

Application of Simplified QFD for Selecting 3D-CAD FOSS in Mechanical Engineering Education: A Case Study in Private Educational Institution

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Abstract

The aim of this research was to present a selection method for “Free and Open-Source Software (FOSS)” type of three-dimensional computer-aided design (3D-CAD) by using the Simplified Quality Function Deployment (Simplified QFD). The research was conducted into 4 tasks: searching for the alternative 3D-CAD FOSS which have been popular used among makerspace communities, extracting appropriate criteria used for selecting 3D-CAD FOSS from research literature and makerspace communities, brainstorming to select the most suitable software by using QFD matrix among 11 stakeholders from top executive down to student representative of Rajapark Institute, and validating the selected software by real teaching experiment. Teaching experiment was performed on a sample of 8 undergraduate students who enrolled in the elective subject of “Computer for Mechanical System Design” from academic year of 2025. With three alternative 3D-CAD FOSS (namely FreeCAD, Blender and Autodesk 123D Design) that were brainstormed and selected by using the simplified QFD, FreeCAD is the most suitable software with a maximum score of 31. Results from student questionnaires after teaching experiment pointed out that students were more positive on FreeCAD than Autodesk 123D Design and Blender respectively.

Keywords: 3D-CAD FOSS, Software Selection, Multi-Criteria Decision Making, Simplified QFD



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1. Introduction

The widespread application of 3D-CAD modeling in the industry throughout many decades has necessitated engineering institutions to integrate commercial 3D-CAD software into their curricula with a significant investment. The small private institutions that lack funding frequently update such software, tolerated the use of outdated versions that fail to meet the demands of occupational market requiring proficient students in the advanced levels of CAD technology such as computer-aided manufacturing (CAM) and computer-aided engineering (CAE). Today, however, many Free and Open-Source Software (FOSS) have been emerged and continuously developed by non-profit organizations. Its effectiveness has been proven by public communities for a certain year. A makerspace can be viewed as a collaborative community that maybe comprises of high school students, hobbyists, startups, or whoever has the same passion, gather doing various activities such as exploring, learning, making and sharing by employing non-technological to high-technological tools such as integration of 3D-CAD and 3D printing (Kantaros et al., 2022). With the factors of investment and other benefits, administrators of Rajapark Institute realized the potential of FOSS to replace the existing outdated commercial 3D-CAD software. Therefore, researchers, as part of the institute, conducted a study to select the most suitable 3D-CAD FOSS under various criteria beyond investment considerations solely.

Fusiripong & Nuansomsri (2022) proposed the evaluation criteria for 3D software selection by following the ISO/IEC 9126-1:2001(E), identified Those criteria by comprehensive and matching meaning techniques, and found 18 criteria that could be adopted in the 3D software selection with the item objective congruence index of 0.9. Most of their interested criteria, however, were weighed on the license fee and its related investment that focus on the selection of commercial 3D-CAD software. Considering some research (Okudan, 2004; Prasad & Chakraborty, 2016; Özsoy, 2020; Gaha et al., 2021), without pointing towards FOSS directly, the overall criteria for selecting 3D modeling software remain consistent in terms of core functionality, diverse supplementary features and user-friendly interface (GUI). In recent years, there has been research to use 3D-CAD FOSS into various application that can view its continuous development (Di Donato & Abita, 2019; Hebebecci & Maya Hebebecci, 2021; Le et al., 2026). Junk & Kuen (2016) reviewed the use of various 3D-CAD FOSS. One of them is Autodesk 123D Design that has been used in the elective subject of “Computer for Mechanical System Design” at Rajapark Institute since 2022. They described the proper characteristics of CAD by considering the needs of users with little experience and concluded that users still need comprehensive functionality and friendly GUI included a special need of free or affordable accessibility to CAD systems.

However, by considering the source of criteria for 3D software selection that were extracted from the research, the authors found that those criteria were limited and extracted from a few professors or consultants only. This may lead to biased judgments (Okudan, 2004) and lack of participation from all stakeholders. Hence, the authors wanted to provide a forum with reliable tools in which all stakeholders in the institute could brainstorm to select the most suitable 3D-CAD FOSS. Even Özsoy (2020) presented the valuable method for selecting 3D-CAD based on Analytical Hierarchy Process (AHP), but the authors tried to avoid the “rank reveal” problem due to adding any alternative 3D-CAD software during brainstorming and lead to inconsistency in results. The authors thought that using the Quality Function Deployment (QFD) to select the 3D-CAD software by Prasad & Chakraborty (2016) should be more effective. To avoid any mistrust about behind calculations QFD from stakeholders, every voted score must be transparent and conducted in a simple format that could reach a conclusion within a face-to-

face brainstorming session, therefore the authors proposed a simplified QFD (Brussee, 2004) for selection of alternative 3D-CAD FOSS instead.

2. Research Objectives

1. To explore and establish a list of alternative 3D-CAD FOSS for selection to be used in mechanical engineering education.
2. To explore and establish a list of proper criteria which is used for selection the 3D-CAD FOSS to be used in mechanical engineering education.
3. To present a method for selecting the most suitable 3D-CAD FOSS for mechanical engineering education by using Simplified QFD.
4. To validate the proposed 3D-CAD FOSS obtained from Simplified QFD-based selection method by real teaching experiment and student questionnaires.

3. Literature Review

3.1 3D-CAD FOSS which is Suitable for Mechanical Engineering Education

Today, 3D-CAD software is simply categorized by its modeling technique. The most common types include “3D Parametric - Solid Modeling” used for precise dimension-driven engineering, “Parametric - Surface Modeling” used for curved shape objects, “Mesh or Sub-D Modeling” used for digital sculpting or organic shape objects, “BIM (Building Information Modeling)” used for architectural and construction. For clearly, 3D-CAD software in this research mainly focuses on “3D Parametric - Solid Modeling” which is normally used in mechanical engineering. While commercial 3D-CAD software does not have publicly available source code, end users are limited as consumers. Without any customize allowing, they must rely on the workflow and trust the results which the commercial software presents. In contrast, almost 3D-CAD FOSS provides publicly accessible source code, avoids vendor lock-in, allows end users to fully customize, and share among social communities without licensing fees. In this research, hence, authors are interested in 3D-CAD FOSS only.

To avoid the need for high-performance commercial 3D-CAD software that require licensing fees and expensive hardware, as an alternative, many literatures have been proposed to use 3D-CAD FOSS that is gaining popularity within the makerspace communities and is growing through public support, as an alternative. Castro et al. (2019), presented a study of download behavior from the SourceForge platform, one of the popular web-based repositiorium committed to support FOSS projects along with open design (OD) communities, showed that the top 3 most downloaded 3D-CAD FOSS are rattleCAD, BRL CAD, and FreeCAD with stable cumulative downloading throughout the years. This indicated the ability to maintain public popularity and implied a likelihood of continued and sustainable development. Currently, the number of 3D-CAD software available as cloud-based services is continuously increasing, driven by the growth of Industry 4.0, where virtually all operations are based on the cloud and the Internet of Things (IoT). It looks like there is no longer investing in high-performance computing hardware, requiring minimal maintenance, and avoiding software version conflicts. Software updates can be performed directly through the software provider's servers without requiring manual upgrade requests. Some software is entirely hosted on the cloud, meaning it can be accessed directly through a browser without prior installation on a personal computer and can be displayed on any device. Gaha et al. (2021) compared two software along this idea; Onshape and Autodesk Fusion 360. Each software offers a trial

version that allows any registered student to use it for 1 year at a time and renews the access annually for as long as they remain an actively enrolled student at a qualified institution. Although Onshape looks more appealing than Fusion 360, particularly making all functional features work similarly that allow students to identify errors more quickly, Fusion 360 has a more user-friendly assembling function. Furthermore, Fusion 360 can be used offline, which is a significant advantage in cases of unstable internet connections. They further commented that while cloud storage eliminates the need for users to manage data on personal computers and avoids investment in highly stable-expensive storage devices, it comes with a certain fee that depends on the agreement between the software provider and the institution. However, this cloud storage also has some drawbacks, such as the inability to control the own files, as they are stored on the provider's cloud. To avoid the commercial cloud-based 3D-CAD software, paper by Hebebcı & Maya Hebebcı (2021) offered the open -source ones. They found that Tinkercad is the most popular 3D-CAD software among the web-based software. Considering software fees, only the free versions of Tinkercad and FreeCAD offer full functionality. In terms of learning curve, however, Tinkercad, Vectary, and 3D Slash are more efficient in situations requiring limited learning and practice time, while SketchUp and FreeCAD require more time, skills, and professional engineering experience. Authors think that, for mechanical engineering students who will graduate and work in the industrial sector, they cannot avoid these functional skills. Today, information tracked from social networks points FreeCAD is beginning to be popular and widely applied in various engineering fields with its inherent versatilities and compatibility to connect to other software packages, via workbenches developed by open design communities. Some of its compatibility can be demonstrated by work of (Di Donato & Abita, 2019) to expose the capabilities of FreeCAD in creating a BIM model of a bus stop roof-structure that showed its potential for integration with 3D-CAD FOSS for project scheduling and management like ProjectLibre. They compared FreeCAD with the famous software that come with a motto “CAD for Everyone” like Sketchup and its 4D Virtual Builder add-on, and commercial software like Teka Structure which possesses ability to complete 4D BIM tasks. Although the project progress tables obtained from FreeCAD looked not as visually appealing and communicative as Sketchup, and the automatic updating of project progress at each stage based on allocated resources looked also as good as in Tekla, they still believed that FreeCAD showed further potential for development to improve interoperability between FreeCAD and ProjectLibre in terms of cost management related to the stages and resources defined in ProjectLibre. Another paper of Le et al. (2026) demonstrated the flexibility and efficiency of a FreeCAD-GDML Workbench, in designing geometrically complex parts such as detectors, collimators, and structural assemblies in the development projects of PET and SPECT nuclear medicine scanner through XML- scripting, which is an accepted protocol for Monte Carlo Geant4 particle physics modeling. Those papers expose the flexibility and compatibility of development on FreeCAD that should be fruitful continued among makerspaces. Here, while the authors are beginning to recognize potential in FreeCAD, this potential still needs to be proven.

3.2 Multi-Criteria which is Used for Selection of 3D-CAD FOSS in Mechanical Engineering Education

Over the years an enormous amount of paper has been published on identifying of selection criteria for 3D-CAD software, it is practically impossible to present exhaustive review on them; hence only a few selected papers are explained. In Thailand, during last three years past, there is only one papers about criteria on software selection by following the ISO/IEC 9126-1:2001(E) for software engineering-product quality (Fusiripong & Nuansomsri, 2022; International Organization for Standardization, 2001). Now ISO/IEC 9126-1:2001(E) is revised and replaced by ISO/IEC 25019:2023 (International Organization for

Standardization, 2023). This summary indicated that the “3D parametric function” for creating the geometric features is still being most essential criteria. 3D parametric modeling is a kind of CAD that is usually used for mechanical engineering, which is created by using mathematical parameters instead of the constant values. This approach allows any modifying onto the solid model via changing the parameters inside. This included possibilities to develop dimensioning and 2D-drafting for manufacturing then. Even through the “License fee and investments in high-performance hardware” are also crucial criteria in the papers, but with the expectation of this research on using 3D-CAD FOSS which should be affordability (Kantaros et al., 2022), this point could be looked over. Except core function of 3D parametric modeling, junior students who use 3D-CAD software probably not expect to see and play “Special capability” such as motion analysis when they open software at the first class (Gaha et al., 2021). Okudan. (2004) exposed that the proper adapted version of user manuals could obtain “Ease of use”, he could lead two groups of students created the same 3D solid model even they used the different software. Final issue, “Accessibility via internet includes cloud and collaboration” looked appealing to new generation students (Di Donato & Abita, 2019; Kantaros et al., 2022). But there are some weak points from unstable internet connection and expensive fee for cloud servers (Gaha et al., 2021).

Okudan (2004) offered an interesting idea for validation of the software selection in practically. He adapted user manuals for two selected software and designed exercises allowing two student groups who were assigned to use two different software to model the same 3D model by using the same basic functions. He found that each group could spend equal time studying and completing the exercises in classroom. His research indicated that well-designed user manuals with similar functions could lead to consistent learning of students. Minor differences occurred from varying levels of user familiarity onto user interfaces (menus and GUI). The authors will follow his validated methods by separating students into certain groups. Each group will be assigned to use the different choices of 3D-CAD FOSS that pass the QFD-based decision-making as will be discussed then.

3.3 Simplified Quality Function Deployment as an Effective Tool for Decision Making on the Selection of 3D-CAD FOSS

The quality function deployment (QFD) is one of non-statistical tools which is widely used in the Six – Sigma to manipulate the requirement of customers (often called as voice – of – customers; VOCs) which are mainly obtained by market research. QFD can transform the qualitative needs of stakeholders into quantitative criteria in a matrix format (commonly known as “house of quality”) which allows stakeholders to brainstorm and prioritize their needs within concurrent engineering environments. Even though Prasad & Chakraborty (2016) presented a software selection methodology based on the QFD concept. but instead of face-to-face meetings among stakeholders, a graphical interface developed using Visual BASIC was created for individual stakeholder voting and prioritization. They claimed this avoids arguments, interference leading to opinion manipulation, and reduces the time spent on collaborative evaluation. Regarding this point, the researchers disagree, arguing during face-to-face brainstorming is essential because confrontation does not always imply interference or manipulating the opposing idea. In the other hands, it is probably an opportunity for everyone to learn, exchange ideas, or even dismantle preconceived notions. To utilize face-to-face discussion more simply, however, the authors do not implement the full version (as house of quality) of QFD, but work with the simplified QFD instead (Brussee, 2004). It looks simply format but still maintains the concept of QFD completely. To easily understand for the readers, the author will omit explaining how to create simplified QFD at this step of literature review

but will explain it via the real proposed decision criteria and choices of 3D-CAD FOSS using in this research at the step of research methodology instead. In addition, the comprehensive details of making QFD matrix can be studied from textbooks on general multi-decision analysis, and review paper worked by (Chan & Wu, 2002; Aytac & Deniz, 2005).

4. Conceptual Framework

The conceptual framework of the research can be depicted as Figure 1. below.

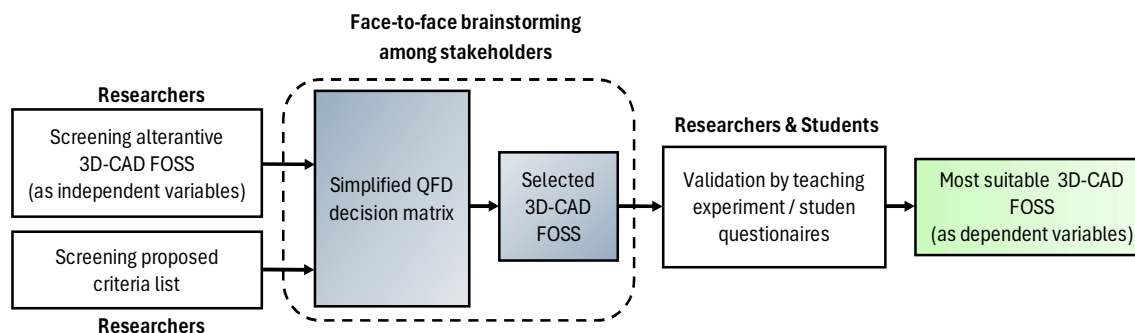


Figure 1. Conceptual Framework of Research

The authors imitated as general users who have little experience and usually start to find any interactive information such as 3D-CAD FOSS from social channels like YouTube or Facebook first. In parallel, the selected criteria for software should be preliminary recognized from this stage. This information will be cross validated by literature review. The alternative 3D-CAD FOSS and selected criteria will be input to simplified QFD-decision matrix as a brainstorming tool for a face-to-face session. In finally, the most suitable 3D-CAD FOSS which are selected will be validated by real teaching experiment and student questionnaires.

5. Research Methodology

The proposed methodology for selection of 3D-CAD FOSS by using simplified QFD is divided into six consequent steps. Each step is explained in terms of its inclusion of this methodology as below.

5.1 Explore and Establish a List of Alternative 3D-CAD FOSS for Selection

This step is included in the methodology to compile information and answer the question, “Which open-source 3D-CAD is popular used among the makerspace communities?”. Initially of screening, the authors assumed the role of makerspaces who typically start by watching beginner- friendly tutorials on YouTube such as (Print N Repeat, 2026; Tutorialfied, 2026) and even searching for recommendations through online forums like Reddit. Of course, in addition to the voices on social networks, academic evidence from research papers is needed to confirm those voices. To get more firmly consistency, authors searched the papers by using the keywords such as “Open-source 3D-CAD software”, “Open-source 3D parametric modeling”, “3D-CAD FOSS” etc.

The beginning draft of possible 3D-CAD FOSS was simply validated by discussion with the second-year undergraduate students who enrolled in subject “Engineering drawing”. A list of alternative 3D-CAD

FOSS that must be input into the QFD decision matrix was the result of this step. Details of consideration of the alternative 3D-CAD FOSS were explained in the result 6.1.

5.2 Establish a List of Proper Criteria which is Used for Selection the 3D-CAD FOSS

This step is included in the methodology to compile information and answer the question, “Which criteria is proper used for selection of open-source 3D-CAD software?”. To answer the question, as well, the authors still started watching on YouTube and even searching for recommendations through online forums like Reddit. To confirm the voices from social communities, authors searched the papers by using the keywords such as and searched the research papers by using the keywords such as “Criteria for CAD software selection”, “Multi-criteria for CAD software selection”, “Decision making for CAD selection” etc.

The beginning draft of possible proper criteria was validated by discussion with the second-year undergraduate students who enrolled in subject “Engineering drawing”. A list of criteria for selection of 3D-CAD FOSS that must be input into the QFD decision matrix was the result of this step. Details of consideration of the selection criteria were explained in the result 6.2.

5.3 Make the Simplified QFD for Selection the 3D-CAD FOSS

At the beginning of face-to-face brainstorming session, the authors provided the blank form of simplified QFD as shown in Figure 2. on white board. A list of alternative 3D-CAD FOSS from 5.1 was proposed among the stakeholders and must be input at the top row of simplified QFD matrix. Similarly, a list of criteria for selection of 3D-CAD FOSS from 5.2 was proposed among the stakeholders and must be input at the most left column of simplified QFD matrix.

QFD for selecting the open-source 3D-CAD		Software No.1	Software No.2	Software No.3
Selected criteria	Criteria score			
Criteria No.1				
Criteria No.2				
Criteria No.3				
Criteria No.4				
Total Score				

Figure 2. The Blank Form of Simplified QFD for Selecting the 3D-CAD FOSS

5.4 Brainstorm to Decide on the Selection of 3D-CAD FOSS with Simplified QFD

This is the most critical step to realize the happening of simplified QFD in practically. The stakeholders were consisted of 1 Dean of faculty of engineering (acting as Head of mechanical engineering department), 1 Head of industrial engineering department, 3 researchers as members of mechanical engineering department, 1 Head of computer and IT systems section, 2 representatives from the institute's administration both in academic affairs and finance, and 3 student representatives selected from previous and current semesters. Those 3 students were selected from the third-year undergraduate students who passed the subject of “Engineering drawing”. The main selection criteria for those students are possessing the background of vocational certificate and experience in the metal working and related sectors. The authors expected that their background and experience would be useful for evaluation the 3D-CAD FOSS.

All stakeholders must use the blank form of simplified QFD from 5.3 to brainstorm and evaluate the scores for each criteria and each alternative 3D-CAD FOSS by following steps as below. The authors decided to use score ranges which were specified by Brussee (2004).

1. Score of each criteria for selection of 3D-CAD FOSS is put into each row of the adjacent column beside the most left column of criteria, namely 3 is score for important criteria which are not against safety and legal measures, 2 is score for minimum criteria which cannot be avoided, and 1 is score for “nice to have” criteria. The scoring can be refined for more than three ranges. However, it often leads to confusion during the scoring and may not be worth time and effort. Score each customer’s need and put it into each row of the adjacent column beside the customer ‘s need.

2. Similarly, score of each possible 3D-CAD FOSS that can be responded with the corresponding criteria is put into the upper part of each intersection box of each row of criteria and each column of software, namely 3 is score for completely respond to criteria, 2 is score for well-fit respond, 1 is score for moderately respond and 0 is score for unable respond. In many cases, however, a minus score for conflict with the criteria can happen. It is not unusual due to attempting to respond to a criteria may conflict with others criterion.

3. Multiplying result of score of each criteria and score of each software is put into the lower part of each intersection box.

4. Finally, sum of multiplied scores from the lower part of each intersection box of all rows in the same column as the total score of each software is put at the lowest part of simplified QFD.

At the end of this step, stakeholders obtain total scores of each alternative 3D-CAD FOSS. Basically, they should select the software that possesses the highest total scores to achieve the criteria as much as possible. However, some stakeholders may wonder and recognize something wrong insight their selection based on the total scores and want to rethink their scoring again. This is normal and valuable situation that often leads to scoring back and forth about two or three times to get the most suitable software, especially software that respond to the high scored 3 of the criteria.

5.5 Validation the Selected 3D-CAD FOSS by Teaching Experiment

This teaching experiment was planned for 8 third-year undergraduate students who are enrolled 12 weeks (3 hours a week) in the selective subject “Computer for Design Mechanical Engineering System” during academic year 2025. They must follow the training manual of the selected 3D-CAD FOSS from simplified QFD and then assess their performance by assignment. Certainly, student performance is measured from using some predetermined basic 3D-parametric modeling functions e.g., extrusion, sweep, revolve. The class is conducted by same instructor teaching on different 3D-CAD FOSS from simplified QFD during the same semester. Due to a few students (8 students) while a bit of long teaching periods, the authors did not separate students from using each alternative 3D-CAD FOSS. All students were scheduled to learn all alternative 3D-CAD FOSS which are selected from simplified QFD as block course. At the end of course, all students must complete the questionnaires that were initiative from the selected criteria of simplified QFD.

6. Results

6.1 The Result of Exploring and Establishing a List of Alternative 3D-CAD FOSS for Selection to be Used in Mechanical Engineering Education

The voices among makerspaces in social networks exhibited that the most popular votes of 3D-CAD FOSS are FreeCAD and OpenSCAD. Authors verified the votes by analysis the number of downloads software via SourceForge platform. Figure 3. shows that FreeCAD has achieved 4,753,860 downloads since registering in 2003, while OpenSCAD looked contrary to social vote with just 9,307 downloads since

registering in 2019. Although the number of downloads does not mean that the software is used by makerspaces after downloading exactly, it can imply the potential to being 3D-CAD FOSS for makerspaces. Especially in Thailand, download statistics from SourceForge exposed that FreeCAD (32,970 downloads in Thailand) is more popular than OpenSCAD (24 downloads in Thailand) significantly. Authors believed it is because FreeCAD is a traditional GUI based parametric modeling where 2D profiles are sketched and then are transformed into 3D solid models by specific tools, so people should be familiar. While OpenSCAD is programming CAD in which 3D solid models are built via script-based language. This contradicts the natural inclination of people to communicate the shape of objects through drawing rather than through typing. At this stage, FreeCAD was the possible 3D-CAD software that passed the screening.

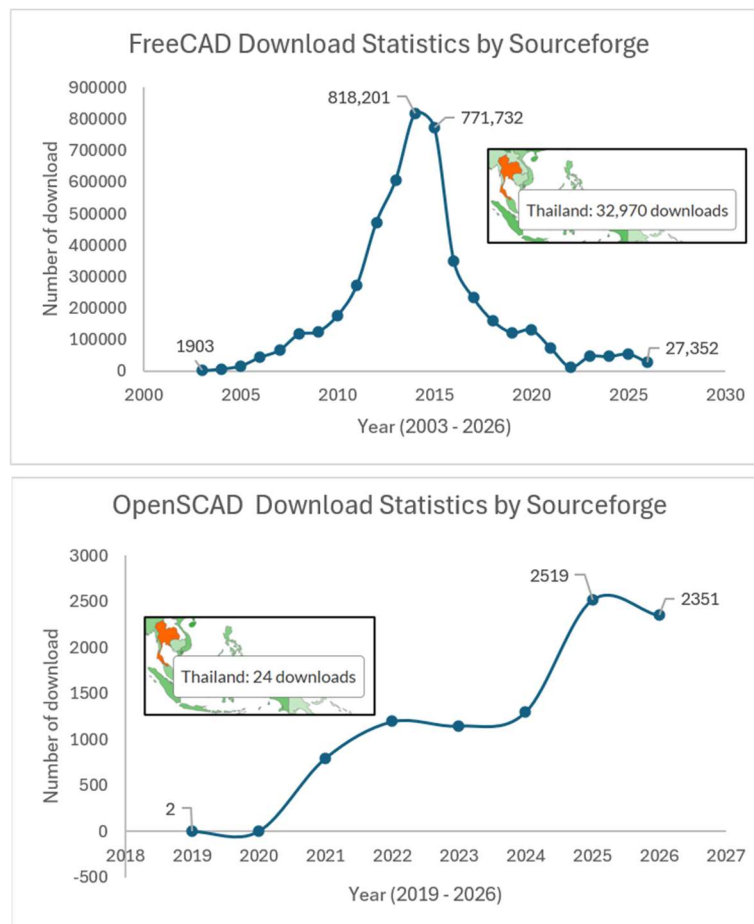


Figure 3. Download Statistics of FreeCAD and OpenSCAD via SourceForge Platform

Although results extracted from Castro et al. (2019) showed that rattleCAD, BRL CAD, and FreeCAD are the top three of 3D-CAD FOSS downloaded from SourceForge platform, the authors found rattleCAD scoped as specialized 2D parametric CAD for design bicycle frames only, it could handle 3D by exporting a macro that need to be linked to other 3D-CAD software such FreeCAD or OpenSCAD (OpenSCAD, 2026), while BRL-CAD was mathematically accurate 3D-CAD software that heavily specialized in the defense sector and ballistics simulation (Rosenberger, 2026). Hence, rattleCAD and BRL CAD were cut away from the research framework in terms of 3D parametric creation and general used in mechanical engineering education. Additionally, the authors validated using both FreeCAD and OpenSCAD by discussion with the

second-year students (most students were vocational graduates and almost were already working in industry) in the subject “Engineering drawing”. They chose to use FreeCAD if possible and denied using OpenSCAD due to avoiding script-programming. At the time, they also feedbacked on 3D-CAD FOSS they have used for work normally or even for hobbies. Surprisingly, the survey results coincidentally aligned with research by Junk & Kuen (2016) which pointed out using some FOSS such as SketchUp, Blender and Autodesk 123D. Certainly, those software have been widely used for makerspaces in Thailand as well. At the time, the license-free 3D-CAD software that was being used at authors’ institute was Autodesk 123D. Although Autodesk’s official support for 123D Design is over today, it is still available to be downloaded via Autodesk community and can be used until today. While SketchUp is free only for people without business expected, but is not free for educational institutes, Hence, Sketch is cut away from the research in terms of licensing fee. Finally, three software were included in the evaluation and selection: FreeCAD, Blender3D and Autodesk 123D Design.

6.2 The Result of Exploring and Establishing a List of Proper Criteria which is Used for Selection of the 3D-CAD FOSS to be Used in Mechanical Engineering Education

Authors extracted selection criteria for 3D-CAD software from a few selected papers (Okudan, 2004; Prasad & Chakraborty, 2016; Junk & Kuen, 2016; Di Donato & Abita, 2019, Özsoy, 2020; Hebebcı & Maya Hebebcı, 2021; Gaha et al., 2021; Kantaros et al., 2022) and could summarize them into a list as Figure 4.

Criteria which are referred in the literatures	Okuda n,2004	ISO/IEC 9126, 2001	Prasad et al, 2016	Junk et al, 2016	Donat o et al, 2019	Özsoy, 2020	Hebebcı et al, 2021	Gaha et al, 2021	Fusiripon g et al, 2022	Kantaro s et al, 2022	Count
3D parametric function includes engineering capability such as assembly and 2D-drafting	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes		8
Licensing free includes hardware requirement and maintenance (investing)	Yes	Yes	Yes	Yes					Yes		5
Ease of use includes friendly GUI, tutorials, training, and language (learning curve)	Yes			Yes			Yes				3
Special capability such as animation, rendering, analysis and CAE		Yes				Yes			Yes		3
Interfaces for data transfer such as STP, STL, OBJ that available to connect other software					Yes		Yes	Yes			3
Available multi-OS platform				Yes			Yes			Yes	3
Accessibility via internet includes cloud and collaboration							Yes	Yes			2

Figure 4. Summary of Selection Criteria for 3D-CAD Software

Regarding to the Figure 4., it was indicated that the “3D parametric function” for creating the precise geometric features was still being most essential criteria (with 8 tally). Although the “License fee and investments in high-performance hardware” were also crucial criteria for commercial packages (with 5 tally), with the expectation of this research on using FOSS which should be inherent affordability, hence authors decided to cut this criteria off the evaluation. “Ease of use” seems to be a secondary importance (with 3 tally), however, with the aspect of using FOSS, it was not only about friendly GUI or familiar menu. But it was about friendly user manuals. As discussed with students in “Engineering drawing” class about

the expected 3D-CAD FOSS, almost looked desire to use them, but they appealed lack of proper tutorial availability merely in Thai language. Authors believed this is the most disadvantage of FOSS for Thai students. Authors thought that the junior students who use 3D-CAD are probably not expect to use “Special capability” (with 3 tally) such as motion analysis at the second-year subject of “Engineering drawing”, however, authors kept this criteria for considering by other stakeholders in the brainstorming session. The authors disagree with summary on criteria “Interface data transfer” (with 3 tally), as surveying via social networks, “CAD-file exchange” indicates it was one of the most important criteria especially file exchanging among makerspaces who applied the different FOSS. “Available multi-OS platform” was the most dominant of general FOSS and it should not be requested to the new software development anymore. For final issue, “Accessibility via internet includes cloud and collaboration” (with 2 tally), it looked appealing to some new generation students. For Thai, however, except the problem of unstable of internet connection, cloud-based applications probably not user-friendly for someone. The authors as a former generation would not comment here but deployed this criteria into QFD for brainstorming in which students must be joined and voiced by themselves.

6.3 The Result of Presenting a Method for Selecting the Most Suitable 3D-CAD FOSS for Mechanical Engineering Education by Using Simplified QFD

QFD for selecting the open-source 3D-CAD		FreeCAD	Autodesk 123D	Blender
Selected criteria	Criteria score			
3D parametric function include engineering capabilities such as assembly and automatic 2D-drafting	3	3	1	1
		9	3	3
Ease of use include tree, friend GUI and menu, teaching tutorials & materials especially in Thai language	3	2	1	2
		6	3	6
Special capabilities such as animation, rendering, engineering analysis both mechanism and CAE	2	3	1	1
		6	2	2
Interface for data transfer such STP, STL, OBJ that available to connect other software	3	3	2	2
		9	6	6
Accessibility by internet and cloud that facilitate the collaboration	1	1	2	1
		1	2	1
Total Score		31	16	18

Figure 5. Complete Simplified QFD for Selecting the 3D-CAD FOSS

During the 8 hours-brainstorming session (4 hours in the morning and afternoon periods), authors observed that, in addition to the research team presenting information on alternative software and selection criteria from point 5.1 and 5.2, participants exhibited two distinct behavioral patterns. The first group, exhibiting significant input and demonstrating a certain knowledge about 3D-CAD software, consisted of student representatives and representatives from academic affairs. The second group, which did not raise any negative opinion and readily agreed with the majority, consisted of representatives from financial and Head of computer and IT systems section. By overview of the brainstorming session was smooth and positive. However, some participants had some confusion about the scoring and struggled to visualize the concepts presented. At times, the researchers had to present videos demonstrating about

CAD-file exchange between software packages and specific applications such as finite element analysis and 3D printing via YouTube, leading to revision of the simplified QFD many time throughout the session.

The completely simplified QFD decision matrix obtained from the list of possible 3D-CAD FOSS and the list of criteria for selection of 3D-CAD FOSS as shown in Figure 5. Results obtained by simplified QFD showed that FreeCAD got the highest score ($9+6+6+9+1 = 31$) that was identified as the most suitable 3D-CAD FOSS based on considered criteria, followed by Blender ($3+6+2+6+1 = 18$), and Autodesk 123D Design ($3+3+2+6+2 = 16$) respectively.

Finally, all participants recognized and agreed to validate three selected 3D-CAD FOSS by real teaching experiment to ensure their consistency, and discussion about teaching plan as explained in 6.4.

6.4 The Result of Validating the Alternative 3D-CAD FOSS Obtained from Simplified QFD-Based Selection Method by Real Teaching Experiment and Student Questionnaires

Results obtained from complete simplified QFD decision matrix that was validated with students' questionnaire after teaching experiments on three 3D-CAD FOSS namely FreeCAD, Autodesk 123D Design and Blender. 8 students were scheduled to learn three 3D-CAD FOSS throughout 12 weeks (4 weeks for each software). As consulted with students, although students could complete the assignment to create 3D solid model by using those three alternative 3D-CAD FOSS identically as shown in Figure 6., but they complete it with the different efforts based on each software. FreeCAD and Autodesk 123D Design could work in 3D parametric style for precise engineering objects. While non-parametric modeling software like Blender is more focused on sculptural objects, dimension and shape cannot be controlled identically.

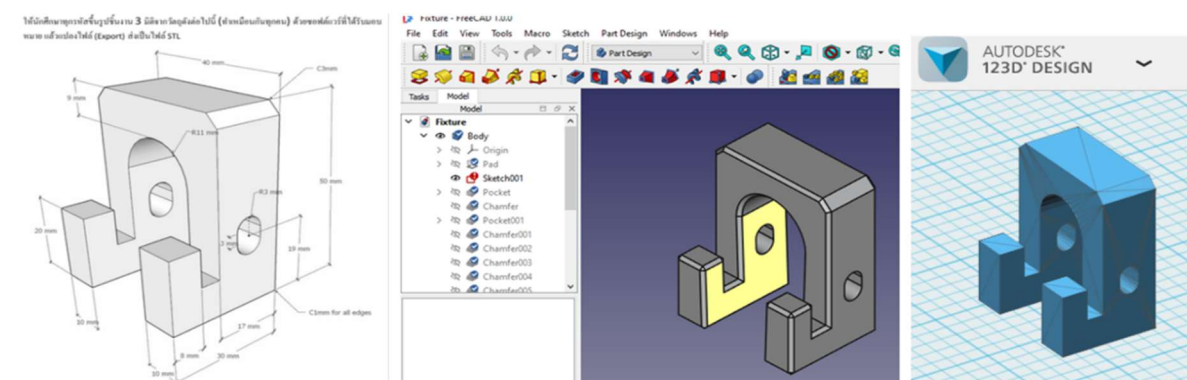


Figure 6. An Example of Assignment to Create 3D Solid Model by Blender, FreeCAD and Autodesk 123D

By overall survey, 8 students unanimously voted FreeCAD as the most suitable 3D-CAD FOSS for use in mechanical engineering education, achieving the highest score of 143 from total score 192 (or 74.5%), as shown in Figure 7. and Figure 8. Therefore, verifying the consistency of the scores is unnecessary.

However, upon closer look in details, it can be found that FreeCAD rather be good for “parametric function” and “interface data transferring”, but it rather be dropped for “ease of use” about GUI and especially worst about available tutorials.

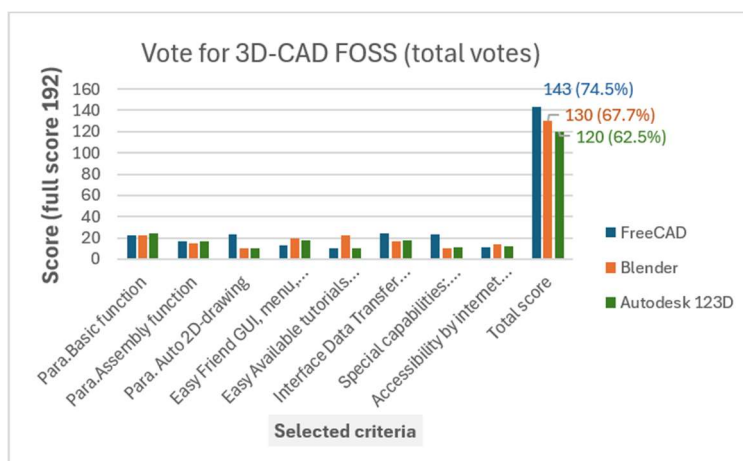


Figure 7. Total Students' Vote After Using Three 3D-CAD FOSS (FreeCAD, Blender and Autodesk 123D)

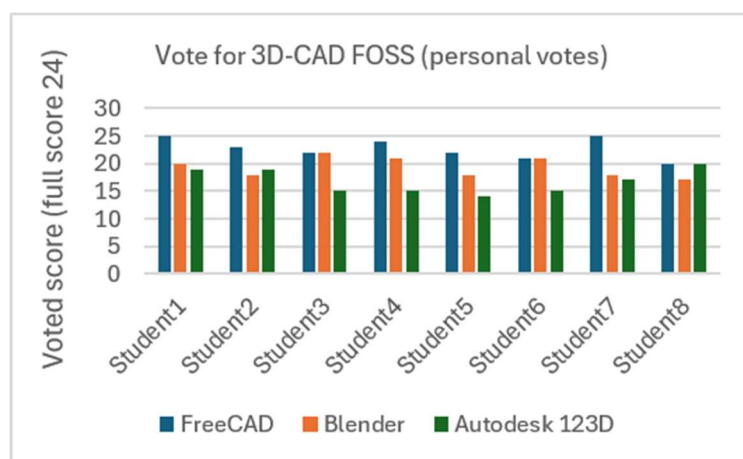


Figure 8. Personal Students' Vote After Using Three 3D-CAD FOSS (FreeCAD, Blender and Autodesk 123D)

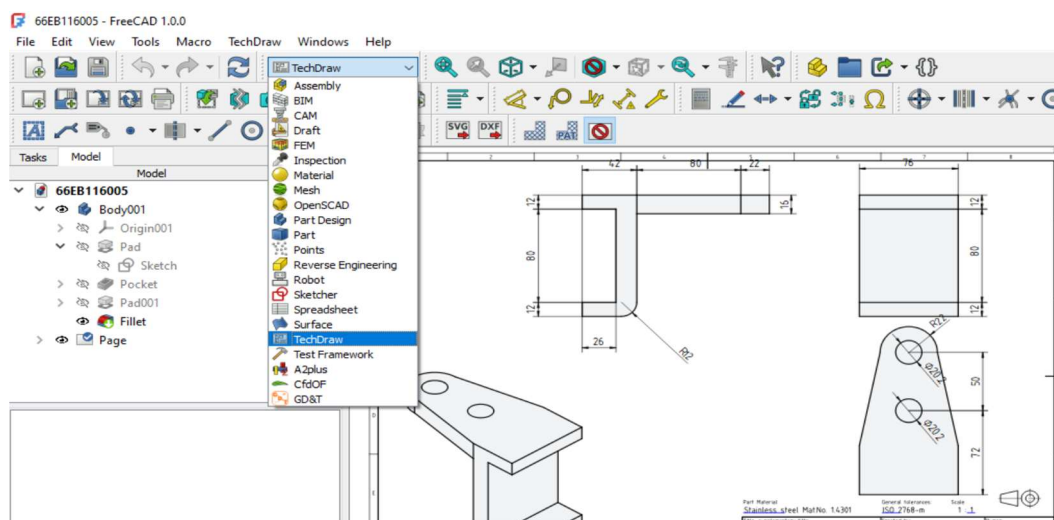


Figure 9. 2D-Drawing with Dimensions of Another Assignment that Obtained from FreeCAD “TechDraw”

Students also complained that Autodesk 123D and Blender could not provide formal 2D-drawing which needs to be used for manufacturing as they obtained from FreeCAD via “TechDraw” workbench as Figure 9. This is the main disadvantage of Autodesk 123D and Blender for mechanical engineering applications. Students also commented that FreeCAD has some special capabilities that Autodesk 123D and Blender lack, namely “FEM workbench” for finite element methods. Although students do not use this capability even do not know their performance right now, however, they know that they will take this courses in the next academic year, and they noticed FreeCAD has studying aids for the courses in the FreeCAD menu.

7. Discussion

The authors follow the concept of Okudan (2004) by providing effective teaching materials, focusing primarily on basic functions with sufficient examples and exercises before conducting the teaching experiment. Although the authors were not concerned about the time to complete the assignment as his research, the students in the teaching experiments could create 3D solid models completely by using three alternative 3D-CAD FOSS. This can confirm the need for a teaching manual for 3D-CAD, either commercial software or FOSS. Some students also reported that, in addition to the user manual prepared by the authors as their instructors, they could search the ways to use the 3D-CAD FOSS through other channels, mostly videos posted in YouTube. They reflected the main problem of using CAD FOSS, especially FreeCAD and Autodesk 123D, is lack of comprehensive tutorials in Thai, unlike other commercial CAD software. Most in-depth tutorials on special capabilities of FreeCAD are in foreign languages other than English that lead it more difficult for Thai beginners. Therefore, it points that successful implementation of 3D-CAD FOSS such as FreeCAD depends on responsibility of the instructors, who need to dedicate sufficient time to preparing effective teaching materials based on basic functions. Then students who are familiar with the basic functions should be able to build upon this by exploring advanced features independently.

The authors also applied the concept of Okudan (2004) in which software-selection criteria should not be limited to a few experts but should involve all stakeholders. Authors applied this concept to QFD that contrasts with the work of Prasad & Chakraborty (2016) who developed QFD developed from Visual Basic to ensure independent selection by each individual, believing that each selector would not be swayed by others even selectors have not in-depth technical knowledge of the functionality, capabilities, cost-effectiveness, and suitability of the CAD software. Instead, authors created and implemented simplified QFD in a face-to-face environment among diverse selectors as stakeholders to avoid incompleteness of selection. Although the authors found the situation in which some participants readily agreed with the majority as Prasad & Chakraborty (2016) commented, there is nothing to point which one is correct, the results obtained from teaching experiment still imply successfulness of using alternative 3D-CAD FOSS selected by simplified QFD.

There is an issue concerning software versions. FOSS can be updated frequently without prior notice. In this case of FreeCAD, it has been updated three times in the past three years, and it may no longer be possible to download familiar older versions. Furthermore, the new versions may not be compatible with older operating system. This means users must constantly monitor its updates, both in terms of downloading and trying out new versions to familiarize themselves in which some functions may be changed or even cancelled (which often leads to updated teaching materials) and the possibility that

some FOSS may be discontinued such as Autodesk 123D, which can pose a significant learning risk for the beginners. However, for at least, download statistics as shown in the previous Figure 3., FreeCAD has achieved 4,753,860 downloads since registering in 2003, this confirms its sustainability to a certain extent.

8. Conclusion

Establish a list of alternative 3D-CAD FOSS and a list of proper criteria which is used for selection of the 3D-CAD FOSS to be used in mechanical engineering education could be easily performed by rough surveying and screening via various social network-channels especially makerspace communities who are exhausted about FOSS. The most benefit of information obtained by social networks is fast recognition about technology trend, but it must be weighed with reliability. Therefore, they need to be validated by results from research papers.

Certainly, simplified QFD still needs reliable information from both ways. Application of simplified QFD for Selecting 3D-CAD FOSS that is presented in this research can be used to evaluate and select 3D-CAD FOSS reasonably, because it is a powerful tool that can be implemented in concurrent engineering environment among stakeholders.

The consistency of the selected results obtained from simplified QFD can be finally validated through the real teaching experiments that can be evaluated by assignment and examination during the class or even questionnaires at the end of the course.

While educational institutions achieve the goal of providing the 3D-CAD FOSS, students themselves gain awareness of the methods and experiences in selecting FOSS, which is likely to expand and become more diverse in the future.

9. Recommendation

Authors just aware of an interesting criteria during the teaching experiment namely “sustainability” of the 3D-CAD FOSS. This is the criteria that concerns the existence of FOSS in the future. The existence of FOSS usually originates from someone independently, moving on among specific communities, often lacking financial support. Membership within these communities is informal and free from business obligations, resulting in development and modifications that are largely unregulated. For example, version changes can often happen without being announced in advance, or development can suddenly cease without explanation. This is significant risk for those seeking and using FOSS, especially for Thai users who face against difficulties accessing it at the first time due to language barriers and limited user manuals. Investing effort and time in FOSS but finding it discontinued would be severe loss. Therefore, the authors think for this criteria should be continuously studied.

Authors admitted that this research did not use this research problem by comprehensive tools of multi-criteria decision-making such as AHP, ANP, TOPSIS, PROMETHEE, ELECTRE, VIKOR etc., because of the limitation of time that committed to institutional executive. Therefore, the authors paved the scope of this research as case study research. For at least the authors could recognize some insight into this research problem and can be continued more comprehensively with FOSS for CAE application in the future.

To further enhance students' proactive use of 3D-CAD FOSS in their learning, starting with conceptual 3D drafting in mind, creating and modifying the 3D model via CAD software, culminating in the real production of tangible 3D workpieces, the author used a freeware 3D printing software; Creativity

Print (Creality, 2026) to print the students' CAD files from the teaching experiment as shown in Figure 9. The author observed the students' enthusiasm when seeing on their real workpiece, evident in their discussions.

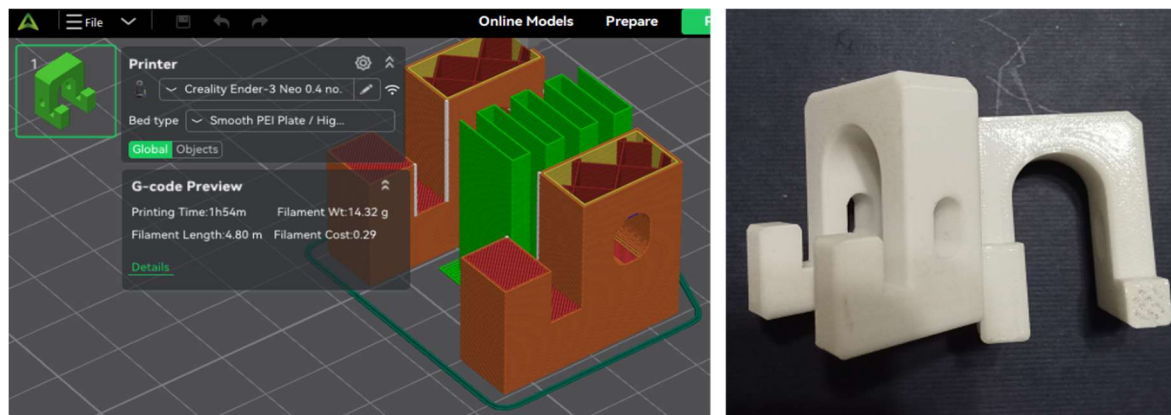


Figure 9. Real Workpiece is Made from the Tested CAD File of Student by 3D Printing

This reflects the possibility that incorporating 3D printing into CAD teaching would make studying more enjoyable for students, fostering further learning and allowing them to envision the future of open design (OD) technology. Institutions themselves might not need to invest in expensive CNC removal manufacturing machines such as CNC milling for teaching; instead, they could utilize much cheaper CNC additive manufacturing such as 3D printers. This issue, however, should be further researched.

10. Declaration of Generative AI

During the preparation of this work, the author(s) used Google Translate to refine the language of the manuscript. The authors reviewed and verified the text generated by the AI tools and took full responsibility for the content of the publication.

11. CRediT Author Statement

Chatchawan Sornsiri: Conceptualization, Methodology, Investigation, Resources, Classroom Instruction, Data Analysis, Writing and Editing the Manuscript, Supervision and Project Administration

Soontorn Wongsen: Training manual providing, Classroom examination, Resources, Consulting, Reviewing the manuscript. Investigation, Formal Analysis, Writing – review & editing, Resources, Project Administration

Vit Wanvijit: Resources, Consulting, Reviewing the Manuscript, 3D Printing. Investigation, Writing – Review & Editing, Resources

All authors read and approved the final manuscript.

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