Learning to Create 3D Models via an Augmented Reality Smartphone Interface

Jeff K.T. Tang
School of Computing and Information Sciences
Caritas Institute of Higher Education
Hong Kong
jeff.tang@ieee.org

Tin-Yung Au Duong, Yui-Wang Ng, Hoi-Kit Luk
School of Science and Technology
The Open University of Hong Kong
Hong Kong

***Abstract*—The ordinary way of creating 3D models (a.k.a. 3D modeling) requires people to sit in front of the computer for a long time working with professional software. The license fees of these software are expensive, and it is very time consuming and not easy to learn. Teachers sometimes find difficult to teach students the concept of 3D modeling because the newbies need to spend a lot of time to familiarize with the tool interface beforehand. In this paper, we introduce a mobile application that assists students to learn 3D modeling skills and concepts. We provide a natural modeling style with the aid of Augmented Reality (AR). Through a smartphone user interface, the user builds a model with primitive blocks in a "bottom-up" manner like "LEGO" bricks. These blocks are visualized on the printed marker cards that allow users to manipulate (rotate, translate, etc.) them in the same way of manipulating real building blocks. User studies have been conducted and we have identified some aspects that help people to model 3D objects.**

Keywords—Augmented Reality; 3D Modeling; Mobile Learning; Interactive Learning; Smart Education

I. INTRODUCTION

It is always difficult to teach student the concepts and skills of 3D modeling. Normally, we need to master the ordinary 3D modeling tools such as 3D Max, Maya, etc. The licenses of professional grade 3D modeling software are always expensive. Even though people want to make a simple 3D model, they need to take courses and spent a lot of time to practice in order to master the 3D modeling skills. It is desired for the students to learn simple concept such as functional elements, dimensions, positions, orientations etc. of 3D modeling in simple way first [1], before they are stepping into the world of professional 3D modeling.

In this paper, we propose a mobile application that eases the process of creating 3D models, which aims at easing and attracting students to learn the 3D modeling concepts and skills. It is a mobile application that incorporates with Augmented Reality (AR) capability. It aims to make the 3D modeling easy, in a WYSWYG manner. We adopted a "bottom-up" modeling approach: with different AR markers (that represents different primitive shapes) as shown in Fig. 1, students can build 3D models by putting these primitive shapes together in order to form a bigger model, with their hands just like playing with "LEGO" bricks.

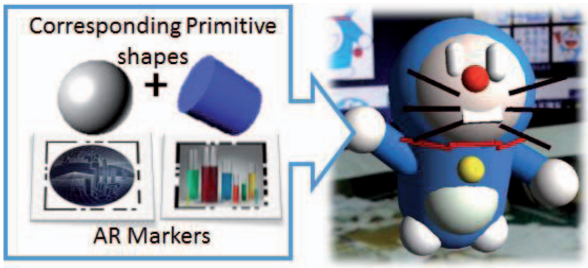


Fig. 1. Through manipulating the printed AR marker cards on hand, user can call the corresponding primitive shapes and construct a bigger 3D model.

We are not going to replace professional 3D modeling tool. Professional tools can make very detailed 3D objects but people need to spend lots of time to do tedious operations. Many people may lose their interest during early learning stage and dropout the course. In contrast, our tool provides a natural and hence easy-to-use way for 3D modeling. We aim at easing the process of creating simple 3D models and hence attracting people to learn 3D concepts and modeling techniques. We are not targeting on expert users who are going to make fine 3D objects.

The paper is organized as follows: Section II will compare and contrast the existing applications and related research. The user interface and functional operations of our proposed application will be introduced in Section III. In Section IV, we will evaluate the result after user studies, followed by discussions and suggestions. Finally, we conclude the work with possible future extensions.

II. RELATED WORK

Researchers has long been studied the ways to ease the 3D modeling process. Igarashi *et al.* [2] proposed Teddy that provides a novel drawing interface for users to create 3D models by 2D sketching. Their system is capable to convert the drawn 2D stokes into 3D polygonal meshes automatically. Besides, users can manipulate the 3D model with simple stroke gestures e.g. drawing a single straight to cut the model into parts. However, Teddy did not provide zooming in/out functions so the user cannot view a point-of-interest for refinement. Also, the 3D models created by Teddy are mono-colored. If the users want to paint it with more colors, they have to use third-party software. Furthermore, Teddy users cannot draw parts and merge them together as physical toy bricks do.

Chameleon [3], the enhanced version of Teddy, proposed by Igarashi and Cosgrove considers a 3D model is consisting of parts. In every time the user has modified the model, a texture bitmap image is generated that marks which meshes are affected, and the algorithm groups them together in respond to the user manipulations. 2D sketching is simple and portable as it can be running on tablet PC, which has an advantage that allows users sketch-to-create 3D models anywhere [4] but it restricts the user in 2D world because they have no idea about the positions, orientations, and distances between the smaller parts in a 3D model.

Recently, interactive technique has been a popular research direction and more applications with Natural User Interface (NUI) are introduced. NUI emphasized on "hands-free", i.e. the users do not need to interact with computer systems via a physical controller [5]. Instead, they can interact with the computer via everyday interaction such as movement, etc. Diniz and Branco [6] proposed a tool that able to capture 3D freehand drawing. Two red LEDs are attached to each of the user's hands. When the hands are moving, the images of different planes are recorded and the algorithm combines the result into a final model. However, the quality of this tool is quite low. The NUI technology breaks through the traditional 2D interface like Teddy, and enables users to interact with virtual world just like everyday interaction. In particular, Augmented Reality (AR) has been a popular technique for such kind of interaction. Bazzaza *et al.* [7] proposed an immersive AR (iAR) smartphone application that overlays additional multimedia content on top of the pictures in a book.

According to a recent survey [8], AR has been popularly used in medical visualization, maintenance and repair, annotation, robot path planning, entertainment, and military aircraft navigation and targeting. AR is a technique that overlays real world and the virtual world together [9]. Some AR application uses printed markers, which are small square card boards printed with black-and-white patterns. AR provides an interface for people to interact with virtual objects. Users can interact or manipulating with the 3D model by playing with the marker cards. There are some AR applications allows users putting premade 3D models together and overlaying on the real scene. The tool proposed by Tang et al. allows user placing the 3D furniture models onto the real scene displayed on a computer screen, and the system is capable to suggest an optimal arrangement of the furniture [10].

There are some markerless AR applications, which the 3D scene is solely identified by computer vision methods without the aid of printed markers. These methods are convenient and able to be applied to augment a larger scene. For example, Prasad et al. proposed a markerless AR mobile application for interior decoration [11] that allows user placing the 3D furniture models in the real world scene without using printed markers. Up to recently, the markerless AR methods are not mature and stable yet because a lot of computation power is needed to recognize and match parts of interest in a real scene. Structural information provided by the depth camera might be useful to enhance scene recognition in markerless AR [12].

AR technology may help in 3D modeling applications. Lau et al. introduced an application on a wearable device that allows user to create virtual 3D furniture by placing different primitive components together [13]. The wearable device is looking like a helmet (or a pair of glasses) with small monitors that display the AR scene in front of our eyes. They divide the printed AR markers into "tool markers" and "component markers". Similar to a carpenter, the user has to pick a component and then pick a tool for desired manipulation function. This provides a very good interaction experience to the users because they can directly move and rotate the virtual components with the printed marker cards. On the other hand, users may always interact with the objects by touching them on the screen directly. ARkanoid [14] is a smartphone 3D AR game. Player needs to controls the paddle by touching, to prevent a ball from falling from the playing field, attempting to bounce it against a number of bricks.

We believe that the hybrid approach (screen-touching with AR marker method) would be pleased by novices who want to learn 3D modeling.

III. The Proposed 3D Modeling Application

In this section, we are going to introduce the user interface design and the functional operations of our proposed 3D modeling/learning application.

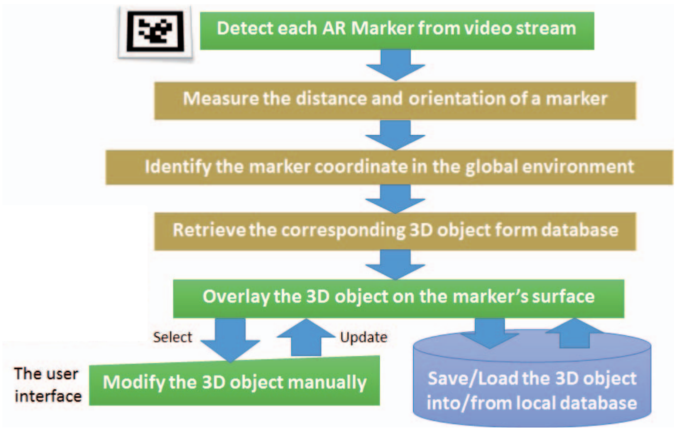


Fig. 2. An example 3D chair model that the users are told to built with the assigned tools in the different experiments.

Fig. 2 gave the overview flow of our proposed application. First of all, the camera captures the real scene into video stream and identifies the printed AR markers. And then, our tool measures the distance and estimates the orientation of the markers, follows by identifying their global coordinates. These steps prepare for recognizing the marker patterns and the latter overlaying step. Next, the patterns of the captured and aligned markers are processed and matched with the database, and the corresponding 3D objects are retrieved. Finally, the objects are overlaying onto the markers in the real scene. With the smartphone interface, the users can move the markers and touch the screen in order to modify the 3D models in real-time. The user can save the modified 3D models into database for future use or sharing them elsewhere.

There are a few advantages of implementing our application on smartphone platform rather than PC platform.

Firstly, it is ubiquitous. A mobile phone is just like a portable video camera, which enables people to create 3D models anytime and anywhere, e.g. in a classroom. Secondary, the mobile application connects users and virtual world with its touch screen capability, which provides a greater interactivity in 3D modeling. In the past, people can just use mouse and keyboard. Thirdly, smartphone offers a natural-to-be interface for AR applications, as it allows the users to interact (e.g. touch) the 3D objects through the screen. It is similar to our everyday interaction with real objects. Altogether these features enhance users to learn 3D concepts and model 3D objects as easy and natural as everyday interaction.

A. Interface Design

The proposed application is implemented on top of the state-of-art technologies. We used Vuforia Augmented Reality toolkit [15] for AR marker recognition, and OpenGL ES [16] and Unity3D [17] (which are professional 3D frameworks) for rendering the 3D models. Fig. 3 shows the patterns of the markers and their corresponding 3D primitive shapes. Since Vuforia toolkit is able to recognize color patterns, we selected some everyday colored object patterns to represent each shape.

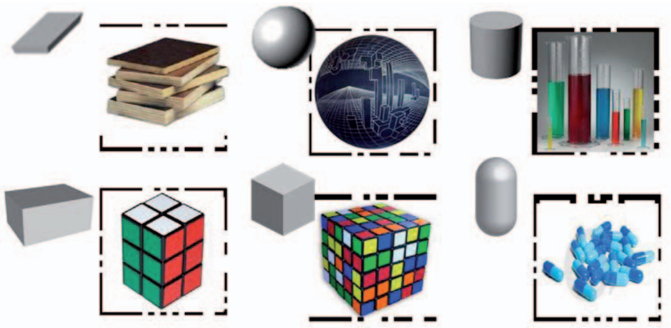


Fig. 3. The AR markers and their corresponding 3D primitive models.

Our tool provides users a natural way of 3D model creation. We adopted a hybrid AR interaction, where the user can touch the smartphone screen and pick the interested AR marker with their finger. User can touch the screen to control the system, for example, touching a button for selecting a special function on the menu shown on screen. As shown in Fig. 4, three perpendicular lines visualize the x-y-z- axis in reference to a primitive shape. It helps user to align the current shape with others and hence the small parts can be put together easier.

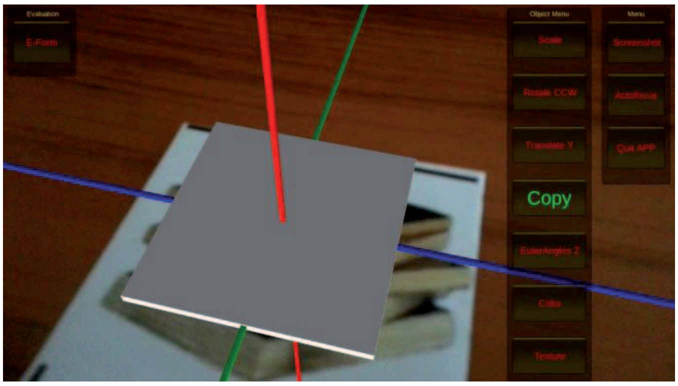


Fig. 4. An example 3D chair model that the users are told to built with the assigned tools in the different experiments.

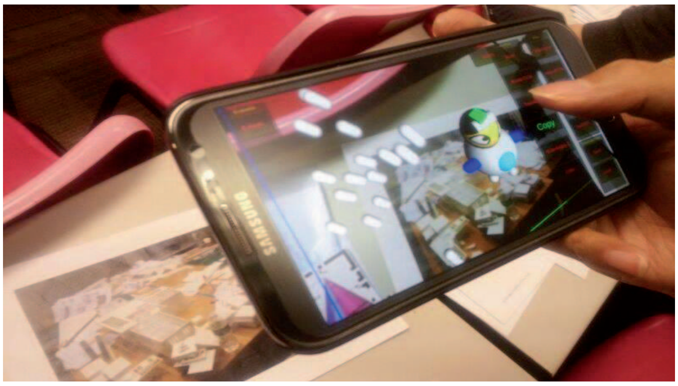


Fig. 5. The photo shows how the user select the functions when creating the 3D model. The primitive shapes and the model are overlaying on the real scene and the result can be seen through the smartphone screen.

B. Operations

In this part, we are going to describe what functions our tool provides for model creators.

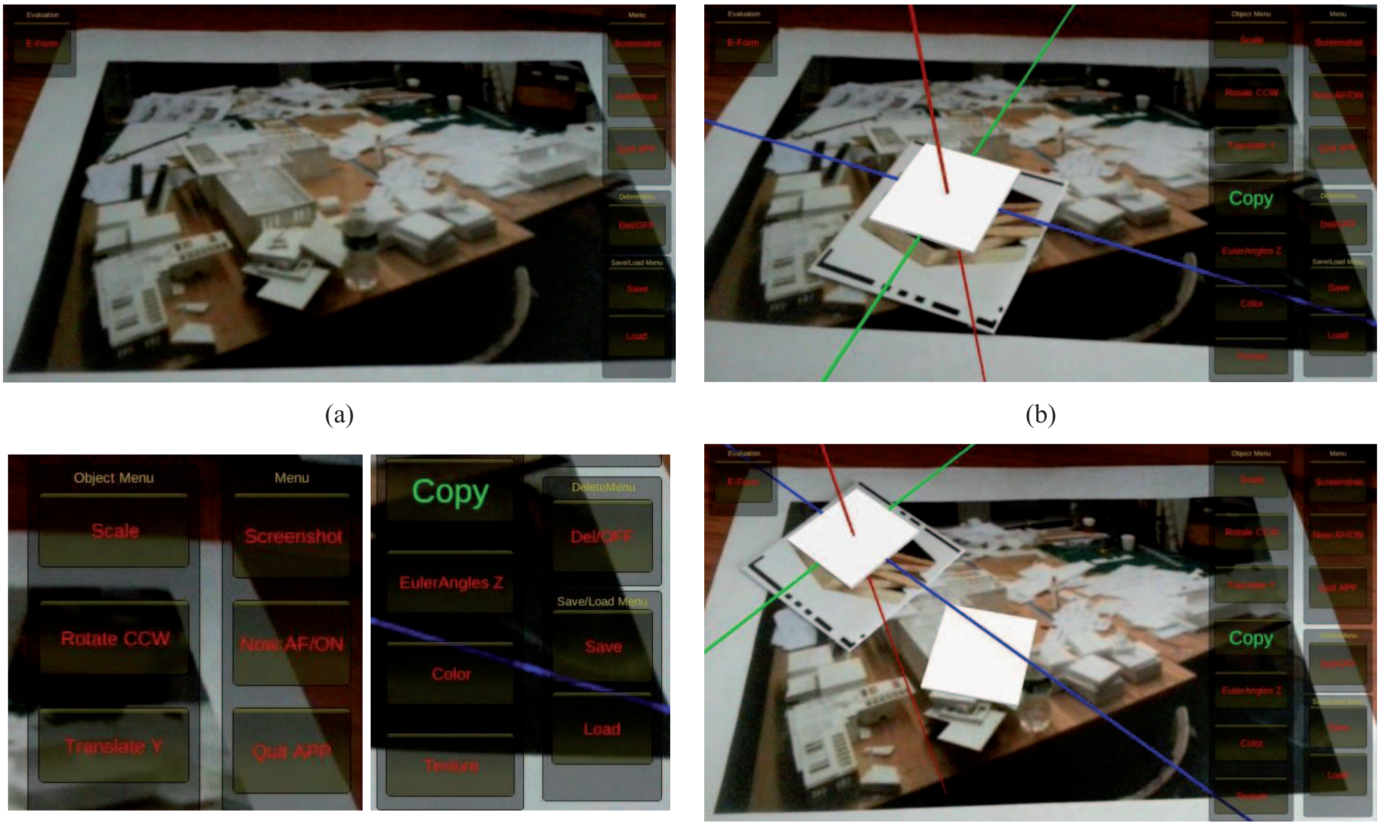
First of all, the user should place a cutting-mat marker, which is an A4 size printed picture, on the table as shown in Fig 6(a). Its center point serves as the origin of the virtual world, which is the reference point of all the primitive shapes and the final model.

And then, the user has to move the printed AR markers to the desired 3D position by hand. The video camera of the smartphone keeps tracks the cutting-mat marker and other AR markers in use, and then renders the corresponding 3D model on the screen. Fig 6(b) showed the situation when a square tile model is retrieved and moved along the position and orientation of its AR marker.

At this moment, the function menu will be popped up on the right hand side automatically. In the setting, we provided an option for the left-handed user to change the menu to left hand side. To build a 3D model in "bottom-up" way, people always need to call the copying function. Hence, by default we highlighted and placed it at the middle of the menu so the user can access to this function easily.

We provide vital manipulation functions as shown in Fig. 6(c), such as rotation (change the orientation), translation (change the positions), scaling (change the size of the object), texture changing, color picking tool, copying (replicate a primitive model), deleting (remove the selected primitive model), as well as saving and loading a model to/from a file. Besides, we provide screen capturing and auto-focusing functions. The latter function is very useful especially when the lighting condition is not so good. Fig. 6(d) showed that a primitive shape is duplicated after tapping on the copy function.

Besides, it is quite user-friendly that most of the buttons are placed in the right hand side as shown in Fig. 5. Hence, the user can play with the AR markers using left hand while press the button using right hand at the same time. After that, users can create their own model like this. The menu can be set to the left hand side in order to take care of the left-handed users.



(a) (b)

(c) (d)

Fig. 6. The major operations provided in our proposed application. (a) a *cutting-mat* marker is placed on the table, and capturing by the video camera of smartphone; (b) ; (c) vital manipulation functions are shown. The *copy* function is highlighted and let the user access to it easily; (d) a primitive shape is duplicated after tapping on the *copy* function.

IV. Experiment and Results

In this section, we are going to evaluate the performance of our proposed application. A user study has been conducted to investigate how the users feel when using our application to create a 3D model as compared to existing tools.

We have invited twenty users, and divided them into two groups of ten. They are university students and most of them were taking Computer Graphics course when they were participating in this experiment. These users are required having plenty of experience in using personal computers and smartphones. Each group is told to create a 3D chair model like the sample shown in Fig. 7 with different tools: one uses our proposed tool while the control group uses ordinary UNITY 3D.

We choose UNITY 3D as the ordinary tool used for control experiment because its user interface is relatively simpler than other 3D software. To make the result fairer and comparable, we provided guides and steps for both groups that sufficient for them to make the 3D chair model.

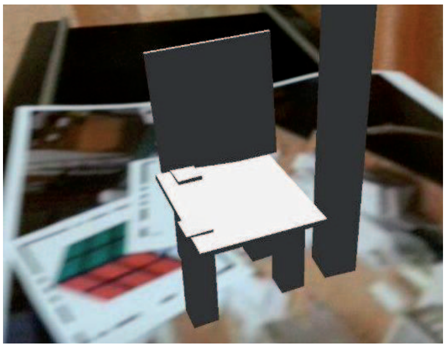


Fig. 7. An example 3D chair model that the users are told to built with the assigned tools in the different experiments.

In the experiment, we counted the time spent by each tester for creating the 3D models. Afterwards, they are told to fill up a post-experiment questionnaire. They are told to rate the statements, which are about their learning and usage experience, in a 7-point scale. The more they agreed with our statement, the higher they rate it. The statements are listed in Table 1.

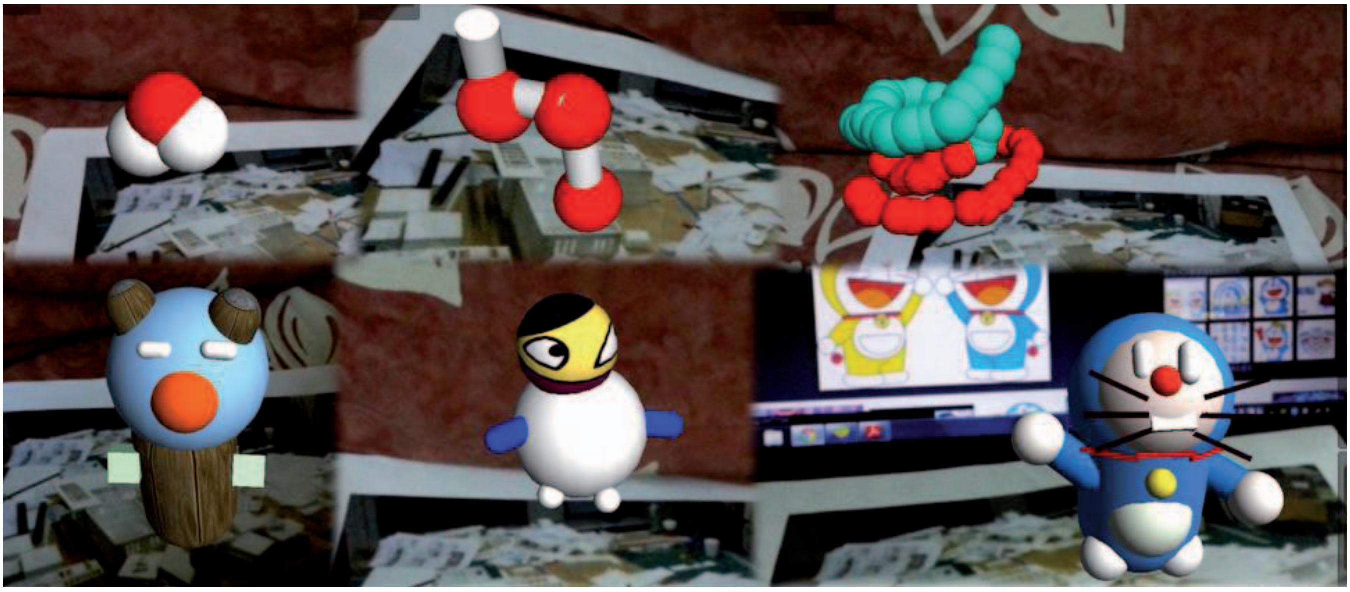


Fig. 9. Some practical and challenging 3D models created with our proposed tool.

TABLE I. THE QUESTIONNAIRE STATEMENTS

#	Questionnaire statement
1	The 3D modeling user interface is natural
2	It makes 3D modeling as natural as playing with LEGO bricks
3	I can master the tool and learn 3D modeling in a short time
4	It is easy to use
5	I satisfy with the 3D chair model I built
6	I believe that this tool is able to build complicated models
7	I would like to learn/play with this application again
8	The marker recognition is fast and accurate

A. User Studies Results

The result of user studies is shown in Fig. 8. The users felt our application makes 3D modeling process as natural as playing with LEGO bricks. This can be reflected in the first two questions. Our proposed tool received a score of 6.2 in question 2 while ordinary tool got a score of 4.9 only.

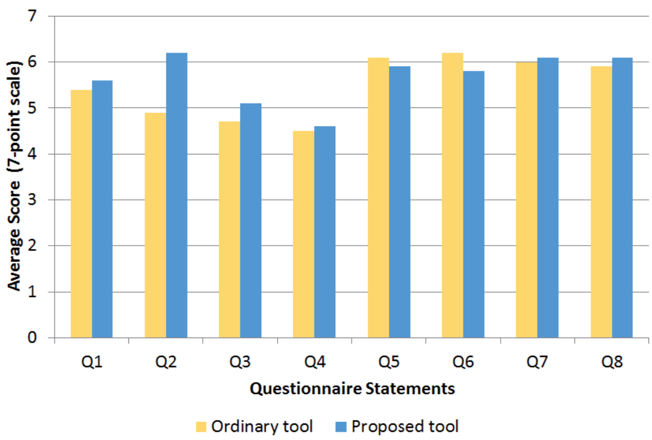


Fig. 8. From average score questionnaire statement

Question 1 asked the users to rate the naturalness of the usability in general, which received a score of 5.6 while ordinary tool got a score of 5.4. This supports this argument of question 2 too. One user verbally commented that the single-handed operation design is easy to handle and he can free one hand to move around the printed markers in the modeling task.

In our design point-of-view, the operation menu is simplified and the related functions are popped up automatically. This argument is supported by question 3. Our proposed tool received a score of 5.1, which is slightly higher than the ordinary tool (score = 4.7). Hence, the users have a stronger believe that they can master our tool and learn how to create 3D models in a short time, as compared to whom in the controlled experiment.

However, the scores of both experiments are very similar in questions 4 to 8. Especially, they are satisfied with the stability of the system and they are feeling good with our tool and willing to learn 3D modeling with it again. In overall, our proposed tool and ordinary tool (e.g. Unity 3D) received scores of 5.7 and 5.4 respectively, which are very similar. We are not going to compete with Unity which is a very mature professional tool. We just want to figure out which aspects the user enjoys learning 3D modeling, and to see which aspect could assist them to learn 3D concepts.

Our tool can be used to build complicated models. Fig. 9 shows some challenging 3D models made by our users after they have using our proposed tool.

B. Discussion

We have identified some aspects that help people to model 3D objects. Firstly, visual clues are important for them to estimate the distances in each dimension. Our tool is interactive and allows the user to manipulate the 3D objects via physically manipulating the printed markers. Hence, we displayed the *x-y-z-* axis on the each on-focus primitive shape. It provides the capability for user to align objects by eye more easily. Also, they could estimate the distance between the current object with others.

Auto-alignment would be useful too. Just like the magnets, sticking nearby surfaces together without overlapping and gaps could make the 3D modeling process faster and more accurate. In the user study, a few users noticed the advantage of this kind of function and suggested us to include this in the next version. However, in current version we did not provide this capability. We noted it as one of our future enhancements. Not the least, we will apply our proposed tool in education, entertainment and training [18].

V. CONCLUSION

We proposed a mobile application that offers a natural modeling style with the aid of Augmented Reality (AR), which could help students to learn 3D modeling skills and concepts more easily. We adopted a "bottom-up" modeling approach, such that users can build a 3D model with putting primitive blocks together like "LEGO" bricks, by rotating and moving the printed marker cards with their hands. The user studies showed that the users felt our user interface is more natural than traditional desktop 3D modeling applications. We have identified some aspects that help people to model 3D objects. For example, visual clues are important for them to estimate the distances in each dimension. Besides, users suggested auto-alignment would make the 3D modeling more efficient.

As future work, we will extend the proposed tool into serious games. For example, students can use it to learn atomic structures in a more fun and interactive way in Chemistry lessons. Moreover, we will adopt this tool to wearable devices like the Microsoft HoloLens [12] that would lead users to a more natural interaction with the 3D models and building blocks using both their hands. Also it would be a good idea to add physics property to the model in order to achieve a better merging of model parts [19].

REFERENCES

[1] H. Otto, and F. Mandorli, "A framework to support 3D explicit modeling education and practice," Computer-Aided Design and Applications, vol 12, issue 1, pp. 104-117, 2015.

[2] T. Igarashi, S. Matsuoka, and H. Tanaka, "Teddy: a sketching interface for 3D freeform design," In Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH), pp. 409-416, 1999.

[3] T. Igarashi, and D. Cosgrove, "Adaptive unwrapping for interactive texture painting," In Proceedings of the 2001 Symposium on Interactive 3D graphics (I3D), pp. 209-216, 2001.

[4] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent advances in augmented reality," IEEE Computer Graphics and Applications, volume 21, issue 6, pp. 34-47, 2001.

[5] J. Moeller, and A. Kerne. "ZeroTouch: an optical multi-touch and free-air interaction architecture," In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12). ACM, New York, pp. 2165-2174, 2012.

[6] N. Diniz, and C. Branco, "An approach to 3D digital design free hand form generation," In Proceedings of Eighth International Conference on Information Visualisation (IV), pp. 239-244, 2004.

[7] M. Bazzaza, B. Al Delail, M. Zemerly, and J. Ng, "iARBook: An Immersive Augmented Reality system for education," In Proceedings o the International Conference on Teaching, Assessment and Learning (TALE), pp. 495-498, 2014.

[8] R. Azuma, "A Survey of Augmented Reality," Teleoperators and Virtual Environments 6, 4, pp. 355-385, 1997.

[9] J. Tang, and J. Tewell, "Emerging human-toy interaction techniques with augmented and mixed reality," Mobile Services for Toy Computing, P. Hung Ed., Springer, pp. 77-105, 2015.

[10] J. Tang, W. Lau, K. Chan, and K. To, "AR interior designer: Automatic furniture arrangement using spatial and functional relationships," In Proceedings of the 20th International Conference on Virtual Systems & Multimedia (VSMM), pp. 345-352, 2014.

[11] P. Renukdas, R. Ghundiyal, H. Gadhil, and V. Pathare, "Markerless augmented reality android app for interior decoration," International Journal of Next Generation Computing Application, 1:7, pp. 12-17, 2013.

[12] Microsoft HoloLens. (2015). [Online] Available: https://www.microsoft.com/microsoft-hololens/en-us

[13] M. Lau, M. Hirose, A. Ohgawara, J. Mitani, and T. Igarashi, "Situated modeling: a shape-stamping interface with tangible primitives," In Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction (TEI '12), pp. 275-282, 2012.

[14] S. Markus, and B. Lee, "ARkanoid: Development of 3D game and handheld augmented reality," International Journal of Computational Engineering Research, vol 2(4), pp. 1053-1059, 2012.

[15] A. Simonetti Ibañez, and F. Josep Paredes, "Vuforia v1. 5 SDK: Analysis and evaluation of capabilities," Master Thesis. Universitat Politecnica De Catalunya, 2013.

[16] K. Pulli, T. Aarnio, V. Miettinen, K. Roimela, and J. Vaarala, "Mobile 3D graphics: with OpenGL ES and M3G," Morgan Kaufmann, 1st ed., 2007.

[17] R. Creighton, "Unity 3D Game Development by Example: Beginner's Guide," Packt Publishing, 2010.

[18] D. Van Krevelen, and R. Poelman, "A survey of augmented reality technologies, applications and limitations," International Journal of Virtual Reality, 9(2), pp. 1-20, 2010.

[19] N. Imbert, F. Vignat, C. Kaewrat, and P. Boonbrahm, "Adding Physical properties to 3D models in augmented reality for realistic interactions experiments," Procedia Computer Science, vol. 25, pp. 364-369, 2013.