

An Exercise Book for Learning 3D Projection Mapping Content Creation

Qinglian GUO, CHADANI Takumi, TAKEUCHI Kota

Projection mapping is a new application area where computer graphics, design, and psychology interest. In such area, there are many unique problems that we encounter for the first time. In addition, multiple solutions can be considered for each problem. Furthermore, the implementation of every solution on a computer will be a new challenge. Due to these reasons, there are various difficulties in education of projection mapping, and researches on educational methods are important.

Since 2014, we have been conducting a special course to teach projection mapping. Summarizing these years of experiences, we have developed an educational method related to 3D projection mapping. First, clarify a specific problem of projection mapping, then propose multiple solutions to deal with the problem, in addition, teach students the solutions and their implementation techniques in the form of exercises. This educational method is presented to students as a book of original exercises. Students naturally acquire knowledges and skills related to projection mapping by learning and practicing the exercises one by one. This paper reports on this educational method and the exercises book. Keywords: 3D projection mapping content, Open space, Exercise book, Blender, Python programming

Introduction

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Since 2014 we have been running a special course in the Department of Information Engineering of KIT (Kanazawa Institute of Technology) to teach about projection mapping. We have been developing original teaching materials since there are few books related to the topic. The first edition of our materials ¹⁾ introduced the minimum equipment required, the software need to be learned, the basic flow of conducting projection mapping events, and safe outdoor environment for students to practice projection mapping. New material was added to the second edition ²⁾, including some computer graphics methods useful to most targets, and ensuring wonderful projection effect. The third edition completed in 2018 added a content design concept of three shapes: the primary

shape representing the actual 3D formation of the target; the secondary shape as an abstraction of the target's formation; the ornamental shape attracting the interesting of audiences ³⁾. By improving teaching materials, our educational course has become more and more complete.

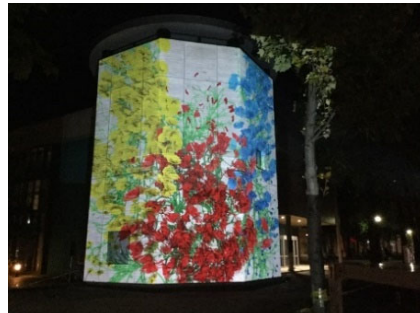
Summarizing these years of experiences, we have developed an educational method related to 3D projection mapping. First, clarify a specific problem of projection mapping, then propose multiple solutions to deal with the problem, in addition, teach students the solutions and their implementation techniques in the form of exercises. This educational method is presented to students as a book of original exercises. Students naturally acquire knowledges and skills related to projection mapping by learning and practicing the exercises one by one. This paper reports on this educational method and the exercises book.

1. A Visualization Problem

Figure 1 shows two types of projection mapping on a target building (a), about 10-meter high and with an octagonal cross section. Fig.1(b) is a 2D projection mapping, projecting an image on the building like a poster. There is no relationship between the image and the structure of the building. Fig.1(c) is a 3D projection mapping using a 3D image modeled based on the architecture of building. Such 3D projection mapping creates a fusion of virtual images and real building. It is relatively difficult and high-level task, but it can show better fantastic and impactful visuals.



(a) a target building



(b) 2D projection mapping



(c) 3D projection mapping.

Fig.1 Examples of projection mapping

3D projection mapping is realized to have a special visualization problem, which we call front side limitation. Since a target (building or object) usually does not rotate and a projector is placed in a fixed location, we can only use the front sides facing to the projector as projection screen. For example, the building in Fig.1 (a) has 3 front sides, and 5 back sides. Projection mapping is limited to the 3 front sides but not the whole building.

How to show three-dimensional shape or interior space when you can only projection on the front sides? Integrating knowledges about computer graphics and visual psychology, we have concluded a guideline on this issue, i.e., make open spaces (or white spaces, or windows) on the front sides to show back sides or interior space. Make open space is a keyword that goes through all the exercises in our educational material.

Exactly, various solutions can be considered according to this guideline. Projection mapping is a

field, where technology and art intersecting, and more than one correct solution existing for every problem. On the other hand, such field bothers beginners and students, who always suffer from many confuses, such as what are effective solutions, which is the best solution, and how to implement to create content. Beginners and students would be stopped by these confuses and do not proceed.

The purpose we developed the exercise book is to help students to overcome these confuses. Through the originally developed exercises, we teach various solutions and implements to create projection mapping content according to the guideline. We believe that teaching through various exercises is one of the most effective teaching methods when complex elements are involved and multiple answers are possible. Working on the exercises, students have learned solutions and implementations to deal with the front side limitation problem, and skills to create effective 3D projection mapping content.

2. Comparison with existing textbooks

When developing our educational materials, we used Blender as a tool to create all the exercises and content. Open source 3D software Blender ⁴⁾ is often used to create 3D images of advertising, data visualization, physics simulation, and projection mapping. We have got many textbooks about Blender, ^{5) 6) 7) 8)} giving user-friendly usage guides, however, still not found a textbook of Blender dealing with projection mapping.

Our exercise book is focused on 3D projection mapping, and has little explanation of Blender. For a beginner of Blender, we give him/her step by step instructions on how to use the software. Following the instructions, he/she can successfully create content. We used only a few tools of Blender and repeated the explanation about these tools whenever used. This enable students to remember these tools naturally. We don't expect students become experts of Blender, but just be able to use Blender to get the goal of creating 3D projection mapping content.

Our exercise book has following unique features that lead to positive learning results.

- (1) Every exercise creates a 3D project mapping content, targeting to a cube box.
- (2) Each chapter presents one original solution of making open spaces and dealing with the front side limitation problem.
- (3) For each exercise, there are a video showing the best process of using Blender to implement the solution and create 3D content. There is also an easy-to-remember production note to explain the modeling methods and Blender tools we used.

We use a wooden cube box of 34cm per side (Fig.2 (a)) for practicing projecting mapping in lab. We keep three factors constant that the orientation of the box, the orientation of the projector, and the distance from the projector to the box. If a 3D image as Fig.2 (c) projected on the box, we will get a projection mapping result as in Fig.2 (d). Here, we must set an virtual camera the same view angle as the projector, and model a virtual box as in Fig.2 (b), having the same size and orientation as the real one.

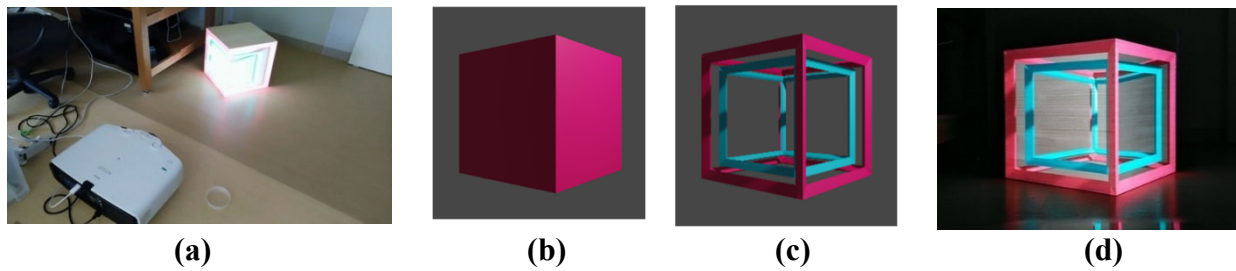


Fig.2 A target of wooden box and our practicing environment (a)(b). When a 3D image of (c) is projected on the box, we will get a projection mapping result as (d).

For each exercise, we provide document in the same format. The first section of the document explains a solution of making open spaces, the second explains Blender tools used to implement, and the third describes the production process in turn, with photos and brief note easy to remember.

Some exercises must be implemented with Blender and python programming. This is an innovation for students to practice python programming skills, which is important for students in the Department of Computer Science and Engineering. These exercises utilizing a large number of particles, require not only the manual mode of Blender, but also in conjunction with python script. Our university has changed educational curriculum to let freshman to learn python programming. It would be interesting for students to realize that python programming is not only useful for AI but also for projection mapping.

3. Collection of Exercises

We will briefly introduce a collection of 14 exercises, classified into three chapters of the book. Exercises in the same chapter share one solution of making open spaces, only their implementation difficulty increases gradually. Also, a my-default Blender file, creating an image as Fig.2 (b), is given so that students could quickly start every exercise, using constant virtual camera, virtual lights, and materials.

3.1 Create open spaces by transforming surfaces to frames

First chapter includes exercises 1 to 4, based on a solution of creating open spaces by transforming surfaces to frames. Here, we teach students a Blender tool, the Wireframe Modifier function, and require them to use this tool repeatedly. It is easy to transform a polygonal surface into a shape like a photo frame surrounding the surface and to change the thickness of the frame.

Exercise 1 (as Fig.3 (a) (b) (c) (d)) teaches the processes to select the surfaces of cube and transform them to frames. Open spaces are created easily by changing surfaces to frames. Even beginners can do this exercise immediately and smoothly.

Exercise 2 teaches variations of using the Wireframe Modifier function. Variations may be setting different colors for the polygons to distinguish between frame's inside and outside (as Fig.3 (e)), using multiple layers of frames to emphasize the shape of space (as Fig.3 (f)), adding frames of other geometric meshes, such as torus in Fig.3 (g) or cone in Fig.3 (h), to enrich the formation of open spaces surrounded by frames.

Exercise 3 teaches variations of placing objects inside wireframe to increase layers in the depth direction. Fig.3 (i) and Fig.3 (j) use object of spheres to create three layers: the front frames, spheres behind, and the frames behind spheres. It is easier to understand the depth of the projection target with the reference of these inside spheres than just wireframes.

Exercise 4 (as Fig.3 (l) (m)) teaches more effective way of placing objects. We should pay a lot attention when deciding a layout for objects. Firstly, make sure that a foreground object does not hide all the objects behind it. Let the objects behind be seen partially, you can naturally get a hierarchy in the depth direction. Secondly, place objects horizontally at the same height. The layout of objects then may show the horizontal expanse of the space. Fig.3 (k) and Fig.3 (n) show the final results of projection mapping on the real target the wooden box.

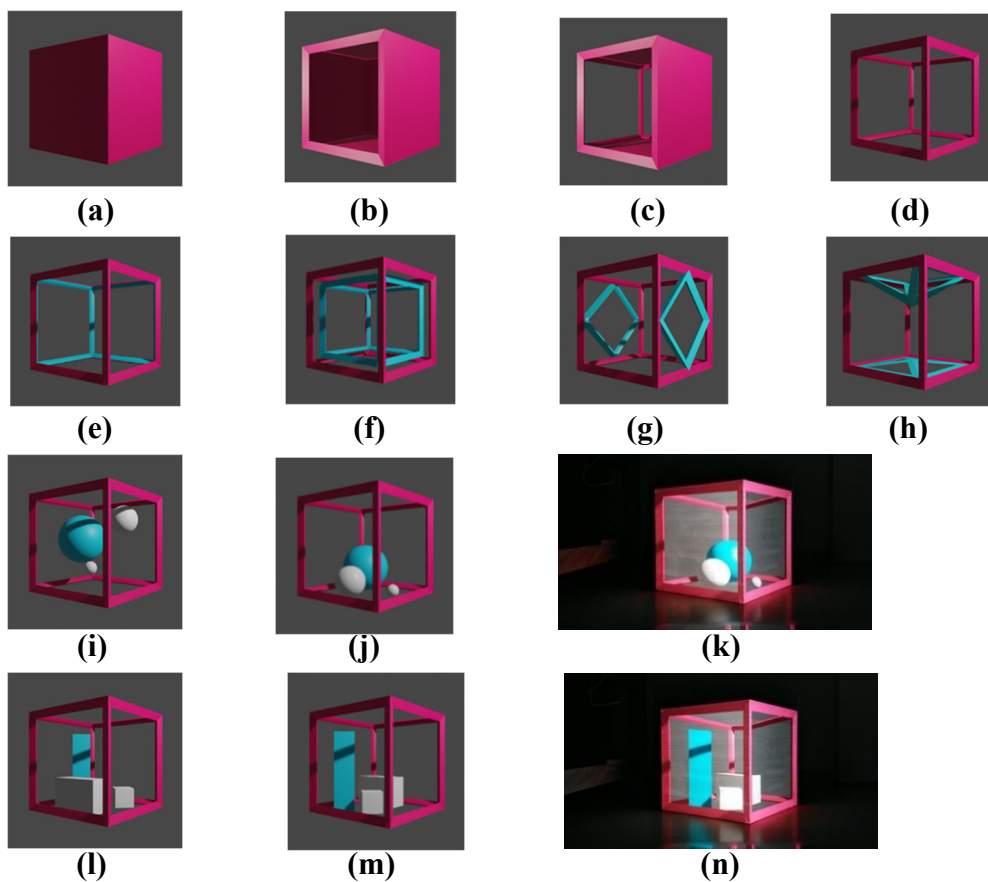


Fig.3 Exercises 1 to 4, creating open spaces by transforming surfaces to frames

3.2 Make open spaces by cutting out

Second chapter includes exercises 5 to 8, based on a solution of making open spaces by cutting out. Figure 4 shows the final results of exercises 5 to 8, which use cubes, cylinders, or curves to cut out open spaces on the front sides.

For implementation, we use a Blender Boolean Modifier tool to cut out a part off front sides. Exercise 5 uses a smaller cube (white) as cutter to open square windows, ensuring the boundaries and corners of the virtual box are remained (Fig.4 (a) (b) (c)). Exercise 6 uses cylinder as cutter,

rotating or changing its location, so as to open circle windows one by one (Fig.4 (d) (e) (f)). It's a simple operation, but requires a little patience and time.

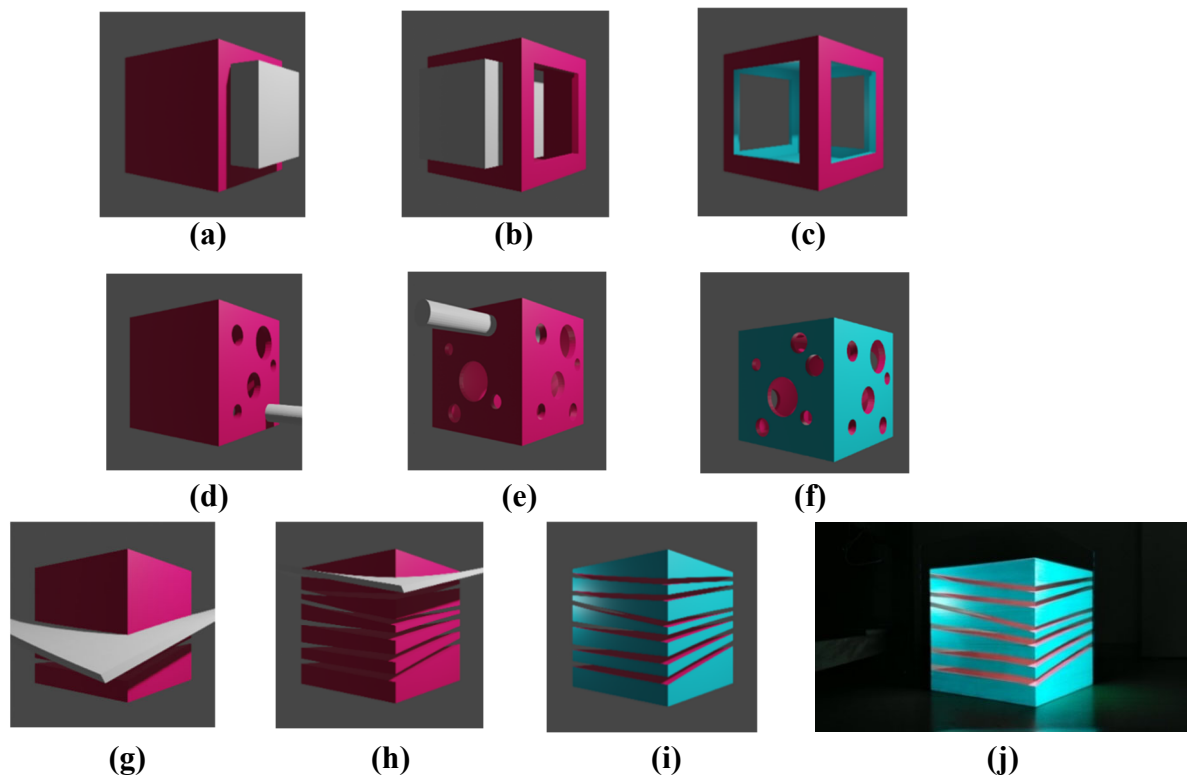


Fig.4 Final results of exercises 5 to 8. (a)(b)(c) cut out square windows, (d)(e)(f) cut out circle windows, (g)(h)(i) cut out wave-like spaces. (j) shows projection mapping of 3D image (i) on the wooden box.

Exercise 7 and 8 use thick plane or thick curve as cutter to make cross-sectional open spaces (Fig.4 (g) (h) (i)). Such open spaces are extremely effective on illustrating three-dimensional formation. Here, we use many Blender's tools, for example, Add Mesh Plane, Scaling, Subdivide, Simple Deform, and Extrude Region, for creating thick plane cutter or thick curve cutter.

Sometimes, we don't give specific numbers for thickness, size, or location, but let the students make their own decisions. Despite following the same steps and using the same tools, each student may create his/her unique piece of wave-like open spaces. Evaluating individuality is one of our educational goals.

3.3 Make open spaces by filling

Third chapter includes exercises of 9 to 14 (as Fig.5), based on a solution of creating open spaces by filling with particles. A collection of particles of the same type is called a cluster. A cluster will show a shape to human. This is a mysterious ability for humans to sense shape. For example, the container of an hourglass is made of transparent glass, but the shape of the container is easy for us to recognize because the sands flowing and accumulating inside the container form in-transparent clusters. Similarly, if we want to visualize the shape and extension of 3D space, we can fill the space with a large number of sand-like particles. As a condition, this should be a loose filling, with

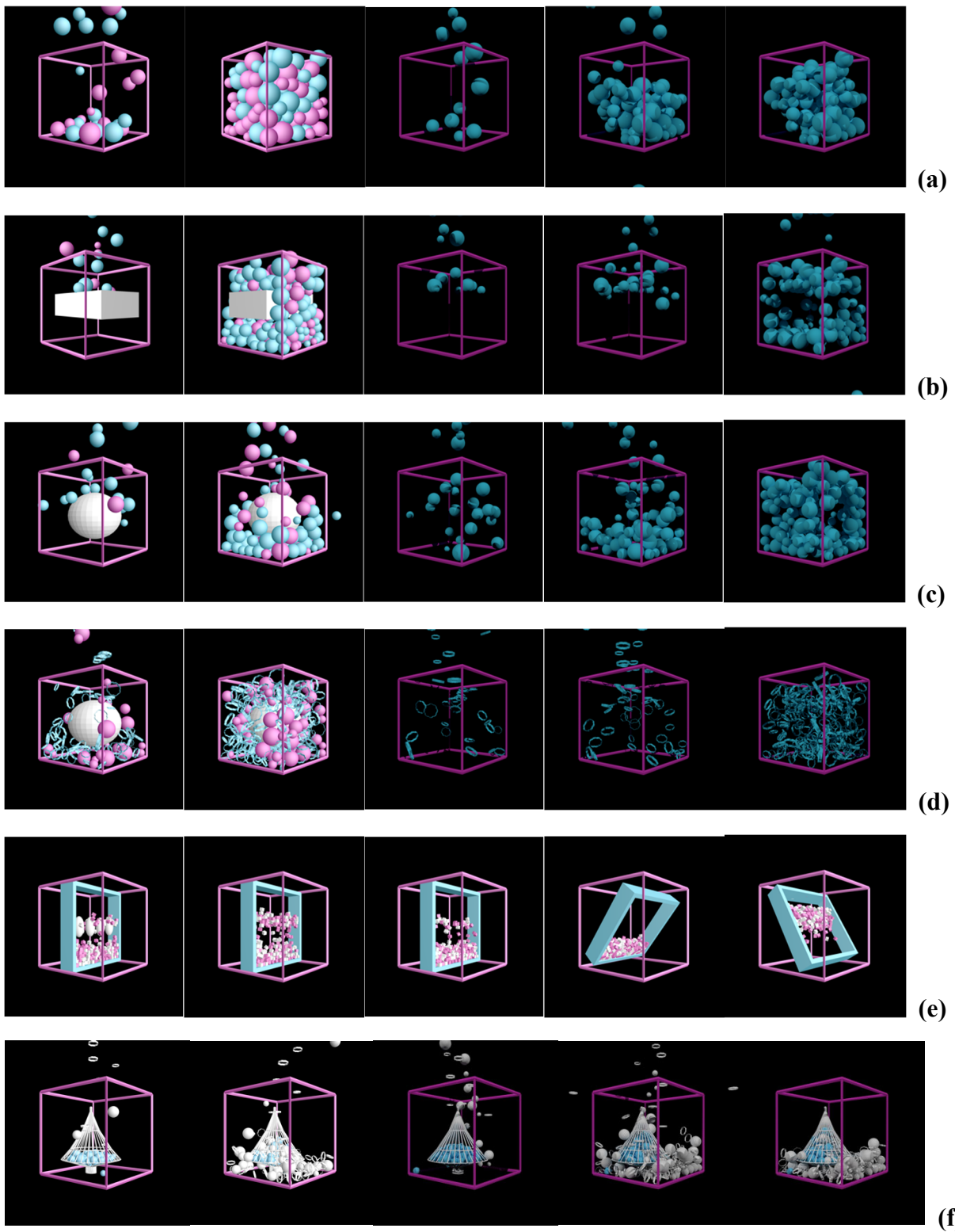


Fig.5 Exercises 9 to 12 that fill space with particles. Blue particles are visible, while pink particles are set invisible to create open spaces among the blue ones.

gaps or holes between the particles. These gaps and holes will be small open spaces we need to show the depth of the 3D space.

Exercise 9 (Fig.5 (a)) randomly drop two type of rigid balls, pink and blue balls, and let them fall down and fill the virtual box, which is visualized with wireframe and transparent surfaces. By setting the blue balls visible and the pink transparent, we created an animation of the blue balls filling the box. Here, pink balls play the role to making open spaces among blue balls and an expected loose filling result.

Exercise 10 (Fig.5 (b)) adds a white rigid cube called a “stopper” that controls the way of balls filling the box. By setting the white “stopper” transparent, we can create open spaces of any size as any location. Exercise 11 (Fig.5 (c)) uses a sphere as the “stopper” to enables the balls falling more smoothly. Exercise 12 (Fig.5 (d)) furtherly changes the shape of blue balls to torus, that brings to a softer and looser filling, more remarkable in visualizing the 3D box.

Exercise 13 (Fig.5 (e)) teaches modeling and animation of sandglass, rotating inside a cube box. The sandglass uses four spheres as “stoppers”, that enable the pink and white sands falling slowly through the gaps between them.

Exercise 14 (Fig.5 (f)) teaches modelling an original form “stopper”, an Yukitsuri tree. We fill the inside of tree with blue balls, meanwhile, the outside of the tree with white balls. It is inefficient to control hundreds of particles manually like previous exercises. This chapter requires students to learn python programming for implementation. For the first exercise, the exercise 9, students have to spend time to learn a long program of 400 lines of codes. This is a hard beginning, however, after they understanding all the codes, things will go much easier for the implementation of exercises 10 to 12, since all these exercises depend on similar python programs.

4. Education effect analysis

Our collection of exercises incorporates a study volume to match 15 lectures. In 2019, for the first time, 13 fourth-year students joined the lectures and use the book, learning and practicing 3D projection mapping content creation. For the first 4 exercises, they use average 20 minutes to get aimed final results. For exercises 5 to 8, they use average 45 minutes to get the results.

For the exercises using python programming, most students felt it become difficult suddenly. The program has about 400 lines of python codes, including functions for setting camera, lights, materials, modeling a transparent cube box, modeling a frame of the cube box, generating 300 rigid particles, and so on. Anyway, students have to type the program, execute, debug and understand line by line. We expect students sense of the power of programming so as to be more eager to learn programming skills.

From students' questionnaires, we got generally positive feedback, with comments such as "Very easy to understand", "Interesting and self-learning", "I feel more confident in content creation", "I became better at python", and "I felt the difficulty of projection mapping".

After completing lectures, they chose projection mapping as their graduation research topics. Spending about three months of hard working, they created original content and presented at the 2019 KIT Festival. Figure 6 shows two content, "Four Seasons" and “The Tech Clock”, particularly

well received by audiences. The frames representing the building, the placement of objects in the interior space, and the movement of particles, all techniques learned from the examples are applied here in real projection mapping event.

Obviously, the students have developed the ability to integrate and apply knowledge. In the document material, explanations for each exercise cover knowledge in many fields, such as computer graphics, visual psychology, geometry, and mechanics. Speaking of students' weaknesses, they often fall apart in isolation when using knowledge in practice. In the case of projection mapping, however, good content comes from integrating and using diverse knowledge. In projection mapping education, it is the ability to integrate that we are constantly struggling with. It requires a lot of training to be able to apply the acquired knowledge to solve real problems. This exercise book is designed for doing such training also.

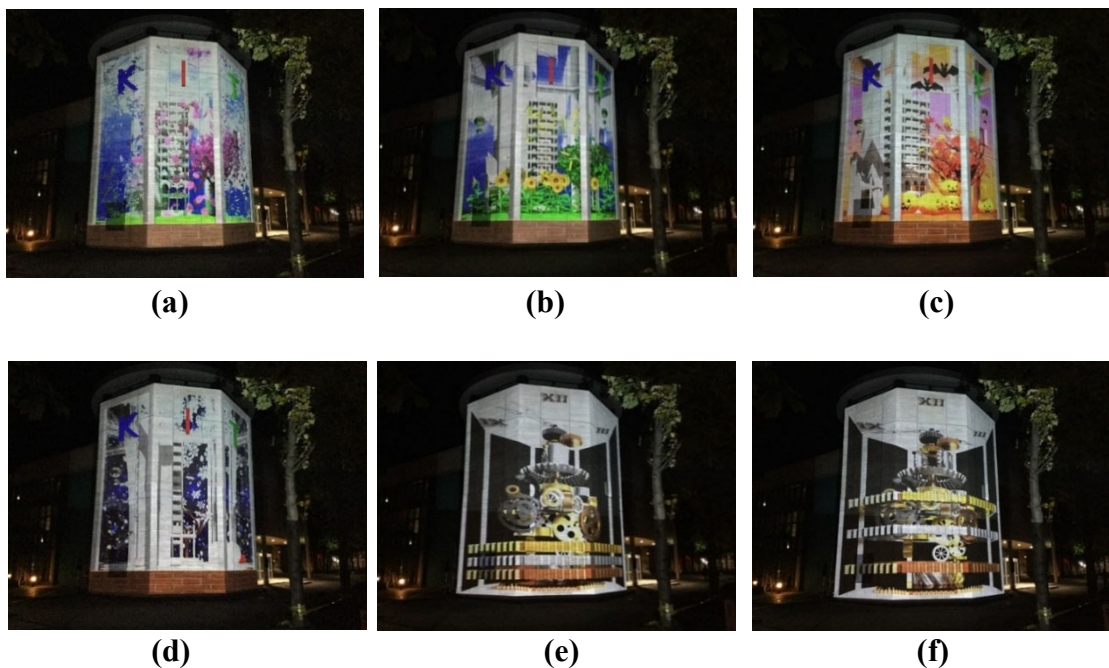


Fig.6 Students' original projection mapping content, presented at the 2019 KIT Festival. (a)(b)(c)(d) "Four Seasons", and (e)(f) "The Tech Clock".

Conclusion

The paper reported a new educational material, an exercise book, for teaching 3D projection mapping content creation. For the first time, we introduced a visualization problem related with 3D projection mapping, the front side limitation problem. We also proposed solutions to solve the problem. Furthermore, we developed the exercise book to teach students to implement these solutions on computer and create projection mapping content.

The exercise book has some unique features resulting in very positive learning effects. For each exercise, we provide a video showing the best creation process, and an easy-to-remember production note to explain the Blender tools we used. For exercises using particles to fill space, the book provides an innovation for students to practice python programming skills, which is important

for students in the Department of Computer Science and Engineering. Starting with this exercise book, and through 3 months of practice and training, our students got big success in developing their knowledge and skills to create 3D projection mapping content.

It is expected for the next edition of this book to include content about no-professional training. For the students majoring art or design, we may provide more knowledge about math and programming. For science students, we may explain more about psychology and humanities. Related to the knowledges, we may give more interesting assignments that students would like to challenge. By increasing knowledge about multiple areas, students would be able to think deeper and represent their ideas in richer formations.

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Qinglian Guo

郭 清蓮

教授・博士 (理学)

工学部

情報工学科



CHADANI Takumi

茶谷 卓実

工学研究科

情報工学専攻

博士前期課程 2 年



TAKEUCHI Kota

竹内 浩太

工学部

情報工学科 4 年