Master's Thesis (Academic Year 2019)

Mass-market-oriented FAB system development / 3DP-based online gift platform

Keio University

Graduate School of Media and Governance

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Abstract of Master’s Thesis Academic Year 2019

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Summary

Today, Additive Manufacturing (AM), which is so-called 3D printing, has already been a very mature technology, through different types of machine and diverse materials, it is not difficult any more to make creative works. Yet, if we take a look at our everyday lives, it is clear that 3D printing technology has not been embraced by most people even though there are numerous 3D libraries and convenient remote printing services, the fact is that this technology is still restricted within laboratories and makers who mostly own the design or engineering background.

There is a fundamental difference between makers who use 3D printers and others who do not use 3D printers: a constant motivation. While makers and researchers have the constant needs to make prototypes of what they are developing, normal people do not have a clear and constant motivation of using 3D printers. Although there are many researches or even commercial products in the field of 3D software/approach, but they are either professional CAD products or general 3D tools, none of them have truly shown the specific motivation driving people to the world of 3D printing, in other words, why do people need to use 3D tools and make things via 3D printing?

As a result, this research is not only about the development of a 3D system; it is meant to point out a potential 3D printing application integrated with real-world needs that could provoke people’s constant curiosity and desire of trying 3D printing.

Keywords

1. Digital Fabrication, 2. Web 3D System, 3. 3D Printing Application, 4. Open Design, 5. Additive Manufacturing

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論文要旨

近年、積層造形（3D プリンティング）技術の精度や速度が向上している。多様な方式の機械が登場し、さまざまな素材を制御できるようになり、クリエイティブなアイデアを実現することが可能になった。しかし、3D プリンティングは研究チームやデザイン工房で使われているものの、一般の人々（デザインやエンジニアリングの未経験者）には正しく認識されていない。

一般の人々が、デザイナーとエンジニアと異なるのは、3D プリンティングを試すモチベーションが無いことである。

デザイナーとエンジニアは、仕事で、色々なプロトタイプを制作する必要性がある、しかしながら、一般人には、3D プリンティングの認識が不足している状況で、試すモチベーションを特段持っていない。

そのため、未経験者に 3D プリンティングの使用を促すために、容易に 3D データが作れる研究やソフトが増えつつあるものの、その効果は限定的である。これまでの研究やソフトは大部分が 3D アプローチに対して、新たなアイデアを提案しているが、一般市民に 3D プリンティングの日常生活にの応用性を見せるものにはないっておらず、結果として、ユーザーの 3D プリンティングにの興味はあまり高まっていない。

そこで本研究では、「一般市民による 3D プリンティングの日常応用」に対して、その応用を重視した 3D プラットフォーム・サービスのデザインと開発を行う。本研究はユーザーに 3D プリンティングの可能性（日常生活）を感じささせるには何が必要かを詳細に検討し、さらに、ウェブ上の３D モデリング・プラットフォームの実装と実験を通じて、3D プリンティングを人々の生活に落とし込むためにに必要な要素と、未来に対する有効性を検証したものである。

キーワード

1. デジタル・ファブリケーション、2. ウェブ 3D システム、3. ３D プリンティングアプリ 、 4. オープン・デザイン 、 5. 積層造形法

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[1] General Background Information

[1.1] Background information

Digital fabrication, FabLab, personal fabrication, open design.
Digital fabrication, including the well-known manufacturing approaches such as 3D printing and laser cutting, made a tremendous breakthrough on both experimental and commercial side in the past decade. In the case of the most common digital fabrication tool, 3D printer, more than ten types of machine had been developed and applied to different industries according to the specialty of each type. In addition to diversity, the decrease in the price of 3D printers also played an important role, for instance, the price of a basic FDM (Fused Depositing Modeling) machine could go down to 200 to 300 US dollars, meanwhile, those affordable machines mostly had the sufficient printing quality which was better than we thought, making exquisite assembling parts with those affordable machines was highly feasible.

Furthermore, the expansion of FabLab, which was a small-scale workshop offering digital fabrication tools and space, made it possible to materialize one's thought without paying a lot of money on the equipment. Up to 2019, over 1200 FabLabs were established all over the world.

Figure 1.1 FabLab Vestmannaeyjar Iceland

Apart from the hardware, the software of digital/personal fabrication also made a huge progress in the past few years. The emergence of 3D libraries such like Thingiverse and GrabCAD made it easier to reach 3D data. Beginners of 3D printing no longer had to make their STL files for the first print, but download them from these open-source libraries. Also, more and more companies were trying to launch the remote 3D printing service, which could help people who were busy or not familiar with machines complete their works.

All of the factors mentioned above were breaking down the obstacles of individuals making their thoughts come true, and facilitating the growth of personal fabrication.

Other than that, in recent years, the form of “Open Design” gradually became a trend in the design industry. The phrase, Open Design, was first coined by Ronen Kadushin in his thesis, the concept of it was mainly about sharing the design and manufacturing information, then getting more innovative designs through the accumulation of people’s work. Open Design was also a form of co-creation, one of the core values of it was that designers or companies did not design the final product directly, but build an open-source framework or platform with which users create their own products. For an example, Arduino might be the most popular case of Open Design in the world, it was not a complete product but a kit for building digital devices and interactive objects, the kit included both hardware and software, a single-board microcontroller and its programming environment. The community of Arduino created hundreds of thousands of derivative works based on the original framework. A well-designed framework generating unlimited possibilities, this was the power of Open Design.

Based on the high-speed evolution of personal fabrication technologies, it is firmly believed that Open Design had its chance to become the mainstream of design and manufacturing industry in the future.

[1.2] Literature review / Case study

Autodesk 123D suite, TinkerCAD, OpenSCAD

Due to the high-speed development of digital fabrication tools, the corresponding platforms and services were growing as well. For people who started using 3D printers, after the first few trials, most of them would come up with their own thoughts and hope to build their own printable data, yet, making new printable 3D data (STL, OBJ and so on) was never an effortless mission for those who did not have design or engineering experiences. In fact, a lot of beginners gave up on 3D printing gradually because of the barrier of making new 3D data, people were tired of searching and watching countless tutorial videos then getting frustrated by the results. One of the numerous reasons was that professional CAD (Computer-Aided-Design) software contained the concepts of traditional manufacturing approaches, so it would take more time for people who did not have these knowledge to understand and adapt to the rules.

Therefore, in the past few years, some companies or organizations were enthusiastic about developing new approaches of 3D modeling which were simpler than in the past, and trying to attract beginners. This type of platforms were usually free, and because of the simpler 3D approaches, beginners could learn faster and materialize their ideas in the shorter period of time, even though it might be difficult to make complex works through these new approaches.

The products launched by Autodesk in recent years could be the famous cases. Autodesk 123D was a series of 3D tools including a CAD application, a 3D scanning application, a virtual circuit application and so on, it was meant to help hobbyist and amateurs generate 3D data in simplified methods. Autodesk 123D was also the very first complete software circle trying to fill the technical gap between 3D printing and non-technical users. As an example, 123D Design, the 3D modeling tool of the 123D suite, was build based on the conventional CAD approaches, but the manipulation of 3D objects was simplified, for instance, when users were trying to extrude a column, it was not necessary to define the accurate parameters in the beginning, a rough 3D model could be created simply by clicking and dragging.

However, except the 123D circuit, all other applications of Autodesk 123D suite were discontinued by Autodesk in 2016, some of them were replaced by alternative applications such as TinkerCAD and Fusion360. Both of TinkerCAD and Fusion360 supported more of the 3D modeling functions, while Fusion360 was designed for more professional users, TinkerCAD was defined as a beginner-oriented 3D platform.

Comparing with 123D Design, TinkerCAD contained more modules and plug-ins. Unlike conventional CAD software, it was built based on the browser, therefore, the compatibility of operation system would not be a problem.

In addition to Autodesk, other organizations and developers also proposed different 3D approaches. For instance, OpenSCAD, a 3D tool known for its parametric flexibility, would be the special one. Distinct from most CAD software, the 3D functions in OpenSCAD was not a GUI (Graphical User Interface) design, but a script-only based interface using its own language, parts build by users could be reviewed in the window, but OpenSCAD did not allow users to select or modify by mouse in the 3D view. The programming-like feature of it maximized the simplicity of parametric adjustment and made it a popular tool among users who did not have too much needs on curved surfaces and details.

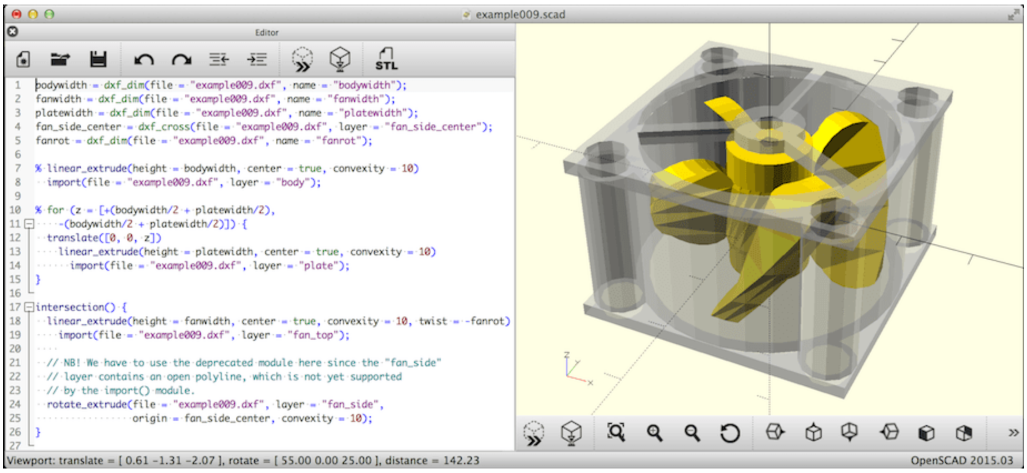

Figure 1.2 OpenSCAD User Interface

[1.3] Problem framing

Even though all of the 3D tools and approaches mentioned above are meant to shorten the distance between non-technical users and 3D printing technology, if we look back to the reality, 3D printing has not become a part of our daily lives yet.

The blossom of new 3D modeling approaches happened in the past decade, to a great extent, do fill the technical gap between 3D printing and users. However, technical support is not everything we need when it comes to promoting a new system or technology. In fact, when technical section is overemphasized, non-technical users would tend to look up to it instead of coming into contact with it. History has presented to us many times, the decisive factor of launching a new technology is the application.

The iphone, the game-changing device designed by Apple, would be a great example. Before the iphone was presented, the technologies of touching screen, mobile computing chips and the internet had been quite mature. Those PDA (Personal-Digital-Assistant) manufactured ten years ago also had the similar technical configuration. But before the materialization of the iphone, PDA was considered as a business device, rather than a device for daily uses. The birth of the iphone showed us the potential possibilities of “a mobile device connected with the internet”. The better quality of touching screen, the more elegant user interface and the stronger computing power were magnificent, these improvements brought us the better using experience, but the key element in the victory of the iphone was its application. Instead of merely showing off the specification of their design, Apple clearly indicated and actually developed the applications for the iphone which were able to make our everyday lives more convenient.

Now if we put the focus back to 3D printing technology, we found that up to now, the development of 3D printing and the processes of popularization still center on producing cheaper machines, increasing the fabrication spaces and developing more user-friendly 3D platforms. The above factors definitely will minimize the difficulty for users to try to comprehend the feasibility of 3D printing technology, nevertheless, these are not the main things to which non-technical users would pay attention.

In fact, we could still hardly see a product or a research demonstrating the evident applications which are close to our daily lives and can lead to constant requirements. The attraction brought by the current 3D printing development is stronger to designers and engineers rather than non-technical users, because now they could make the rapid prototypes in a shorter time and with a lower cost, but apparently, 3D printing is capable of more than rapid prototyping.

Therefore, the biggest lack of current products and researches on 3D printing is that they are not designed with a clear application that is close enough to people's lives and can generate the constant motivation.

[1.4] Research question / Research purpose

Given the fact that 3D printing has not indicated a clear application for non-technical population yet, most people still do not know what they can do with this technology even though all the printing services and 3D tools are well provided. Apparently the initial purpose of the current developments is to bring more people to 3D printing community, however, due to the lack of real-world applications, it is not working as the software companies or development organizations planned, and the present status should not be defined as succeeded. Therefore, considering the current situation of 3D printing industry, our research question is: how to make 3D printing technology truly a part of people's daily lives?

As mentioned above, we have plenty of 3D tools and producing/printing services on the market, most of them either provide us new and simpler approaches reaching 3D printing or optimize the workflow of 3D printing for us. These updates are tremendous in terms of engineers or designers making prototypes, but are these what non-technical users pay attention to? In fact, the actual problem which we are confronting now is that those services do not point out what is possible to be made by 3D printing. Even if users make things with the current 3D software because of educational purposes, there is no enough motivation driving them to print out what they have made.

Hence, this research intends to build a system integrated with a real-world need, which is the gift-giving behavior, then lead to the result that non-technical population attempts to make things with 3D printing spontaneously.

[1.5] Value of research

As we mentioned above, the current developments on 3D printing industry, in summary, make this technology easier to use. It is an enormous contribution, but meanwhile, the expected effect of bringing more users to 3D printing community seems to be restricted at this point of time. To make a real breakthrough under the circumstance, instead of emphasizing the technical specification, this research provides people a clear reason, a motivation to use, to manipulate 3D printers.

So far, 3D printing technology is known for its abilities of generating diverse and parametric designs, and with the progress made by many different organizations in the past few years, it is now widely applied to design and engineering workflow. But outside of the technical circle, among the non-technical population, people can only capture the incomplete information through public media such as magazines and the internet.

People may unintentionally read an article rendering how easy the new 3D approaches are from one's blog on the internet, or have a glance at the commercial page of a magazine showing how affordable the machines are and what superior mechanism is implemented. But from beginning to end, there is no proper entrance for non-technical population to experience 3D printing technology and harvest their outputs from it.

The system developed for this research, giftGO, is designed as a bridge between non-technical population and 3D printing technology. It indicates a new solution of gift-giving based on 3D printing. While some people are often confused about what to buy as a gift, this system allows its users to actually make a customized gift in a short period of time. Unlike the current developments, this research is meant to solve an actual problem which exists in the daily lives of non-technical users via a specialized 3D approach, and provoke non-technical users' constant needs of 3D printing.

[2] Research Method / Proposing System Stage.1

[2.1] Web-based 3D system development

The ultimate goal of this system design is to become the bridge between non-technical population and 3D printing technology, then have as much people as possible enroll in the 3D printing community. Therefore, the system itself must be highly accessible. While the growth of desktop software on the market is often restrained by the compatibility of operating system such as Windows, Mac OS and Linux, the internet offers another feasible option, browsers and cloud. Web-based system design allows users to access from every type of operating system, including but not limited to computers, it also works on mobile devices such as smartphones and tablets.

Apart from the system compatibility, web-based systems have another feature making it much easier to use for non-technical population. With the web-based design, users will not have to go through the complicated processes of download, installation, manual settings and so on, all they have to do is to register on their browsers and get ready to start. Moreover, web-based system also provides developers or companies a simpler method to collect users' works and the relevant data for the further manipulations such as analysis and research through the internet connection.

Due to its simplicity of use, both in commercial and academic fields, we can see more and more actual cases of 3D web applications emerging in the past few years. Including TinkerCAD, a famous online CAD tool owned by Autodesk, and SketchUP, a famous architectural 3D tool. Even though currently web-based systems might still be a little unstable in contrast to traditional desktop software, however, with the high-speed improvement of web technology, the stability of web applications will catch up soon, and because of the convenience and ease of use, web-based design will eventually become the main stream of casual 3D applications.

Therefore, considering that the 3D system in this research is defined as a specialized 3D system which will not be involved with complex 3D manipulations, web-based structure is implemented in this research.

Followings are the actual design workflow of this system:

Step 1. Setting an intuitive game-like 3D approach (Stacking)

Step 2. Building up the basic units (3D modeling)

Step 3. Setting up a web-based 3D environment via JavaScript (Three.js)

Step 4. Combining/Importing the basic units we have designed

Step 5. Creating an interactive interface

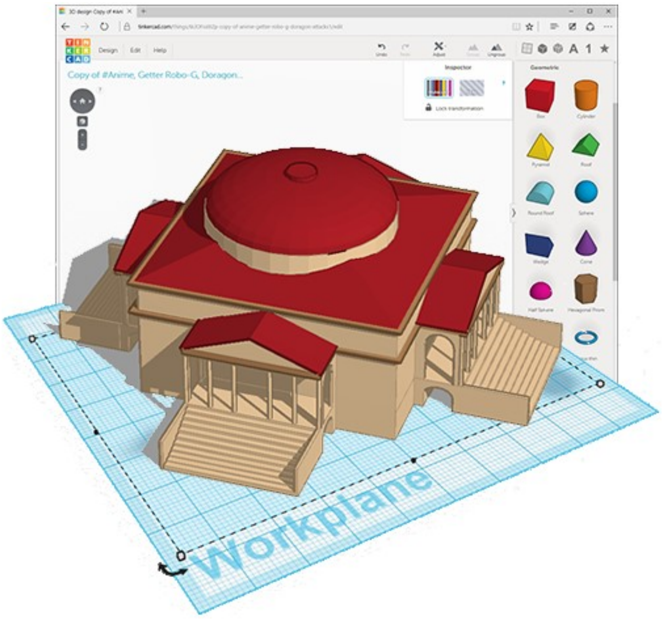

Figure 1.3 Autodesk TinkerCAD

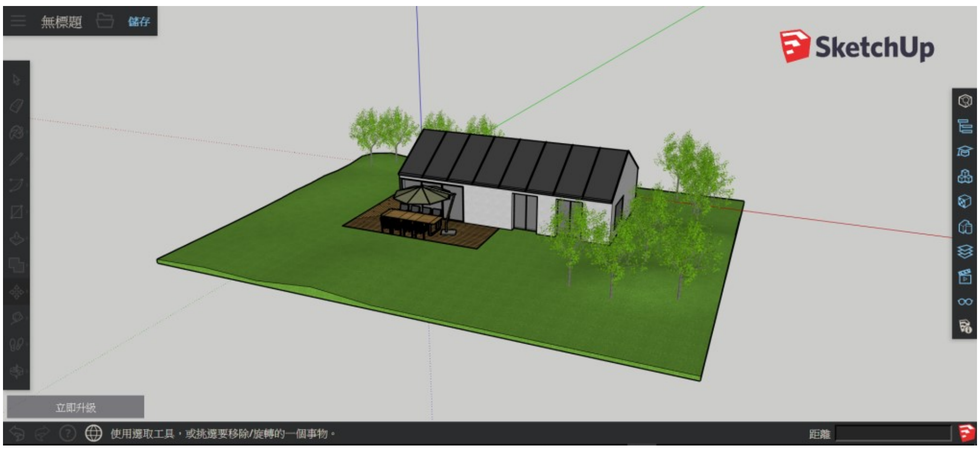

Figure 1.4 SketchUP Web version

[2.1.1] 3D approach designed for unexperienced users

As mentioned above, the specialized 3D system in this research is built based on web, and the next step is to define how users interact with the system. Currently, if one who does not have any experiences of design or engineering needs to learn how to build an object through a CAD software such as Solidworks, PTC Creo, or Fusion 360, this person will have to spend tens of hours on watching numerous tutorial videos on the internet or reading the detailed explanations on the official manual. The reason is that most of today's CAD software is built for designing general products which are manufactured in factories, therefore, a lot of functions in the conventional CAD software contain concepts of manufacturing or the related knowledge, which are usually not so intuitive, for example, extruding, shell, curved surfaces and so on. Thus, users could feel highly frustrated when they are not familiar with those concepts.

Due to the fact that 3D tools are being the barrier between 3D manipulations and unexperienced users, software corporations such as Autodesk and Adobe have been working on new 3D approaches for years. Their products launched in the past few years have showed us the prospects of future 3D application. Most of 3D approaches embedded in their products are meant to help users create their own 3D data more easily. For instance, 123D Catch, one of a series of programs of Autodesk's 123D suite, allows users to make 3D scanned data via smartphones by taking several 2D pictures from the designated angles, even though this 123D series had been discontinued and replaced by other applications since 2016, the way in which users create 3D data remains the same, most of today's popular 3D scanning applications on smartphones such as Trnio and Qlone are also designed based on the same manner.

Figure 2.1 Scanning tutorial of Trnio

However, instead of merely generating 3D data but making 3D objects through an adjustable manner, the concept of piling objects should be the ideal one. In terms of making a thing, the most intuitive behavior is stacking the smaller units and turning them into the expected form, which can be found from sandcastles on beaches or children's clay works in classrooms. Also, LEGO, one of the most successful toy manufacturers in the world, provides us a compelling evidence as well. As some people might think of stacking bricks as a children behavior, it is worth mentioning that LEGO is not a mere toy designed for children, a lot of famous designers, engineers or startup teams also use LEGO bricks to materialize the very first prototype of their creative thoughts, and the reason is simple, it is simply because piling bricks is easy, quick and highly modifiable.

Of course, stacking bricks is not a completely perfect 3D solution, the weakness of it is obvious. Building 3D objects through stacking small units might not be capable of creating detailed curved surfaces and fillet parts in comparison to the conventional 3D CAD tools. However, in this research, the application is not meant to compete with conventional 3D tools on capabilities or generate highly complex 3D model, but indicate a practical use of 3D printing technology, thus, the easy-to-learn and highly modifiable features make stacking bricks the 3D basis embedded in this application.

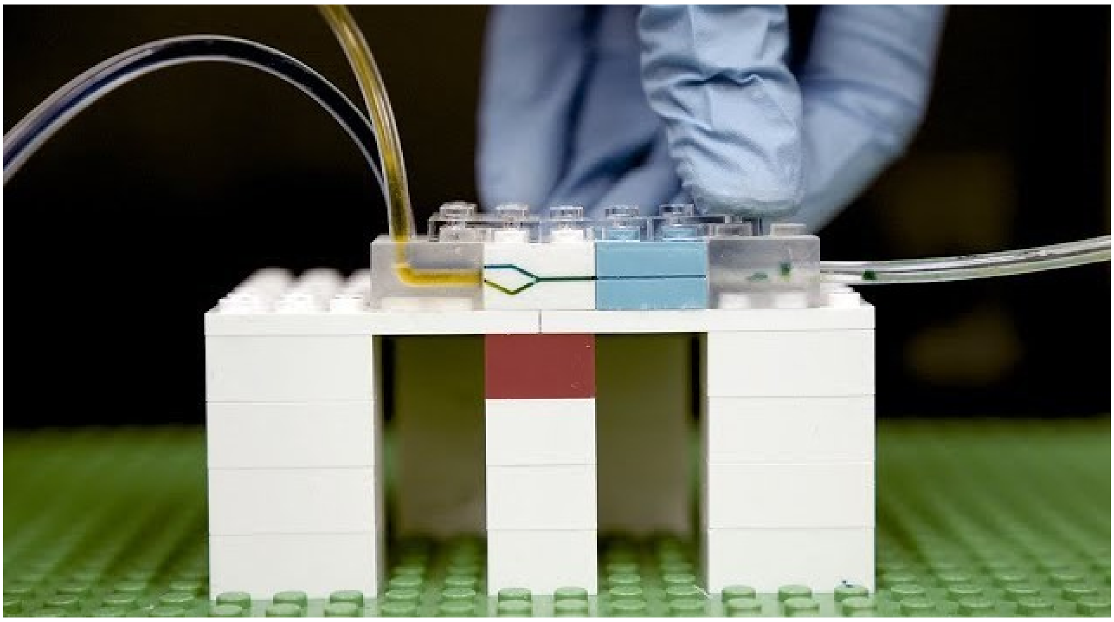

Figure 2.2 MIT uses LEGO bricks to prototype low-cost micro pumps

Furthermore, the Tetris patterns are implemented as the main concept of the basic units. As one of the most popular games in the world, most people have experienced Tetris game in the past, and even though Tetris is not exactly about making 3D objects, the core concept of it is still stacking units. Besides, the Tetris patterns could bring this system the game-like feature, which is supposed to break down the technical barrier and increase the accessibility for non-technical population. As a result, having Tetris patterns as a part of basic units implies the basic manipulation of this system and augments the diversity of basic units.

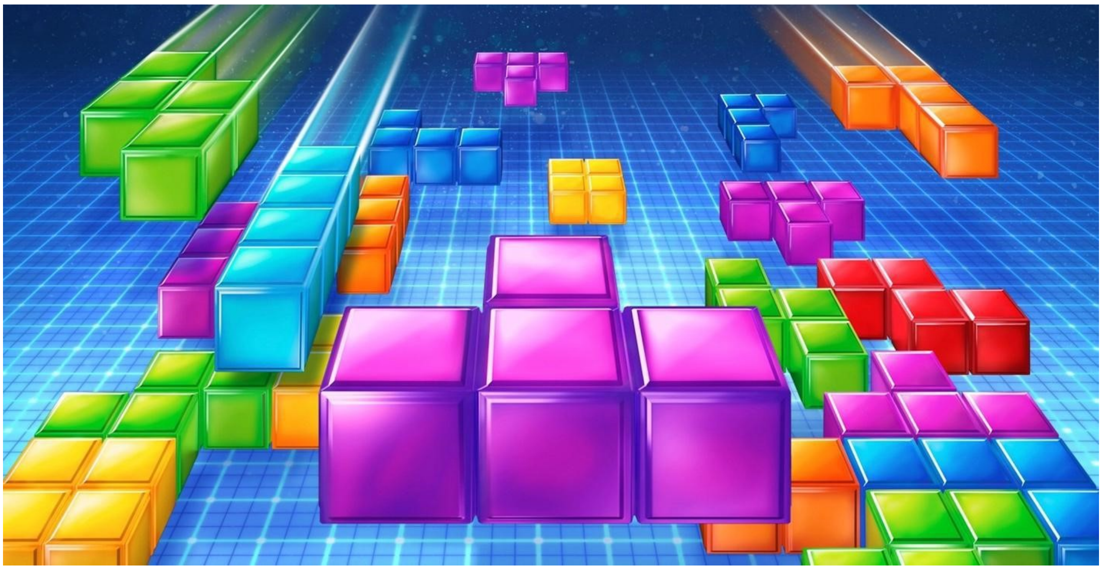

Figure 2.3 This research uses Tetris patterns as the basic 3D approach

[2.1.2] Implementation of basic unit / 3D Tetris model

Before designing 3D Tetris models, we have to figure out what to build. A 3D model built by stacking smaller units is called voxel model, and in terms of voxel model, although it provides an intuitive manner for beginners to create 3D data, yet, it has its own weakness.

If the individual unit is not small enough (Ex: 1mm*1mm*1mm or smaller), the whole model, especially curved surfaces would not be as delicate as the one made with conventional CAD methods, which is similar to 2D pictures we take almost everyday, the less pixels/units contained in a picture, the more blurred a picture looks, because the size of each pixel/unit becomes larger. And this problem may lead to a limitation of creativity, the most importantly, it might decrease the satisfaction when users see the outputs.

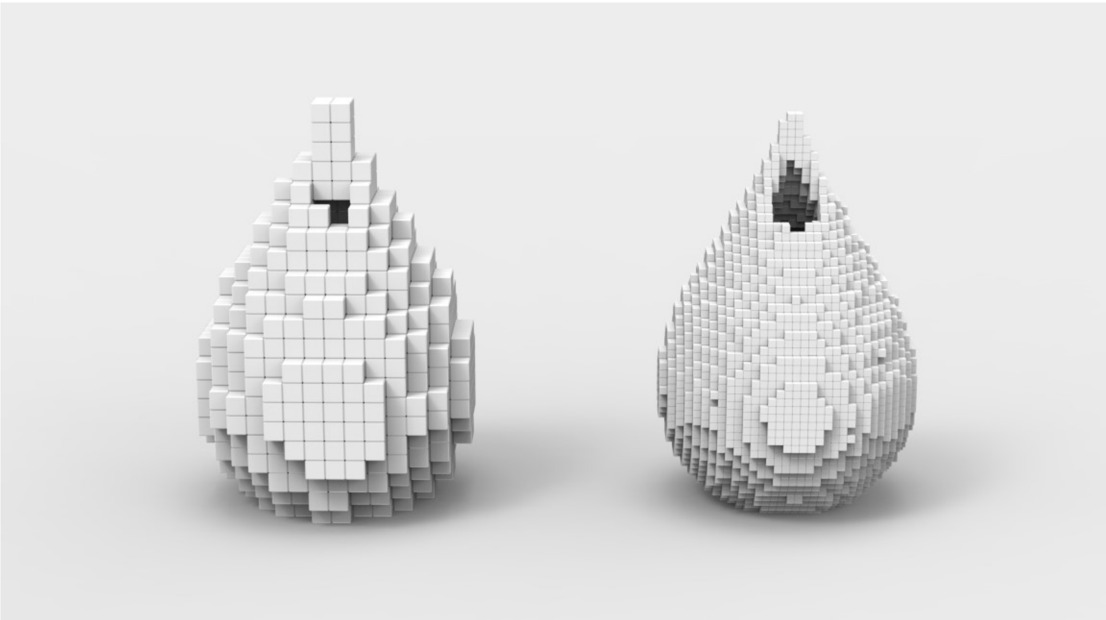

Figure 2.4 Low-resolution (left) and high-resolution (right)

Nevertheless, just like some developers turning low-resolution 2D pictures into a fashionable mosaic style, it is also possible to make the model interesting when it comes to a low-resolution 3D voxel model.

The method implemented in this system is to increase the diversity of the basic unit and make basic units a part of users' design. Instead of merely having one type of block, we tried to build various types of unit through cutting and making fillet based on a cube, and made those designed blocks a part of the final creation. Eventually, six types of basic unit were embedded in this system, including three types of solid cube and three types of hollow cube.

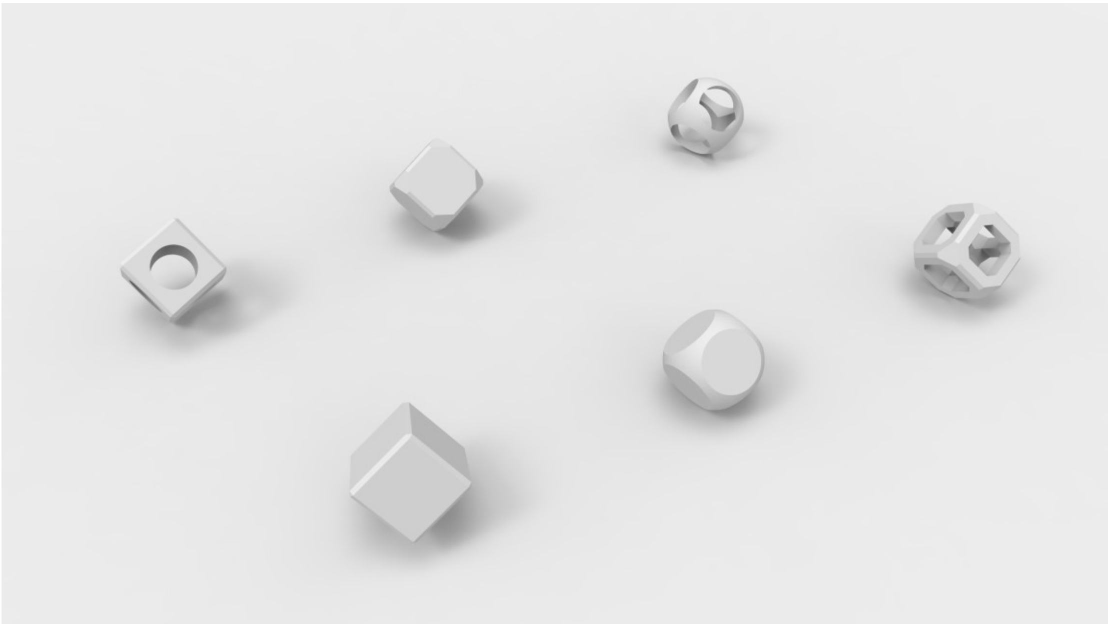

Figure 2.5 Six types of basic unit

The next move is to combine these designed bricks with Tetris patterns. Except for the classic Tetris patterns, one-block pattern is also added to the group for detailed adjustments.

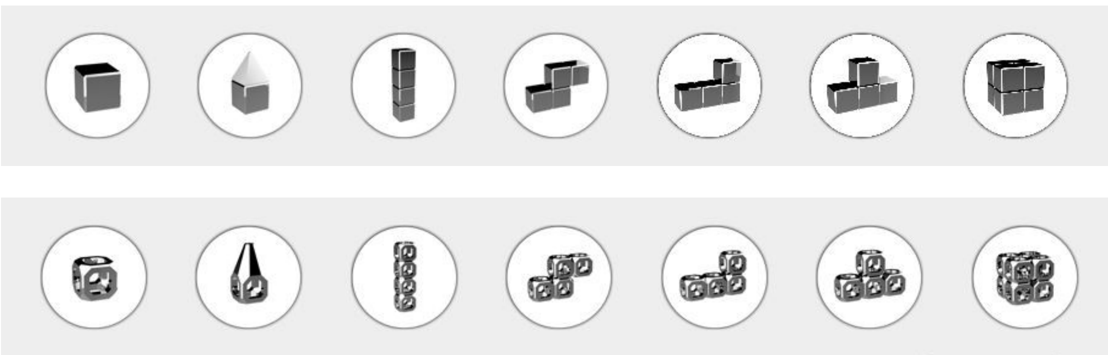

Figure 2.6 3D Tetris patterns

[2.1.3] System development based on WebGL / Three.js

As mentioned above, comparing with desktop software, web-based system is more accessible for users, but how exactly does 3D performance work on the web environment? The key to today's web-based 3D applications, which is also the fundamental technology used in this research, is the WebGL.

In fact, back to a decade ago, we did not have so many web-based 3D applications like we have today, until WebGL technology was launched. One of the most crucial breakthrough brought by WebGL is the new 3D processing method integrated with GPU (Graphics Processing Unit). Computing 3D models, shadow, perspective, and physics would be a heavy job without the help of GPU, which is why the web-based 3D applications developed before the launch of WebGL could not be as fantastic and smooth as today's ones, in other words, the GPU-driven style of WebGL highly accelerates and optimizes the whole 3D performance on browsers, therefore, it becomes feasible to build more complex and big-scale 3D games or 3D applications based on the web environment. However, since WebGL programs consist of not only control code written in JavaScript but also shader code written in GLSL ES (OpenGL ES Shading Language), it will take much more time if web developers directly use WebGL to build up their projects, as a result, senior developers all over the world reorganize and classify the initial code of WebGL then come up with a series of API according to the needs of different 3D applications, for example, Babylon.js, Egret, Layabox and the one used in this system, Three.js. These API built based on WebGL simplify the code for the initial settings of 3D environment, including material/color rendering, 3D coordinates, light and so on, and provide developers the quicker way to jump to the truly creative part of their projects.

Each API has its own strength, developers choose the most suitable API to build their projects. In this research, Three.js is the main API used to build up the 3D environment. Three.js was released in 2010, but the origins of the library could be tracked back to the early 2000s. Three.js contains classes to set up the scene, camera and renderer, and with Three.js library, it is effortless to add new geometries to the scene, besides, not only static performance, it also provides classes for 3D animation on browsers. Today, Three.js has already been widely used by developers and corporations, including famous brands such as Apple and Nike.

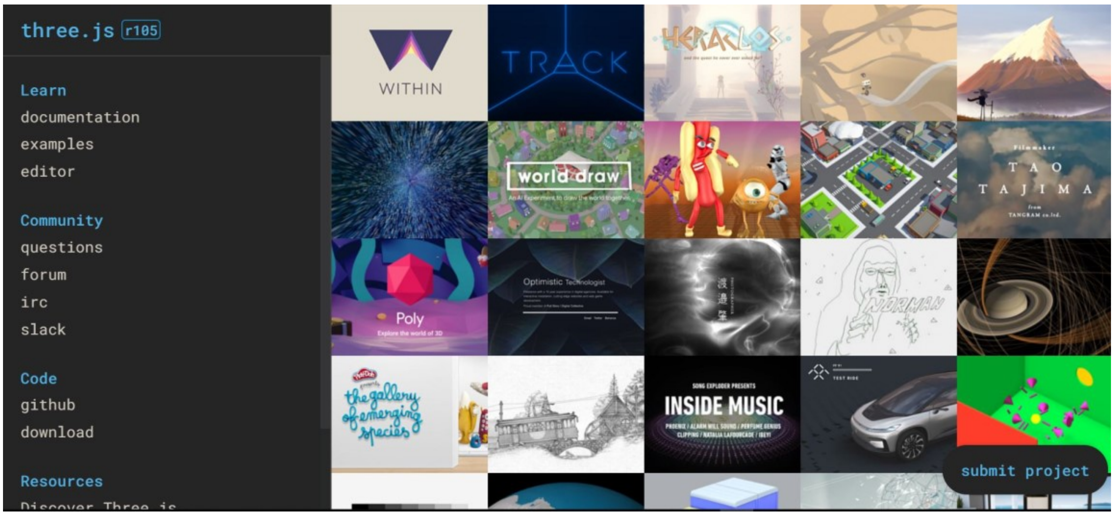

Figure 2.7 Three.js samples

Moreover, Three.js also contains classes for creating interactive interface. To develop the 3D system for this research, we took use of the these classes and created the game-like interface for users to interact with, including how the units are selected, moved and rotated (Objects are moved and rotated by arrow keys and some other keyboard buttons). And the most importantly, Three.js provides both of the loader and exporter for several types of 3D formats, by implementing them in our system, our users can easily import the default units/3D Tetris models that we provide or other 3D files downloaded from open-source 3D libraries such as Thingiverse and GrabCAD, then edit them and export their work as a binary STL file, which is currently the most common 3D printing format, through our program, then start 3D printing what they have created.

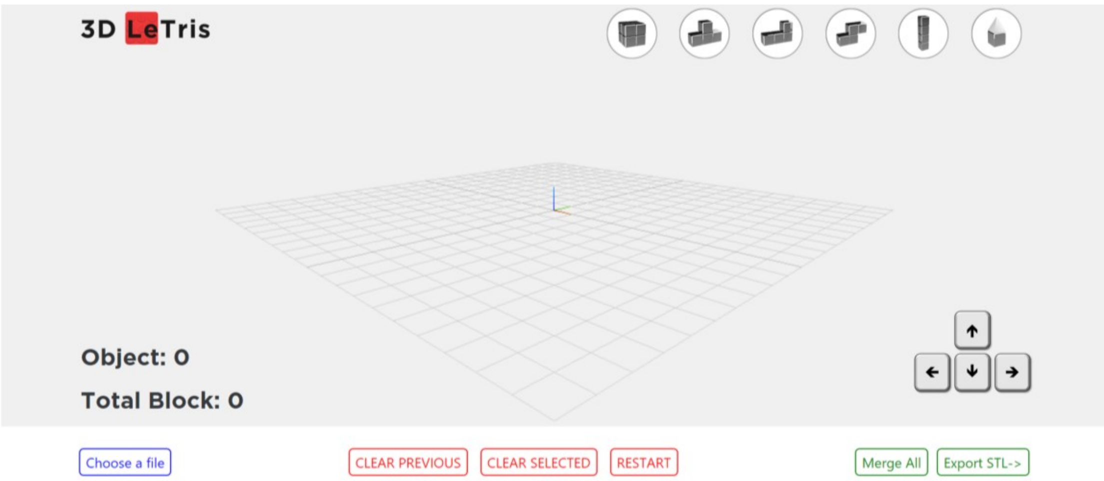

Figure 2.8 System Ver.1 containing functions mentioned above

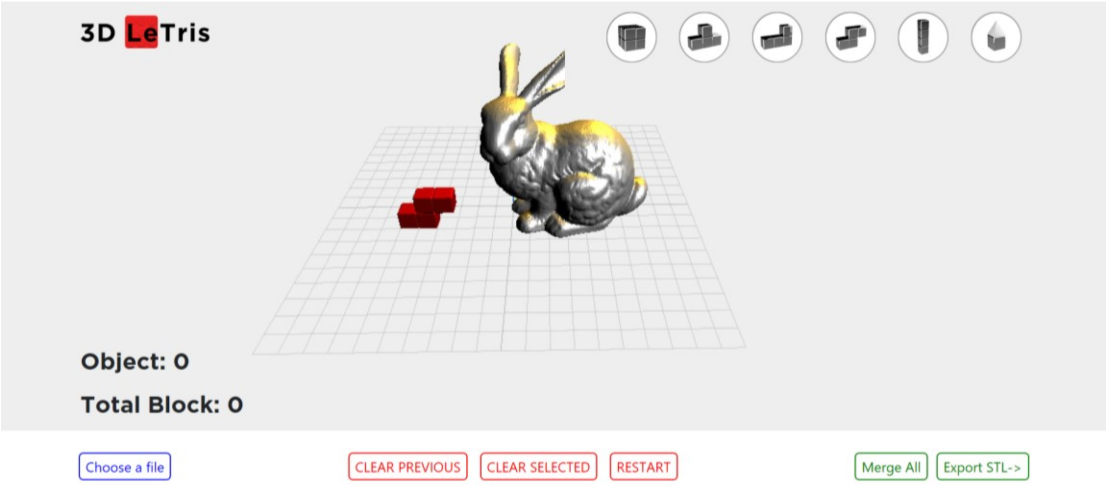

Figure 2.9 Importing basic units and STL model then control them (move, rotate)

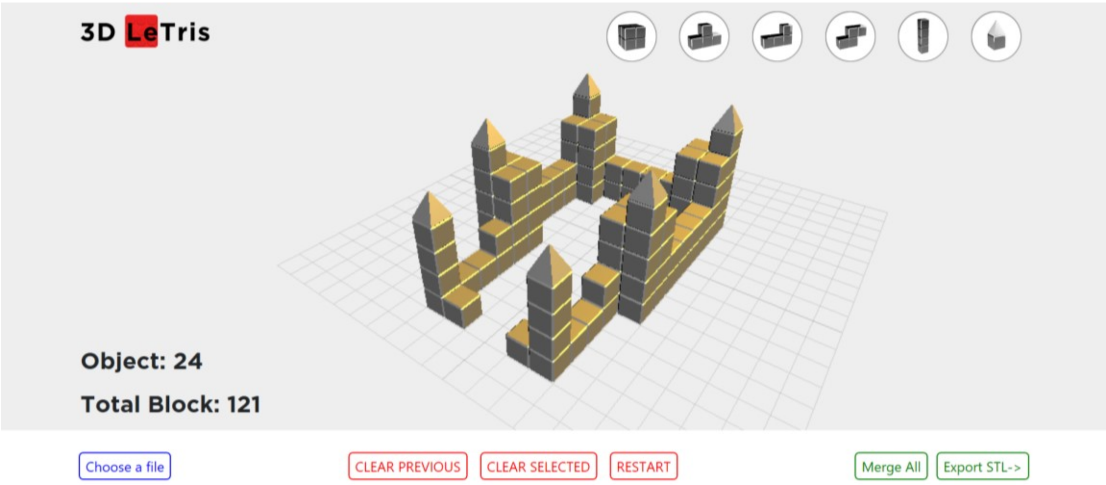

Figure 2.10 Castle built by stacking basic units

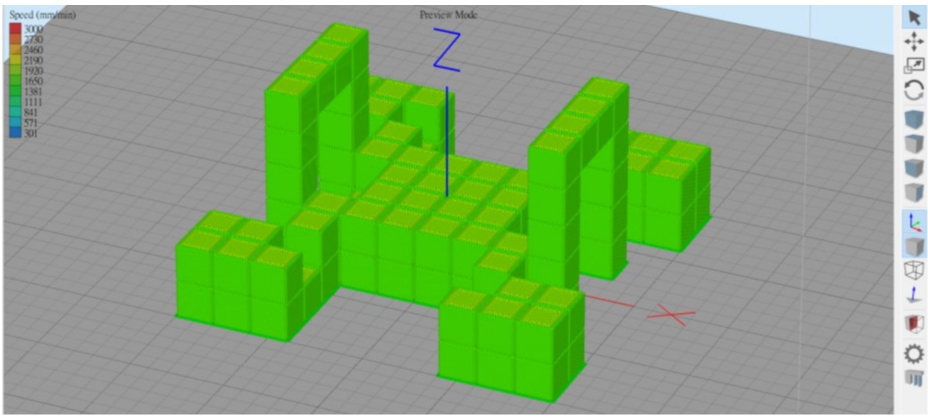

Figure 2.11 Exported file is 3D printable (Sliced by Simplify3D)

[2.2] Introspection and shortcomings

So far, the first version of the web-based 3D system has been developed, it is already functional to import models, edit models and export the final works as 3D printable formats, yet, the system still has not pointed out any clear applications, which makes the system no different from the current 3D tools. If the system is a mere online 3D tool built for general purposes, then why would users choose it over the current services? And how could the system be attractive to people who are new to 3D world?

The ultimate goal of this research has not changed, it is meant to indicate a clear motivation for non-technical population to try and keep using 3D printing, and eventually turn 3D printing technology a part of daily lives. To achieve this goal, there must be a reason, a strong motivation driving people to print out what that have made with this system. The sample works shown above, a castle, a bunny, do not actually form a specific need, the outputs coming from this system must demonstrate the more concrete theme, which will be the unique value of this research.

Besides, the current 3D tools such as SketchUP and TinkerCAD, are developed by numerous sizable teams with a wide range of database in a long period of time, competing with them in the general way, for instance, the amount of functions or the scale of software, is not practical. The valuable research method should be finding out the lack of current tools in terms of 3D printing and building up the corresponding specialized software which is expected to fill the current gap between usage and technology.

Therefore, up to this stage, the development still seems general, which has to be adjusted. The details of pivoting and the specific application will be described in the next chapter.

[3] Research Method / Proposing system Stage.2

[3.1] Adjusting and pivoting – the birth of giftGO

To differentiate this system from others and provoke users' needs of 3D printing technology, it has to be designed for a certain application instead of being designed for general purposes. The application must meet the following conditions, being close enough to our daily lives, and being able to bring people constant needs. Therefore, through careful deliberation and filtering, this system is eventually defined as a web-based gift platform, giftGO, which is meant to allow its users to make their unique presents on the go.

There are four main benefits brought by gift:

Benefit 1. The essence of gift is quite close to the feature of 3D printing, which is about being unique, diverse and customizable.

Benefit 2. The business chance does exist in the gift industry. Currently, people often get troubled when it comes to customizing a gift for someone without spending too much money and time.

Benefit 3. In almost every culture, gift is always necessary for maintaining and strengthening different types of relationship.

Benefit 4. By the social behavior of human being, gift is able to generate endless needs.

Unlike thinking about technologies, the decision of application requires more of cultural and social elements. From the cultural and social perspective, no matter in which country, we have the custom of giving and receiving presents on special occasions. "Gift" has always been an important part of human's culture. Preparing presents is regarded as one of the most common and popular ways to celebrate festivals, sustain social relations, show respects, say hello, say goodbye, show kindnesses and so on. When people give presents to others, they want to show that they care about them and make them happy, therefore, as the container, the representation of emotions, people always want their gifts to be unique, creative and memorable, which perfectly fits to the features of digital fabrication.

However, at the same time, people do not want “preparing presents” to be troublesome or take too much time from them. And this is where 3D printing technology comes in handy, with 3D printing, it is truly possible to create something peerless for someone without spending too much time and money.

But so far, because of the difficulty of the whole process, for instance, building a 3DP-ready file, merging 3D printing with our everyday lives seamlessly is still on its way. If a total amateur wants to make his own things, he may have to spend tens of hundreds of hours on learning how to use a specific CAD software before jumping to 3D printing, and usually, this sort of process would burn out people’s passion.

Therefore, this system, giftGO, intends to bring people a whole new experience of 3D printing, it is designed to help users accomplish their 3D data of unique gift within twenty to thirty minutes by specialized functions, and export their gift data as a 3D printable format. Just as we mentioned above, with giftGO, everybody is allowed to make matchless gifts on the go.

[3.2] Gift-oriented program structure

Since giftGO is a specialized system designed for making unique gifts, we programed a series of gift-oriented functions on it. These functions must meet certain conditions.

First, being able to make objects that are often given as gifts, second, being truly customizable so that even though a lot of objects might be generated by the same function, each of them is still special, third, unlike traditional CAD software, these gift-oriented modules must be capable of helping unexperienced users make customized outputs in a short period of time, in other words, the workflow of each function must stay simple.

Followings are five main modules embedded in giftGO:
(Each module will be explained particularly in the coming chapters)

Module 1. 3D picture module, which allows users to import a normal 2D picture (.jpg or .png format), and then turn it into a 3D printable model through color analysis.

Module 2. Casting module, which can turn a 3D model (imported STL file or objects built by default blocks) into a mold, the mold could be the final work or be used for making the original model with different material via casting (Ex: snacks like cookie).

Module 3. Lampshade module, which is able to turn a 3D model (imported STL file or objects built by default blocks) into a lampshade (a hollow model with the same outer shape).

Module 4. 3D text module, which is able to create 3D alphabets with five different fonts (expandable).

Module 5. Voxelization module, which can transform a 3D model of certain formats (expandable, currently STL only) into a voxel model, both of the basic shape of voxel and voxel size are adjustable.

To make the whole system more accessible for users, the interface is highly graphical, also, all of the functions are separated as blocks, each block includes a designated type of modules, so it becomes easier to learn and find a specific module in the beginning. Except for the voxelization module, all other gift-oriented functions are contained in the bottom-right block (voxelization module involves STL import, therefore, it is grouped with "Import 3D" function in the bottom-left block).

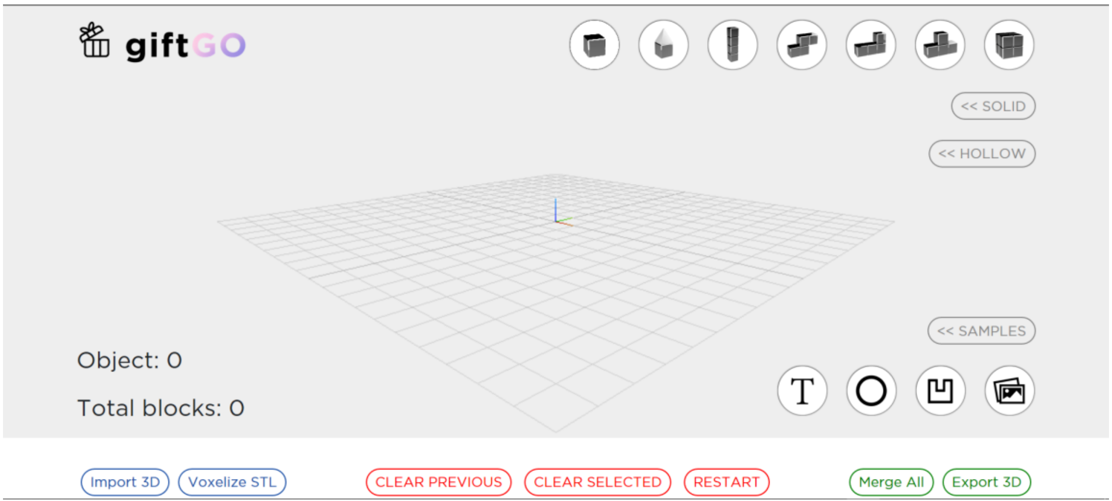

Figure 3.1 The complete user interface of giftGO

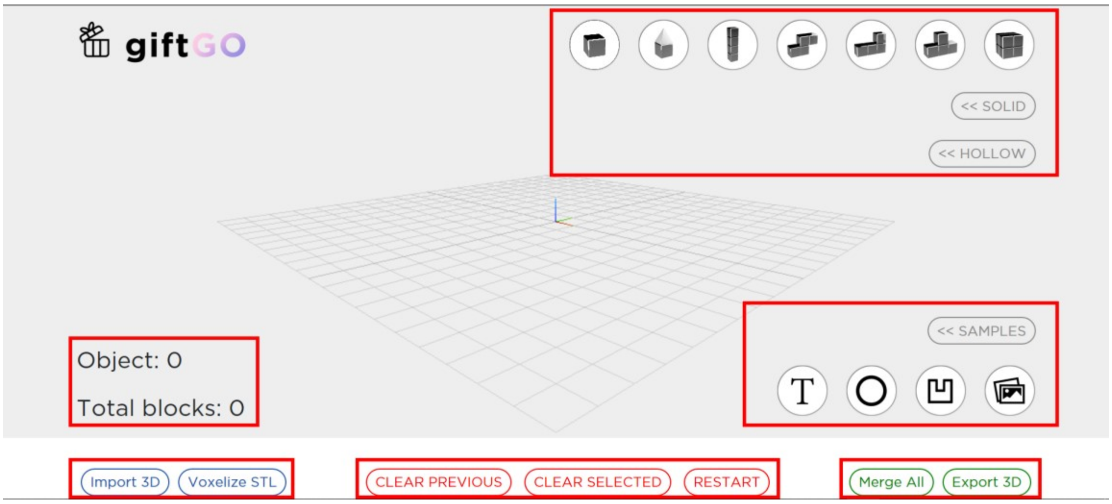

Figure 3.2 Every block contains a certain type of functions

[3.2.1] 3D voxel picture mode development

Taking picture has been the most common way to record our daily lives and save the precious memories since the popularization of digital camera and smart phone, hence, photos always play an important role when it comes to gift-giving, a great photo can not only make a gift delightful but also deliver how close people are and then strengthen the relationship.

Due to the value of photos, corresponding services emerge as the times require, these services allow people to do the further manipulations with their photos. For instance, some companies develop the edible ink and help couples who are going to marry print their photos on cakes, cookies or some other snacks, while some studios may provide services to help their customers print photos on daily commodities such as cup coasters, blankets, cushions and so on. What about 3D printing? Can we 3D print a 2D photo? In fact, it is not difficult to 3D print a 2D photo, there is a lot of tools turning 2D photos into so called “3D Lithophane”. The method of 3D lithophane is simple, the darker color of a photo will be generated as the thicker part, so less light will be able to go through it when the model is put in front of a light source. The following figure is a popular online tool (3D Printing Rocks) for making 3D lithophane, it is capable of generating lithophane with different shapes such as cylinder.

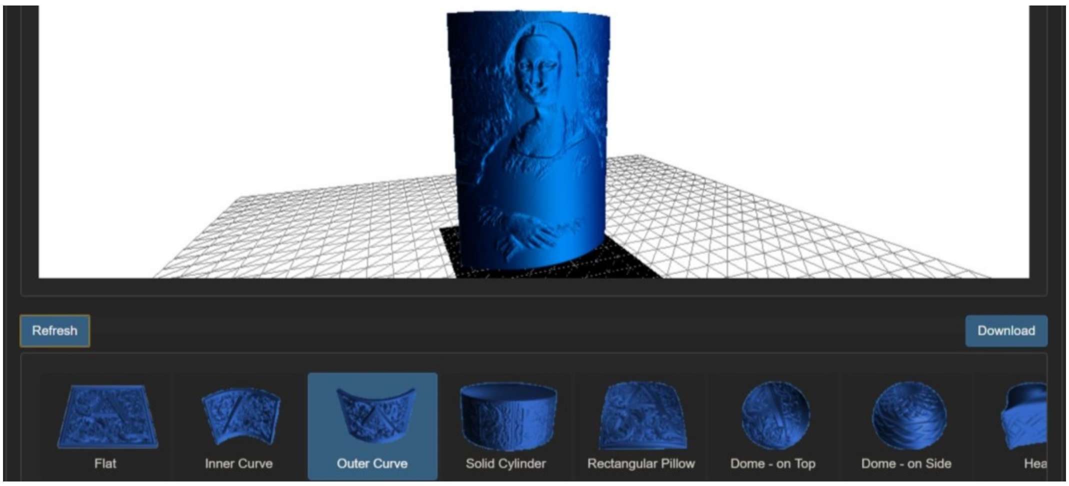

Figure 3.3 Screenshot of online 3D lithophane tool (3D Printing Rocks)

With these 3D lithophane tools, users are now able to 3D print their 2D pictures, but the goal of giftGO is to make pictures a part of gifts. In other words, giftGO does not merely turn 2D pictures into 3D models, we consider the generated models as a part of gifts and allow users to make further manipulations with the generated models. Our design allows users to separate the generated 3D model and adjust (add or delete) it for their entire design, which may be a plant pot with a human face or other creative gifts.

Figure 3.4 Not only make 3D photo, but manipulate it

The following paragraph indicates how we designed this module with JavaScript. Firstly, we need to evaluate each pixel of a picture with the same standard, which is greyscale, so we get the detailed data of a picture by the built-in JavaScript method, getImageData(), this method is able to gain the data of each image pixel, and each pixel contains four numbers, which are the data of RGBA (A color model including Red, Green, Blue and Alpha), once we know the RGB data, we can get the greyscale number via averaging these three numbers. So far we have the greyscale data, so it is possible now to evaluate each pixel with the same standard, the next step is to remap these data and turn them into the parameters for Z axis, for example, remapping with the scale from one to ten. And eventually, create 3D geometries by Three.js library using the remapped data as Z axis parameters (parameters of X and Y axis should be fixed).

Step 1. Gaining the detailed data of a picture (Each pixel's RGBA data)
Step 2. Averaging the RGB numbers to get greyscale data of each pixel
Step 3. Remapping the greyscale data and turn that into Z axis parameters
Step 4. Using Three.js to generate 3D model for each pixel with the remapped data

Here is how we manipulate the pixel data with getImageData() method in JavaScript:

```
var canvas = document.createElement( 'canvas' );
var context = canvas.getContext('2d');
context.drawImage( image, 0, 0, resolutionX, resolutionY );
var imageData = context.getImageData(0, 0, resolutionX, resolutionY);
```

So far those RGBA data will be stored as an array, then we use a “for loop” to calculate the greyscale data. (Every four numbers represent the complete data of one pixel)

```
var greyScaleData = [];
for (var I = 0; I < imageData.data.length; I += 4) {
   var greyScale = (imageData.data[i] + imageData.data[i+1] +
         imageData.data[i+2]) / 3;
   greyScaleData.push(greyScale);
}
```

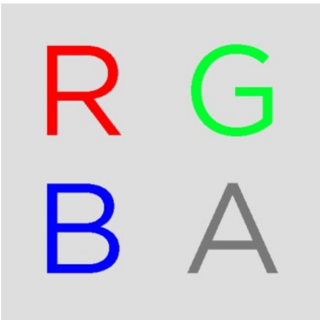

Figure 3.5 Dataset of each pixel

Then this paragraph is about how users interact with this module.
In terms of the user interface, we tried to make the process of generating 3D models for imported pictures as flexible as possible. Users are allowed to set the most suitable parameters for their pictures, which include background color, final size of the generated model, height of model and model resolution. Also, before importing a picture, users could choose whether to separate the final model into a hundred pieces (10*10), so that they will be able to do the further manipulations or export the model as a 3D picture puzzle.

Moreover, unlike some experimental 3D tools showing all parameters at the same time, all of the settings mentioned above are designed as a series of web modals, as a result, instead of being confused because of seeing all of the parametric settings at the same time, users could set those parameters step by step with their own pace, the next modal will not appear until one is done.

The following explanation indicates how users make 3D photos through this giftGO module.

Modal 1. Background color. Since pictures may be taken under different circumstances, the first modal allows users to pick the suitable one (The selection will affect how the module remaps pixel data).
Modal 2. XY size of final model. XY size is especially important when a picture is taken with 16:9 or 4:3 scale, the suitable setting keeps the original scale.
Modal 3. Thickness. Users could set the thickest part of the generated model, the input will affect the remapped result.
Modal 4. Resolution and separation. The final modal shows the adjustable resolution and separation choice (With default value).

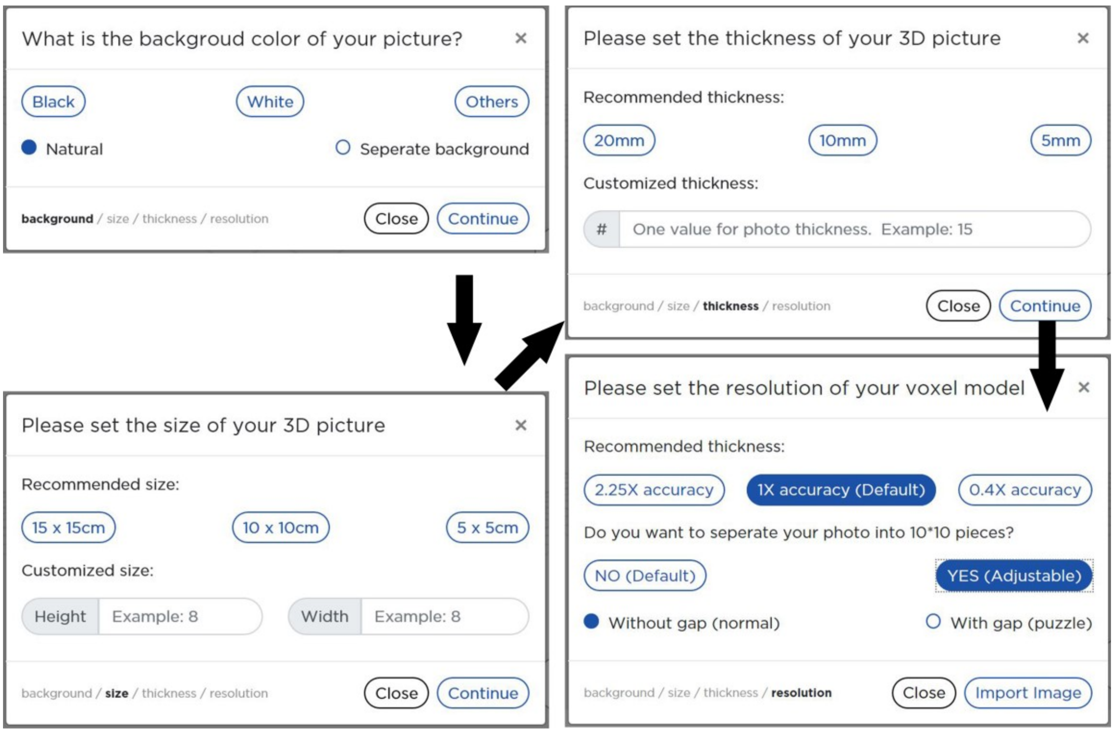

Figure 3.6 Order of parameter modals

The following figures indicate how the parameters mentioned above affect the final model.

Figure 3.7 One photo with different background selection (Left: Black, Right: White)

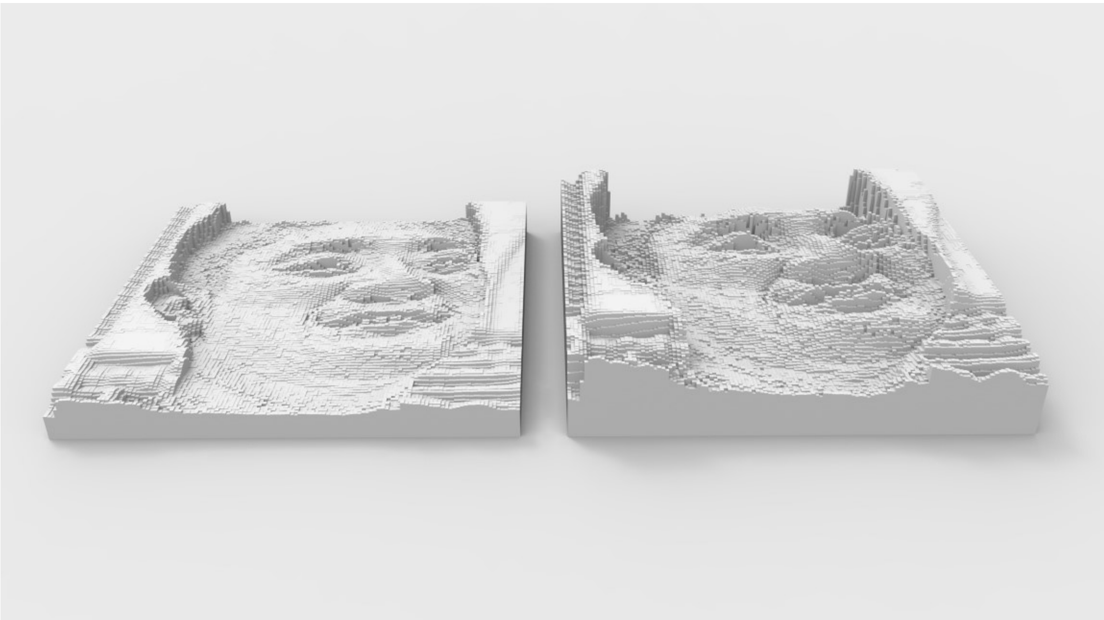

Figure 3.8 One photo with different height parameter (Left: 10mm, Right: 20mm)

Figure 3.9 Adjustable XY size (Left: 10cm*10cm, Right: 8mm*12cm)

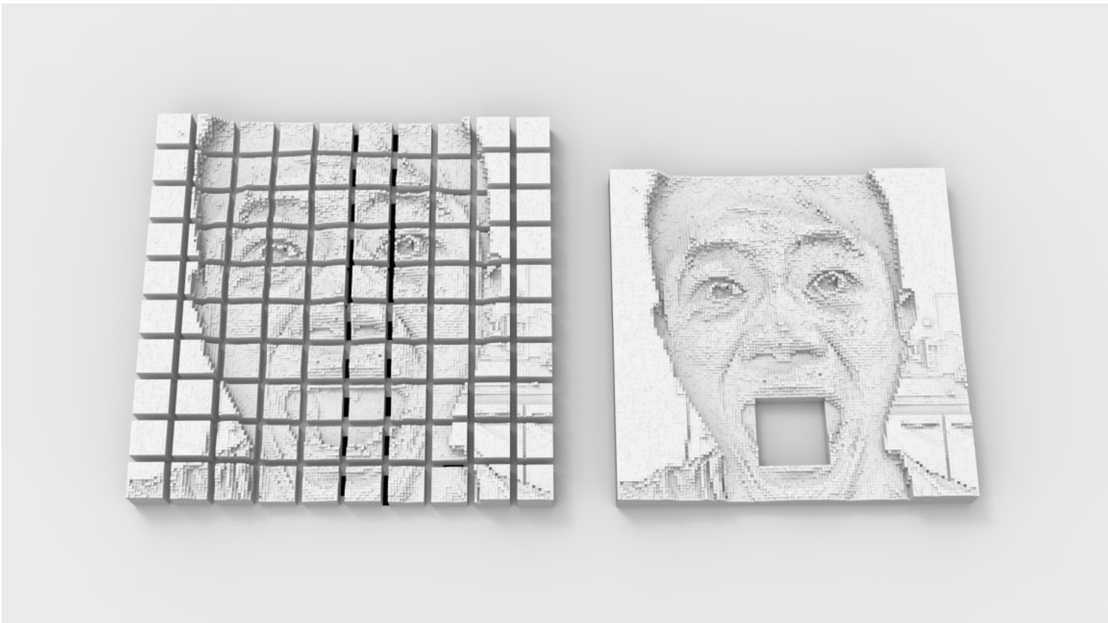

Figure 3.10 Separation setting for the further manipulation

[3.2.2] Casting mode development

When it comes to creative gifts, DIY snack is always one of the top choices, for example, cookies with animal patterns, cakes with vehicle shapes, chocolates that look like human skull and so on. The most common method to make this type of snacks is casting, therefore, another gift-oriented module embedded in giftGO is the casting module. Including but not limited to making DIY snacks, a casting mold also allows users to make a replica with different materials, especially with materials which are difficult to configure with 3D printers. For instance, if one intends to make a bracelet as a gift for another person, then the common materials applied to 3D printing such as ABS (Acrylonitrile Butadiene Styrene) or PLA (Polylactic Acid) might not be able to satisfy this need, however, with a proper casting mold, it becomes possible to make the bracelet with other materials such like colorful resin or even metal materials. This casting module in giftGO broadens the potential of making a gift with 3D printing.

The following paragraph explains how the casting module works technically.
This module is able to turn users' works into a hollow mold. After merging, the casting function becomes available, and when the casting function is triggered, it centers the merged work and generates a cubical geometry according to the size of the merged object (Bounding box), the X and Y sizes would be ten millimeters longer than the bounding box, and the Z size would be five millimeters longer.
The bounding box and generated mold box are shown below.

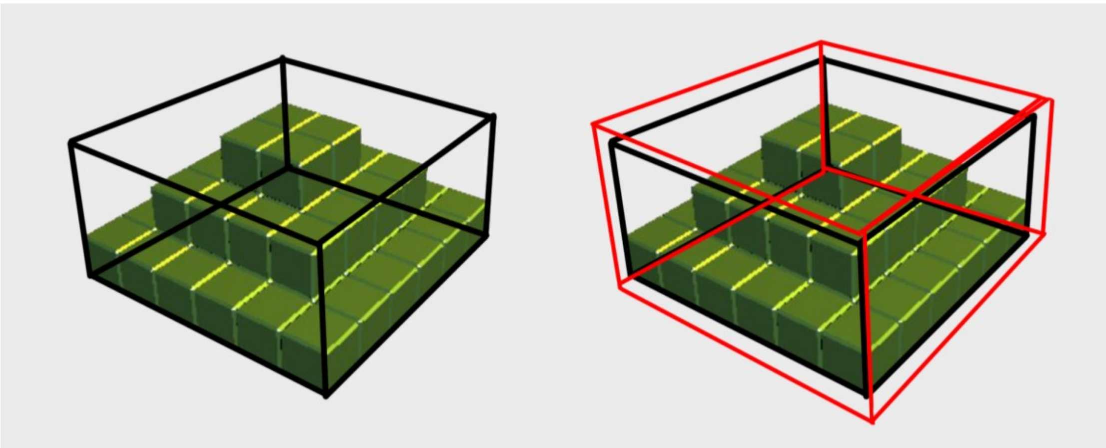

Figure 3.11 Bounding box(Black) and the generated mold(Red)

After centering the merged object and generating the mold box, the next step is to make a Boolean between them. In this case, we implemented a plugin called ThreeCSG.js.

ThreeCSG.js is a library built for the other JavaScript library mentioned above, Three.js, ThreeCSG.js provides us a quicker and simpler method to execute union, subtraction and intersection. Of course it is possible to accomplish Boolean calculations without ThreeCSG.js, but it takes way more works to check and compare the data tree of geometries. With ThreeCSG.js, Boolean calculations could be materialized in just a few lines of codes.

Here is how ThreeCSG.js is used for this casting module (Subtraction).

```
var a = new ThreeBSP(moldBox;)
var b = new ThreeBSP(mergedObject);
var result = a.subtract(b);
var resultMesh = result.toMesh();
```

In terms of practically casting things, the outline of replica may be limited due to the direction of demolding, however, today we already have plenty of soft materials manufactured for 3D printers, with soft materials, it is possible to minimize the limitation of demolding and maximize the potential of casted gifts.

The following steps indicate how users trigger this module.

Step 1. Make or import a model. Users need to use the built-in functions and make an object or import a downloaded STL file first.
Step 2. Merge with the "Merge All" button. Merge all the objects shown on the scene into one, after that, the casting function will be available.
Step 3. Trigger the casting module. Click the casting button and the system will automatically turn the merged work into a casting mold.

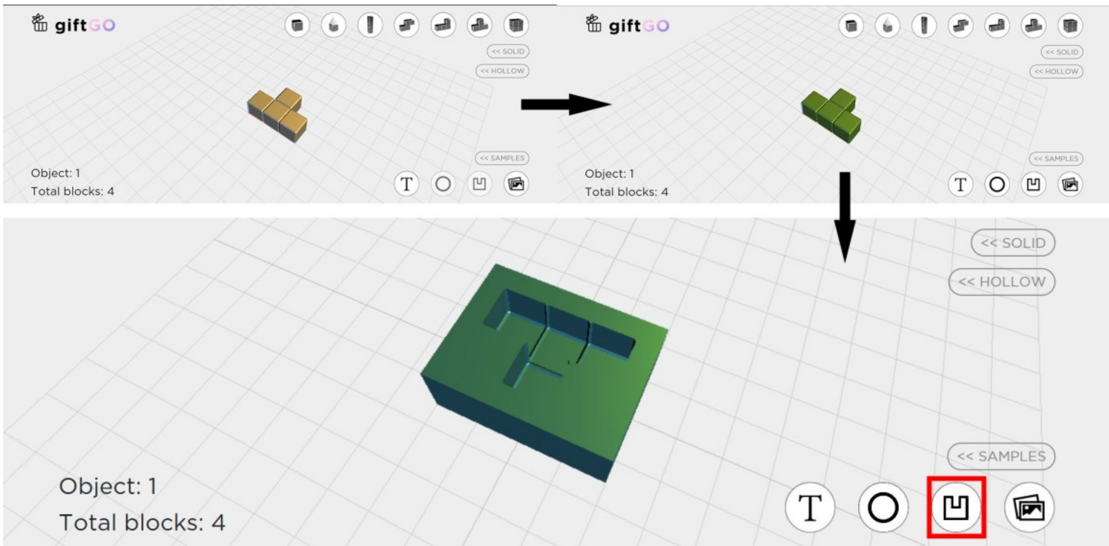

Figure 3.12 Workflow to make a casting mold with giftGO

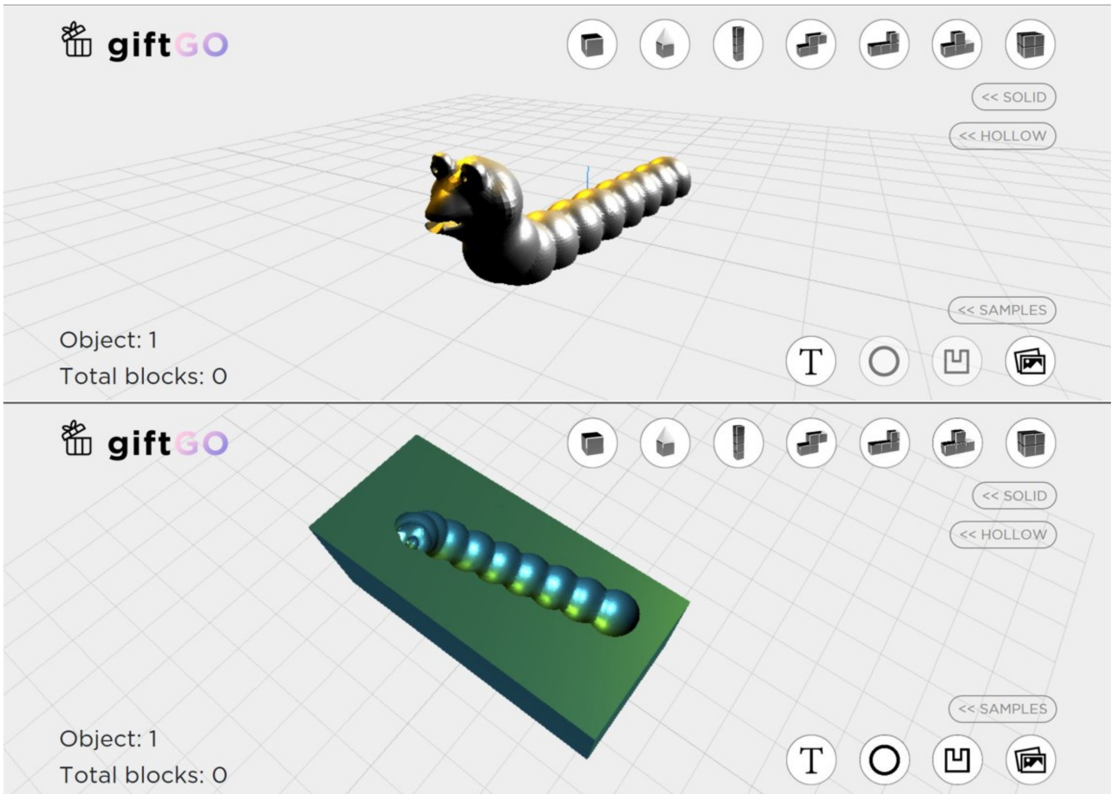

Figure 3.13 Making mold with downloaded STL model

[3.2.3] Lampshade mode development

In addition to photos and casting, lampshade is also a popular choice when it comes to gift-giving. Functional, practical, and when they are chosen or made with care, they can enhance or alter the look of any spaces. Therefore, we designed a lampshade mode helping users turn their creative works into hollow lampshades.

The same as the casting module, this lampshade module only becomes available after all things are merged. However, so far, we still have not reached a perfect solution of making hollow models with the fixed thickness for every type of geometries, our current method only works for cubical geometries (Built-in 3D Tetris models).

This following paragraph explains the method implemented in this module.
When a 3D Tetris model is loaded, the system generates a spare geometry with the same shape, with the same size but without the decoration (cut or gap on the Tetris model), this spare geometry is translucent (invisible), and it will be moved when the matrix is moved (position is always the same).

Then once the “Merge All” button is clicked, just like the matrix models, all of the spare geometries are also merged into one, so there would be two merged geometries on the scene, merged matrix model and merged spare geometry, and then, once this lampshade module is triggered, the merged spare geometry will be moved with a certain distance (depending on the expected thickness) along five directions, front, back, left, right and down (up is not needed because lampshade requires an opening side), each move would generate a clone (so it leads to five clones after all of the moves).

Afterward, the system would calculate the intersection of the original merged spare geometry and other five clones, and eventually, the merged matrix model trims off this intersection via ThreeCSG.js (the same plugin used in the previous chapter) and generates the final lampshade model.

Graphical explanations are demonstrated by the following figures.

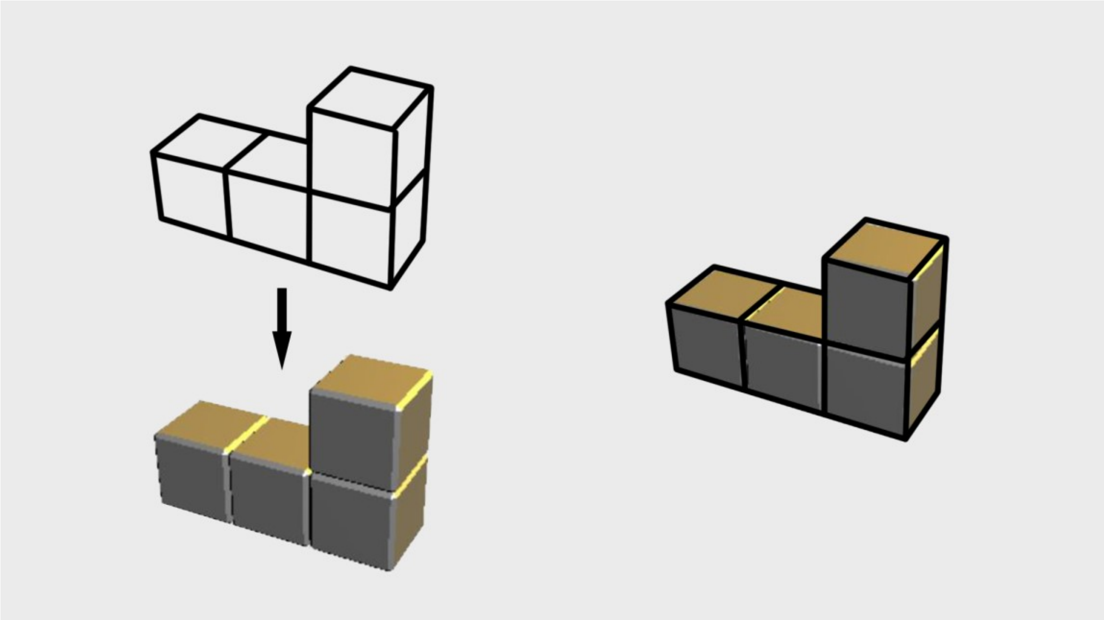

Figure 3.14 Generating a geometry with the same shape and size

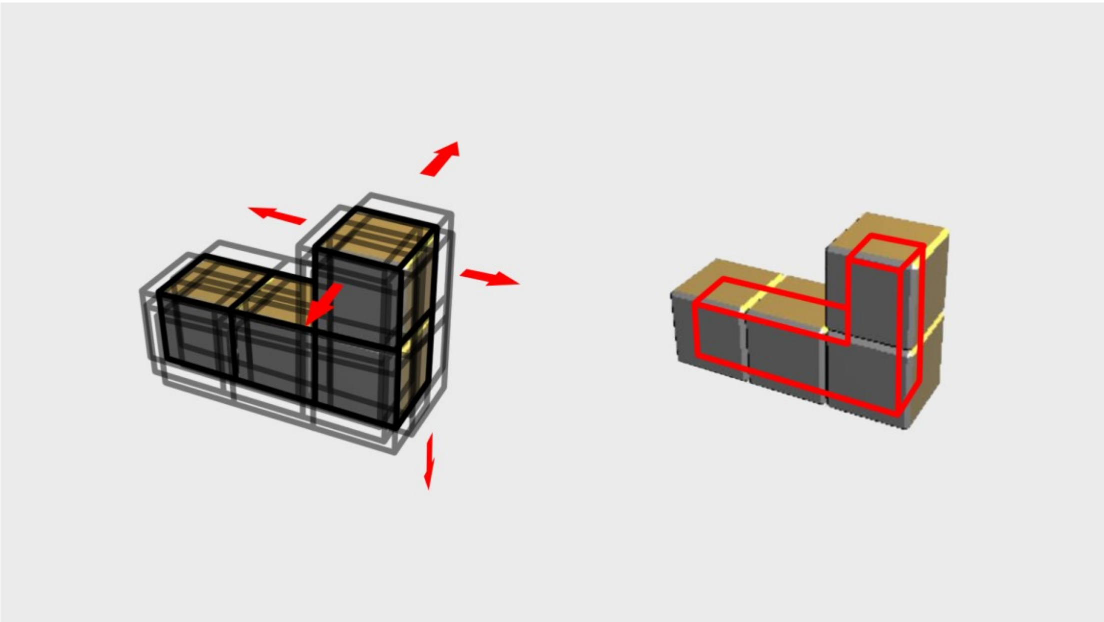

Figure 3.15 Moving along give direction and calculating the intersection part to trim

[3.2.4] 3D text development

In terms of DIY gifts, people tend to attach some words on them to express their emotion and show how much they care about each other, therefore, text function is also implemented as a part of the gift-oriented functions in this system, and since giftGO is a gift platform designed for 3D printing, the text function in it is also 3D.

Comparing to other gift-oriented functions designed for this system, 3D text does not require so much calculation, the library used in this system, Three.js, already provides us a method that simplifies the process of generating 3D text. The TextGeometry() method is able to generate 3D text with the designated content and font, besides, it also possible to set the parameters for text size, text height, curve segments, bevel, bevel thickness, bevel size, bevel offset and bevel segments.

The following code indicates how TextGeometry() method is used in this module.

```
var loader = new THREE.FontLoader();
loader.load( 'fonts/helvetiker_regular.typeface.json', function ( font ) {
    var geometry = new THREE.TextGeometry( 'Hello three.js!', {
        font: font,
        size: 80,
        height: 5,
        curveSegments: 12,
        bevelEnabled: true,
        bevelThickness: 10,
        bevelSize: 8,
        bevelOffset: 0,
        bevelSegments: 5
    } );
} );
```

The same as the 3D photo function mentioned above, the user interface of this 3D text module is also designed as a web modal, once it is triggered, the modal will appear and guide users to set the necessary parameters for generating their texts.

The following steps indicate how users interact with 3D text function.

Step 1. Trigger the button. This function can be triggered by clicking the text icon on the bottom-right corner.

Step 2. Set parameters. After the modal appears, users follow the guide and set the content and parameters which includes text size and thickness. Five types of font are currently available.

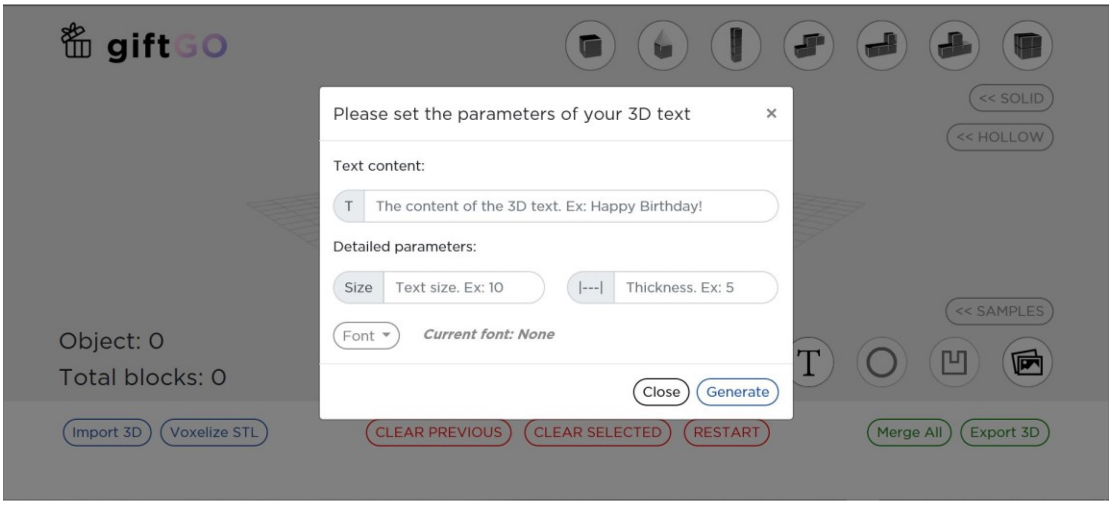

Figure 3.16 Web modal for generating 3D text

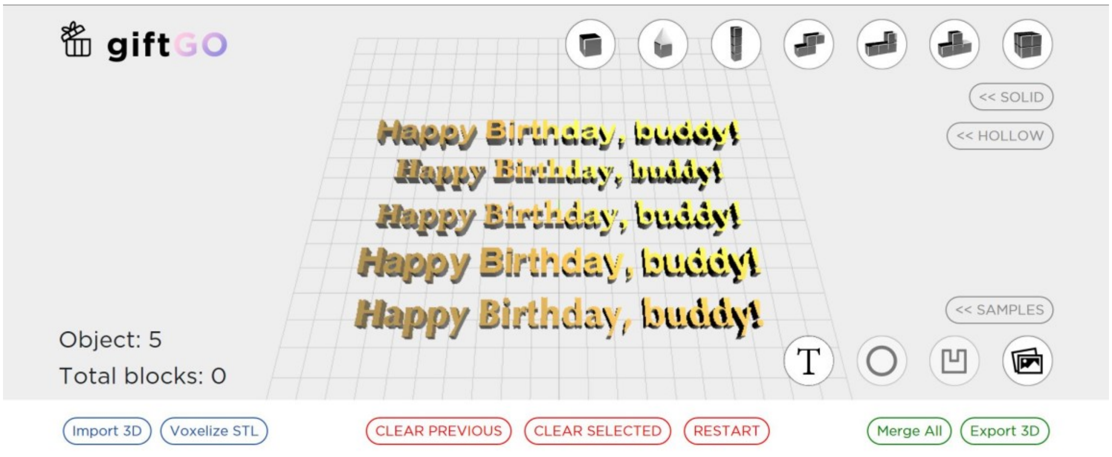

Figure 3.17 3D text with different font settings

[3.2.5] Voxelization mode development

As mentioned in chapter [2], giftGO is capable of importing STL files downloaded from open-source online libraries such as Thingiverse and GrabCAD. However, at the same time, giftGO is a block-based 3D tool, users build their works through piling the built-in blocks, as a result, the outputs would be voxel works, and if users need to unify the 3D style when it comes to importing a STL file, a voxelization module would be necessary.

In fact, STL voxelization has been taken for research for years, there are different methods to turn a mesh data into a voxel data, and the results can basically be classified with two types, first, surface voxelization, which only generates voxel according to the surface data of a mesh file, second, solid voxelization, which not only voxelizes the surface of a mesh data, but fill up the closed space among the mesh data. The final purpose of files generated by giftGO is to be used by 3D printers, therefore, the implemented voxelization method in giftGO is surface voxelization. Surface voxelization has two benefits, first, the calculation is lighter, and second, the generated file can save a lot of time when it comes to 3D printing, because instead of printing all of the inner voxels, the generated file would be filled with support material of hollow structure by slicing software.

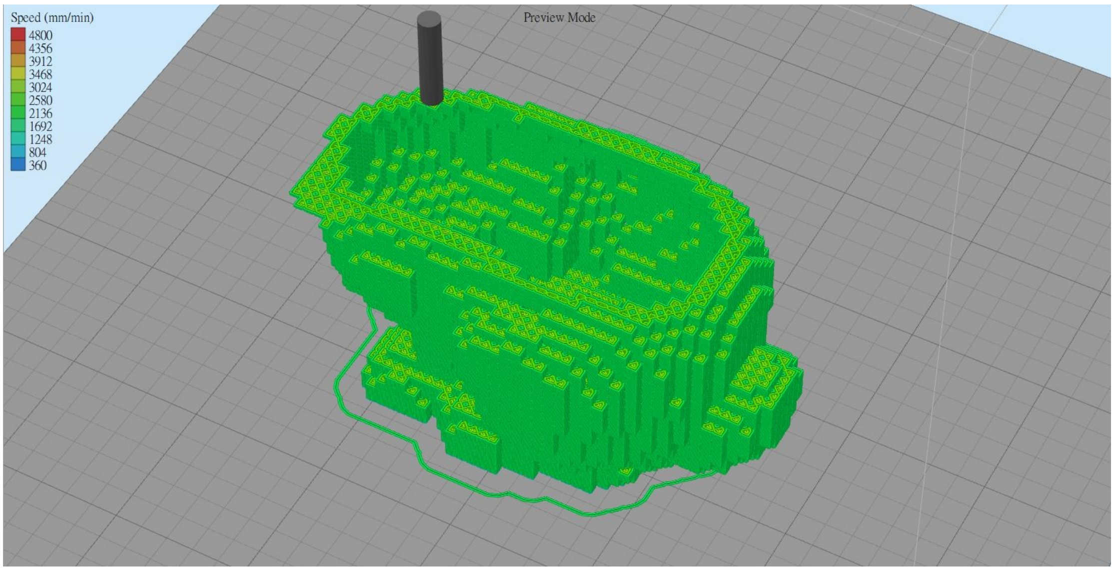

Figure 3.18 A hollow voxel model generated by giftGO

The following paragraph indicates how the surface voxelization works in this module. Firstly, the designated STL file is read and imported to the scene, afterward, the system centers the mesh model and starts calculating the bounding box (the minimum enclosed box for a certain geometry), once the coordinate data of bounding box is obtained, the system generates a certain size of voxel and moves it inside the bounding box, if the collision detection is positive between the voxel and the imported mesh model (using the point data of mesh model to do collision detection, detailed method is shown below), then the voxel makes a clone and keeps moving, otherwise the voxel just moves to the next spot without making a clone, this will continue until the entire bounding box is covered.

Here is how collision detection between AABB is done.

$$
\begin{aligned}
&(AminX<=BmaxX \land AmaxX>=BminX)\\
&\land (AminY<=BmaxY \land AmaxY>=BminY)\\
&\land (AminZ<=BmaxZ \land AmaxZ>=BminZ)
\end{aligned}
$$

And here is how collision detection between AABB and point is done.

$$
\begin{aligned}
&(MinX<=PointX \land MaxX>=PointX)\\
&\land (MinY<=PointY \land MaxY>=PointY)\\
&\land (MinZ<=PointZ \land MaxZ>=PointZ)
\end{aligned}
$$

More specifically, the voxelization concept used in this module is called AABB algorithm (Axis-Aligned Bounding Box), which is a well-known method of 3D collision detection constructed because of performance reasons in the beginning.

The basic thought of AABB method is pretty simple, just like what we mentioned in the previous paragraph, calculating a bounding box or a bounding sphere before starting doing the detailed collision detection for each point or face. Because when one object is out of the other’s bounding box or bounding sphere (collision detection between boxes or spheres is much easier to calculate), it is impossible to have a collision between them, so that the system will not have to run the further calculations and the performance can be raised.

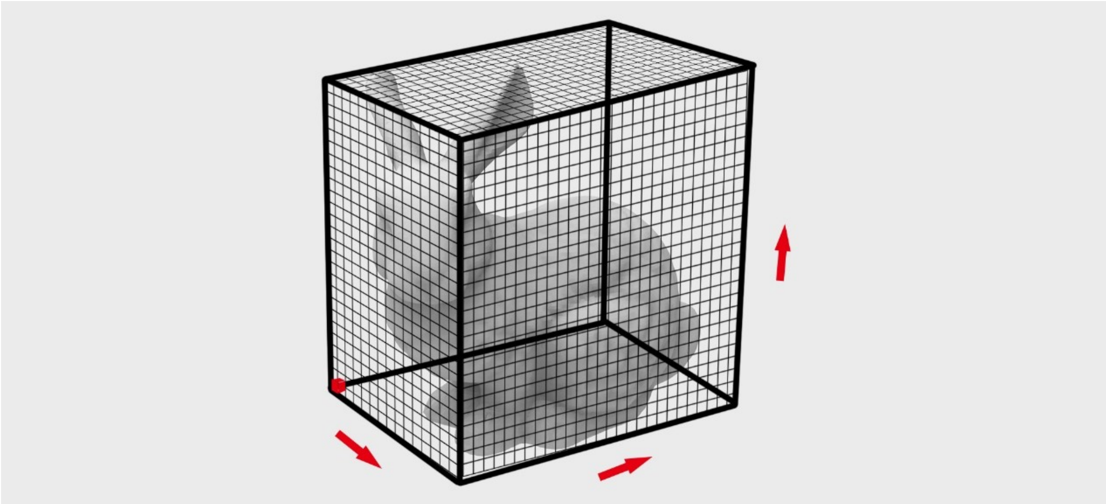

Figure 3.19 Collision detection within a bounding box

Furthermore, in giftGO, the basic voxel type is selectable, just like the 3D Tetris models mentioned in chapter [2], we provide six types of brick as the basic voxel, users could choose the voxel type before importing STL files (the importing interface is also designed as a web modal).

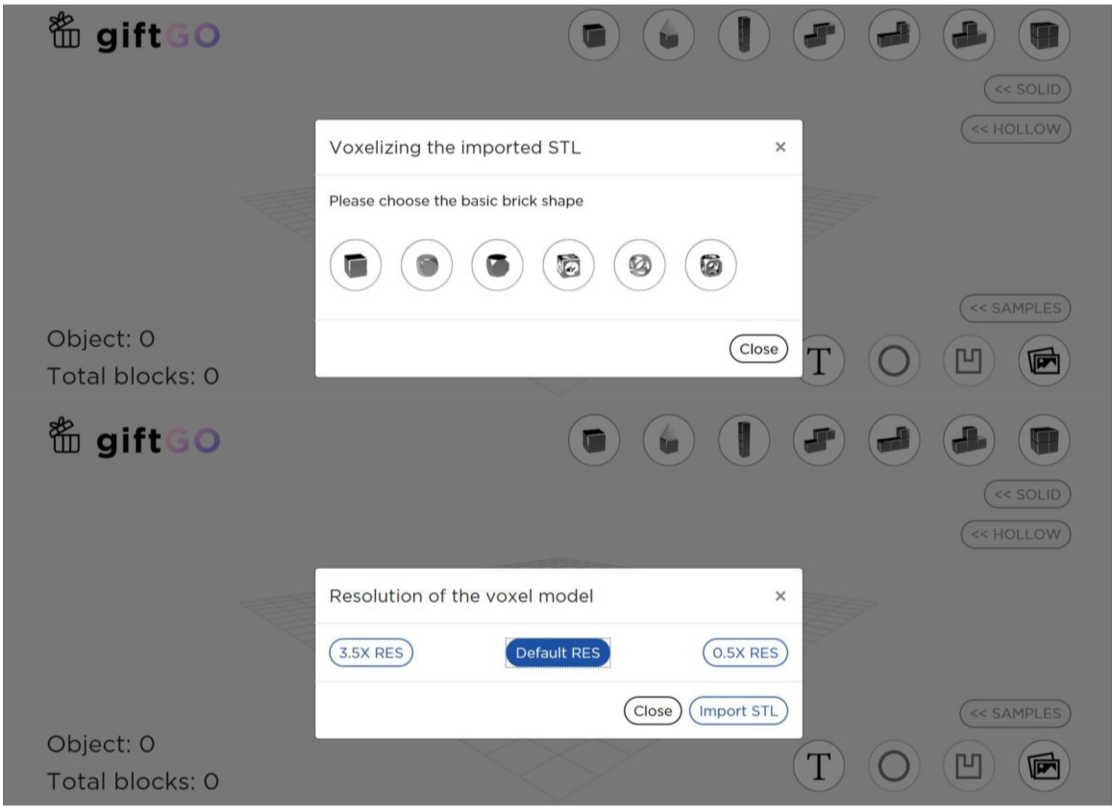

Figure 3.20 Modal interface of voxelization module

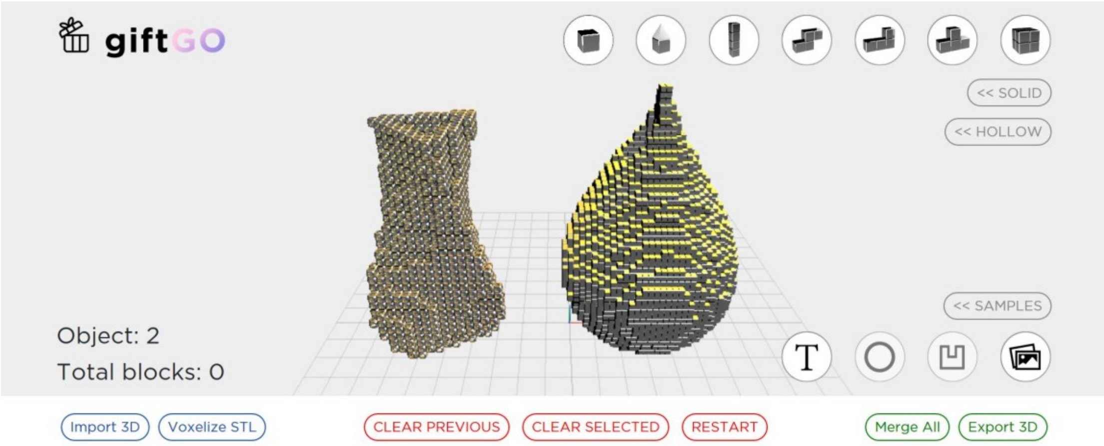

Figure 3.21 Voxelization with different type of voxel

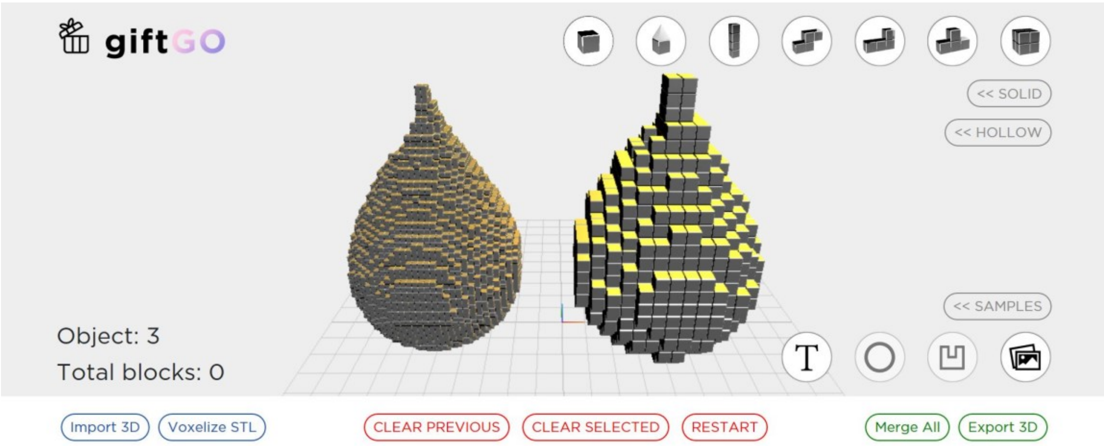

Figure 3.22 Voxelization with different resolution

[3.3] Sample models design

So far, even though giftGO is designed with a series of gift-oriented modules explained above, however, for unexperienced users, it is still confusing when a 3D tool opens with a total empty modeling space.

To make giftGO more accessible to non-technical population, it is necessary to help users build something from nothing in the beginning. Therefore, we embedded some models of popular gifts in the system, including a mug, a headphone stand, a smartphone stand, a plant pot and a pen holder, users who are not familiar with this system will still be able to create something based on these default models.

All of the default models are originally built by giftGO, the system would load the model when it is called (the same as loading 3D Tetris models). Sample menu is designed as a part of the bottom-right function block.

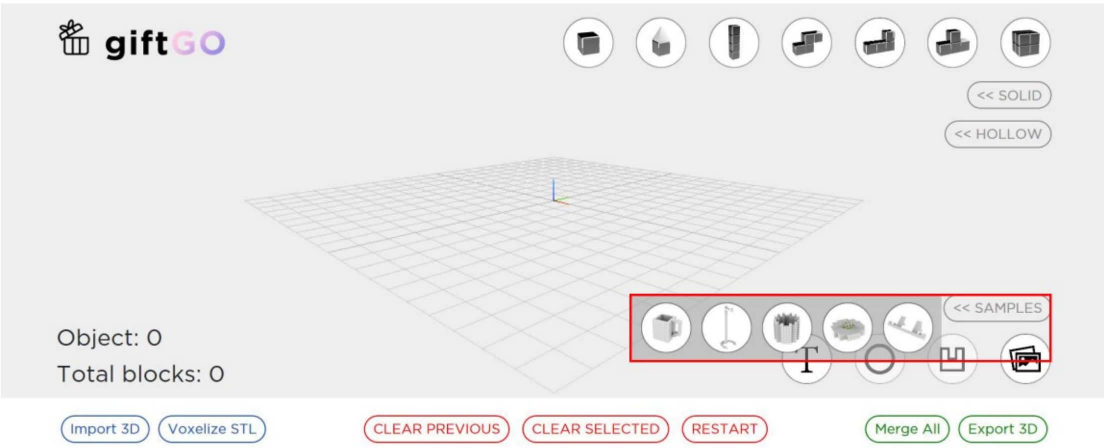

Figure 3.23 Sample menu to call default models

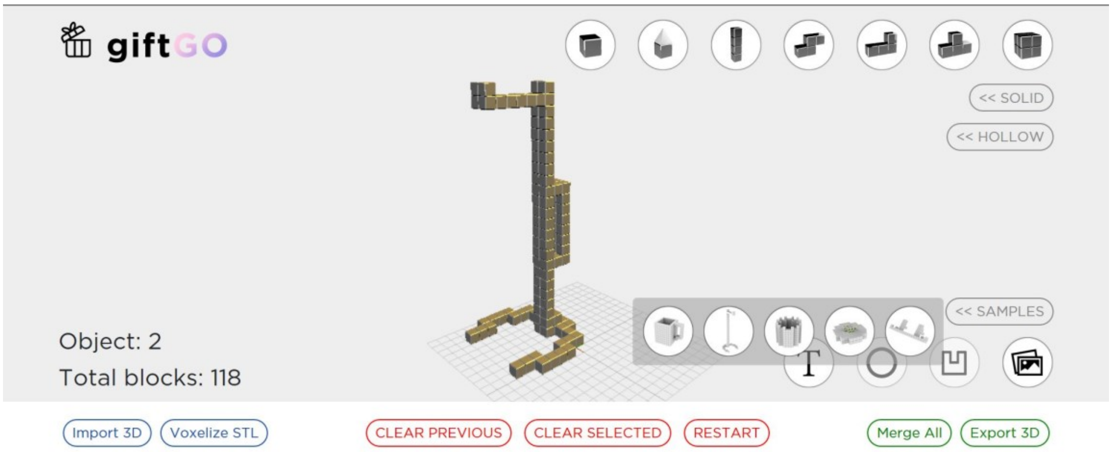

Figure 3.24 Loading a default headphone stand

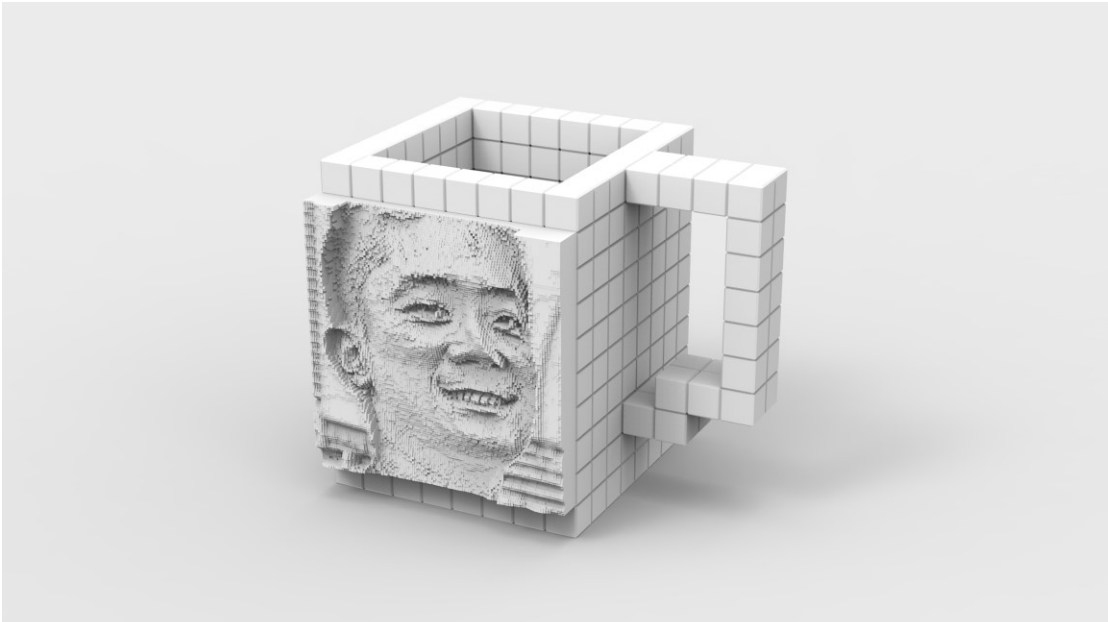

Figure 3.25 A default mug with a 3D photo

[3.4] Voxel model and FAV

[3.4.1] Voxel file format

The 3D objects generated from giftGO are formed through stacking small voxels, which is a simple method for unexperienced users, however, when it comes to exporting, it may cause some problems.

Currently, the most popular 3D format used among 3D printers and the related services is STL (STereoLithography), which is a type of data consisting of polygon mesh, a polygon mesh is a collection of vertices, edges and faces that defines the shape of a polyhedral object in 3D computer graphics and solid modeling. The 3D manipulations run in giftGO are based on mesh data, in the gift-oriented modules mentioned in previous chapters, for an example, voxelization module, calculating works of it rely on the vertices and faces data brought by imported mesh files, yet, if a complex voxel model is saved as STL format, the file size of it may be ridiculously huge (Gigabyte-base).

Therefore, to promote the feasibility of voxel model in 3D printing industry, TanakaLab and Fuji Xerox collaborated and developed a new 3D format connecting voxel model and 3D printing, the FAV format. FAV format records the necessary information of a voxel model, especially the most important ones, position, material and color. With FAV format, the file size of a voxel model could be reduced to Kilobyte-base.


```
<voxel_map compression="none" bit_per_voxel="4">
  <layer><![CDATA[000000001100001111000011000000000000000000000000000000000000000000000010100000111000000000000000]]></layer>
  <layer><![CDATA[000000001100001111000011000000000000000000000000000000000000000000000000100000110000000000000000]]></layer>
  <layer><![CDATA[000000001100001111000011000000000000000000000000000000000000000000000011100000110000000000000000]]></layer>
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  <layer><![CDATA[000000000000000000000000000000000000000000000000000000000000000000000000100001011111111100000000]]></layer>
  <layer><![CDATA[000000000000000000000000000000000000000000000000000000000000000000000000001100110111111100111000]]></layer>
</voxel_map>
```


Figure 3.26 A .fav file recording a voxel model with binary layer by layer

[3.4.2] A complete FAV software circle

To fulfill the actual applications of FAV format, other engineers in TanakaLab constructed the other application based on FAV format, and it forms a complete using experience for FAV software circle. The other software designed by TanakaLab members is a sketch-based 3D system powered by artificial neural network, users are able to generate an approximate 3D model simply by drawing a 2D sketch, and allowed to make an adjustment by drawing more sketches. The figure shown below is the full user interface of this AI (Artificial Intelligence) software.

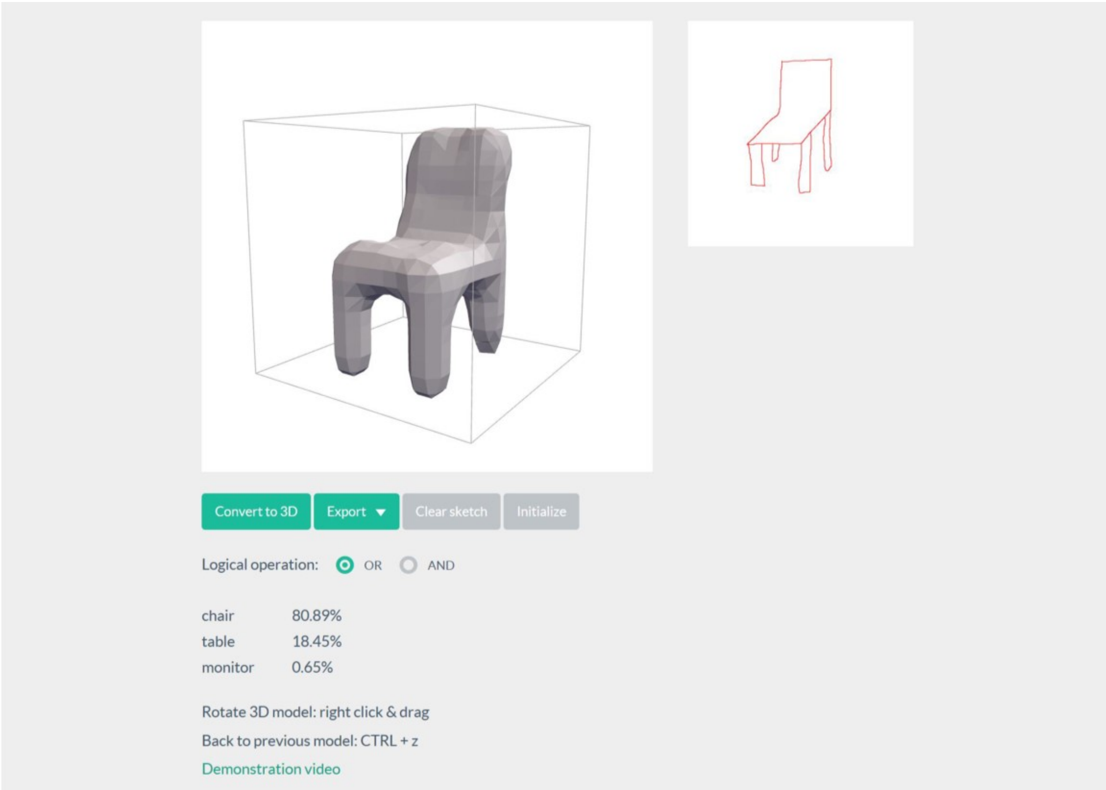


Figure 3.27 Sketch-based 3D system designed by Moriya Takumi (TanakaLab)

After generating an approximate 3D model from this sketch-based system, users will still need some detailed adjustments in order to print it out with 3D printers, which is what giftGO is capable of. We implemented a FAV loader in giftGO, so that it is able to recognize and form the voxel model once a FAV file is imported. The following figure shows how giftGO loads the FAV file generated by the sketch-based system introduced above.

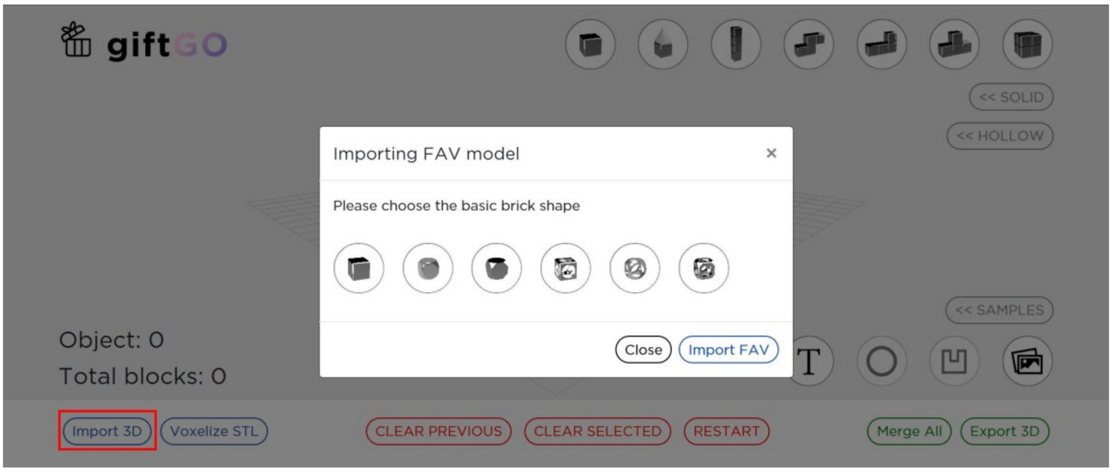


Figure 3.28 Users are allowed to choose voxel type before importing a FAV file

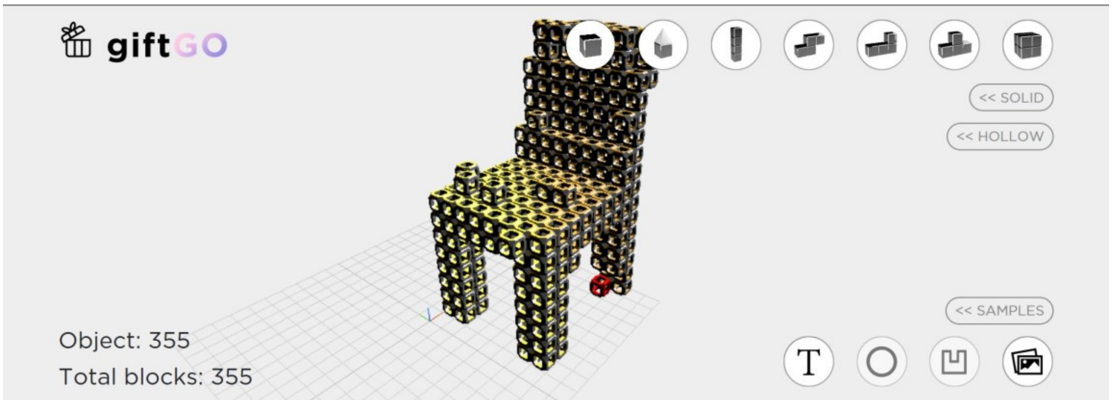


Figure 3.29 Detailed adjustments of FAV could be done in giftGO
(A voxel chair model generated by the sketch-based system introduced above)

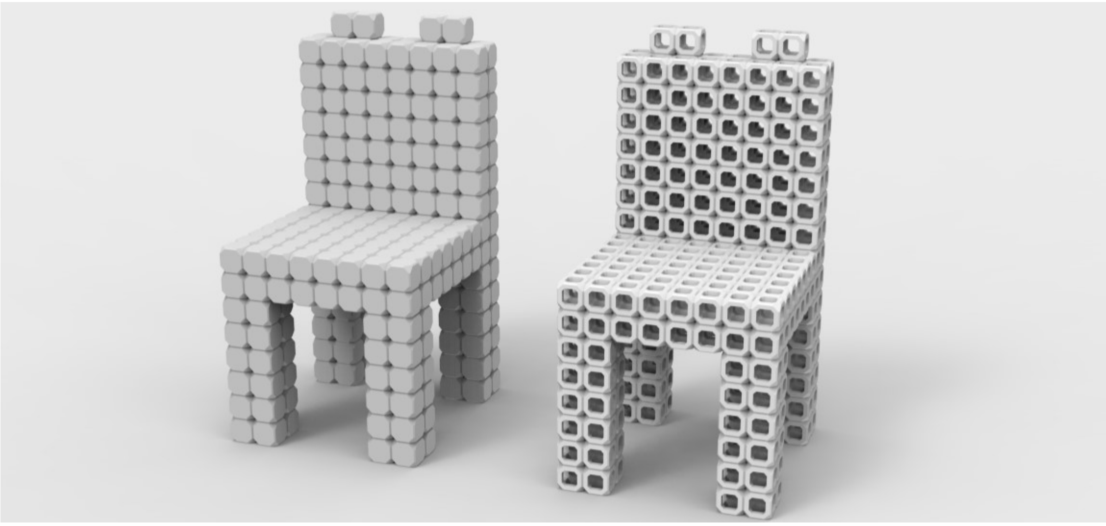


Figure 3.30 Voxel chair models after adjustments with giftGO (3D printable)

[3.5] Intro/Registration page design

In addition to the system itself, to help users know more about what they could make with giftGO, an introduction page is necessary. A good introduction page should be able to demonstrate the charm of its product and catch people's attention, as a result, our page not only explains the features of giftGO but also shows the actual examples built with giftGO.

Firstly, a short clip of 3D CG (computer graphics) video is put on the top of this page as the main visual element, the full version of it is shown as a link, the 3D video does not indicate the functions of giftGO directly, but imply the possibilities of this system.

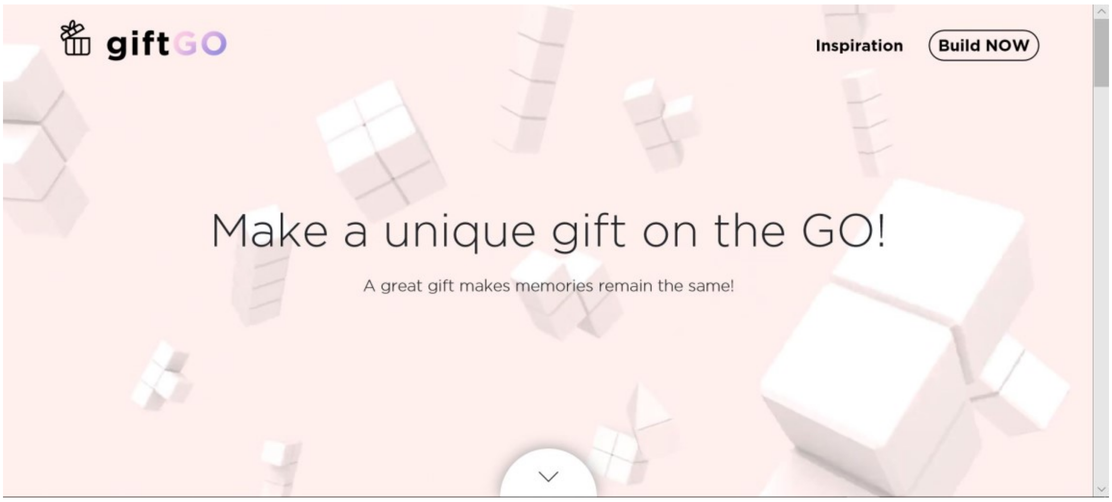


Figure 3.31 Visual design of the introduction page

Below the 3D CG video, a short paragraph indicates the main features of giftGO, which contains the concept of digital-handmade, introduction of gift-oriented modules, and a few slogans expressing the true value of this platform. After the text-based introduction, the page shows a series of photos which are the actual works generated by giftGO and printed out by 3D printers, these pictures are expected to inspire the potential users of giftGO.

On the bottom of this page, a "Start" button leads users to register and start their first trial. The full interface of introduction page is shown in the next page.

giftGO
Inspiration
Build NOW
A learning process that is shorter than ever
A great gift makes memories remain the same!
From Hand-made to Digital-hand-made
No matter who you are, giftGO allows you to design your peerless gifts in 20 minutes!
The goal of giftGO is to help people who do not have engineering background build unique gifts digitally, and print it out physically with 3D printing technology!
Simpler than ever!
Without complecated 3D concepts, for the first time, you may focus on designing your precious gift.
Main features
3D photo / Voxel manipulation / Tetris patterns / Molding / 3D text
Through the combination of these functions, giftGO allows you to create stunning works in just a few minutes!
Imagination is the only limitation!
You have an idea? Let's make it the reality!
Gallery
LET'S DO IT!
START
CONTACT
© giftGO 2019. All Rights Reserved.

[4] Testing

[4.1] Modeling and printing tests

After the development of all of the functions and interfaces, giftGO is ready for being tested. Since this system is a gift platform built for 3D printing, the testing process would not be merely about importing, modeling, and exporting, it should be engaging with actual 3D printers.

Firstly, in terms of the modeling tests, it is meant to check if every module and function works as we expected (not working individually, but working as an integration), and find out bugs and technical errors that happen during the modeling process. To achieve this goal, our method is to make models of different gifts by mixing as much functions and modules as possible, gift models such as pen holder, headphone stand, smartphone stand, 3D photo puzzle, personalized plant pot, 3D photo casting mold and voxel portrait are tested in this stage.

During the course of modeling, we found that the combination of all modules and functions did bring us some new problems, however, most of technical errors between modules and functions were found and well fixed.

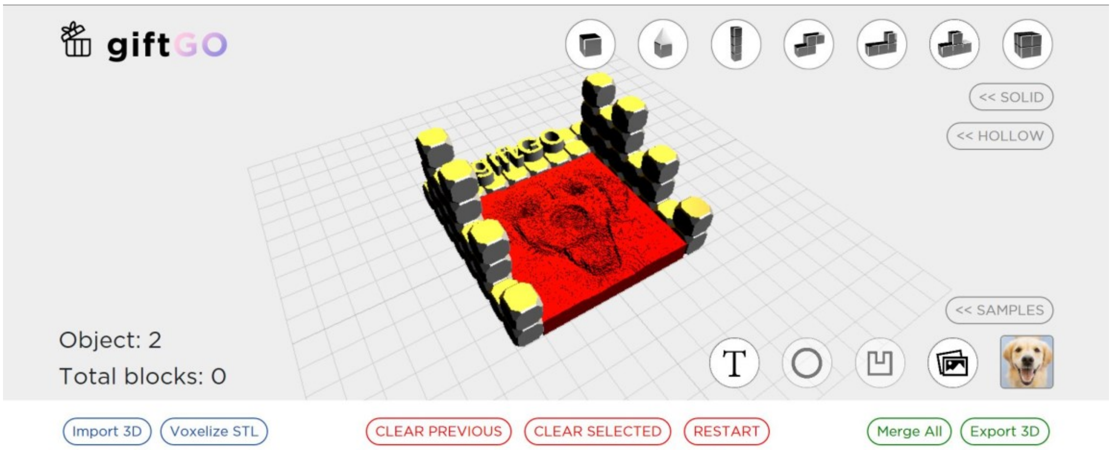


Figure 4.1 A gift (pen holder) made by 3D Tetris models and 3D photo/text module (Changeable design for the 3D photo)

In the printing test, the 3D printer used in this research is a CR-2020 printer designed and manufactured by a 3D printing equipment company, CREALITY. And the slicing software used for slicing 3D models generated by giftGO is Simplify3D. The following figures shows gifts generated by giftGo being 3D printed.

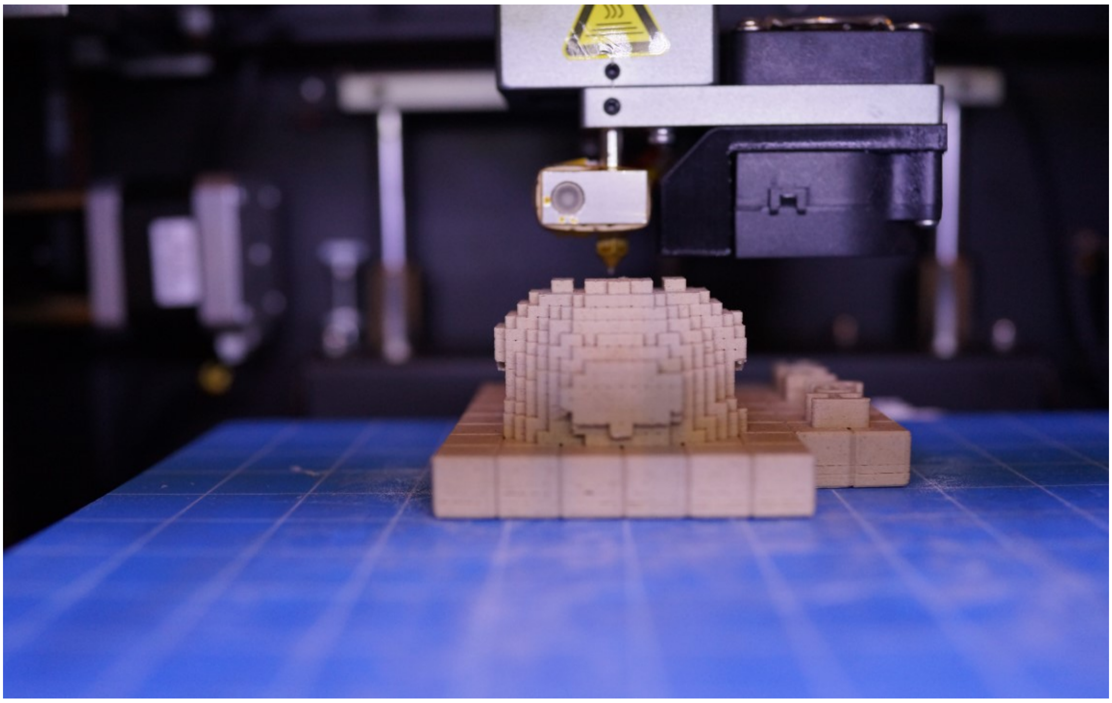


Figure 4.2 voxel portrait made by giftGO being printed

Figure 4.3 Pen holders with changeable 3D photos

Figure 4.4 3D photo puzzle

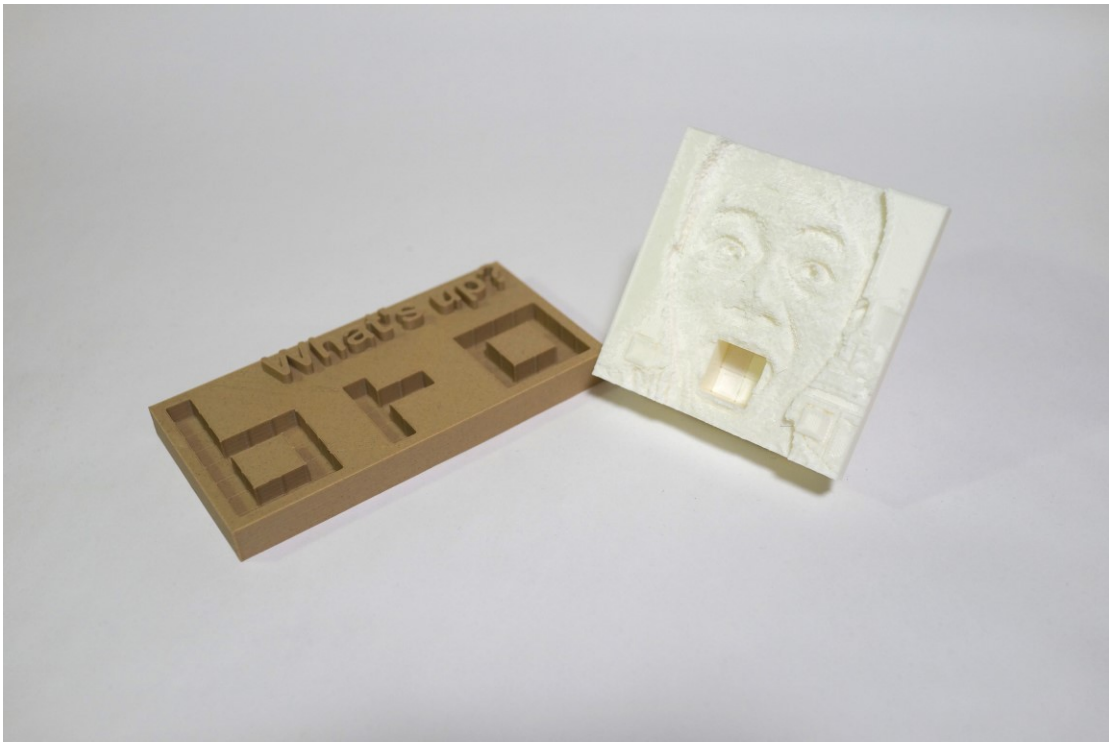


Figure 4.5 Personalized plant pot (made by 3D photo module and casting module)

[4.2] User testing

Given that the previous technical testing is held by ourselves, we may have some blind spots because we are the developers of this system, thus, having real users test giftGO is the next step to go. Through user testing, we would like to confirm how exactly users interact with giftGO, what functions and modules are being used the most, what kind of outputs users generate in their first use, how users feel after using, what type of users show the higher interests in this system, then make the further analysis and improve giftGO based on those information. As a result, we designed a system to collect users' data during the testing process. The collected data include users' personal information, the time on site, command history, final works, a series of questions and comment.

And in terms of the structure of user testing system, it is implemented with Node.js, which is an open-source and cross-platform JavaScript environment, in this user testing system, Node.js is used to build a REST server (Resource Representational State Transfer) simply hosting GET and POST requests. Since the system has not been ready to be completely opened, instead of public hosting service such as AWS (Amazon Web Services), a local machine is used as the server, users who are under the same LAN (Local Area Network) are allowed to access giftGO page by inputting the IP address of the local server to their browsers.

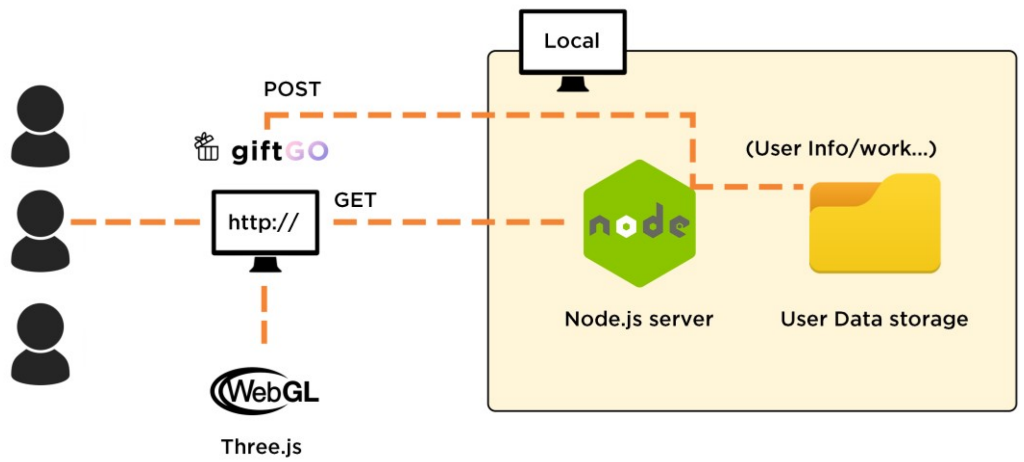


Figure 4.6 System structure of giftGO for user testing

Once users input the correct IP address to their browsers and access the server, the introduction page/registration page would appear and guide users to start their first trial of giftGO. The introduction page is designed with a modal (triggered by clicking the “Start” or “Build now” button) collecting users’ personal information, including age, gender and the most importantly, experience of 3D CAD software, with these information, users could be classified properly. And after submission, the main modeling page of giftGO appears and allows users to start building their gifts.
By the registration page mentioned above, users were separated into experienced users and unexperienced users. It is expected that experiences of 3D CAD software would not affect too much when it comes to using giftGO to build 3D models because this system is designed with intuitive 3D approach and interface for everyone who has the basic computer knowledge, in others words, unexperienced users are also supposed to make things that are as fascinating as experienced users’ works.

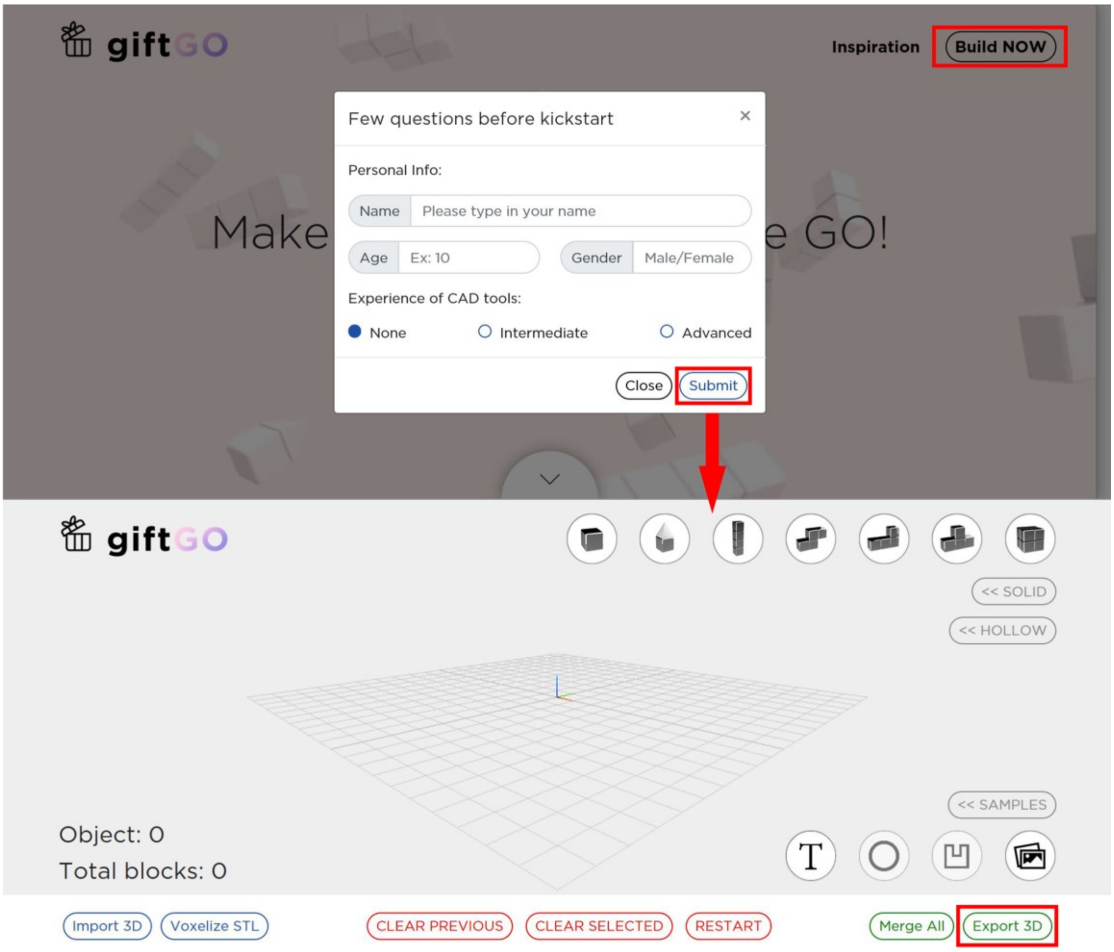


Figure 4.7 Going through registration and starting building 3D gifts

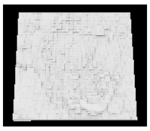
	3D Experience None	Aged 19	Female	Time 2m 41s
	3D Experience None	Aged 20	Female	4m 47s
	3D Experience None	Aged 21	Female	3m 43s
	3D Experience None	Aged 24	Male	0m 56s
	3D Experience None	Aged 24	Male	4m 29s
	3D Experience None	Aged 30	Male	2m 42s
	3D Experience Intermediate	Aged 26	Female	1m 44s
	3D Experience Intermediate	Aged 22	Male	9m 45s
	3D Experience Intermediate	Aged 19	Male	7m 17s
	3D Experience Intermediate	Aged 24	Male	2m 13s
	3D Experience Advanced	Aged 24	Male	1m 56s
	3D Experience Advanced	Aged 21	Male	7m 46s

Chart 4.1 Users' data (12) from user testing (Including first-stage and second-stage)

The “Time” data above only indicates the consumed time for final outputs, once users clear their works and restart, the timer returns to zero and start counting again. The total time (from beginning to the end) is around twenty minutes per user.

From the above chart, it is obvious that 3D photo is the most popular module within giftGO (before users starting using the system, they see the 3D printed samples generated by each giftGO modules first), and we can find that the experience of 3D CAD software does not affect the quality of users’ results too much, however, the experienced users would be more willing to use 3D Tetris models to build objects while unexperienced users only tend to use gift-oriented modules such as generating 3D pictures and typing 3D text.

After the model is exported, the system transfers to the comment page, according to the stage, comment page is designed in different ways (with different questions), the details of comments and evaluations are described in following chapters.

Figure 4.8 User “A” working on his gift with giftGO (Aged 23 / No CAD experience)

Figure 4.9 User “A” with his decorative gift generated by giftGO

Figure 4.10 User “B” working on his gift with giftGO
(Aged 30 / No CAD experience)

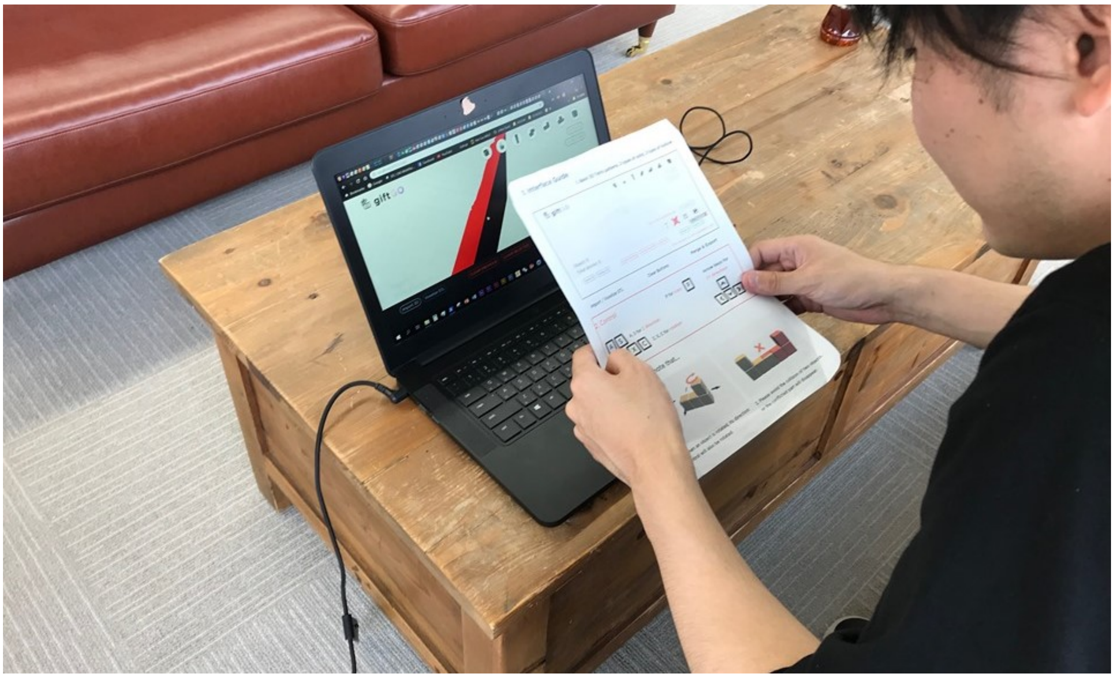


Figure 4.11 User “B” checking the manual for user testing

Figure 4.12 User “B” with his final work

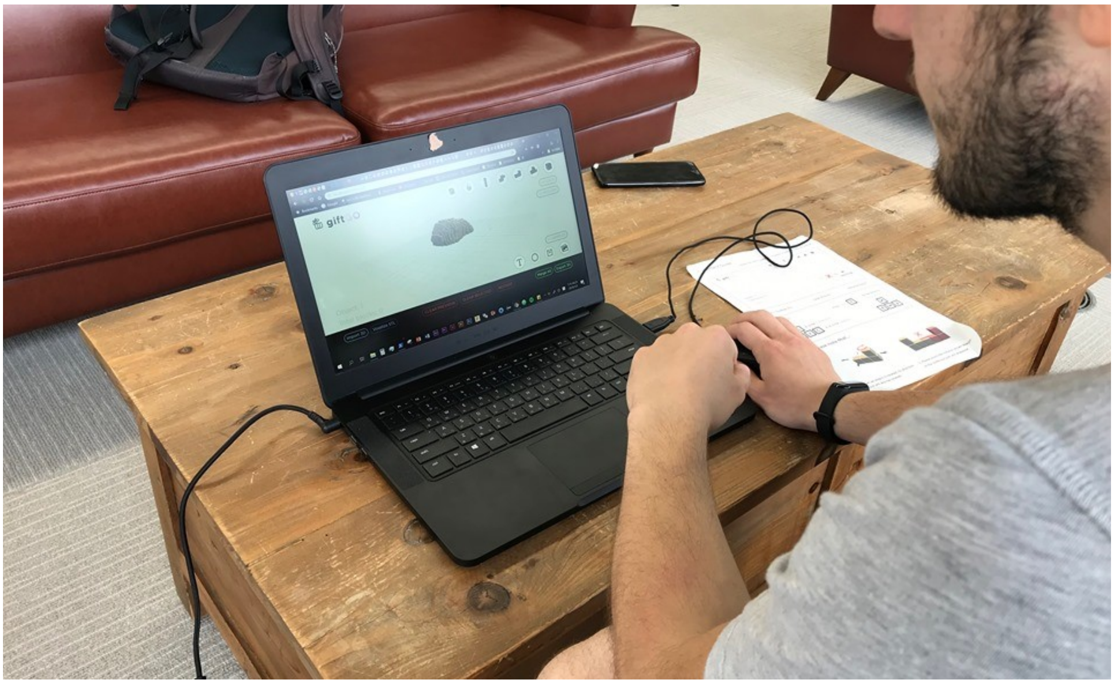


Figure 4.13 User “C” working on his gift with giftGO
(Aged 24 / Intermediate CAD experience)

Figure 4.14 User “C” with his final work

[4.2.1] User testing stage.1 (Technical Feedback)

The first-stage user testing is meant to understand how real users feel about the commands and interface, then collect users' comments for improvement. These comments could be very detailed, users, especially unexperienced ones, may find a command strange while developers assume that it is logical. As a result, in this stage of testing, users are asked to write down their technical feedback on the comment page which appears after the submission of 3D models.

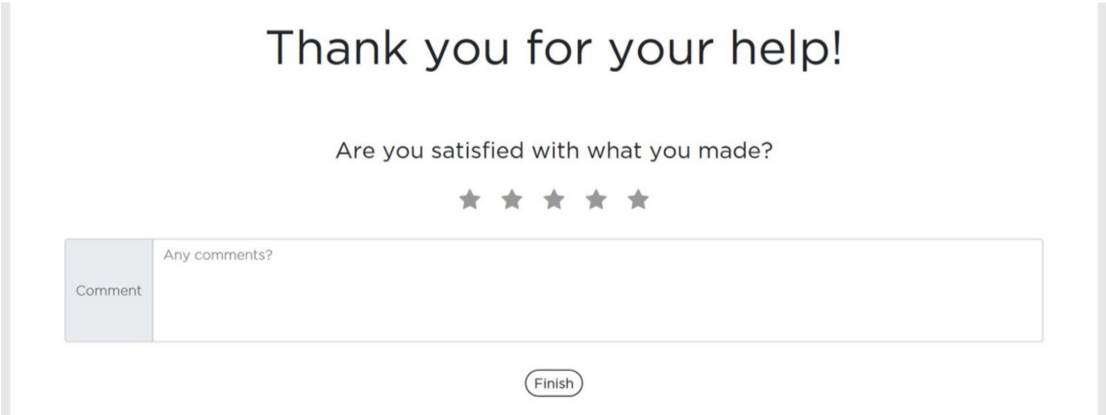


Figure 4.15 Comment page appearing after the submission of model

Seven users (aged from 19 to 30) attended the first-stage user testing, the chart shown below includes the technical feedback from them.

	Comments
Unexperienced	Very good. When I move the object. Also move screen view together. I want to fix screen view. 自分が持っている写真を取り込んで作れるので希望通りにできて、使いやすくて、初心者でもすごく扱いやすかったです。 オブジェクトの移動に関してオブジェクトの移動コマンド入力後の状況が、「半透明の当該オブジェクト」でプレビューされるといいかなと思った。例えば、方向キーを押すと、当該の、半透明化したオブジェクトが移動し、方向キーを放すと実際の確定した移動として反映される、など。 文字を作るインターフェイスがわかりづらかった。merge と export の関係が初見でわかりづらかった。

Experienced	It's great! I want a back one button. And fix screen view when I move the objects. xy の移動が思ってたのと違う方向とかいって動かしづらい Minecraft みたいにベーシックなパターンを組み合わせてモデルを作るのはめんどい 画像を取り込む時に、パソコンのカメラでその場で写真撮って取り込みたい。 部分的に Merge して動かしたい オブジェクトを移動させると、画面全体も動くから、移動させすぎると画面が変な感じになる。

Chart 4.2 Technical comments from the first-stage user testing

According to the comments written by the users from the first-stage user testing, the problem mentioned by most of them is the view being moved while the objects are moved, this problem has already been fixed.

Another issue that some users mentioned is the direction of moving, some users suggest to set colorful arrows that indicate directions when an object is selected, so that they can know better about which direction key to press. Since the axis direction of objects could be changed when objects are moved in Three.js environment, adding colorful arrows may be an useful advice for the next version of giftGO (Because adding arrows may lead to other corresponding changes on the current user interface).

[4.2.2] User testing stage.2 (Emotional Feedback)

The second-stage user testing is designed for the evaluation of this system, instead of collecting technical comments from users, in this stage, understanding how satisfied users feel is put in the first place. Even though in the first-stage user testing, there is also a simple evaluation system designed with stars, however, evaluating a product with stars is too general and ambiguous, as a gift platform, giftGO needs a more specific way to be evaluated. As a result, the comment page of second-stage user testing is designed with five more specific questions, which could help us understand more about how users feel about this system and users' satisfaction level of final outputs.
The five questions are shown below:

- *How do you think about giftGO in terms of the simplicity of use?*
  1(Super easy), 2(Easy), 3(Normal), 4(A little difficult), 5(Difficult)

- *Are you satisfied with what you made? Would you give it to someone as a gift?*

- *Before using this system, how did you think of 3D printing? What about after?*

- *How much would you price a service like giftGO*
  (Allowing you to make a 3D printed gift online and sending it to you)?

- *Would you recommend giftGO to others? If yes, to whom?*

Each question listed above is designed with a specific purpose. The first question is meant to know the simplicity of use; the second one is trying to know users' satisfaction with their outputs; the third question leads to the value of giftGO in 3D printing community; the fourth question draws forth the direct/real evaluation via a real-world factor (money); the final question indicates users' overall impressions on giftGO.

Five users (including experienced and unexperienced users) engaged in the second-stage user testing. The following chart presents their comments of evaluation.

	Comments
User 1 (Unexperienced)	"Q1": "Super easy and I really enjoyed the process." "Q2": "Yes! It would be a nice alternative to a card or a postcard." "Q3": "Before giftGO, I thought that it was used only by people who has the technique." "Q4": "4000 yen for this service." "Q5": "Yes!"
User 2 (Unexperienced)	"Q1": "Easy to use." "Q2": "YES I WOULD!!" "Q3": "I never thought I would use this kind of technology, but after trying this, I'd like to use it more often!" "Q4": "5000 yen for this service." "Q5": "Yes I would recommend this to my friends!"
User 3 (Unexperienced)	"Q1": "Super easy!" "Q2": "I think the design is quite unique so it would be a good gift for my loved one." "Q3": "I thought it was too difficult to learn, but right now I am more confident with 3DP!" "Q4": "1000 yen per design." "Q5": "I would recommend this to my friends and relatives."
User 4 (Experienced)	"Q1": "Quite easy to use." "Q2": "yes, absolutely." "Q3":"It makes the customized shape and model possible to be printed out, which is unique." "Q4":"3000 yen for this service." "Q5":"yes, I would like to recommend this to my friends who want to get their friends or family members a gift"
User 5 (Experienced)	"Q1": "Super easy to use!" "Q2": "Yes, absolutely." "Q3": "giftGO enables some customized shaping easy to be got by normal people who do not have the knowledge." "Q4": "2000 yen for this service." "Q5": "Yes, I would like to recommend this to the people who want to give the gift to their friends or family members."

Chart 4.3 Emotional comments (evaluation) from the second-stage user testing

According to the result of second-stage user testing, altogether, the user interface design is still considered to be easy enough (according to Question1) even though users from the first-stage testing do find some places to improve. And based on users' responses to Question2, 4, 5, users are satisfied with and confident of their works on giftGO, and willing to pay a reasonable price for a service like giftGO.

Also, the most importantly, we could see that a clear application being close to daily lives does help shorten the distance between 3D printing technology and non-technical population (according to Question3), which is the most crucial value for this research. From a user's perspective, giftGO provides an entrance to 3D printing technology for them.

[5] Conclusion and Possibilities

[5.1] Conclusion

In this research, the most important purpose is to enhance the practicality of 3D printing for non-technical population via providing a real-world application of 3D printing technology. Today, in terms of feasibility, personal 3D printing has already been a very mature technology. Nevertheless, the current manufacturers and developers are overemphasizing the machine specification or technical approaches, they have not reached the actual needs of non-technical population yet.

Therefore, a real-world application which can generate constant needs and motivation, gift, is employed in this research, and is used to shorten the distance between 3D printing technology and non-technical population with a 3DP-based gift platform, giftGO. Through giftGO, we would like to create a new experience: giftGO is not a tool or kit for learning 3D printing technology, but a platform helping users build their unique gifts while most people may suffer from preparing special gifts, 3D printing is just the technology that makes gifts truly unique.

By the two stages of user testing, we are able to see the success in this research. Users, especially unexperienced ones, do enjoy the process of building their own unique gifts with giftGO, despite the fact that giftGO still has some interface problems to solve. The most importantly, after using giftGO, unexperienced users who have never used 3D software or 3D printers change their minds about 3D printing, they no longer think of 3D printing as a technology which they will never use, instead, they are amazed at the gifts that they can make with 3D printing. Metaphorically, 3D printing technology is like an amusement park built with roller coasters, pirate ships, Go-Karts and so on, the current developments and researches are trying to make all of the equipment better and easier to play with, however, for non-technical population, there is a lack of a proper entrance (application) to enter this playground, which indicates the true value of this research, giftGO fills the gap between them and decrease users' insecurity of trying a new technology.

[5.2] Future works

Firstly, according to feedbacks coming from users, our solution has shown its potential to be a real web service, which allows users to customize their unique gifts on browsers and sends the submitted works (3D printed objects) to users' designated addresses. However, to achieve this goal, there are still several technical issues to overcome. One of them is the speed, as we know, the current 3D printers take quite a long time to print out an object (the more detailed and bigger the product is, the longer time it takes), therefore, the object size and the total throughput may be limited. These issues still take so much efforts to solve, but overall, if they could be solved properly, perhaps in the future, instead of buying general gifts from Amazon, people may customize their unique gifts with 3D printing technology from giftGO.

Secondly, based on the observation (during user testing), even though our gift-oriented modules are widely appreciated by users, the detailed workflows of each module are still too complex for the first-time users, there is still a room for the further simplification. In terms of the most used module, 3D photo, currently users have to go through four modals (interface of settings) in order to generate the final 3D photo. The original idea of this design was meant to allow users to customize more variables, but it turned out to be a little confusing for users (especially each modal was explained by text only). For the next-level optimization, perhaps we need to either make the explanation more graphical or show the default variables in the first place.

Finally, although the current focus (application) in this research is "gift", this system still has potential for other fields. The thought of "expanding the system" was also mentioned by some users after they tried. For instance, the system could be a food printing platform by turning the current gift-oriented modules into food-oriented modules such as 3D printing customized pasta or 3D printing a pizza with special patterns. The concept of "series application" is definitely the next crucial issue/development for this research in the future.

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The completion of this thesis is attributed to many people's supports and encouragements.

First and foremost, I would like to thank my academic advisor, Dr. Hiroya Tanaka. Prof. Tanaka's door was always open whenever I ran into a trouble spot or had a problem about my research direction. The crucial pivot mentioned in the beginning of chapter[3] was also inspired by one of our discussions. While Prof. Tanaka steered the whole research into the right direction, he consistently allowed this research to be my own work without over-managing details. The most importantly, he gave me the full trust in my learning and developing ability especially I did not have any web developing experiences before this research, he had never doubted me even though the entire development was full of challenges.

I would also like to acknowledge Dr. Fujii and Dr. Savage accepting to be my vice academic advisor without hesitation, and I am gratefully indebted to their very valuable comments on this thesis.

I would also like to thank my lab members who gave me feedbacks from diverse perspectives during the process of system development. Especially my good friend, Moriya Takumi, with whom I consulted the programming and technical problems of giftGO. Also, I deeply appreciate the users who were involved in the first-stage and second-stage user experiments. The verification tests could not be successfully conducted without their passionate participation and input.

Finally, I must express my profound gratitude to my parents for providing me the continuous support and encouragement throughout my years of study and through the process of researching and writing this thesis. This would not have been possible without them. Thank you.

Author

Chen, Yi-Ting

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