. Instancing is an operation which uses the same pivot object selected for instancing, and only “transports” it to another place, but without the body, vertices and faces, so instead of 2 MB increase for two same objects, now it is something a little over 1MB because the rendering shows another object, but in memory, it is still the same first object, but with another location (it is also possible to add different materials and texture to the second instance). When thinking about this procedure, it is hard not to think of the design pattern named Prototype and this is exactly what the operation does except for one slight difference – if the pivot object is changed in size or shape , so are every other instances of this object. This condition is at first considered unwanted but it is actually even more effective because in that way, it is really easy to create families of objects that are similar and in great number (visible in picture 10 – all of the instanced objects, color blue, have the same face selected when selecting any of them – color red).



Picture 10. Instancing of same object multiple times at different location

Next step in making these models approachable was to create simple objects with complex texture and bump maps (picture 9) to make the structure looking complex at the time of rendering with shading and ray tracing, and not all the time during the modeling of the model.

For some objects, the bump maps/displacement maps were hand made by the author, for other were acquired over several specialized web sites containing such files. It was of great importance to responsibly divide the families of objects made for this building in order to have the lightest model possible. As in any information system, the principle of scalability stands and with this experimental technology, it is not to be exhausted with resources on the first model. Guided with that thought, the usual division of objects, when modeling a building or other architectural structures, should resemble a furniture catalog categories meaning it should be divided into big categories at the top level: architectural (walls, ceilings, floors, roofing, stairs, piers, any other object of construction importance), core units (doors, windows, panels, boards, handles, etc.) and interior furniture (tables, chairs, closets, hangers, etc.). It is also common to add the category of miscellaneous items of depending on the context of the model like computers, keyboards, elevators, plants, etc. (picture 11).

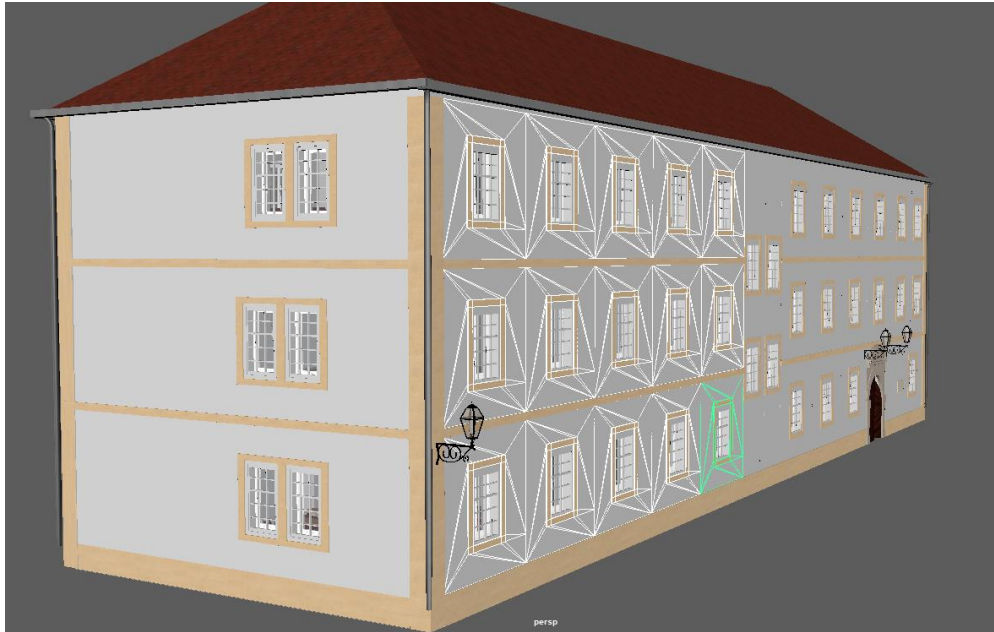


Picture 11. Visible categorization of the objects - architectural, core units, interior furniture and miscellaneous

3.1.2. Model of Faculty of Organisation and Informatics

Also created over a period of 4 months, the model is completed and made by special architectural guidelines for 3D modeling resulting in the whole building “weighing” around 69MB. Both east and south wings are modeled and the ratio is maintained as truthful to the real building as possible. Most of the rooms were left empty for several reasons, but mostly because of the platforms limitations memory wise. The rooms that were re-created to the end are D5 (lab room), D10 (lecture hall), D2 (lecture hall), D1 (lecture hall) and the faculty office.

Nevertheless, with a smart categorization system and the instancing procedure, it was fairly straightforward when it came to equipping the lecture halls because of the object prototyping/instancing. The biggest problem was assembling the halls and the floors/walls connections to resemble the real scene. By making the elevator shaft and the toilettes an independent individual module, a lot more freedom was added to the modeling of the building because that is the only “anomaly” on the façade of the building from the inner side.



Picture 12. Pattern of instancing objects on the model of FOI

Being that the most of the building is symmetrical and repeatable (picture 12), instancing was the main operation during the creating of this representation. It was essential to break down the whole building to “repeatable” parts and to plan smart so that the scope of the modeling could be reduced from the unnecessary. The plan for the building could be broken down to several core fragments – the “window” segment, the “side-window-and-wall” panel, the “stairs-and-windows” panel, the piers between the window segments in the back (picture 13), “elevator shaft and toilettes” module and some exceptions where necessary.



Picture 13. Independent modules fitting to instanced objects



Picture 14. Interior furniture nicely combined with core units to create realistic scene

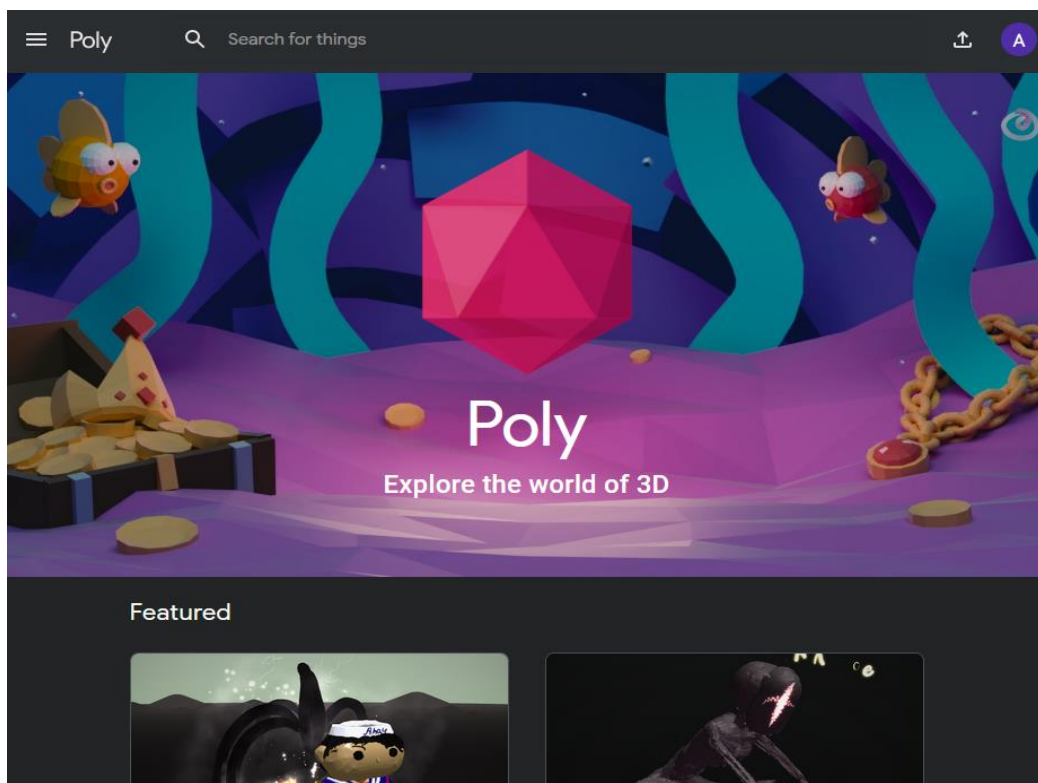
Given that no layout was available for this building, most of the objects were created in relative size one to another and this is where instancing comes to shine. Instead of changing/resizing 90 seats and 18 tables, it is as easy as resizing one (usually any one) object so each and every one of them is resized from that family of objects. By making the objects modular and in families, it was achievable to make changes on entire series of projects at the same time, and the same goes for replicating. It is very possible to instance a whole instanced lecture hall without any bigger memory spike in the file size. The tool is “smart” enough to connect instance of an instance to the pivot object and therefore cut back on memory, leaving enough space for a whole another family of objects whether it is complex as a car or as simple as a plain cube.

3.2. Testing platforms

After finishing the creation of the abovementioned models, it was time to check several platforms and their offered features. Because the most common memory limit is 50MB per scene, the biggest scene in file size will be tested on the chosen site so scenes and sizes will vary from platform to platform.

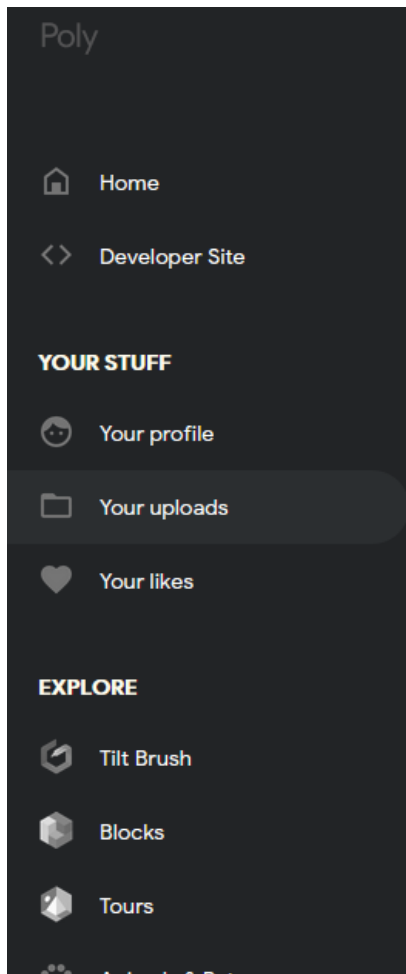
3.2.1. Google Poly

The first one in line for testing was Google Poly (picture 15), a 3D warehouse and gallery for any .obj files under 100MB (for a free license) launched on November 1st, 2017. The initial use of the site is to browse, distribute, and download 3D objects and for artists to effortlessly share, explore and review available objects.



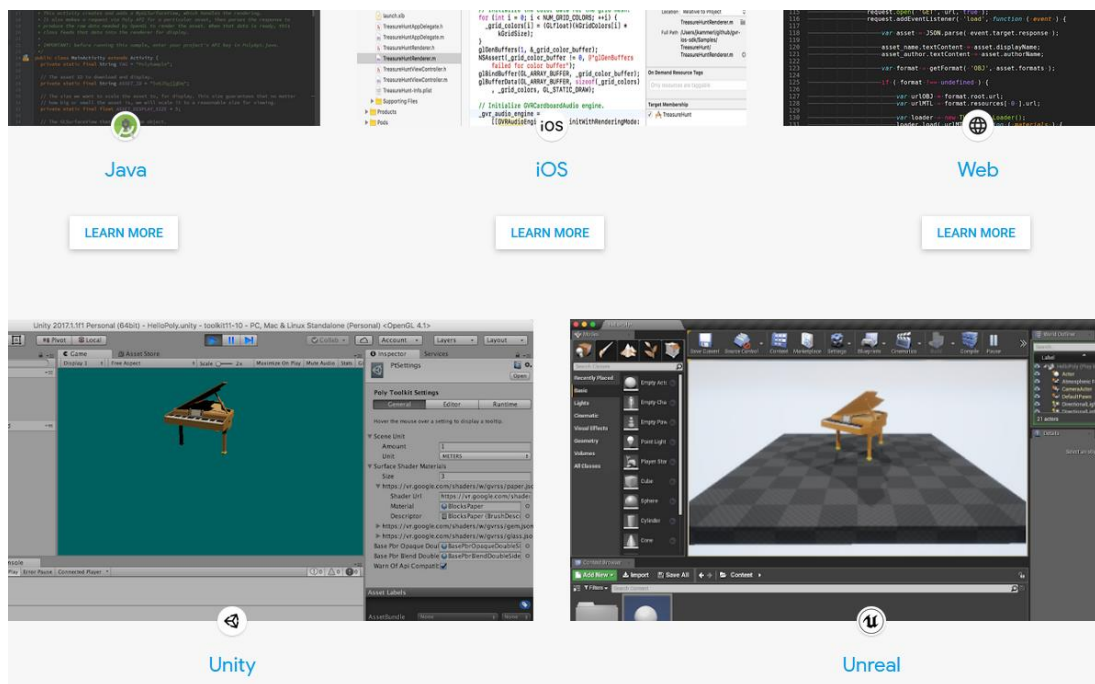
Picture 15. Google Poly

At first glance, a very neat and clean GUI is something Google is known for so Poly is no exception. A distinct separation of areas containing the navigation bar with upload shortcut, search field, help and profile options. Below the navigation bar and the hero component with the logo and animations, there are "Featured" models to be explored and reviewed. Most models can be "remixed" using Tilt Brush and Google Blocks application integration which is a nice and new feature of the platform.



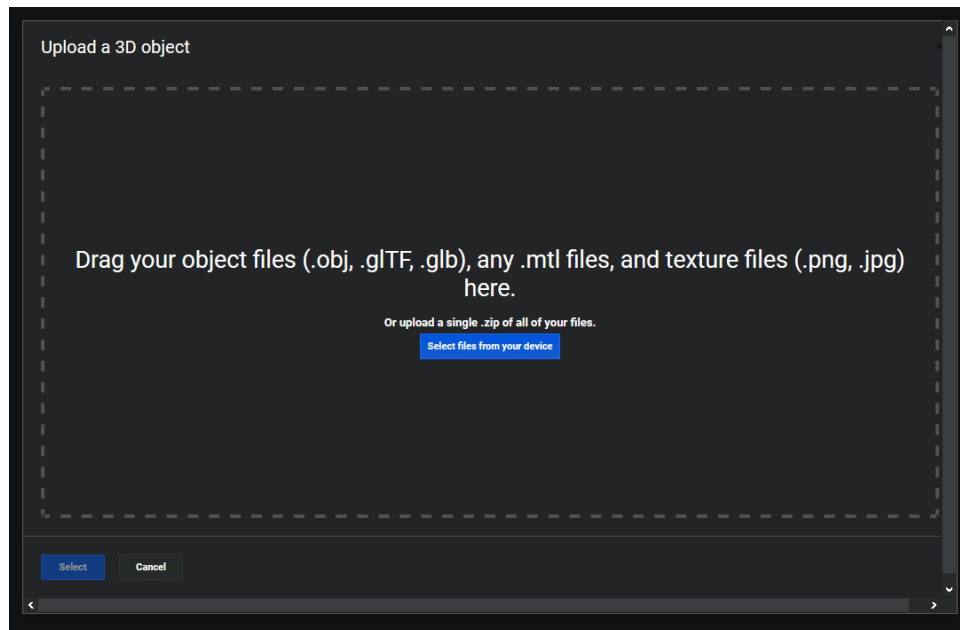
When pressed, the “burger” icon (picture 16) transforms into a side panel which offers a nice set of options including a shortcut to users profile, uploads and likes. Also, it is worth to point out the clean and easy access to categories underneath. An orderly list of classes of objects to be explored really contain all the necessary groups and ease up a search if the client is in a hurry or needs to download something promptly. The whole “look & feel” of the site is pretty nice and smooth, the population of models is not too crowded, but yet not too rarely populated, the loading speed of the models is quick and responsiveness is quite good. When clicking the “Developer Site” option from the “burger” menu, a new site opens up and presents the technologies supporting the exports and integration of the platform via API key with instructions. (Picture 17).

Picture 16. “Burger” icon options



Picture 17. “Developer site” on Poly

When talking about the upload segment, the appearance of the file selection window really meets the eye. Unambiguous instructions on which files are acceptable and simplicity are a something of this page to be pointed out with a reason. Google managed to make yet another great product which seems to be successful amongst the 3D artist.



Picture 18. Google Poly upload window

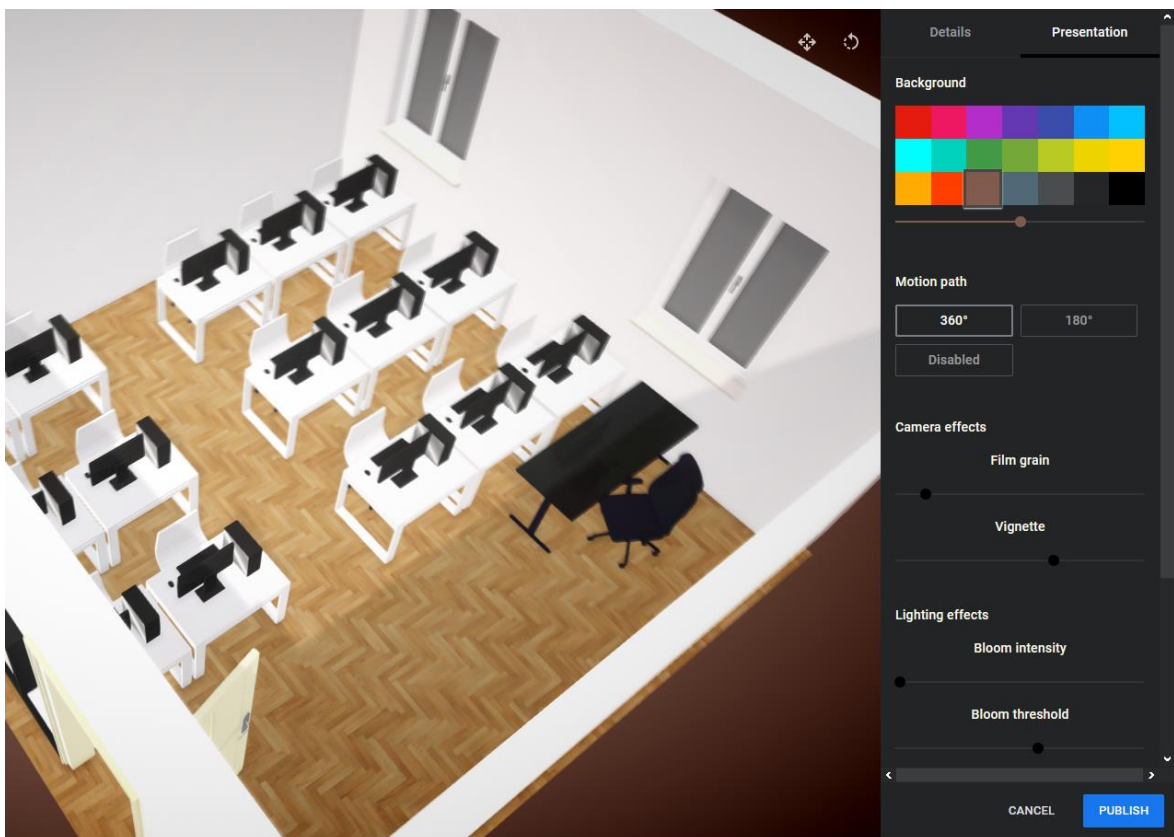
After the first upload, the first impression is that the engine behind the model and the rendering is impeccable. The smoothness and the physics of the models are something Poly stands out with.



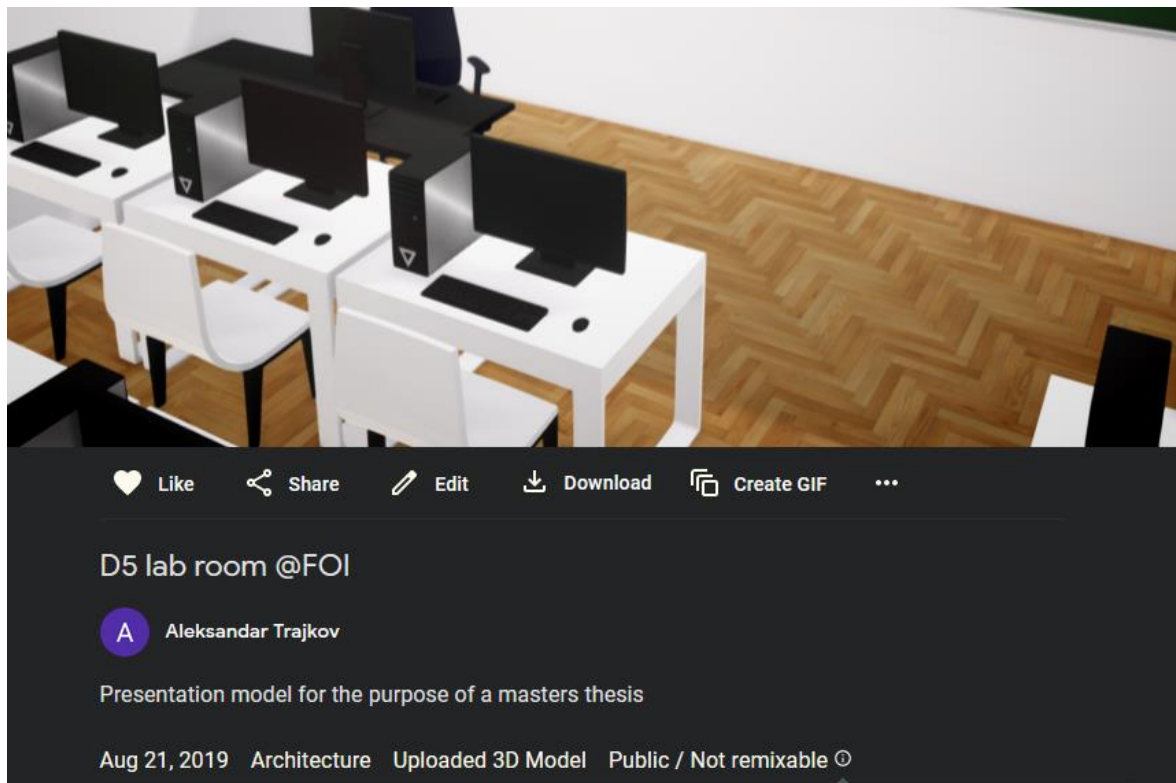
Picture 19. Rendering on Google Poly

No frame “glitching” or any sort of visual impairments that could indicate a doubt in this platform. Orbiting of the scenes is nice and smooth, but the controls seem to be a little insensitive or less responsive than on the other sites. To zoom in on an object, takes a fair amount of mouse scroll-ins whereas on other platforms, it feels much more reactive when rotating or exploring the scene.

Right after the upload scene, a new window with the model details pops up prompting the user with essential details like model name, description, visibility, etc. After filling in the necessary details, next phase is the presentation tab in which options like background color, motion path, camera or lightning effects are present. This is only kind of tweaking available for the online editor. This is something that Google obviously that was unnecessary to develop to the fullest (or maybe is still under development figuring that the platform is only 2 years old). The client is left under the impression that not much can be done with the existing options and that is definitely something Poly could use getting upgrades with. Most of these options are just artistic and are camera/shader related with making objects materials glow more or less, or something as adding a black gradient to the edges of the scenes.



Picture 20. Presentation tab in the editing window

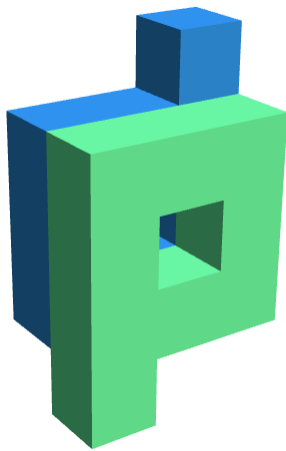


Picture 21. Final look after publishing

While some of the effects really do make the transition and camera orbiting look more professional, the final imprint is that this platform is still limited to its original ideas of what the site should contain. The physics of the platform look really solid and the shading is respectable, even though some materials are not transported at all or not transported completely with the characteristics to the site leaving them unfinished (glossiness, roughness, transparency, etc.) but this is something that happens when the upload goes through as an object (.obj file with textures) and Google is aware of that so they made a plug in to upload directly through a 3D client to the website and that definitely is a step forward in the progress of Poly. There is still an inevitable impression that, while the rendering is still at a really impressive level, everything looks like a scene for a video game so there is definitely a possible step up to make that transition from “video game” quality to photorealistic scenes and models that Google will probably make in the years coming given that the Poly platform is really at the beginning of its development.

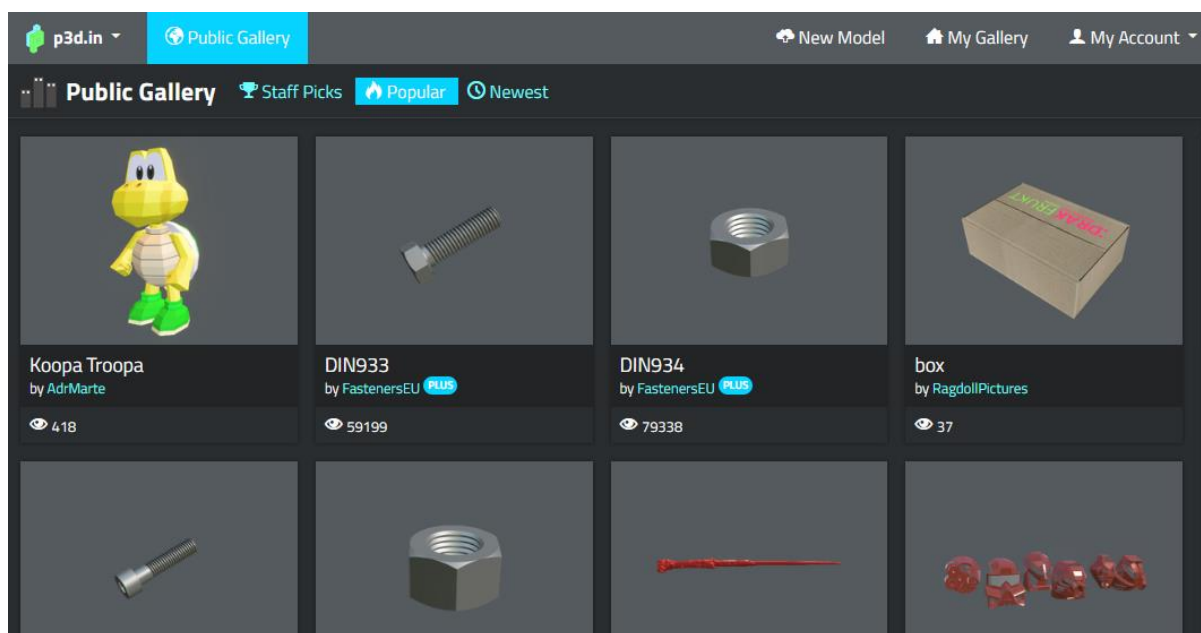
3.2.2. P3D.In

P3D is made by a group of developers who at first, as a hobby, started creating a web site with capabilities to upload, browse and render 3D objects to make screenshots obsolete in the world of representing 3D graphics. As from 2016, they have been purchased by a Danish company called Global Scanning Denmark A/S and thus, made a lot of improvements ever since. Now, almost 3 years later, even though the official releases are missing, the site is still at really high level regarding to others and, to be said, definitely are in the top 5 sites of 3D hosting and browsing.



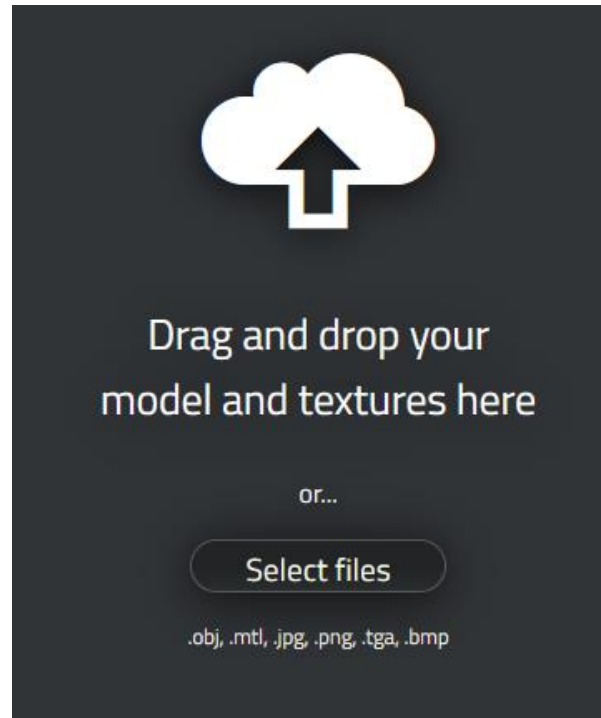
P3D's motive was to make a world of 3D more approachable and as practical as possible to the both first-comers and the experienced ones. Without having to spend any money, everything seems really accessible and understandingly simple. The graphic interface (Picture 23) looks really intuitive and transparent, the design of the site is really neat and orderly, while the colors and the style have a sense of a "signature" or identity.

Picture 22. P3D.in logo (Source: [17])



Picture 23. p3D.in landing page

When pressed, the “New model” button takes the client to the upload window (picture 24.) where clear and easy instructions are displayed about whether to upload by drag and drop process or to hand-pick each of the files through the file system by themselves. The file extensions are also displayed which makes the process transparent and faster than to experiment which files are acceptable and which are not. Before uploading some files – there are things that should be clear to a customer about what kind of account is being used – the free one is “basic” and

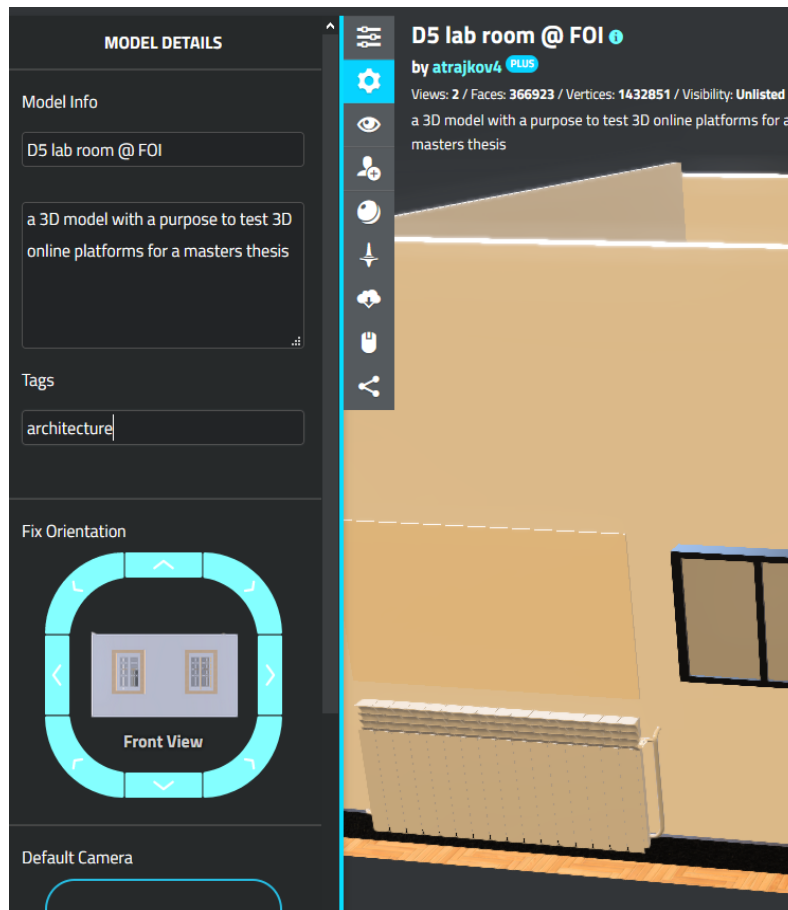


Picture 24. Upload window, p3D.in

it equals to having up to 4GB in storage space, maximal scene size is 100MB which is common, but texture resolution is at 1024px maximum so HD textures are not acceptable for a basic account. Downloading of the source files are limited to only the creator of the model, and customizable embed of the scene is limited, just like custom backgrounds.



Picture 25. Editing scene in p3D.in

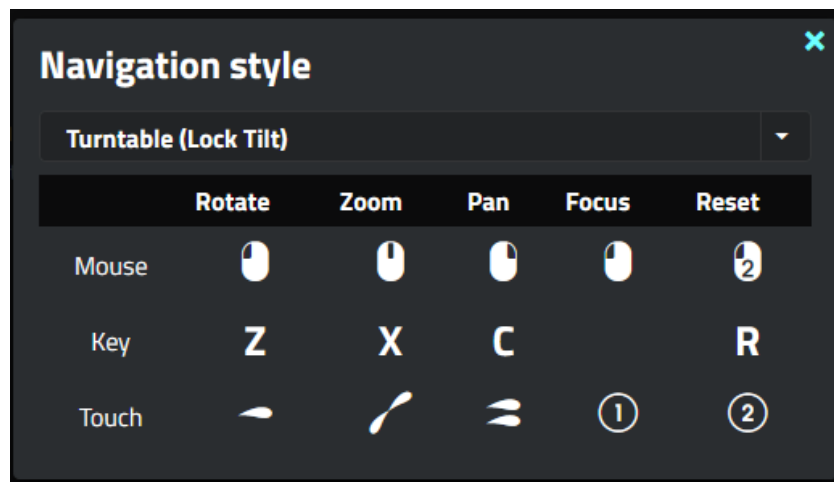


Picture 26. Double tabbed side menu with options is full of choices

Like mentioned before, it is still important to highlight it once again – the controls over a model in p3D.in are spot-on. The model feels so light and responsive, and the control seem effortless. Also, the depth of changes to make astonishes even the harshest of critics. This fully justifies the “editor” part in the description of the page. The list of options and variations seems overwhelming and the palette of options is by far better than, say, in Google Poly. From the possibility to select any material in the scene, to options it contains per material (roughness, metalness, clear coat, etc.) is really liberating. Any error that goes through from Maya to p3D.in is leisurely fixable in this side menu, and that is only the first tab. Second tab (“eye” label) is related to viewer customization and offers options like “Environment – HDRI or Basic”, Post-Processing (Bloom strength and threshold), camera settings, viewer background and etc. There is even the possibility to select “Orthographic” option on camera settings/ perspective and in that way ensure a way of exploring a model as a first-person user (VR glasses?).Vignette, Logo and Navigation Style are also

options worth mentioning. If the Environment is set to “Basic” instead of HDRI, an interesting menu pops out prompting about the type of environment the designated scene needs to be in regarding the lighting. More or less cloudy and dusty, or more or less shiny with a bit of a glow. Every of these presets come with a slider for a selection of intensity going from 0.000 to 1.000 with a long range for needed selection.

Next in line is “privacy settings” with options such as generating a link to the model, editing the list of collaborators with the permissions like “can view”, “can edit” and “can manage” they carry with themselves. Definitely a handy feature helping the user to limit the options on their scene, but still deliver the necessary service. Below the privacy settings are “viewport display” options offering a variety of displaying styles like full, full with wireframe, shadeless, shadeless with wireframe, clean, x-ray or wireframe only. The level of details on these options really leave an imprint the designers did not want to leave the user with a feeling of desperation over a lack of options, but feeling empowered by the control they have over a model.

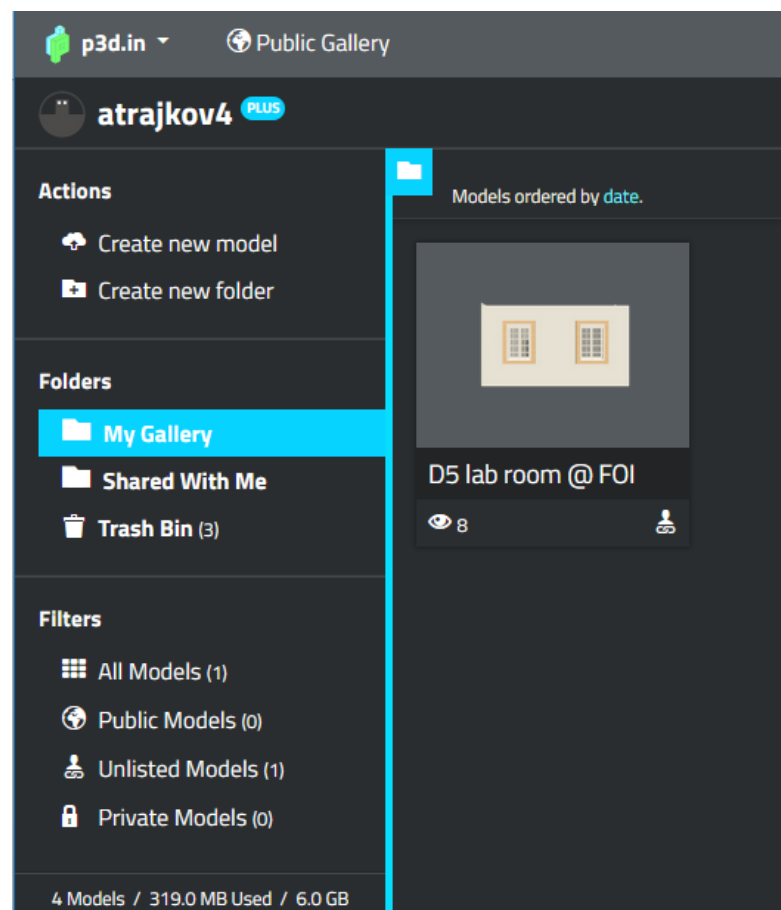


Picture 27. Options for navigation style

Next feature is the “spin model (auto-rotation)” which makes the model “live” and rotates clockwise, but because of all the other features having a lot of options to select from, the spin models feels experimental meaning no tweaking is possible for this feature. After the abovementioned feature follow “download model”, “navigation style” and “share” options. The “download model” brings the possibility to choose between a snapshot (512px, 1024px, 2048px or 4096px in a .png format) or a model

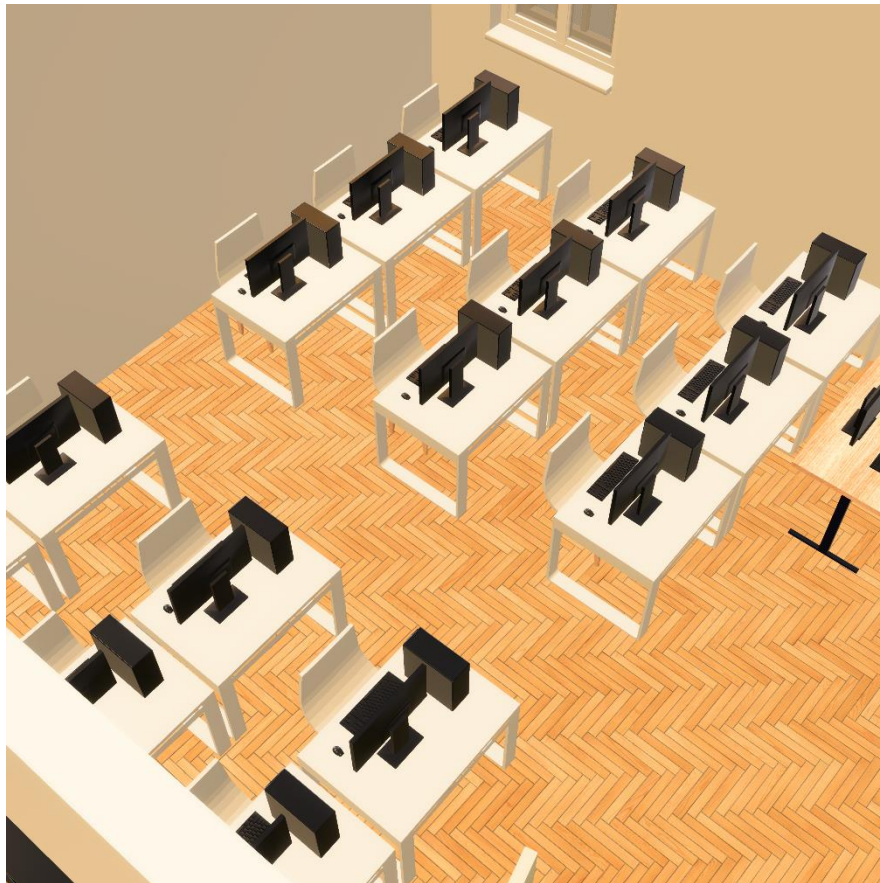
to download (.obj format) and the checkbox options for allowing other people to download the .obj model or download the snapshot images (picture 29). Underneath the downloading options comes the navigation style offering a list of controls for both mouse, key or even touch options (picture 27). On the top of the window are the available presets as “Default navigation”, “Trackball (Free)” or “Turntable (Lock Tilt)” bringing the difference in the rotation and behaving of the model when interacting with it via mouse, key or touch screen.

And the last feature in the list is the “share” option with possibilities such as sharing quickly through a link, sharing on Facebook, Twitter or Google+. Underneath the quick-sharing options are also the options to share to a forum (Partner forum or other forums) and to a website through which one can embed it (“iframe”), directly connect it either to a Wordpress site or to a self-hosted wordpress.org site.



Picture 28. Side panel in the gallery with displayed stats

Upon finishing up the details of the scene just uploaded, the model can be found in the “My Gallery” section on the navigation bar with a really orderly design and the possibilities that it comes with. There is an option to organize the models into folders, categorize them for easier navigation or simply divide them into scenes for a future reference. There is an existing selection of models by filters and the presets are already there on “public”, “unlisted” and “private” models. The whole gallery stats are displayed at the bottom of the side panel displaying the number of models uploaded, the size of the memory that is used and the whole storage size available which is a useful stat to show being that the platforms are mostly limited memory wise.



Picture 29. Snapshot taken with “Download” options at the maximal resolution (4K)

When finished with editing and publishing of the model, the quality of the rendering is astonishing. The materials are glowing appropriately and just enough to wow someone instead of over-doing it and making it look cartoonish. The lighting on the scene is immersive (HDRI – settings on the editor) and the scene feels warmer than it was on Poly. The high number of tweaks possible contributes to the possible numbers of look and feel of a certain scene whether the user wants to make

it surreal with no possible glows, basic lighting, photorealistic materials and shading options that bring the feeling of “real”, or to go with the glow, flashier and more dispersive lights, softer colors and smooth rotation set for the scene thus making it feel like a gaming cut scene frozen in time or creating a feeling of an object being glorified with the aftereffects (Picture 30).



Picture 30. All the available options to tweak on materials contribute to rendering scenes authentically

3.2.3. Sketchfab

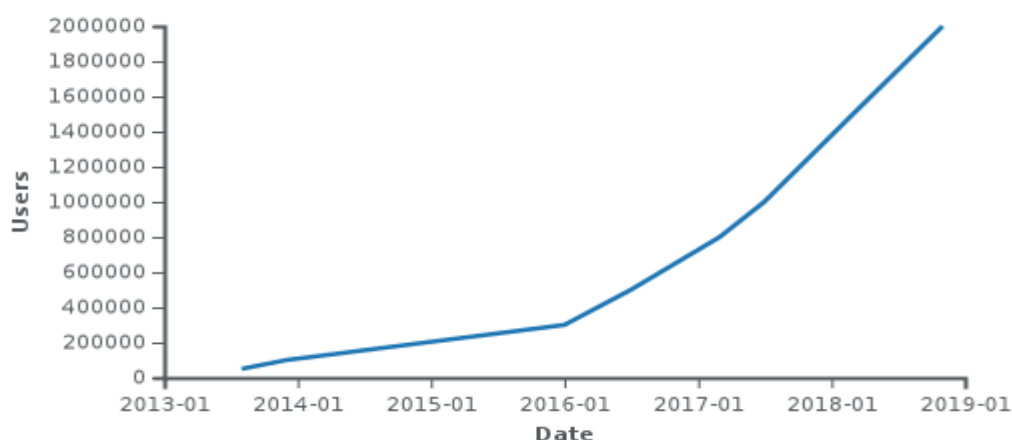
With the number of 2,000,000 active users, Sketchfab is the biggest and strongest competitor in the world of 3D publishing, selling and discovering. Rising constantly since the launch back in March 10th, 2011, Sketchfab grew to the absolute leader in the domain and developed technologies that other alike sites mostly replicated or made variants of.



Picture 31. Sketchfab logo (Source: [17])

Firstly created by an entrepreneur and 3D enthusiast named Cedric Pirson, its initial name was “ShowWebGL” dating all the way back to 2011, but when accompanied by Alban Denoyel later in 2012, the site was relaunched under the new identity - “Sketchfab” (Picture 31).

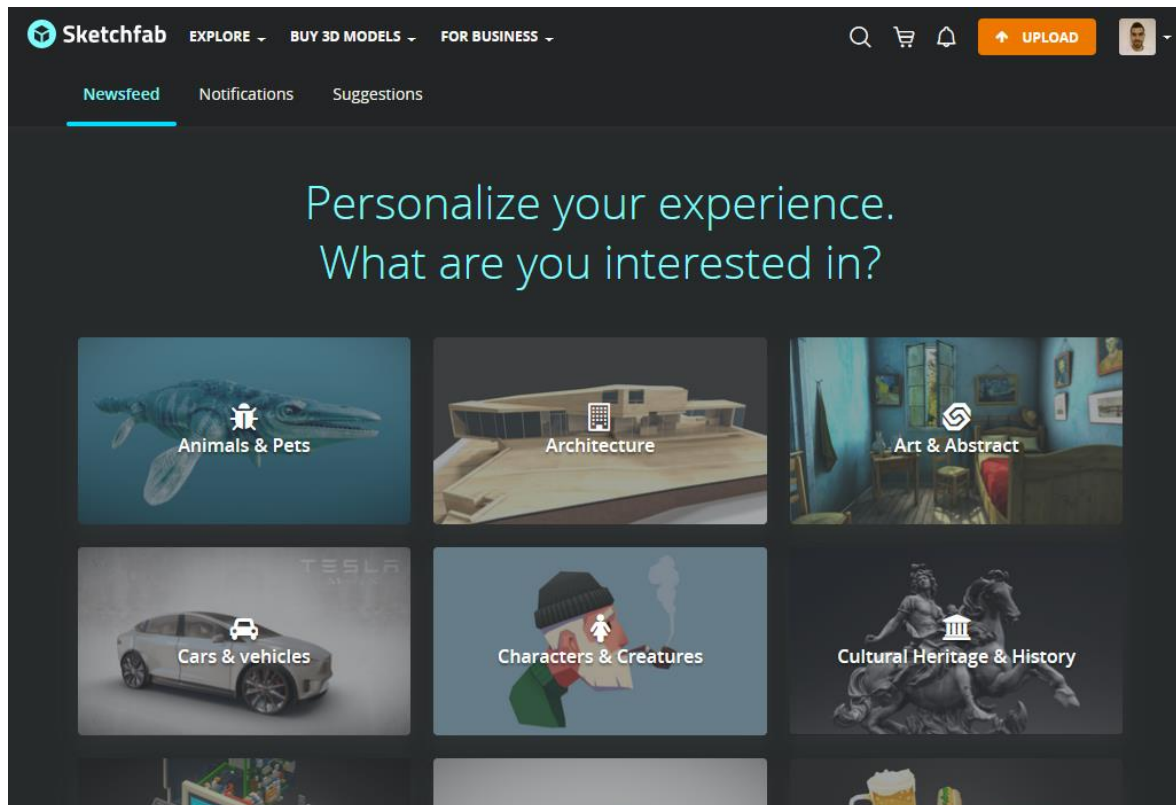
On two occasions, Sketchfab took part in the “TechStars” New York City startup accelerator program and acquired more than 9 million dollars combined (December 2013 and June 2015)! [17]–[19]



Picture 32. Number of users on Sketchfab through years (Source: [19])

The main product of Sketchfab is a 3D and VR model viewer. It enables viewers to move freely around or inside the 3D scene using mouse, touch manipulation or in Virtual Reality. In addition to static 3D models, the viewer is able to play and control 3D animations. Viewers can enable the Virtual Reality mode to make the model viewable in Virtual Reality headsets. The 3D viewer is used on the Sketchfab website and mobile apps, but can also be embedded on external websites, notably on Facebook, Twitter or Wordpress [19].

Mostly relying on technology like WebGL JavaScript API, the platform does not include other third-party plugins for displaying the 3D content over the web browsers. Its unique technology allows it to provide a virtual reality experience over compatible VR headset by implementing the WebVR JavaScript API and making it its content of differentiation on the free market of 3D.



Picture 33. Sketchfab landing page

With great support for VR headsets like Google Cardboard, Samsung Gear VR, Oculus Rift and HTC Vive, Sketchfab immediately became a leader in the sphere of 3D world. To make things easier, a plugin for several big 3D tools came out in the years coming and the number of models uploaded on the page exploded in second half of 2016. Going from 900,000 in July 2016 to 2,000,000 in November 2017 to even a bigger jump in July 2018 when the number of uploads hit 3,000,000 models![20]

Seeing that the number of users grows steadily in correlation to the number of models (figure 6) means the community is getting bigger and that is definitely good news for the platform. Today, in august 2019, the number of active users is around

2,000,000 artists and the number of models is around 3,500,000 which means that the community is active on the platform and it is not a “dead-end” project.

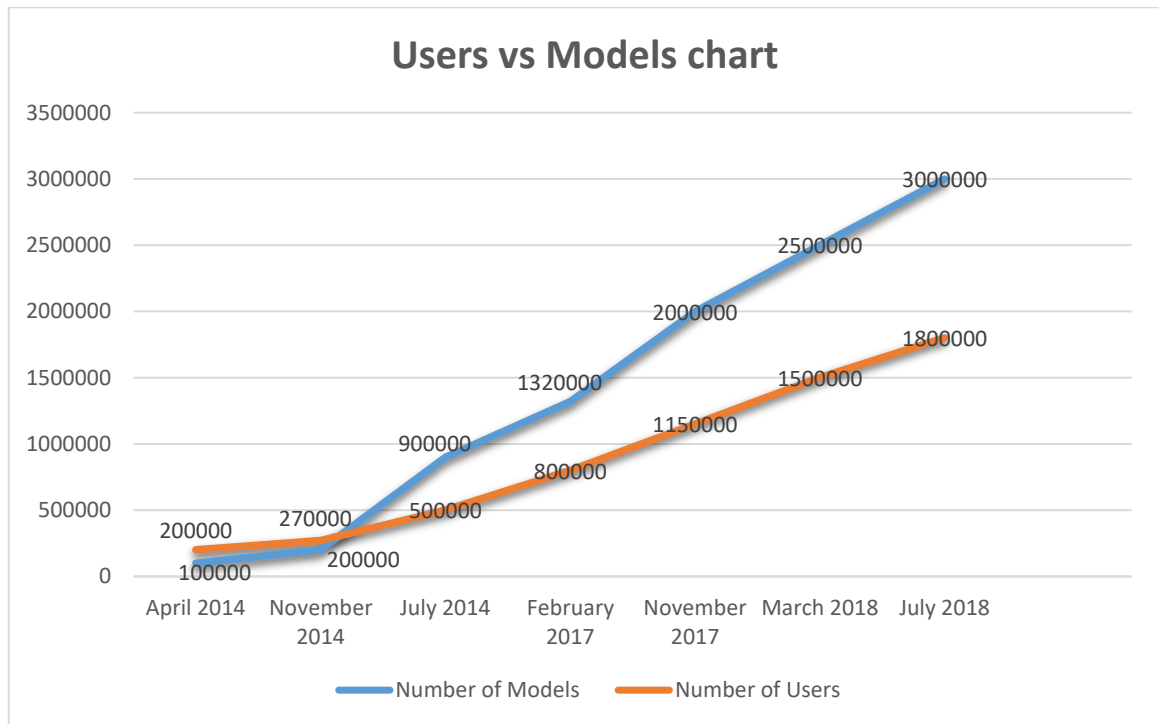
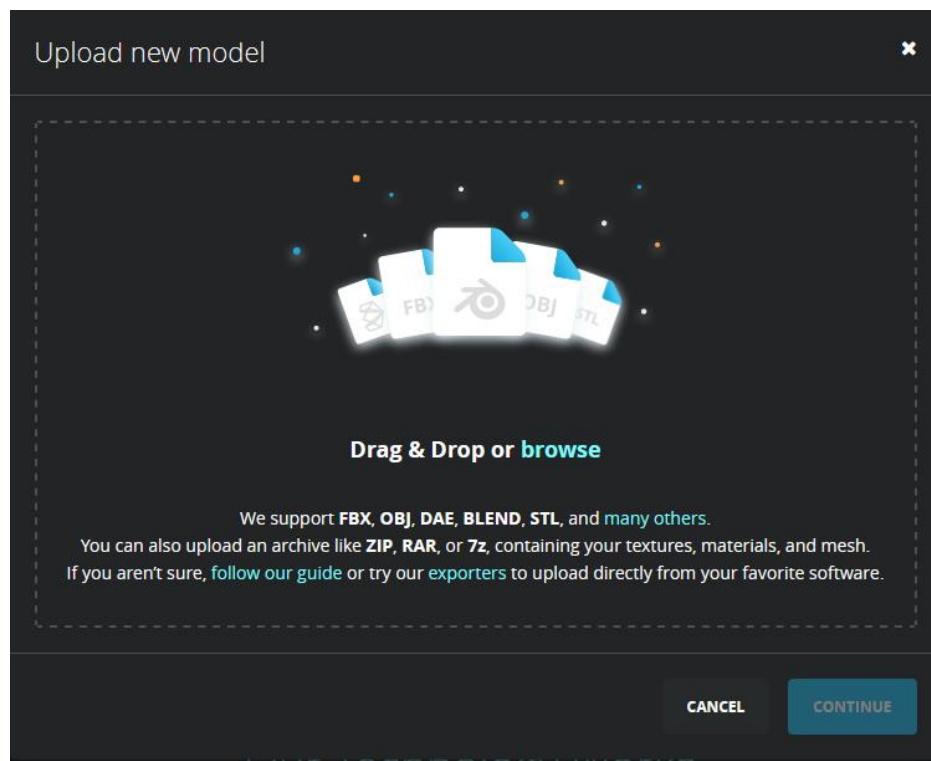


Figure 6. “Sketchfab Users versus Models chart growth” chart displaying a promising future (Source:)

Indubitably, Sketchfab is, by far, number one and the leader in the 3D technology domain with a lot more space for progress, but let’s leave the numbers and history there and proceed towards the experience/service it offers.

The navigation bar offers a lot of options like “Explore”, “Buy 3D models” or “For business” and each of them is populated with a lot of possibilities. The “Explore” dropdown offers several predefined lists like “Staff picks”, “Popular”, “Downloadable” and “Collections” and immediately narrows user’s search time. A nice categorization is present, dividing scenes and models into 18 different categories starting with “Animals & Pets”, “Architecture” and alike, all the way to “Weapons & Military”. There are also a few shortcuts available in the mentioned tab, like blog, forum or community members and that is certainly a handy thing in this tab. If the user wants to acquire a professional object or scene, then the “Buy 3D models” is a tab to go. With same categorization from the previous tab (but probably with all non-free objects) and a few categories that should make the search easier

and faster: “Best-selling”, “Animated”, “PBR”, “Low Poly”, “High Poly” and “3D printing”. Moving to the right, “For Business” dropdown offers options related to prices, 3d configurators and 3d advertising, developers & API, etc.



Picture 34. Sketchfab upload window

As shown (Picture 34), the upload window shows instructions to uploading an object and the file extensions that are acceptable are definitely in higher number than seen previously. From .fbx, .obj, .blend, .stl to .kmz (Google Earth, Keyhole Markup Language), .ftl (Open flight), .ply (Polygon File format) and many more. Sketchfab supports up to 50 formats in total and that is certainly an incredible number for one platform to cover.

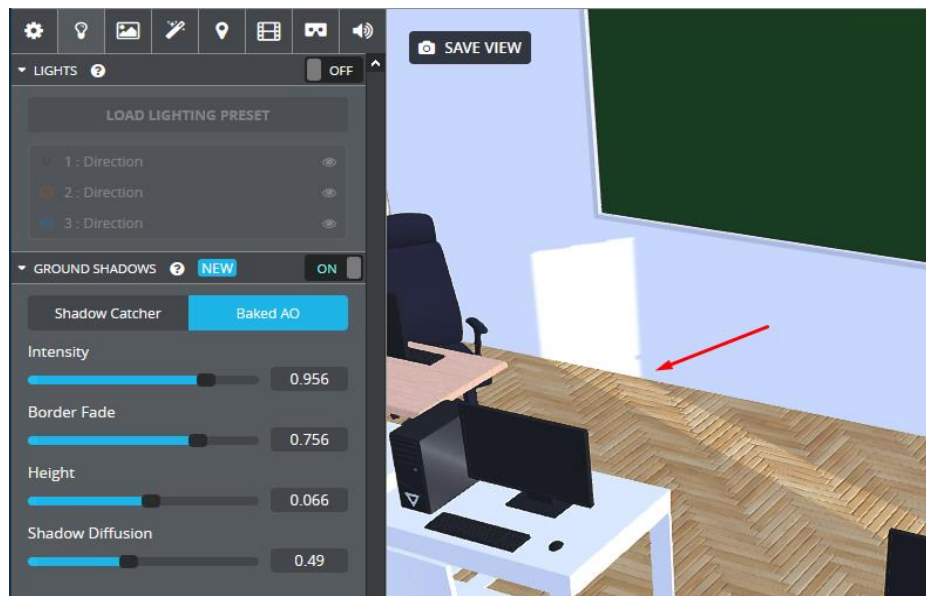
After the upload is done, the user gets transferred to preview window with the option to go to 3D settings which is necessary to review all of the settings offered by Sketchfab. Once transferred to 3D settings window, the amount of changeable settings is just incredible. The tabs on the top of the side panel keep track on what area of finessing the user is currently focused on and makes it really straight-forward so the user does not get lost in the process of after-editing scenes. Options like “Scene”, “Lighting”, “Materials”, “Post-processing filters”, “Annotations”, “Animation”,

“Virtual Reality” and “Sound” are to be found in the tab above the side panel. The “Scene” tab mainly consists of options like choosing a renderer (Classic / PBR / Matcap), choosing from shading presets (Lit / Shadeless) for the “General” section. As for the “Camera” section, the options to choose from are Field of View (slider with degrees) and an available option to limit the orbit camera, but that could only be used with a Sketchfab PRO license. Besides the “Wireframe” section where there is simply an “on/off” switch with a slider to highlight the color and saturation of the wireframe lines, a “Background” section contains a few alternatives such as “environment”, “image” or “color”. It is even possible to activate “ambient environment” which only displays blurred out and faded colors in the background.



Picture 35. Sketchfab editor options

“Lighting” tab is more focused on things as shadows, directional lights and environment in the way of dispersive light and general intensity. After selecting the option of ground shadows (picture 36), an immediate difference is obvious on the scene.

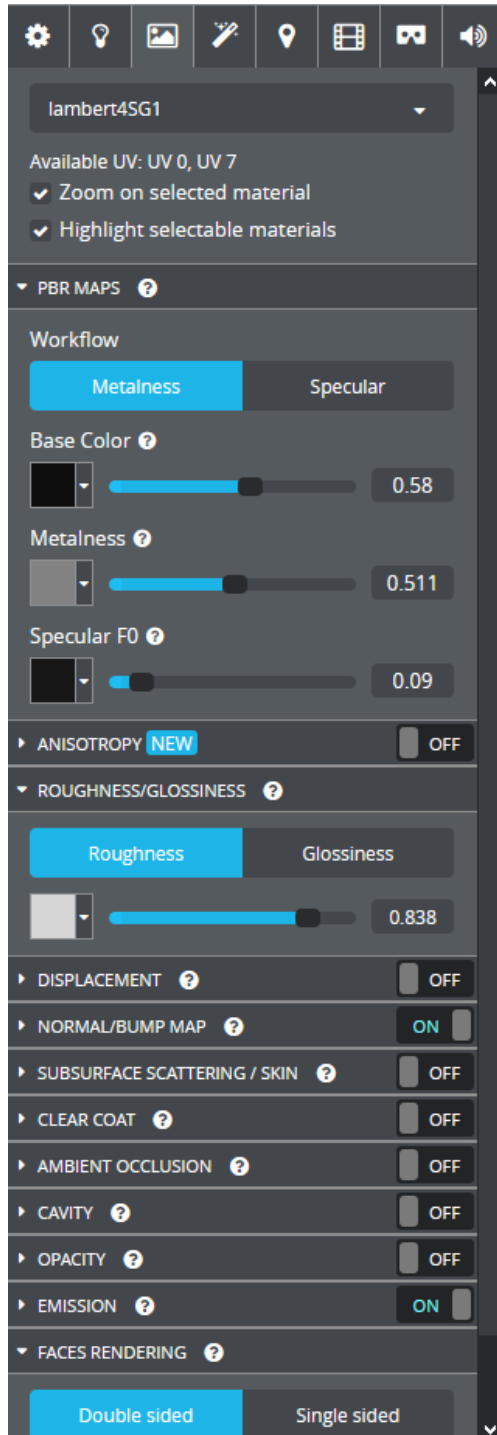


Picture 36. Ground shadows appearance

Upon entering the “Materials” tab (Picture 37), it is easy to understand all those prizes and awards the platform won in the early beginnings. Even for someone who is new to this, handling of all of the materials is incredibly easy and intuitive. Without any confusion or ambiguity, the Sketchfab designers and developers did an amazing job with this panel.

On the top is the dropdown list with the possibility to select any of the available materials and textures, and the “selected material” animation highlighting is something certainly worth pointing out. Having the possibility to quickly change between “Metalness” and “Specular” is something that only the professionals of the technology could innovate, because the biggest number of materials is divided exactly in those two directions when talking about refractions and glossiness.

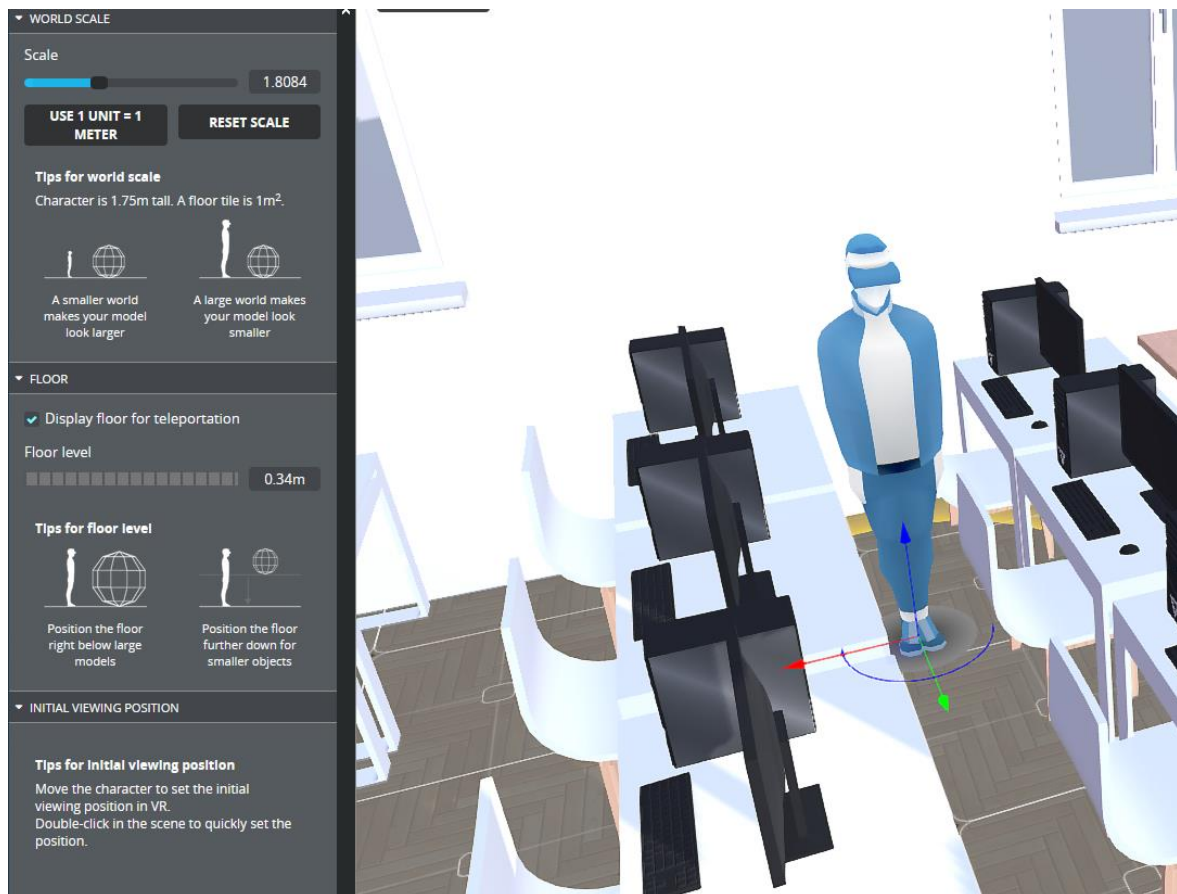
A load of features to be tweaked like anisotropy, displacement, clear coat, subsurface scattering, cavity, opacity, emission and faces rendering make the 3D tool editor obsolete. With all these options being so simply shown on the platform, there really is no need to go material after material in, e.g. Maya and select the



materials to have all kinds of different settings, when it can all be done here. It is even possible to select a normal or bump map in the editor. That is not the usual case in online editors and should be pointed out. Tab named “post-processing filters” offers 10 new options related to the rendering of the scene as “Screen space reflection”, “SSAO”, “Grain”, “Sharpness”, “Tone mapping”, etc. It is also nice to know that antialiasing is available even though it is temporal antialiasing. This platform also supports the option of having animations in the model, meaning it can also work with “heavier” and more complex scenes and render them without any problems. Seeing that there are no animations or sounds on the scene, these areas are set on default and without options to choose from.

Upon entering the “Virtual Reality” tab, the scene changes and a character is added to the scene with options available in the side panel to be resized relatively on the size of the scene. Being that the scene will be rendered in the size selected here in the “World scale”, it is important to select approximately the correct size in order to have a real and faithful virtual experience with the help of a VR headset.

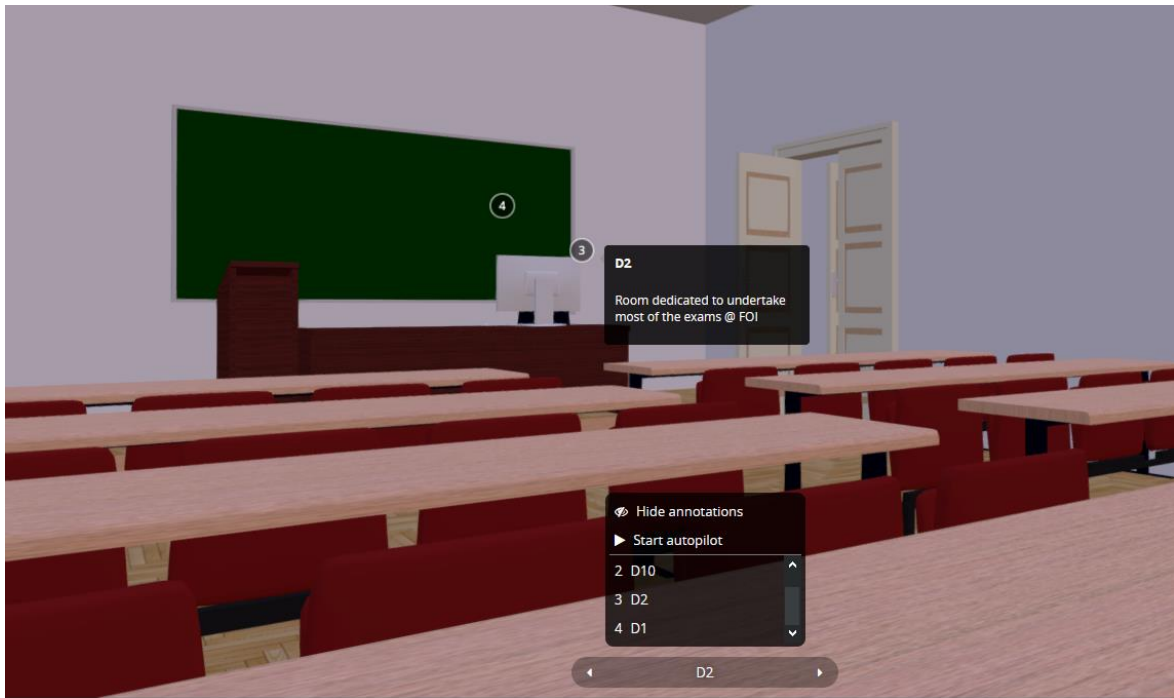
Picture 37. The level of details on 'Materials' tab is astonishing



Picture 38. Settings for “Virtual reality” tab and the addition of a reference character

There is also an existing feature to select the floor height and the spawning height of VR user (Picture 38) so that it does not feel like the user has dropped below floor level.

Something that is definitely one of the biggest hits on this platform is a feature called “Annotations” which is basically a snapshot in 3D space and it preserves the coordinates and orientation of the viewport as a pin in the background and then later, when selected, animates a “trip” to that same exact spot and in that way has an enormous potential in easily pointing out any possible detail in the scene, no matter the size, color or shape.



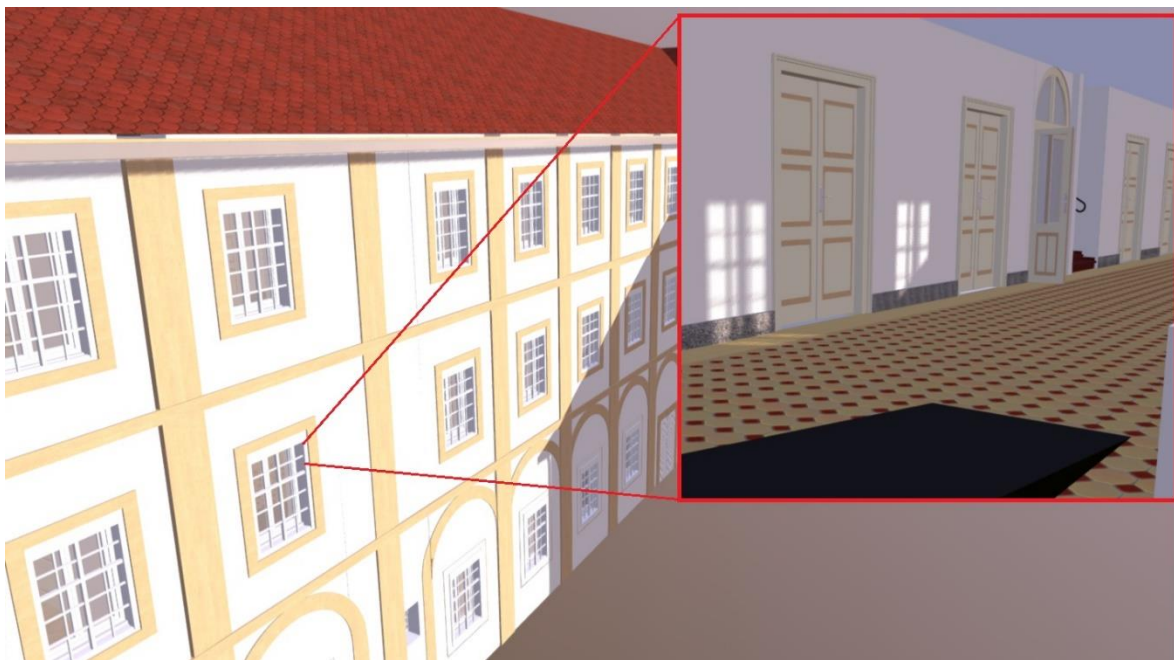
Picture 39. Options available with annotations feature

When the focus was on uploading window, it was interesting to notice that Sketchfab accepts 7z and zip files which means it is possible to compress bigger scenes and objects than the common 50 MB and then upload it to the platform. After all, it is unlikely that the whole model of the building of Faculty of Organisation and Informatics could then be uploaded inside of memory limits the platforms usually have.

With the possibility of such memory capacities and the technology used for annotations, there are a lot of scenarios as in where to use these features, with some of them being:

- Faculties – showing students and participants something of bigger importance with more ease and with more information than usual traditional ways (e.g. Medicine students learning something about an organ – this is a great way to showcase something)
- Navigation – e.g. someone is trying to get around in a new building or institution they have never been in before. With the use of 3D pins called “Annotations”, it is a fast and a straight-forward way to highlight a room or an office for someone who still is learning his way around.

- Therapy – placing pins in periodical distance could be used as a treatment to someone in need of physiotherapy and making the treatment more effective and entertaining thus making the patient happier and more eager to work out more often – accelerating his recovery.
- Virtual walks – e.g. Not having to go to the other part of the continent to sightsee and review another property (with a real-estate agent), but only put on a headset and see all the important information about the property immediately.

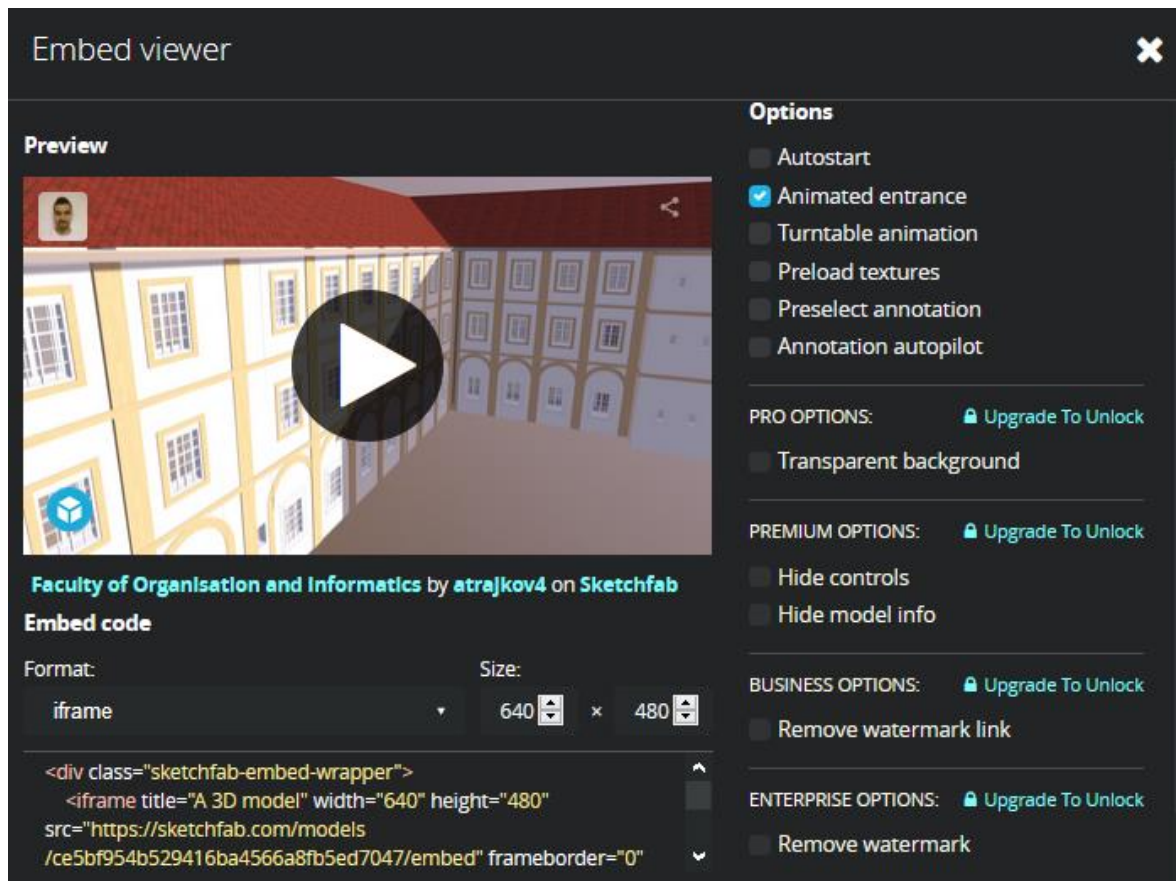


Picture 40. Rendering quality (basic settings) seems impeccable

After finishing with the 3D settings adjusting, it is time to review the model and the quality of the rendering shown in the viewport. The controls are intuitive and even the lighting direction can be adjusted differently for another angle of reviewing the object rendered (Alt + left click drag over the viewport). Because of the controls so responsive, the scene seems light and easy to investigate. Even when the case is with the largest of scenes (The whole building), the responsiveness is still present and that is an impressive characteristics of the engine behind the platform of Sketchfab. A big contribution is made to the quality of every scene by plugins made specifically by Sketchfab for more than 81 tools in total which is an enormous number of technologies covered, supporting the software of tools like Unity, Maya, SolidWorks, 3dsMax, Blender, Cinema4d, SketchUp, Adobe Photoshop and many,

many more. The quality of the materials is original and persuasive, rendered exactly like in the 3D environment, no materials went missing and there are no “wrongfully set” traits caused by the exporting into the platform.

With the editor having a comfortable set of features for each material available emerges a question is material finessing really necessary inside of 3D environments, or is the mesh creating and applying textures enough for the model to be ready to be exported and finished in the editor Sketchfab offers.



Picture 41. “Embed viewer” window with features for content sharing

Having an extensive feature like this, Sketchfab offers the most detailed sharing module over all alternatives in the business. With possibilities like previewing the content, preloading textures (important for loading speed), preselecting annotation or annotation autopilot, it is obvious that the developers paid attention even to the smallest of details and definitely delivered a platform with the highest quality available on the market.

Even though some parts of the platform are limited or locked, and thus limiting the extensive use and practice of all of the available features, it is to be said with

great confidence that the platforms features could only get better and more effective when all of the options would get accessible. Even the basic account that is free is having a wide range of options and modifications that could even get a stronger practice with a PRO license.

4. Side by side comparison

Now, after seeing the capabilities of all of the platforms mentioned, it is time to compare them equally in order to get evaluation. Some are better or similar in one area whereas the other are significantly stronger in other areas, so let's get started.

4.1. Design and interface

Even though Google's Poly platform has a recognizable style inherited from the Google's identity, there is still some space to improve. The imprint on Poly is that, despite the fact that the platform is on a good track, it is still lacking that "full professional" competitor feeling unlike p3D.in and Sketchfab. The hovering animations and a more detailed approach definitely contributed to Sketchfab and p3D.in to make an impression that they have been in the business "forever". The side panel on Poly is really practical and the smoothness between the pages (gallery, home, uploads) is certainly a plus, but being that displayed objects are shown really statically, it is obvious that the platform was launched recently (November 2017) and the "look & feel" part of the platform could use some updates.

Sketchfab and p3D.in on the other hand have a high-level and adjusted site with clear and highly functional every part of the platform. From the navigation bar to the last model displayed in the gallery, the quality of the scene thumbnail exudes with excellence, making Poly look like it is still unclear what direction to take off in.

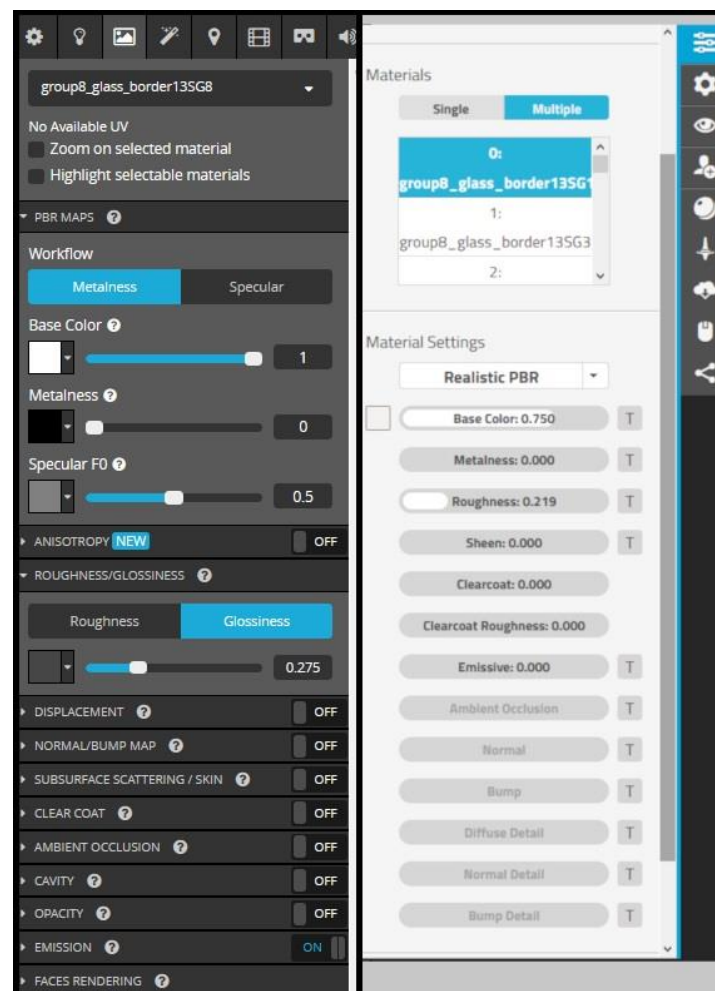
4.2. Upload and supported file types

Whereas Sketchfab is the absolute leader with more than 50 supported file types, p3d.in is severely lacking support in this area as much as Google Poly. With the amount of supported file types available, it can be said that both of the platforms are still specialized in only a narrow range of types. Mostly revolving around .obj and texture/material types, it still a long road to take to catch up with Sketchfab.

If mentioning the file size, Sketchfab once again takes the top. With the possibility to upload an archive of a compressed file, Sketchfab has the capacity to host files a few times bigger than 100MB (when compressed properly under 50MB for a free license). In total, even if file type limits are overlooked, Sketchfab's ability to host compressed archive opens a whole new world to the size of the scene in 3D.

4.3. 3D editor

With Poly having mostly the basic settings focused only on the presentation part like rotation, glow, camera, etc., p3D.in certainly out-did Google in the area of editing. With a high number of possibilities, p3D.in can stand side to side with Sketchfab in this round as the service quality is similar. Even though Sketchfab offers a bigger set of adjustments and fine-tunings than p3D.in, it is normal to sense a slight difference between those two especially when remembering the difference in time spent online (Sketchfab release year is 2011, p3D.in's is 2014). It is definitely worth pointing out that p3D.in is on good track and if the developers proceed with such good progress, there is no doubt they will be total peers in terms of quality.



Picture 42. Difference in adjustment details level - Sketchfab (left) and p3D.in (right)

4.4. Rendering and controls

There is not a lot of times one can say that Google's product is not the best product available in its domain but this time it seems Poly is dragging behind by a far distance compared to p3D.in and Sketchfab. Controls-wise, it still feels like the object is heavy, colossal and passive, while on p3D.in and Sketchfab, it feels lighter, more responsive and active, accompanied by a great shading and light effects (physics). It looks like the engine behind this is severely better in abovementioned platforms than the one behind Poly, but being that Poly is still amongst the "youngest" on the 3D market, there is definitely time to catch up the leading duo.

When speaking about the rendering quality (picture 43), there is definitely material to discuss. With Sketchfab being the most "professional" with an eye-watering rendering quality, it is worth pointing out that, even though its rendering is also high level, p3D.in's shading and lighting levels up the difference between the renderings quality and certainly beats Sketchfab's lighting by some distance. With this kind of quality shading, it is really easy to analyze each material only by looking at it without further inspection and get a feeling of realism with all the dispersed lights. Also one of the things missing on the Poly platform is lighting-direction editing that p3D.in and Sketchfab already have implemented. By simply pressing "Alt" and moving the mouse while holding left mouse button pressed, the lighting circles around the object in a smooth movement thus having a better representation of the displayed objects hardly visible edges or shapes.

Some materials are rendered too saturated by default in p3D.in whereas in Sketchfab and Poly, it does seem a bit more "normal" without any special settings, but that can also be finessed in the 3D editor. It is also important to highlight Poly's inability to show bump maps or to edit materials online and that is a big lack of features from Google's developers.



Picture 43. Comparison between scene renderings (Sketchfab top, p3D.in middle, Poly bottom)

4.5. Overall impression

It is futile to fight the impression that Poly's service, when reviewed, definitely lacks quality and depth that p3D.in and Sketchfab do offer. All the way from the uploads, to controls, editing and rendering, Poly was never a clear winner in any of the categories abovementioned and sometimes did not even come close to the competition.

When talking about p3D.in and Sketchfab, it is hard to divide those platforms as both of them have great technologies, a wide range of features to offer and an impeccable engine as shown earlier. Rendering qualities, when compared, are too close to call. While p3D's warmth of the scene and the excellent lighting contribute in making the scene an absolute sight, Sketchfab's physics and bump map renderings are equally breath-taking and give off the scent of photorealism that p3D is possibly lacking, but that is a thing of preference. The orbital camera is of great use in all three platforms, but first person approach supported in only Sketchfab is something other platforms could rethink about implementing.

Editor-wise, both p3D and Sketchfab are exceptionally set with all sorts of adjustments that make a world of difference for a scene, thus making it difficult to decide the winner here too. Both engines look impeccable and the things that could divide those two platforms are probably in the smallest of details. Furthermore, when talking about potential, Sketchfab does have a small advantage in offering a truly great support with a lot of 3D equipment manufacturers and leading by some distance in the support related to plugins (for more than 80 tools available) and file types (50 file types) opposing to p3D.in's less impressive few. Additionally, Sketchfab's memory freedom and the acceptance of compressed files open the door to a greater future with the possibilities of hosting more complex scenes.

With technology like the "walk-through" camera for scenes and the absolute hit called "annotations", Sketchfab is undeniably declared a leader and an idol for the rest of the competition with a great potential to be used in all of the medical, academic, engineering and architecture domains and innovations mentioned in the second chapter.

5. Conclusion

The models built for this master's thesis and the research that has been made on the three platforms are only a glimpse of the potential 3D technology can and will provide. It is now clear that the greener and more sustainable future lies in drastically changing the core of human behavior towards newer technologies and start using them.

3D technology can provide a significant impact across a lot of fundamental domains that shape people's days and lives. From medicinal advancements like virtual physiotherapies, better treatment and diagnostics, evolution in organ and tissue mapping and revolution in 3D organ printing, to cutting expenses and plastic waste with 3D printing (whether the object being printed is a car's fender or a whole family house) 3D has a bright future with the tools and technology available at this moment.

The survey that has been done as a part of this thesis also shows that most of the younger generations already know and believe in the potential of 3D, no matter the profession. Even though this technology is already available and awaits for a more practical commercial use (whether it is through VR glasses, or as part of some other 3D technique), it is still remaining undisclosed to the greater masses with all of its benefits. Undoubtedly, academic approach would evolve making the lectures more interesting and having the students more focused on the knowledge presented to them; engineering would see the rise of 3D as its latest progress after the CAD system integrations whereas architects could benefit in ways more than one, starting with the possibility to present their work to a client, inside and outside, through VR glasses, therefore raising the bar in quality and standards across the whole field.

The possibilities are endless and the potential is undeniable. Whether or not 3D will get fully involved in people's everyday lives is a mystery only future will show, but having the opportunity to transform the future tremendously and not applying it, only symbolizes that maybe, even though the technology may be ready, the people inventing it simply are not.

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