The 3D Model Retopology with Papercraft Technique

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ABSTRACT

Augmented Reality (AR) technology is frequently applied in simulation, particularly in medical training. The AR application renders the 3D model on mobile devices that be resource constraint devices. Hence, the characteristics of the 3D model for the mobile devices are low polygon is to reduce the resource constraint in rendering time and realistic rendering in the animated model. The topology of the polygon is the key to these issues. This paper proposes the retopology of the polygon based on the papercraft technique. We compare our approach with the experience of the digital artist in two groups of samples. We compare the performance in terms of the number of polygons, man-hour, and the quality of the model. The result shows that our approach reduces the number of polygons and man-hour better than the control group whereas the quality of the model is not different significantly.

Keywords: *Retopology, Papercraft Technique, Augmented Reality, 3D Model, Medical Application.*

INTRODUCTION

Augmented reality (AR) is a new technology that incorporates virtual information (3D models) into the real world to generate virtual data (Cheng, 2020). AR technology is employed in a variety of industries, including medical, education (Cicek et al., 2021), entertainment, and marketing (Yavuz et al., 2021). Large-scale data visualization is a typical job in healthcare, computational physics, and a variety of other domains. Mobile devices are used to provide materials, demonstrations, and practice for orthopedic practice and education (Keating & Jacobs, 2021; Negrillo-Cárdenas et al., 2020). For the 3D model courseware, the bone pieces are shown in a 3D model. The models should be lightweight and resource efficient. The 3D model's quality, on the other hand, must be comparable to that of the original. For the application in orthopedic practice courseware, the bone is scanned with high quality and imported into 3D software to create a realistic 3D bone in a mobile device (Matthews et al., 2009). This technique skips the basic mesh and topology stages to save time and guarantee the excellent quality of the 3D model. However, because the 3D model has many polygons, the AR application consumes a lot of resources. As a result, a digital artist must retopology the scanned 3D model to decrease resource usage when the model is displayed.

Article history:
Received 4 May 2022; Received in revised from 7 June 2022;
Accepted 7 June 2022; Available online 31 December 2022.

The 3D model is a virtual representation of information around the surface that was created using any of the following methodologies: polygon, NURBS, and Subdivision Surface Modeling (O'Rourke & Streinu, 1998; Wronecki, 2006). Polygonal modelling is a process for modeling three-dimensional shapes that involves measuring the surface using polygons. This is linked to sub-division, which involves increasing the number of polygons on a surface to smooth it out and make it more detailed. NURBS is a flexible and smooth surface that is known to be mathematically exact and is used to create things like ship hulls, automobile bodies, and other structures because they can be replicated whenever technological requirements arise. Sub-division modeling is a digital 3d modeling method for creating clean models with scalable detail that render well. Almost every industry that employs digital artists uses it to some degree.

For the polygon modeling approaches, the vertex is the smallest unit of a 3D model. An edge connects two vertices, and a polygon is a closed plane with three or four vertices. As a result, a polygon could be a triangle or a rectangle. The surface, which is made up of adjacent polygons, is used to create the 3D model. The simple workflow of 3D modeling consists of base mesh, topology, sculpting, unwrap, and bake. The base mesh creates the model with the shapes such as squares, spheres, pyramids, cylinders, etc. Then, the vertices are marked, and the edges are linked between vertices to create small polygons or wireframes. This process is called topology The sculpting is using the software as tools to manipulate a wireframe to be the 3D model like clay sculpting in real-life. The textures are wrapped and mapped in polygon in the final stage (Baechler & Greer, n.d.).

However, the rendering of 3D models has a significant impact on device specifications. It makes use of the 3D texture mapping capabilities found in most contemporary GPUs (Naik Dessai, 2012). The method's main notion is to create a 3D texture and then render it by mapping it to a stack of polygon slices. The polygon slices are blended, and the result is displayed in the scene. The majority of polygon and texture mapping has a direct impact on mobile device memory and storage usage, as well as CPU performance (Hachaj, 2014). To display a realistic 3D model on a mobile device, we need to reduce the number of polygons to reduce the surface area and resource usage.

Furthermore, the topology of a 3D model is the organization, flow, and structure of its vertices/edges/faces (Gambetta, 2021). When modeling in 3D using polygons, it's critical to use quads and triangles throughout your model. A triangle is a basic three-sided polygon. It contains three vertices at each corner and three edges connecting them. This is the smallest configuration that a polygonal face can have. A quadrilateral polygon is a four-sided square or rectangular polygon. It contains precisely four vertices at each corner, all of which are linked by four edges. When building digital models, this is the most desirable polygon type, and many artists choose to create their things entirely out of quads to make their work more attractive to consumers in complicated workflows. A polygon having more than four vertices and edges is known as an N-Gon. It should be avoided. Then, an N-Gon may always be split into quads, tris, or a mix of the two due to its geometric characteristics; therefore, they are always simple to remove by adding connecting edges between the boundary vertices (Turbosquid.com, 2019).

For a variety of model-related activities including simplification, surface parameterization, and finite element analysis, ensuring that a model has the right topology is critical. When artifacts, such as superfluous handles resulting from surface reconstruction, need to be eliminated (i.e., topology repair), or when the user wants a variant of the model with a different topology, topology modification is required (i.e., shape design) (Ju et al., 2007). Figure 1 depicts both a poor and good usage of topology. The grid is designed to mimic the muscles of the face, allowing for natural movement. It's obvious that the artist understands muscle anatomy. This is an example of poor topology. The grid structure is inconvenient for the model; the movement will not seem natural once animated since the muscle movement will be wrong, and it will appear strange. When we attempt to go into creating emotion with a face with poor topology, it won't appear natural; but, if the face isn't going to move, such as a statue model, the artist can get away with improper topology (Danan, 2016).

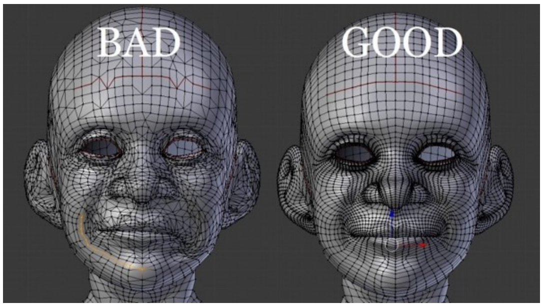

Figure 1 The bad topology and good topology (Danan, 2016).

As a result, retopology is a solution that involves arranging the disarranged polygons into ordered polygons. The number of polygons in the model may alter, resulting in a more realistic representation. In addition, the number of polygons is the most important factor in determining resource use. Moreover, minimizing the number of polygons reduces the quality of 3D models (Webster, 2017). As a result, the investigation is recommended using a variety of methodologies.

The algorithm is developed for the retopology of the 3D model in crafting simulations. It may recalculate the normal while rendering in VR. Duplicate vertices are also sought by traversing the mesh. Differences in normal vectors in faces with the same vertex positions, for example, cause them to emerge. During the simulation, changing the position of a vertex must also influence its duplicate vertices (Chotrov, 2019). The MarrNet algorithm is a topology aware shape autoencoder that addresses high-level topological and design end-to-end virtual reality 3D reconstruction. The method is based on a triangular mesh model for cutting contour and is designed to automate surface mending. This method achieves the 3D model's entity profile, automated complement, and material inheritance in a virtual reality environment, which can adequately describe the 3D model's entity profile in a virtual reality environment and inherit material texture correctly. It has hard real-time performance at the same time (Chen et al., 2020). Proposing a new algorithm has no immediate implications for digital artists. They use software to sculpt the new 3D item based on their prior knowledge and expertise (Kong et al., 2021).

Papercraft is a simple tool in human-computer interaction (HCI) and learning (Sawangtrakul et al., 2015). It is utilized to aid in the development of the imagination (Andreass, 2011) and understand the 3D model. (Lang, 1996) developed a tree approach for designing a crease pattern that folds flat onto a base with any number of flaps. (Liu et al., 2021) suggested using the Electropaper to develop and build prototypes for usage in water environment. Whereas the PaperCraft3D is applied in the animation (Paczkowski et al., 2019).

The main goal of this research is to propose a manual retopology of the 3D model by a digital artist with the papercraft technique. Whereas the number of polygons is minimized and brings to lower resource consumption in 3D model rendering. We use the empirical research approach to demonstrate our concept with two groups of students. We compare the performance in terms of development practice, 3D model quality, and man-hours. The research questions and hypothesis of this paper are:

RQ1: How to adapt the papercraft technique for the re-topology and reduce the polygon of the 3D model?

- H1: Before the study, the average number of polygons was greater than the average number of polygons following the study significantly

RQ2: How the 3D model created based on the papercraft technique have the performance better than the traditional technique?

- H2: The 3D model from the experimental group has a higher performance than the control group significantly.
- H3: The modelling time from the experimental group is less than the control group significantly.
- H4: There was no significant difference in the experimental and control groups' 3D model quality.

RESEARCH METHODOLOGY

A literature review surveys books, scholarly articles, and any other sources relevant to a particular issue, area of research, or theory, and by so doing, provides a description, summary, and critical evaluation of these works in relation to the research problem being investigated. Literature reviews are designed to provide an overview of sources you have explored while researching a particular topic and to demonstrate to your readers how your research fits within a larger field of study.

1) The Papercraft Technique for Retopology

To retopology the 3D model, this paper proposes using papercraft as an imaging technique. The most important requirement for a 3D model in the game industry is that it be of high quality while consuming low resources. The scanned 3D model is used to begin the retopology based on the papercraft.

The simple model is visualized in Figure 2a as a sphere, cube, cylinder, cone, doughnut, prism, or pyramid shape. After that, the simple shapes are joined to build a more complex model. To begin, the digital artist visualizes the shape as a papercraft. Numerous triangles and rectangular polygons make up the surface. Curved surfaces may contain fewer and larger polygons than planar surfaces. The cone shape and circular region should be constructed using triangle polygons, as seen in Figure 2b.

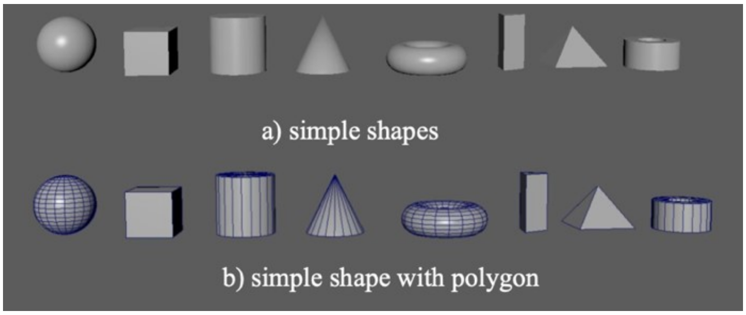

Figure 2 The simple shape for the 3D model

As illustrated in Figure 3, the cylinder is simple and easy to retopology with the papercraft technique. Most polygons are rectangles that are compounded to form a cylinder (Figure 3a). The number of rectangles has a direct correlation with the surface quality. Adding the notch at the joint between the polygons that bend in the curved section (Figure 3b). In comparison to a smaller notch, a greater notch results in more bend. In addition to increasing the number of notches, the smoothness of the curve increases.

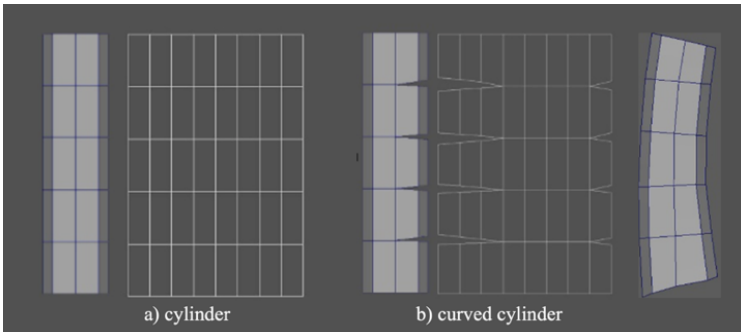

Figure 3 The papercraft of the cylinder

For the compound shape, the chess named queen is a well-known model for illustrating a three-dimensional model. The digital artist imagines the chess in Figure 4a as being constructed from a set of cylinders. The digital artist subsequently represents the model with the few pyramids and two spheres. Following that, as seen in Figure 4b, the digital artist represents the cylinder shape. Chess is reintroduced using the papercraft technique. Figure 4c depicts a checkmark in its first retopology state. As in the original form, the pyramids are added to the center portion of the checkmark to provide slope. To improve the model's quality, the digital artist must re-topologized the mode. Finally, Figure 4d illustrates the predicted quality.

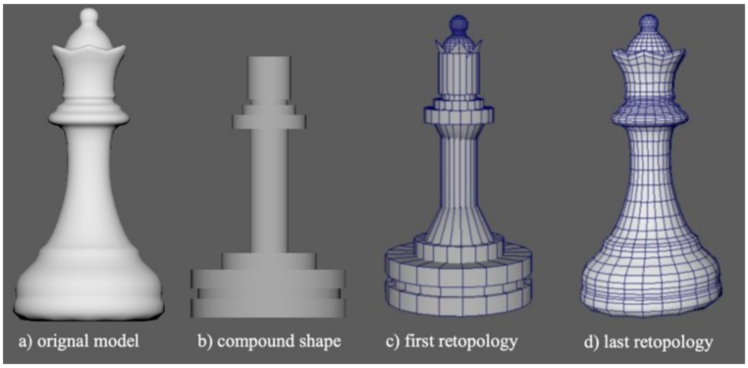

Figure 4 Retopology of the compound shape

Figure 5 demonstrates the retopology of bone. The leg bone is 3D scanned and imported to 3D rendering applications such as Adobe Maya. The leg bone is decomposed into 3 parts: top, middle, and bottom (Figure 5a). the middle part is represented with a curved cylinder whereas the top and bottom parts are alike and are represented by connecting two spheres. The retopology of the curved cylinder is explained before and shown in Figure 3.

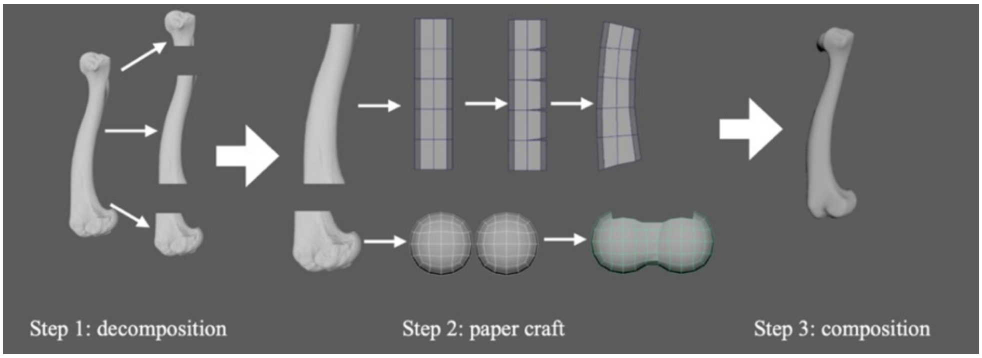

Figure 5 The topology of the leg bone

The bottom part is represented with connected spheres. The choice of a simple shape is subjective and is determined by the digital artist's experience. When the digital artist chooses the appropriate shape, he or she saves time and improves the model's quality. The digital artist imagines each model's component as papercraft, selects vertex, and builds polygons to cover it. Following that, each subpart is reconstructed and rendered to create a new model. The digital artist repeats the procedure until they get the desired level of quality.

2) Participants

Students in multimedia majors cover the study's population, and 3D modeling is a course in the multimedia major's curriculum. Students in each class are expected to be experts at 3D modeling objects. As a result, this study demonstrates the effectiveness of our technique in comparison to the control group. Two groups of students majoring in Multimedia Technology and Animation composed the sample group. The control group consists of 31 samples, and the experimental group consists of 22 samples. All samples had completed an introduction to the 3D modeling course that is studied from the same teaching and evaluation methodology.

3) Research Framework

Based on the papercraft approach, this study proposed the re-topology of a 3D model. There are two groupings of samples. Following that, each group sculpts the model using their prior experience and compares it to the newly taught technique. The models are compared in three ways: the number of polygons, modeling time, and the opinions of three experts. The data is then analyzed using statistical methods: the mean comparison test. The research framework is illustrated in Figure 6.

4) Research Instruments

Compared to the traditional procedure, the research proposes a papercraft technique as an imagination for 3D retopology. Figure 7 shows how both examples sculpt different models: the leg, neck, and spine bone. Three experts assess the model's complexity by applied the item objective congruence index (IoC) method. The question is "Is this model (low/medium/high) complexity sculpt?" whereases Yes (+1), not sure (0), or no (-1) is the response chosen by the experts. If the average of the answers is more than 0.5, it indicated that the model is valid. Figure 7 shows that low, medium, and high complexity models are represented by Models A, B, and C, respectively.

During the pre-test and post-test phases, all participants sculpt the 3D models in Figure 7. Both pre-test and post-test are assessed on three dimensions: model characteristics, modeling time, and similarity to the original.

The number of polygons: the 3D model: Autodesk Maya calculates the 3D model in terms of the polygon. The experiment's objectives are to minimize the number of polygons. The resource consumption directly variance with the number of polygons. On the other hand, the minimal of polygons affects the quality of the model. Hence, the digital artist needs to balance between quality and resource consumption

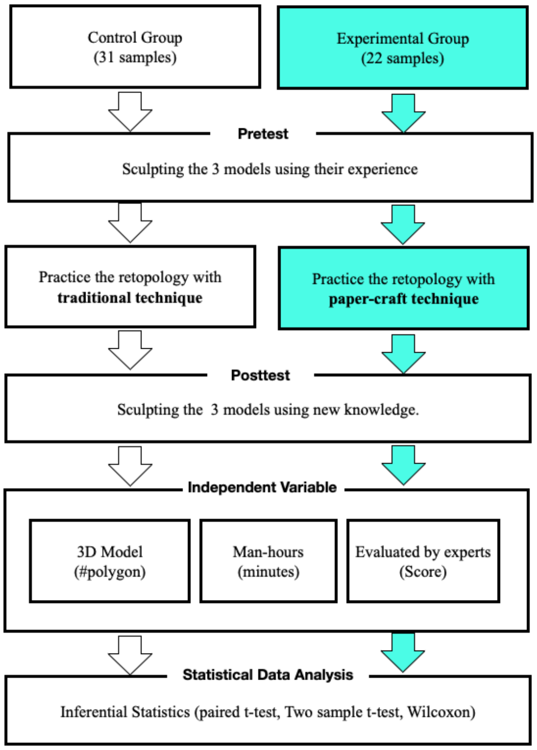

Figure 6 Systematics Research Framework

The modeling time or man-hours represents the amount of time (in minutes) spent on creating the 3D model and covering the entire procedure.

The quality evaluation or score: the digital artist's experience ranges from five to six years. They look at the 3-axis view in the form silhouette mode. The quality is graded on a scale of one to five. The highest quality is represented by the maximum score, while the lowest quality is represented by the lowest score.

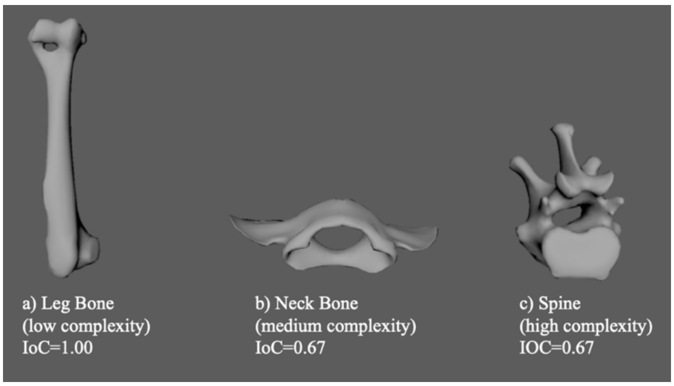

Figure 7 The 3D model of the experimental

5) Analysis of Data

For the inferential statistical analysis, the independent variables are normal distribution is tested with the Shapiro-Wilk method. The t-test method is selected for the parametric statistics while the Wilcoxon signed-rank test is selected for non-parametric statistics. This research comprises two parts: the developmental practice of students and the performance between papercraft technique and traditional technique. The students' developmental practice is assessed using a paired t-test while the performances are evaluated with a mean comparison test (Du Prel et al., 2010)

RESUTLS

1) Sample and Population Analysis

The statistical analysis with the two-sample t-test is to guarantee that all samples are at the same background in the introduction to the 3D modeling course. The results show in Table 1.

Table 1 The t-test result on the number of polygons

Sample	mean	s	n	df	t	p-value
Control	75.74	7.34	31	49.83	-0.7818	0.438
Experimental	77.18	6.02	22			

The statistical analysis shows that the control group was a lower mean score ($\bar{x}$ =75.74, s=7.34) than the experimental group ($\bar{x}$=77.18, s=6.02) We conclude that the fundamental practices of the control group and the experimental group are not statistically different at 0.05 (p=0.438) and that both groups' 3D modeling practices are similar.

2) The papercraft technique for retopology

The first research question is "How to adapt the papercraft technique for the retopology step to reduce the polygon of the 3D model?". The 22 samples study the papercraft technique for retopology of a 3D model to evaluate the technique's effectiveness and relied on two hypotheses.

The number of Polygons

The first hypothesis is "Before the study, the average number of polygons was greater than the average number of polygons following the study significantly". All data sets are normal distribution using the Shapiro-Wilk test that brings to the paired t-test technique to compare the mean of the number of polygons of three paired: leg, spine, and neck bone.

Table 2 The paired t-test results on the number of polygons

Testcase	Sample	mean	s	n	df	t	p-value
Leg	Before	2,460.90	215.68	22	21	22.089	0.0000
	After	1,076.13	123.55	22			
Spine	Before	3,089.77	143.03	22	21	26.419	0.0000
	After	1,973.13	132.04	22			
Neck	Before	4,168.50	228.47	22	21	39.105	0.0000
	After	2,097.00	104.32	22			

Table 2 shows the effectiveness of 3D modeling based on the papercraft technique. After the study of the papercraft technique, the sample reduces the number of polygons better than prior the study on the three bones significantly. Hence, we conclude that before the study, the average number of polygons was greater than the average number of polygons following the study significantly ($p < 0.05$).

The modelling times

The second hypothesis is to prove that “The mean modeling time before the study was longer than the average modeling time after the study significantly”. The Shapiro-Wilk test is used to test the normality. We conclude that all datasets are normal distribution. The results of the mean comparison are shown in Table 3.

Table 3 The paired t-test results on modelling time (minute)

Testcase	Sample	mean	s	n	df	t	p-value
Leg	Before	216.63	10.67	22	21	5.5872	0.0000
	After	200.86	6.03	22			
Spine	Before	307.81	7.53	22	21	4.7654	0.0000
	After	204.18	7.88	22			
Neck	Before	304.59	10.30	22	21	22.26	0.0000
	After	245.72	7.56	22			

The statistical analysis shows that the 3D modeling time is decreased when the papercraft technique is applied in the retopology step. After the sample studies the papercraft technique and experiments the 3 test cases, we found that the paired t-test shows significant scores for all cases. Thus, we conclude that the mean modeling time before the study was longer than the average modeling time after the study significantly ($p < 0.05$).

3) The performance of papercraft technique in retopology

This part presents the statistical analysis of the performance of the papercraft technique in retopology. To find the answer to the research question: “How the 3D model created based on the papercraft technique have the performances better than the traditional technique?”. There are three hypotheses for this search question.

The number of polygons

Firstly, the result related to the first hypothesis: The 3D model from the experimental group has higher performance than the control group significantly. The performance metrics are the number of polygons. The higher performance means that the number of polygons of the experimental group is less than the control group significantly.

All polygons of the leg, spine, and neck are tested with the Shapiro-Wilk technique to evaluate normality. We found that the data sets from the experimental group are normal distribution while data sets from the control group are non-parametric distribution. Moreover, the Wilcoxon rank-sum test method is selected to compare the average polygon of papercraft with traditional techniques.

Table 4 The Wilcoxon rank-sum test results on the number of polygons

Testcase	Sample	mean	s	n	t	p-value
Leg	Before	1,469.90	169.10	31	9.7650	0.0000
	After	1,076.14	123.55	22		
Spine	Before	2,405.93	251.04	31	9.7812	0.0000
	After	1,960.86	121.75	22		
Neck	Before	3,374.93	218.96	31	9.7943	0.0000
	After	2,098.67	106.60	22		

In 3D retopology, Table 4 compares the number of polygons in the experimental and control groups with the statistic method. We compare the average number of polygons in three test cases. When we consider in $\bar{x}$, t, and p-value, we found that the number of polygons from the experimental group was less than the control group on three test cases significantly. Then, we conclude that the 3D model from the experimental group has a higher performance than the control group significantly ($p < 0.05$).

The modeling times

Secondly, the hypothesis is "The modeling time from the experimental group is less than the control group significantly". The modeling time is the amount of time that a sample takes to sculpt a model from start to finish in the 3D model process. As a result, less time is expected to be spent working. To estimate the distribution of modeling time in 3D sculping of leg, spine, and neck bone, the Shapiro-Wilk test is performed. Because the variances were examined using Levene's test and found to be uneven, the two-sample t-test with unequal variances was utilized.

Table 5 The two-sample t-test results on the modelling time (minute)

Testcase	Sample	mean	s	n	df	t	p-value
Leg	Before	216.97	11.16	31	48	6.7612	0.0000
	After	200.86	6.03	22			
Spine	Before	230.45	11.01	31	50	10.1131	0.0000
	After	204.18	7.89	22			
Neck	Before	253.10	8.23	31	51	3.3678	0.0008
	After	245.73	9.76	22			

The following table compares the average modeling time worked by the control and experimental groups. In the leg bone and spine bone sculpting, the control group takes modeling time more than the experimental group. For the most sophisticated model, such as the neck bone, the control group still consumes modeling time more than the experimental group. However, we conclude that the modeling time from the experimental group is less than the control group significantly based on the statistical analysis ($p < 0.05$).

The quality evaluation

Thirdly, the hypothesis is there was no significant difference in the experimental and control groups' 3D model quality. The average of three experts' scores is used to compare the control and experiment groups. The data sets are normal distribution, but their variances are different. Thus, the statistical analysis using the t-test (two-sample assuming unequal variances) is performed. The result is shown in Table 6.

Table 6 The two-sample t-test results on the model's quality

Testcase	Sample	mean	s	n	df	t	p-value
Leg	Before	4.37	0.43	31	48	-0.3650	0.7168
	After	4.41	0.42	22			
Spine	Before	4.46	0.42	31	50	0.3711	0.7122
	After	4.42	0.33	22			
Neck	Before	4.45	0.40	31	44	0.1070	0.9152
	After	4.44	0.41	22			

The expected quality of this paper is the similarity between traditional and papercraft techniques. The model's quality as determined by expertise is shown in Table 6. The average score test of cases is more than 4.00. It is shown that the quality is at a good level. The average score from the control group and experimental group are pointed in the same direction. From statistics analysis, we conclude that there was no significant difference in the experimental and control groups' 3D model quality ($p > 0.05$).

DISCUSSIONS

1) RQ1: How to adapt the papercraft technique for the retopology and reduce the number of polygons of the 3D model?

The application of the 3D model in digital art focuses on reducing the number of polygons to reduce resource consumption. The application uses mainly the scaling, rotate function. The layout of the polygon does not affect texture and realism. A more realistic 3D animation will be produced if the polygons are arranged neatly or in a linear pattern.

As a result, using the papercraft approach as a re-tropology idea will be especially fitting. To create the new polygon, the digital artist imagines the surface folded like a piece of paper and draws the liner line. The polygons are also resized, merged, and recreated. The principle of this technique is to imagine a surface consisting of straight lines both vertically and horizontally. Moreover, adding a triangle on the curved surface will increase the smoothness. As the result, the arrangement of the topology is orderly.

The papercraft technique reduces the man-hour that is better than that traditional technique because the papercraft technique clearly steps to determine and draw the linear line in surface.

The principle of arranging polygons in this research is to add enough folds to give a virtual image. But must not increase the number of polygons so much that it affects the use of resources.

2) RQ2: How the 3D model created based on the papercraft technique have the performances better than the traditional technique?

The decrease in the number of polygons directly affects the use of resources. Therefore, it can be assumed that the resource usage for rendering will also go down. This is consistent with the experimental results assessed by the number of polygons. The higher the number of polygons, the higher the display power consumption as well.

The arrangement of the polygons in the technique presented is a linear arrangement of polygons like the folds of a paper. The method of choosing polygons has a clear pattern, resulting in working time will be shorter compared to the original method The size of the polygon is reduced. and some polygons are larger Due to the selection of an origami cycle, a new polygon is created. So, the number of polygons goes down. according to the hypothesis. The hypothesis was confirmed through statistical analysis.

Imagination from papercraft techniques reduces man-hours because this method supports the selection technique results in shorter man-hours. From the experimental results, it was shown that reduced man-hours. Although considering the numerical, the averages of man-hours may differ slightly. On the other hand, subjects are proficient in different tooling skills (for example with high tooling skills), which reduces the man-hours twice as fast. If considering the statistical method, it can be concluded that retopology using the papercraft technique will significantly reduce man-hours.

The high number of polygons results in high smoothness of surfaces and high resource consumption in rendering time as well. Therefore, the retopology reduces the number of polygons that affect the lower smoothness and resource consumption. From the experiment, we found that although the number of polygons is reduced, the quality of the samples is no different. From the evaluation results, we concluded that the quality of the model from both retopology techniques are not different and the papercraft technique tends to offer better quality.

3) Limitations and Recommendations

The papercraft technique is a solution is to rearrange the topology. This technique suite for the manual 3D modeling that is used in animation in augmented reality applications. The experiments of this research are quite subjective as they are conducted using human samples and evaluated by experts. Although the subjects had been assessed on an instrumental basis before, the experimental results regarding the number of polygons and working time were still dependent on the skill and concentration of the samples. In addition, the trial took quite a long time. Although in the experimental process a rest period was given to the subject. The subject still had fatigue. which may affect the results of the experiment. Moreover, the quality of the model evaluated by the experts may result in the effect of the accuracy.

If this technique is used for teaching in the classroom. It may begin with the study of 3D models on paper, which is a practice for students to understand and practice imagination. To increase the efficiency of the actual practice with computer programs (Paczkowski et al., 2019).

CONCLUSIONS

From the proposing of the retopology of the 3D model with the papercraft technique, we show that this technique can rearrange the polygons with the number of polygons reducing and keep the quality of the model and reduce the sculpt time of the 3D model. This technique is suitable for manual 3D modeling and used models in animated augmented reality.

ACKNOWLEDGMENTS

This research work is financially supported by Walailak University Graduated Research Fund, contract number CGS-RF-2020/10

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