

A 3D Modeling UI Method Focused on Geometry Education Experience for Novices

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Abstract

In creative education through spatial ability, incorporating 3D printer to education enabled 3D modeling education approach to beginners such as elementary school students following the advancement of 3D printer industry. However, the existing 3D modeling tools for graphic works of 3D modeling have a disadvantage in that beginners have difficulties in accessing as they target practical workers. Hence, we suggest UI of the 3D modeling tool that differs from the existing modeling UI scheme so that beginners can intuitively access 3D modeling and combine it with 3D printer. The 3D modeling UI scheme that is easily accessible to beginners also has small burden on educators who have to learn it in advance. We analyze the modeling scheme and UI access scheme of the existing 3D modeling tool to find out their problems from an aspect of beginners and suggest direction for solving them. The suggested UI scheme is aimed at improving 3D printing education and spatial ability focusing on users' educational experience based on geometry. We plan to use 3D modeling writing tool combined with the suggested UI in 3D printing education and expand it.

Keywords: 3D Modeling, 3D Printing, Education, UI, CSG, Snap-function

1. Introduction

1.1. Research Background and Motivation

Graphic design work of 3D modeling became relatively familiar to the public through 3D animation, movies, and special effects. The 3D modeling is widely used in diverse areas including product design, architecture, image, and computer graphic. It is also necessary for contents making in VR that is recently receiving attention. The 3D modeling work is related to 3D printing as in Figure 1, which shows Emerging Technology Hype Cycle published by Gartner. Expansion of printing materials was chosen as one of the ten biggest strategic trends published by Gartner in 2016.

In Figure 1, 3D printer industry can be divided into consumer 3D printing industry and enterprise printing industry. The reason that 3D printer business is centered at consumer can be attributed to the fact that the fields where 3D printer are used can be found in short term by observing contents that consumers create by it. By finding the fields that 3D printers are widely used and searching for the needs by the public including materials for 3D printing or contents, companies can commercially use it. Moreover, it is predicted that product manufacturing structure will be greatly different from now in diverse areas that use 3D modeling following the advancement of 3D printer industry. This time will be the company-oriented 3D printer industry.

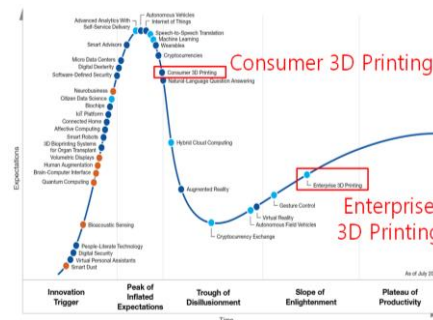


Figure 2. Emerging Technology Hype Cycle published in 2016

Expansion of printing materials was chosen as one of the ten biggest strategic trends published by Gartner in 2016. It is expected that 3D printer industry will expand as companies manufacture more diverse 3D printing materials to make products that consumers want. As such, 3D printer industry should be able to make use of the graphic design of 3D modeling. As a result, education that cultivates talents required in the 3D printer industry is necessary in the future.

1.2. Research Background and Motivation

We suggest UI that has smaller burden on educator and more easily accessible and intuitive for first-time learners of 3D modeling than the existing 3D modeling tool. The suggested 3D modeling UI is focused on beginners' educational experience that develops spatial ability through solid figure, rather than practical works.

In Korea, there are a lot of education programs that develop spatial ability through mathematics aimed at children's creative thinking power. This is because spatial ability makes recognition of modeling easier. Spatial ability is expressed in coordination ability, perception of shape and background, perceptive persistence, perception of one's one location in a space, perception of spatial relation, visual discrimination, and visual memory, all of which are required in 3D industry. Spatial ability increases creative thinking power as expression of limited shape in two-dimensional plane is expanded to creative expression of hidden shape or mobility [1-3]. As a result, education program that combines creative education, which develops spatial ability of converting two-dimensional information to three-dimensional information, with 3D modeling is increasing. Among these education programs, education that incorporates 3D printing is particularly growing. Users' 3D modeling work is essential for 3D printing. As was mentioned earlier, the use of 3D printer so far has been mostly focused on the production and examination of prototype by designers. Second most used area is hobby and third one is production of certain tools. This implies limited usability. To supplement professional workforce and usability of the 3D printer industry, education of 3D modeling to the public is necessary. The current 3D modeling education is under progress by using 3D modeling tools including SketchUp, Maya, Rhino, Blender, and AutoCAD, which is aimed at learning of practical works. As a result, the 3D modeling education is focused on high school students and adults. Problem appears when applying this kind of 3D modeling education to elementary and middle school students. Not only there are few educators who can teach them with the existing 3D modeling tool, but also teaching requires huge amount of energy. Moreover, the existing 3D modeling tools are too complex for children and hence teaching it by combining with creative education has a lot of difficulties.

Ambient user experience was also selected in the ten biggest strategic trends that were previously mentioned. This means the maintenance of UX environment that makes users identically perceive the Smart device. As such, the current interface largely considers design aspect instead of experience aspect. Hence, it is necessary to change the current UI. However, the concept of "experience" differs according to the product, shape, purpose,

and subject. Hence, it is necessary to design UI by specifically determining the range for experience.

2. Related Literature

Following the recent surge of interest regarding 3D printer, studies aimed at forming 3D model from 2D image for those without professional knowledge on 3D modeling are receiving increasing amount of attention. This 3D model generation scheme is very helpful in that beginners can build 3D model with small amount of efforts by using photographs. However, it is not appropriate for educational part that is aimed at enhancing spatial ability. The meaning of “3D printing” is that consumers create their own product from their ideas and share it by ignoring the current product manufacturing and distribution structure. Through 3D printer, consumers can add design that contains sensibility to graphic technology, which occupies a large area in modern society, and formalize it. “Modeling” that can be obtained from 3D printing can cultivate not only spatial ability, but also emotions. This can be seen in infants whose emotion develops through modeling plays such block play [5]. As modeling factors such as shape, color, and texture can enhance emotional intelligence, education that combines 3D printer and 3D modeling can develop children’s creativity. If education program for 3D modeling improves, it can be linked to education where kinetic art that adds movement to modeling are combined [6-7], improving the creativity and expressiveness of children.

Spatial ability regarding 3D graphic is related to scientific thinking. Inferring a certain shape of an invisible object that is hidden by another object can be linked to seeing a certain shape and inferring its intrinsic information [8-9]. In other words, this is intuitive thinking. According to the education engineering dictionary, intuitive thinking is defined as thinking that draws conclusion without going through a logic process of analysis, comparison, and integration. Moreover, [10] defined that intuitive thinking is a cognition form that instantly accepts things without formal method such as proof. Such intuitive thinking is necessary for mathematics education and creative activity is unlikely to develop without intuition. Hence, we attempted to create writing tool that is appropriate for 3D printing education focused on geometry and 3D modeling for creativity improvement. Strongly motivated by [11], we suggest an intuitive UI that is suitable for novices at 3D modeling. Geometric aesthetics is in modeling and visualization and modeling is closely related to visualization. This is because the process for modeling is visually expressed. Hence, intuitive model is useful for visualizing mathematical fact. Since the writing tool that we attempt to fabricate is a 3D modeling tool that helps geometry education in mathematics, modeling scheme and UI are suggested based on geometric UX. In particular, although studies regarding UX design related to education contents [12-14] are currently under progress, there is scarce study on UX design related to geometry. Considering that UX type affects learners’ immersion [15], it is necessary to build UI design based on geometric experience

3. Existing 3D modeling UI

The existing 3D modeling tools include AutoCAD aimed at designing, Rhino and SketchUp aimed at architecture and product design, Maya and Blender for animation, and 123D Design, which is most similar to our suggesting 3D modeling tool. We summarized these by dividing into modeling scheme, object control, icon design, UI access scheme and other subsidiary functions. Since the functions of these existing modeling programs are very diverse and complicated, they are more suitable for practical workers rather than beginners. Hence, sufficient time for adaption is necessary to deftly handle the program. Analyzing the problems of these programs from an aspect of UI in detail, we put stress on which UI schemes are difficult and inconvenient from the viewpoint of beginners.

3.1. Modeling Scheme

Modeling scheme can be divided into a scheme that generates basic solid figures and forms a model from the transformation of point, line, and surface and a scheme that regenerates model in new shape through calculation among the basic solid figures. In particular, intuitiveness of UI is required in case of the modeling scheme through calculation where mathematical thinking ability can be naturally obtained during the calculation process. First, the scheme of generating model can be divided into two: one is to first generate two-dimensional figure and then convert it to solid figure using model correction function and another is to select solid figures that are basically provided. The type of generating two-dimensional figures and then converting them into solid figures is suitable for design as base side is first defined followed by additional height value. Users can find it in tools that provide modeling scheme using point, line, and surface. The type of generating by selecting solid figure is basically provided in most of the 3D modeling tools including Maya, Rhino, Blender, 123D Design, and AutoCAD [Figure 2]. However, solid figures are generated by putting in the size of generating solid figure in advance or are first generated and then corrected using scaling handling manipulation or parameters. Input of the size of the model that is to be generated can be done by either mouse drag or direct input of size value.

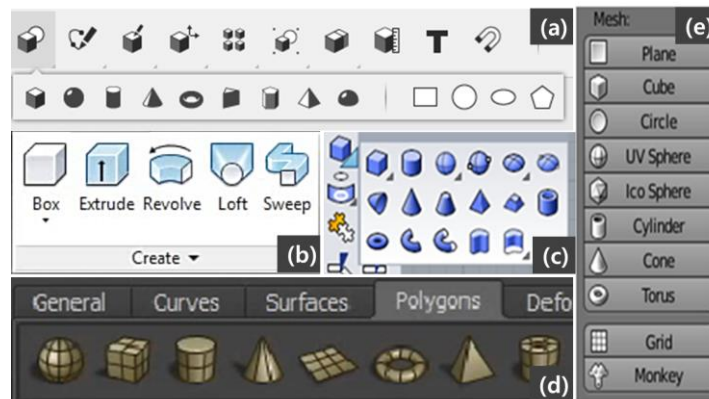


Figure 3. 3D Solid Figure Generation Menu - (a) 123D Design, (b) AutoCAD, (c) Rhino, (d) Maya, (e) Blender

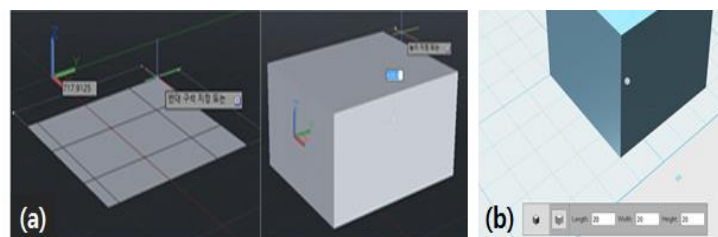


Figure 4. Size Input of Solid Figures - (a) AutoCAD, (b) 123D Design

Drag input scheme such AutoCAD in Figure 3 generates model by minutely selecting desired location and measurement with a mouse. Although it is very suitable for practical workers that require precise process, three times of mouse clicks are required for a single figure generation in the process of generating base side and putting in height. However, when using the scheme as in (b), solid figure can be quickly and conveniently generated without additional input of size as the basic size of figure is determined. Hence, transformation scheme through measurement input after generating figure as in (b) is more appropriate for beginners who has purpose of simple work. After generating a

model by this scheme, model is modified into new shape using model correction function. Model correction can be divided into a method that transforms by selecting and dragging elements of point, line, and surface that compose the model and another method that reforms the model into new shape through Boolean Operation with other objects. In particular, mathematical thinking can be naturally understood through the order and process of object calculation during Boolean Operation. Hence, it is an appropriate scheme for modeling education that uses mathematical thinking.

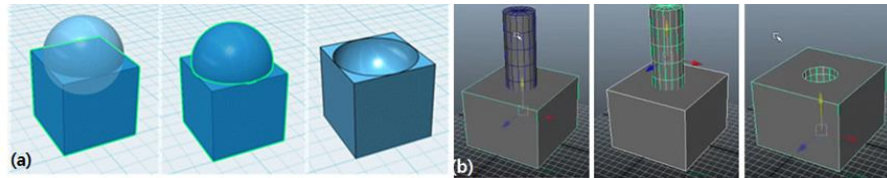


Figure 5. Difference Set of Boolean Operation - (a) 123D Design, (b) Maya

All of the six programs provide Boolean Operation. As shown in Figure 4, computation runs when the first object and second object are sequentially clicked after selecting calculation function. This scheme does not have problem in the calculation process regarding union set and intersection set. However, in case of difference set, completely different outcome is generated according to the order of selecting object and hence process of order selection is very important. However, in case of calculation scheme that sequentially selects two objects, calculation process cannot be checked during the selection process and hence intuitiveness for beginners without understanding about the calculation order is very low.

3.2. Object Control

Handling function for basic affine transform (translation, rotation, and scaling) of object is one of the most frequently used functions in the modeling process. Hence, accessibility should be high and handle selection scheme should be simple in the conversion process compared to other functions. In case of programs other than SketchUp and 123D Design, model can be converted by setting each mode after selecting an object and using handle in three-axis shape that was generated by matching each mode. Generally, translation and scaling handle has a form where figure is attached to the end point of a straight line of three axes and rotation handle is a curve in arc shape that covers three axes.

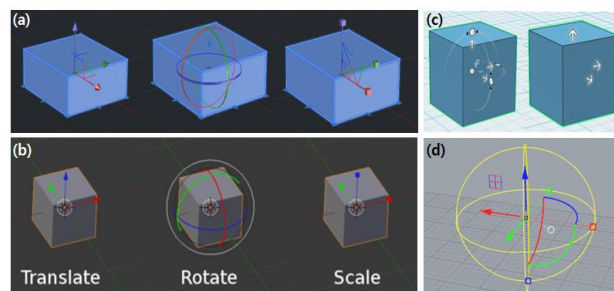


Figure 6. Shape of Three-axis Handle - (a) AutoCAD, (b) Blender, (c) 123D Design, (d) Rhino

As shown in Figure 5, most of the existing programs use a scheme that generates three-axis handle that is differentiated by red, blue, and green RGB colors where the end point of translation and scaling handle, which are confusing, is differentiated by using different figures of triangle and quadrangle. In case of rotation handle, a scheme that generates all arc part of rotation handle can make handling by mouse selection difficult as it has a

shape where three-axis handles are intertwined as shown in (a). Hence, a scheme where handle is generated only in a part that the object is covered from above is better as it makes mouse selection easy as shown in (b). The existing object control scheme that uses three-axis handle can be minutely manipulated by using mouse or keyboard in PC version. However, in case of mobile and tablet programs, accurate selection is unlikely as it totally depends on touch when using handle. Moreover, it has a disadvantage in that convert unit cannot be adjusted in detail. Hence, it is necessary to add another intuitive and simple object control scheme, other than the scheme that uses handle.

3.3. Allocation of Menu Icon

Most of the existing 3D modeling programs have icon menu allocation that occupies more than two lines on the left and upper part of the screen due to their diverse and complicated functions. First-time program users spend a lot of time for understanding all the icons in a screen. Hence, how to allocate icon becomes an important factor that determines the adaptation time of a program. Moreover, making the shape of an icon intuitive and easy to understand by using images that are related to the process of the relevant function is one of the ways to decrease users' adaptation time. As shown in Figure 6, 123D Design uses icons that capture the image of a certain function related to solid figures by using boxes. As a result, beginners can easily conjecture the desired function and use it.



Figure 7. Menu Window where a Variety of Icons Related to 3D Modeling are Allocated - (a) Maya, (b) AutoCAD, (c) Rhino, (d) 123D Design

In case of programs shown in Figure 6, icons with similar function are assembled for allocation by dividing zones inside the menu bar to allocate large number of icons. As shown in (c) and (d), icons are grouped and only the representative icon is displayed and sub menu appears in pop-up when clicking a mouse. Shapes like (c) and (d) are helpful for decreasing program adaptation time for beginners. In particular, in case of 123D Design in (d), the number of icons displayed on the screen is definitely small as only the necessary functions remain by removing additional functions that are unnecessary for beginners. Moreover, it has shorter UI adaptation time than other programs due to grouping of similar functions as users can easily and rapidly find their desired function.

3.4. UI Access Scheme

One important point to be considered in the UI access scheme for beginners is maintaining natural work flow from the currently using function to the next function in the modeling process. Most of the existing programs are cumbersome when using functions related to object in the middle of modeling work as modeling work flow suspends in the process of controlling camera by converting the currently using function.

As for the UI access to camera control, camera should be freely controlled with mouse control only regardless of the currently using modeling function. In addition to camera control, it is important to shrink cumbersome process of diverse functions as much as possible for users' efficiency and convenience.

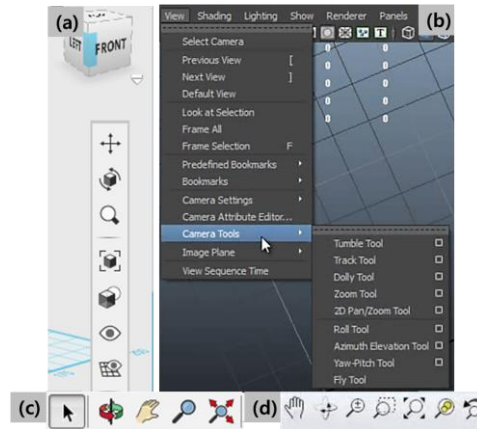


Figure 8. Camera Operation Menu (a) - 123D Design, (b) Maya, (c) SketchUp, (d) Rhino

Most programs provide camera control function by menus as shown in Figure 7. However, frequent menu selection for camera in the middle of work is a very cumbersome process for users. Hence, camera control scheme that uses mouse control regardless of the modeling function should be definitely provided. In case of 123D Design, functions of camera translation, rotation, and zoom-in are provided by using mouse wheel and right button, which enables smooth modeling work flow. Moreover, in case of functions regarding modeling, function that are related to the currently using function are located close to the mouse as much as possible or one-off pop-up menu is made to assist quick work by users.

Moreover, as shown in Figure 9, basic additional functions that are frequently used including object convert handle and material quality correction pop up on the bottom of the screen when object is selected, making the workflow smooth. However, it is inconvenience in that users should search for several important functions related to object including duplication and deletion of object again as they are not included in the additional function that pops up. In case of SketchUp, a function that was selected once is maintained after the use, making it inappropriate for repeated work. However, it is cumbersome to reuse the 'object select' function, which is a default function of most of other programs, since selection menu should be clicked again as shown in Figure 7 (c). However, in case of other programs, function is one-off where it is automatically converted to the default value of object selection function after the use of function, making the connection to the next work smooth.

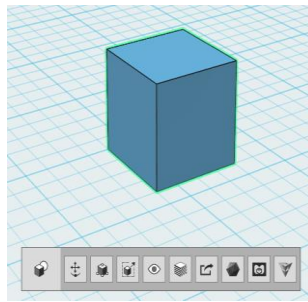


Figure 10. Related Menus in 123D Design that Pops-up when an Object is Selected

3.5. Other Functions

As outcome of modeling is usually linked to 3D printing, a lot of additional functions related to 3D printing are being provided inside the 3D modeling program. In case of 3D printing that generates actual shape different from model, minor errors among the objects completely appear in the outcome. Hence, users should be very careful about small errors among the shapes when modeling. Hence, snap function that removes these errors inside the program is essential. Snap function matches units that are not easily controlled with translation handle and quickly and precisely applies the connection among the objects. Basically, it is divided into automatic snap function that puts the mouse location to a point in a certain distance range when moving or generating an object and manual snap function that directly selects and affixes the parts that users want to connect. Manual snap function is a scheme that conveniently provides snap among objects that are hard and complex to snap with translation only by using mouse click only.

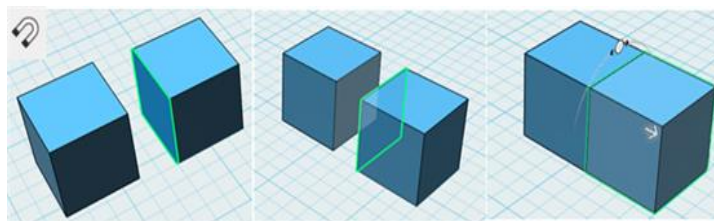


Figure 11. Manual Snap through Surface Selection in 123D Design

Manual snap function in Figure 9 is a scheme that sequentially selects objects that users want to connect. Here, object that translates for snap changes according to the selecting order, calling for an attention for orders when using function. Manual snap function using selection only that is provided in most of the programs is a scheme that users cannot intuitively understand at once without special message. This is the same concept as difference set calculation of the calculation functions among objects that was previously analyzed in modeling scheme. It is important to increase the intuitiveness of UI scheme in the object selection process.

Table 1. Modeling Scheme of the Existing 3D Modeling Program

	Maya	Blender	Rhino	SketchUp	AutoCAD	123D Design
Basic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
CSG	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Provided only in Pro version	<input type="radio"/>	<input type="radio"/>

Table 1 summarizes the previous points by 3D modeling programs. Basic in the modeling scheme means modeling scheme based on point, line, and surface and all of six programs provide Basic and CSG scheme. However, programs except for 123D Design mainly involve modeling scheme based on point, line, and surface and CSG scheme is rarely used as a supplementary tool. On the contrary, 123D Design has main modeling scheme of CSG where basic modeling scheme is a supplementary tool. Method of use is more simply provided than other programs such as making the selected corner smooth with a handle or changing it to curved surface.

Table 2. Types of Object Control of the Existing 3D Modeling Program

	Maya	Blender	Rhino	SketchUp	AutoCAD	123D Design
Basic	-	-	-	Individual	Individual	-
Object	Individual	Individual	All-in-one	-	Individual	Individual

Most of the object controls in Table 2 control affine transform mode by providing separate handle for each of translation, rotation, and scaling. However, Rhino provides these three handles in one, making users conveniently use it without converting the mode. In case of SketchUp, handles are provided on point, line, and surface according to the Affine Transform mode and handle for object is not provided. On the contrary, other programs provide a handle either on object or on point, line, and surface. AutoCAD provide both of the two, increasing the convenience of users. However, it has a disadvantage in that using relevant function becomes cumbersome due to large number of modes on handle. Although it can be conjectured that 123D Design provides handle according to the point, line, and surface as it provides basic modeling schemes, no handle is provided in this case. Instead, it provides handle in translation type for parameter control for subsidiary functions, such as curving of edge or twisting of one side.

Table 3. UI Approach of the Existing 3D Modeling Program

		Maya	Blender	Rhino	SketchUp	AutoCAD	123D Design
Camera	Mouse	○	○	○	○	Command	○
	Keyboard	○	-	-	○		-
Menu	Main Menu	Text	Text, Icon	Text	Icon	Text	Icon
	Sub Menu	Icon		Icon/Group		Icon/Group	Icon/Group
	Pop-Up Menu	-	-	-	-	-	○

As the existing programs are tuned to PC version targeting practical workers, camera manipulation usually takes a form of mouse manipulation only or use of shortcut keys in keyboard. Hence, as was previously mentioned, it is necessary to diminish the use of shortcut keys that beginners cannot easily understand and multiple clicks (touch) in all versions of PC, mobile, and tablet. Moreover, examining not only UI access for camera manipulation, but also access types for use of other functions, most have tab type where main item is distinguished by text and sub functions are made as icon in Table 3. Hence, beginners have difficulties in accessing when there are a lot of subsidiary functions or the intuitiveness of an icon that represents the relevant functions is low. In case of Rhino, AutoCAD, and 123D Design, similar functions are grouped to be provided in menu so that users quickly find the functions they want to use. Moreover, 123D Design has pop-up menu of frequently used functions used for modeling that appears when an object is selected, which decreases time for users to search for the relevant function. Other programs also provide pop-up menu through mouse click or shortcut keys. However, they were not summarized in Table 3 as they are not pop-up menus by object selection.

Table 4. Analysis of Snap Function of the Existing 3D Modeling Program

	Maya	Blender	Rhino	SketchUp	AutoCAD	123D Design
Grid	Shortcut Key	Shortcut Key	Available under function setting	○	○	○
Object	-	-	Available under function setting (it only uses point as a standard)	-	-	○

Snap function is essential function as minor errors in modeling appear as it is in the outcome. Hence, grid snap automatically applies without additional setting in SketchUp, AutoCAD, and 123D Design that are directly related to design [Table 4]. However, it is applied in Maya and Blender under the condition of shortcut key push in case of object generation or translation and it is applicable in Rhino after activating the relevant function. However, only Rhino and 123D Design provide object-oriented snap function. In Rhino, snap among objects takes place centered at point that composes an object or center points after activating the function, similar to grid snap. In case of 123D Design, snap among objects takes place centered at the selected point, line, and surface that are to be contacted. Programs other than Rhino and 123D Design do not provide snap among objects because standard can be met by translation through grid snap. Hence, users can directly adjust the distance through object translation.

Most of the existing modeling programs are focused on practical works and hence have functions that are complicated and hard to understand, calling for long program adaptation time. Moreover, visual UI that helps understanding about the calculation or the selection order in the process of function that sequentially select object such as snap. Hence, beginners without fundamental modeling experience can have difficulties in using the relevant functions.

4. Suggested 3D Modeling UI

4.1. Modeling Scheme

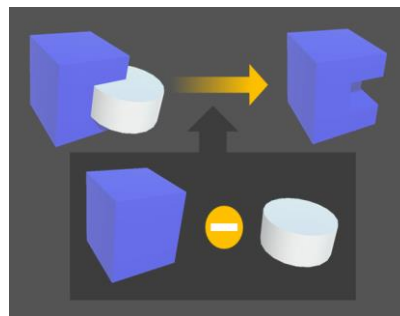


Figure 12. CSG Scheme Modeling

Mathematics education for children include a part where children infer cross section of a solid figure or infer solid figure by looking at a cross-sectional diagram from right, left, top, and bottom side. This is geometric education that improves spatial ability and visualization ability through solid figure. We suggest CSG (Constructive Solid Geometry), which is one of the 3D modeling schemes that are based on block play focused on geometric features, [16-18] as a 3D modeling scheme for beginners. CSG refers to a modeling scheme through logic calculation. As CSG modeling scheme Figure 10 forms the shape of solid figure based on union, difference set, and intersection calculation among the solid figure, those who have no previous experience in modeling can easily

think and compose a shape among figures. Hence, it can be said to be not only appropriate for geometry education, but also an intuitive modeling.

Not only the CSG modeling scheme, but also rotation modeling scheme that is generated centered at a single point or an axis is necessary in the geometry education. Setting of center for rotation figure is the same as the scheme for object rotation that will be mentioned later.

4.2. Object Control

Although generation, transformation, and deletion of object are important functions in 3D modeling, handle is essentially required for this. Handle is a necessary function for users to control Affine Transformation such as location, rotation, and scaling of object. As was shown in the analysis of the existing 3D modeling UI in previous chapter, handle is expressed in similar shape in most cases as well. As such, UI of handle is an intuitive form in the 3D modeling tools. Hence, we suggest a scheme where users can intuitively make affine transformation of object, in addition to fundamental handle.

4.2.1. Location

In case of location conversion of object, beginners can easily translate object if it is based on user experience of block play. In case of object manipulation in PC version, users can appoint their desired location accurately thanks to the diversity of buttons and movement of mouse and keyboard button keys. However, in case of mobile and tablet version, accuracy is remarkably lower due to the manipulation scheme that only depends on touch [19]. Hence, modeling writing tool is required to maintain ambient user experience regardless of the version of writing tools by matching the features of 3D printer and geometry education. The 3D printer is capable of minute expression of model by accumulating layers in 0.1mm unit using nozzle that sprays 3D printing materials and has 0.4mm caliber. According to these characteristics, grid snap is applied in 0.1mm distance in Z axis and 0.4mm distance in X axis and Y axis for the location translation of object through handle. These values are minimum distance when users want precise modeling. Translation of object by unit smaller than this makes expression in 3D printer difficult. Moreover, geometric access to 3D modeling is more important for beginners. Hence, distance of grid snap is determined by users. Object translation through grid snap is shown in Figure 11.

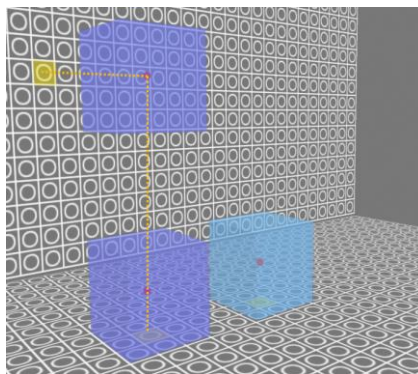


Figure 13. Translation of Object through Cell Selection of Grid Snap

Here, sky blue color expresses original location of the object, violet color expresses translated object and yellow color expresses cell that user selected. When a relevant cell is clicked according to the grid snap, translation takes place by receiving the location value of the cell as coordinate value of the object. Figure 11 shows the translation first by X and Y axis and then by Z axis.

4.2.2. Rotation

Rotation in modeling can be expressed in three forms: rotation on the center of weight of the object, rotation on a single point, and rotation on a random axis. The existing 3D modeling tools basically express handle so that X, Y, and Z axis can be rotated using center of weight as a pivot and provide additional functions for the case of rotation on a single point or an axis. However, the suggested scheme provides two types of rotation: one centered at the center of weight of the object and another centered at a single point. This scheme rotates an object clockwise or counterclockwise using an axis that connects the center of weight or one point designated by the user and the camera location. Since this scheme basically is rotation by axis, both of rotation on a point and rotation on an axis can be expressed according to the user setting (center of weight or a single point) [Figure 12]. Moreover, as precise control is difficult in case of mobile and tablet, the suggested scheme makes beginners easily rotate an object. Rotation basically takes place centered at the center of weight of the selected object and camera where user selects a point in point setting mode and the object rotates on the selected point and camera. We call snap centered at camera as camera grid where users can select one point for rotation, similar to grid snap function [Figure 13]. This refers to a cell plate formed by grids as shown in the right side figure in Figure 12.

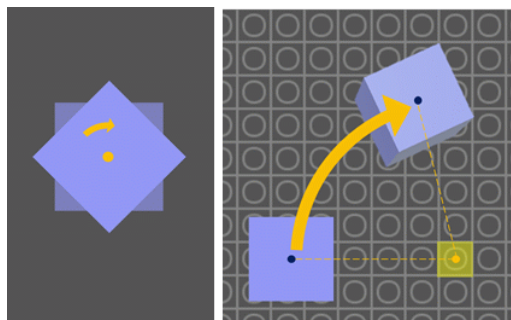


Figure 14. Rotation Using the Center of Weight and Rotation Using One Point/Axis

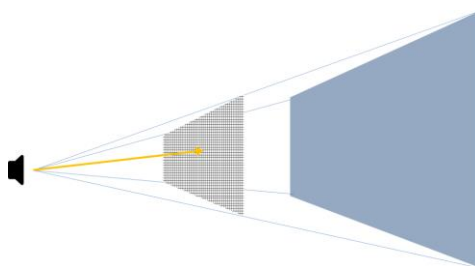


Figure 15. Camera Snap that Lets Users to Designate a Single Point from Camera Direction

The suggested rotation scheme has difficulties in re-correcting according to the camera location and center point when users want to check the object location from another camera angle and reform it. To solve this problem, Undo/Redo function is essentially necessary. Different from the existing Undo/Redo function, Undo/Redo function here enables users to modify rotation by storing information of camera location and center point as well.

4.2.3. Scaling

Scaling is done on each of X, Y, and Z axis according to the grid snap distance designated by the user. As for the match of scaling to grid snap distance, beginners can relatively easily match the distance between objects, similar to the magnet function that connects surfaces of different object in the existing 3D modeling tool. Moreover, users can predict the size of their model based on the previously set grid snap distance and cell number, which enables formation of model according to the standard of the 3D printer that is to be used.

4.3. UX/UI

We suggested CSG scheme for 3D modeling centered at user experience on geometry education. Although CSG is provided by the existing 3D modeling tool, users have difficulties as the used scheme is different from mathematical experience. Previously, model was formed by Boolean Operation after selecting an object that becomes a baseline and another object where function will be applied. This scheme is applicable not only in 3D modeling tool, but also in 2D design such as Illustrator by Adobe. As it is computed according to the order of object that users carelessly selected, users who are not familiar with this function have difficulties. Hence, we suggest a scheme that applies this to the shapes of variable (1), symbols, and variable (2) that are frequently observed in mathematics. That is, Boolean Operation symbols for modeling automatically appear when users select an object. CSG modeling scheme is applied when selecting an object that corresponds to the second variable after selecting symbols that are to be applied. Symbols in Figure 14 were used to express union, difference set, and intersection.



Figure 16. Icons for Boolean Operation

Moreover, different from the existing UI that places icon mainly on the left or top, icons for object generation are displayed on the top left and icons related to modeling are displayed on center right. Movement, rotation, and stretch icons for affine transformation are displayed on the bottom left and function of Undo/Redo is displayed on top right. In case of mobile and tablet devices, users use the device by putting it on the floor or grabbing it with one hand and people who use right hand is dominant. This is to prevent unnecessary touch of icon. However, the reason that icon for affine transformation is put on bottom left is to make users control an object with right hand and make handle convert for translation, rotation, and scaling with left hand when using tablet that is larger than mobile device

5. Conclusion

We proposed UI for writing tool specialized in 3D printing for the education program that combines mathematical geometry and 3D printing so that beginners can intuitively understand solid figure and make 3D modeling.

Existing 3D modeling tools have complicated functions that are hard to understand as they are made for professionals. Hence, beginners need a lot of time for getting familiar with the program. We attempted to decrease the program adaptation time of beginners by proposing an intuitive and simple UI for modeling process or function use. As for the modeling scheme for this, we suggested that beginners use CSG so that visually predictable outcome can be obtained in modeling work through solid figures. Here, function operation for Boolean Operation should be transformed according to the

mathematical experience using equation. Object manipulation that is important in modeling tool not only makes manipulation through handling, but simplifies translation and rotation by providing grid snap and camera grid. Simplification here means that translation and rotation are made possible through one or two axes, instead of three-axis translation and rotation by handle. Moreover, it is made more appropriate for the 3D printer education as users can control grid snap and camera grid function for 3D printer standard and make precise modeling or change the level of difficulty according to cell size. Although the shape can be seen as inconsistent with the existing 3D modeling, understanding of the function was maintained in other tools by maintaining the icon design similar to the existing shape. As such, our suggested modeling scheme and manipulation are expected to be relatively easily adaptable for those who use 3D modeling for the first time without experience of general UI of 3D modeling. However, there is a problem that user adaptation of the suggested scheme cannot be compared with other writing tools as we could not conduct user test. Hence, we plan to transform UI of the writing tools that have been developed so far into the suggested scheme and test the performance. Through this, we plan to expand UI that fits 3D modeling education for beginners.

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