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Supporting Focus and Context Awareness in 3D Modeling Using Multi-Layered Displays

A thesis

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Abstract

Although advances in computer technology over the past few decades have made it possible to create and render highly realistic 3D models these days, the process of creating these models has remained largely unchanged over the years. Modern 3D modeling software provide a range of tools to assist users with creating 3D models, but the process of creating models in virtual 3D space is nevertheless still challenging and cumbersome. This thesis, therefore, aims to investigate whether it is possible to support modelers more effectively by providing them with alternative combinations of hardware and software tools to improve their 3D modeling tasks.

The first step towards achieving this goal has been to better understand the type of problems modelers face in using conventional 3D modeling software. To achieve this, a pilot study of novice 3D modelers, and a more comprehensive study of professional modelers were conducted. These studies resulted in identifying a range of focus and context awareness problems that modelers face in creating complex 3D models using conventional modeling software. These problems can be divided into four categories: maintaining position awareness, identifying and selecting objects or components of interest, recognizing the distance between objects or components, and realizing the relative position of objects or components.

Based on the above categorization, five focus and context awareness techniques were developed for a multi-layer computer display to enable modelers to better maintain their focus and context awareness while performing 3D modeling tasks. These techniques are: object isolation, component segregation, peeling focus, slicing, and peeling focus and context.

A user study was then conducted to compare the effectiveness of these focus and context awareness techniques with other tools provided by conventional 3D modeling software. The results of this study were used to further improve, and evaluate through a second study, the five focus and context awareness techniques. The two studies have demonstrated that some of these techniques are more effective in supporting 3D modeling tasks than other existing software tools.

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CHAPTER 1

Introduction

Advances in computer technology in terms of the faster processing power, increased memory capacity, and better displays have made it possible to create and render highly realistic 3D models. Despite these advances however, the process of creating 3D models has remained largely unchanged. Although modern 3D modeling software provide a large range of tools and functions to assist users with creating, editing, and rendering 3D models, these tasks are nevertheless very challenging and cumbersome.

In a 3D modeling environment, the combination of tasks, techniques and interfaces play an important role in successfully producing a 3D model. Tasks are essentially a set of activities that modelers must perform during the modeling process using a range of techniques. All these tasks are performed using the interface components of a 3D modeling software application.

The first challenge for modelers in learning to create 3D models is to master the techniques, commands and functions of the 3D modeling software being used. The other challenge is to master the skills required to create, shape, and combine all the components of a complex 3D model together. Although the first challenge can be overcome through regular practice, the second challenge can be more difficult to overcome, and often remains despite modeler's experience, especially when creating complex 3D models.

One of the main reasons for the second challenge is due to the fact that modelers always need to comprehend the relationships between all the objects of a model in the 3D space they are working in. This can be rather difficult because 3D modeling software have been developed for conventional 2D displays, and as such, they project the 3D modeling world and its objects on to one or more 2D projection surfaces (viewports), each of which is a perspective or orthogonal view of the 3D world. As a consequence, there is often a mismatch between the targeted 3D model and the 2D modeling environment.

1.1 Motivation

In the current 3D modeling environments users tend to cope with the difficulties of recognizing the relationships between the objects and components of 3D models using existing techniques such as opening multiple viewports, zooming in/out, hiding some of the objects, rotating around objects or scenes, and so on (see Chapter 3). However, even with the aid of these techniques, it is often difficult for the modelers to comprehend the relationship between the objects in the entire 3D space (see chapters 4 and 5). Most research (reviewed in Chapter 3) aiming to understand the difficulty of recognizing the relationships between objects focus on 2D workspaces, using examples such as visual maps or text. However, what is currently lacking is research on developing more effective techniques to deal with 3D models in often overcrowded and overlapping complex modeling context.

Existing techniques developed more specifically for 3D modeling tasks, as reviewed in Chapter 3, can be categorized into the following:

- Distortion-based techniques
- Multiple windows or viewports
- Hide and reveal techniques
- Overlays

As will be discussed in Chapter 3, each of these techniques either distort the information being displayed or fail to provide the overview of the context of the model while working on specific objects of interest. Because of this, modelers are not always able to maintain their awareness of the relationships between all the objects involved in the modeling process.

More specifically studies undertaken as part of this thesis (see chapters 4 and 5) have identified that the problems faced by 3D modelers¹ can be grouped into the following categories:

- Difficulty of maintaining position awareness.
- Difficulty of identifying and selecting objects or components of interest.

¹ Throughout this thesis, the term 3D modeler refers to the person that develops a 3D model using 3D modeling software

- Difficulty of recognizing the distance between objects or components.
- Difficulty of realizing the relative position of objects or components.

These problems have in this thesis been defined as being all related to the issue of maintaining focus on the objects of interest while working in the context of a 3D modeling space (see Chapter 3). The motivation for this thesis is therefore to investigate whether techniques can be developed to solve the issues related to maintaining focus and context awareness in 3D modeling tasks. In the context of this thesis 3D modeling tasks are those use in application areas such as animation, computer games, and movies. The thesis is not concerned with engineering applications such as civil or industrial engineering, where CAD type software is used for modeling purposes. Although the example 3D models used in this thesis include a car and a jet fighter, the only concern is achieving realistic appearance rather than engineering concerns. These 3D models² have sufficient complexity in terms of consisting of multiple overlapping objects and yet are easy to understand.

1.2 Objectives

The primary objective of the research discussed in this thesis is to answer the following key question:

To what extent is it possible to better support focus and context awareness in 3D modeling environments?

To answer this key question the research presented in this thesis attempts to answer the following related questions:

1. *What are the main problems faced by modelers when performing 3D modeling tasks using conventional modeling software?*
2. *How do modelers attempt to overcome these problems using conventional modeling software tools?*
3. *What kind of techniques can be developed to address these problems by better supporting focus and context awareness in 3D modeling?*

² 3D models were purchased from <http://www.3dcadbrowser.com/info.aspx> and the author has been granted permission to use them in this thesis.

4. *How effective are these focus and context awareness techniques in assisting 3D modelers in performing their modeling tasks?*

1.3 Approach

To answer the questions posed above, the research methodology followed in this thesis comprises four stages:

1. Literature review
2. Identification of requirements
3. Design and implementation
4. Evaluation

The research described in this thesis begins with a review of the relevant literature. This literature review is divided into two chapters. Chapter 2 focuses on 3D modeling, and identifies existing tools and techniques used in modeling tasks. This is followed in Chapter 3 by a review of the research on the problems associated with maintaining focus and context awareness, and some of the techniques developed to deal with these problems. As mentioned earlier, most of these focus on 2D environments and tasks.

To gain a better understanding of the issues related more specifically to 3D modeling tasks, a pilot study of 3D modelers was conducted. This questionnaire type study investigated the key challenges faced by modelers while performing their 3D modeling tasks. This study and its findings are discussed in Chapter 4.

A more comprehensive study of the issues related to focus and context awareness in 3D modeling tasks was then undertaken with professional modelers. The findings from this interview and observational type study are presented in Chapter 5.

A set of five focus and context awareness techniques for 3D modeling tasks was then designed and implemented based on the findings of the previous studies and the review of the related literature. These techniques are presented in Chapter 6.

A laboratory-based user study was then conducted in order to verify the effectiveness of the developed techniques in addressing the problems of maintaining focus and context awareness. Chapter 7 discusses the methodology, tasks, data collection methods used, and the findings of this study.

The results of this study identified a number of issues that needed to be addressed. Based on these, several modifications were made to the original focus and context awareness techniques. These modifications are discussed in Chapter 8.

The modified techniques were then furthered evaluated through a second user evaluation. The goal of this study was to identify whether modifications made to the focus and context awareness techniques improved their effectiveness. This study and its findings are presented in Chapter 9

Further alternatives were then investigated to extend the focus and context awareness techniques using multiple viewports and display screens. These alternatives and extensions are discussed in Chapter 10.

1.4 Contributions

The research presented in this thesis makes the following original contributions:

- A critical review of literature related to 3D modeling tasks using conventional 3D modeling software (Chapter 2) and existing methods for maintaining focus and context awareness in 2D and 3D environments (Chapter 3).
- Identifying focus and context awareness problems faced by modelers when performing 3D modeling tasks, and how they deal with these problems using existing software tools (chapters 4 and 5).
- Development of a set of focus and context awareness techniques specifically designed for 3D modeling software (chapters 6, 8, and 10).
- Evaluation of these focus and context awareness techniques to determine their effectiveness in supporting 3D modelers (chapters 7 and 9).

1.5 Thesis Structure

The thesis is structured into six parts:

Part I Background

Chapter 1	Introduction
Chapter 2	3D Modeling
Chapter 3	Focus and Context Awareness

Part II Identifying Requirements

Chapter 4 Pilot Study of 3D Modelers

Chapter 5 Study of Professional 3D Modelers

Part III Development and Evaluation I

Chapter 6 Design and Implementation of a Set of Focus and Context Awareness Techniques

Chapter 7 Evaluation of the Focus and Context Awareness Techniques

Part IV Development and Evaluation II

Chapter 8 Improving the Focus and Context Awareness Techniques

Chapter 9 Evaluation of the Modified Focus and Context Awareness Techniques

Part V Extensions and Conclusions

Chapter 10 Multiple Viewports and Displays

Chapter 11 Conclusions and Future Work

Part VI References and Appendices

References

Appendix A Ethics Approval for the Pilot Study

Appendix B The Assignment Sheet

Appendix C Ethics Approval for the Study of Professional 3D Modelers

Appendix D Codes Used for Determining the Visibility of the Components to be Displayed

Appendix E Ethics Approval for the Study of the Focus and Context Awareness Techniques

Appendix F Instruction Manual and Handout Used in the Study of the Focus and Context Awareness Techniques

Appendix G Ethics Approval for the Study of Modified Focus and Context Awareness Techniques

Appendix H The ordering of the Task and Experiment Conditions

Appendix I Instruction Manual and Handout Used in the Study of
the Modified Focus and Context Awareness
Techniques

Appendix J Video Demonstrations

CHAPTER 2

3D Modeling

The focus of the research presented in this thesis is on 3D modeling, in terms of the processes involved, the tasks undertaken, and the software used. This chapter therefore describes these aspects of 3D modeling using existing related literature.

The chapter begins with a discussion of 3D models (Section 2.1). This is followed by a review of existing modeling software employed by 3D modeler and the types of user interfaces provided by 3D modeling software (Section 2.2). In Section 2.3, usages of 3D models are explored in detail. The types of modeling techniques currently available are discussed in Section 2.4. The common elements between all these techniques are discussed in Section 2.5. In Section 2.6, three type of modeling processes are discussed in depth. The two type activities (i.e. navigation and manipulation) are analyzed in Section 2.7, and the types of input and output devices used in 3D modeling are discussed in Chapter 2.8. The chapter concludes with a discussion in Section 2.9 and a summary in Section 2.10.

2.1 3D Models

Prior to the development of computer-based 3D modeling technologies, objects could only be represented or modeled through verbal description, paper-based sketching or drawings, or sculptured. When verbally described, there is no visible image or object, and therefore the model can only be imagined. A major limitation of verbal or narrative description is that the receiver's interpretation may not match the presenter's ideas.

Paper-based sketching is commonly used at the early stages of the design process (Sachs et al., 1991). Both the Oxford and Webster dictionaries provide very similar definitions of sketches. The Oxford dictionary describes sketches as "a rough or unfinished drawing or painting, often made to assist in making a more finished picture". The Webster dictionary defines sketches as "a rough drawing representing the chief features of an object or scene and often made as a preliminary study". Sketches are normally incomplete or not very detailed, such that some of the features

or information pertaining to the represented object are missing or cannot easily be identified.

With the sculpturing process, models are usually small objects and built to scale. The Oxford dictionary defines this type of model as “a three-dimensional representation of a person or thing or of a proposed structure, typically on a smaller scale than the original”, and it is “a figure or object made in clay or wax, to be reproduced in another more durable material”. The Webster dictionary defines this type of model as “a miniature representation of something”. The level of detail of a sculptured model depends on the required specifications. For example, a model may also include its internal components.

In general, 3D models can be divided into two categories: 3D models created in a non-computer environment and 3D models created by using computers. The three techniques mentioned so far (i.e. verbal description, paper-based sketching or drawings, and sculpturing) are in the first category of models created in a non-computer environment. These days most 3D models are often created using computers.

In a computer-based 3D modeling environment, a model created using a computer is very different from previously described types of models. Such a model is no longer an object, for instance made of clay, or a sketch drawn on a piece of paper. A model of this type is defined as a set of data structures. These structures include all the relevant parameters or information pertaining to the object (Grau, 1996). Foley et al. (1997) have expanded Grau’s definition by stating that a 3D model is a virtual representation of some (not necessary all) features of a concrete or abstract entity and can be either still or animated. This definition clearly indicates that a model does not necessarily include all sections of the represented object, and may only show the parts that are of some interest. Radoff (2008) defines a 3D model as a visual representation of an object created with width, height, and depth. This definition includes depth as one of the key items for representing a model in a 3D space, but does not define how depth can be integrated with a 3D model. Jones (2009) describes further that connected points in three dimensional space form the model, and unlike a 2D model, a 3D model can be viewed from all sides.

There are two kinds of structures used to represent 3D models. These may be implicit

or explicit (Min, 2005). In the implicit representation, a 3D model and its surfaces are created by providing a set of parameters to a 3D modeling software. For instance, when generating a 3D model of a sphere, two parameters (coordinates of its center point and a radius value) are required, while a 3D model of a cone requires three basic parameters, namely the coordinates of its center point, and its radius and height.

In the explicit representation of a 3D model, a set of vertices is often used to represent it (Tan, 2011). In a computer-based 3D model, the “vertex” is the smallest and simplest unit of information. A vertex is defined by its x, y and z coordinate positions. Two connected vertices produce a line, called an “edge”. Three or more connected vertices will produce a single surface called a “face”. A triangle is the simplest form of a face. Two or more triangles can be combined to create a ‘polygon’. For instance, a square is a polygon that can be broken down into two triangles. Figure 2.1 shows a model of a cube, which is made up of 8 vertices, 12 edges and 6 faces. In this particular example, each face is a square polygon, whereby all six polygon faces can be converted into 12 triangle faces.

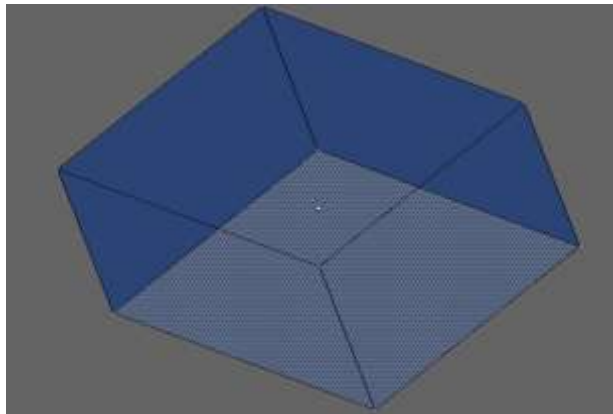


Figure 2.1: Model of a cube consisting of 8 vertices, 12 edges and 6 faces

A more complex 3D model is shown in Figure 2.2. This model, representing a human ear, does not look very realistic looking because it is shown as its consisting polygons. This is generally referred to as the wireframe view of the model. To create a more realistic looking version of a model, a process known as rendering (provided with a 3D modeling software) needs to be performed. Rendering is defined by Choros and Kaczynski (2008) as “a process of generating photorealistic images on the basis of geometrical models”. In another definition, Miller et al. (2010) describe rendering as the process of “automatically converting 3D wire frame models into 2D images with 3D photorealistic effects on a computer”. During the rendering process, the scene

which may contain many such polygonal models, gets converted to a two dimensional image by the rendering engine of the 3D modeling software being used.

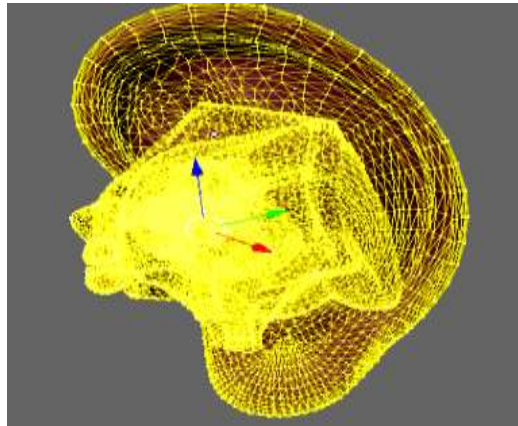


Figure 2.2: Model of a human ear as viewed during the modeling process

The rendering process portrays the 3D scene as a picture. It is taken from a specified location that not only determines the viewing angle of the rendered object but also what will be visible in the picture. In order to see a rendered model from various angles, multiple shots of static rendering can be done. This method represents a non-real-time rendering technique widely used in the movie industry. Another method used in computer games, is known as real-time rendering, where the image “appears on the screen, the viewer acts or reacts, and this feedback affects what is generated next” (Akenine-Moller et al., 2008). In other words, users can control how and when the targeted location is viewed.

During this process of rendering a 3D model, elements such as lighting, shadows, reflection and refraction are applied in order to give a more realistic result. Figure 2.3 shows the example human ear model from Figure 2.2 after it has been rendered.

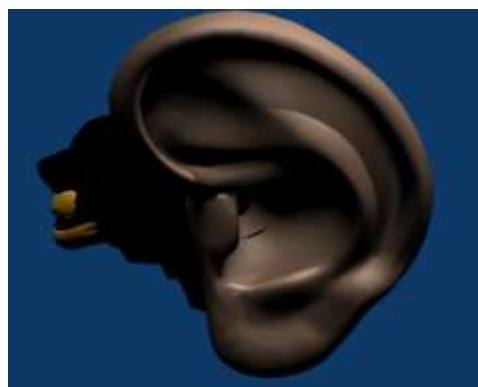


Figure 2.3: A rendered version of the human ear model shown in Figure 2.2

A model may also have internal components in the same way that a human model would contain the organs, where each organ is treated as an individual object.

Similarly, the model of a car might contain an engine and other internal components. As previously mentioned, the position of the viewing camera will determine which parts of the model are rendered and shown to the viewer. With reference to Figure 2.3, because the viewing camera is virtually located in the front of the ear, the internal parts of the ear are not visible, and remain hidden from the viewer.

2.2 3D Modeling Software

Due to their complexity, 3D models are usually created, and rendered, using some kind of a 3D modeling software. There are many commercial and non-proprietary 3D modeling software products available. Some of the well known 3D modeling software are MAYA (Autodesk, 2012), 3ds Max (Autodesk, 2012), Cinema4D (MAXON, 2012), Auto CAD (Autodesk, 2012), and Blender (Blender, 2012). Each of these applications provides a set of tools that a modeler can use to create 3D models.

Most 3D modeling software have similar basic functions. These basic functions enable modelers to import primitive objects, create new objects, shape objects to their final form, transform them, and so on. In this section, some of the main concepts related to 3D modeling software, including their interfaces, the types of views they provide, and the types of display modes they have are discussed.

2.2.1 3D Modeling Interfaces

Each of the 3D modeling software referred to above has its own unique interface. Figure 2.4 shows the interfaces of two different modeling software namely Maya personal Edition 8.5 (left) and Blender 2.5 (right). In this example, there are four different objects in the model being viewed, with each object having several vertices, faces and edges. Four viewports or sub-windows are shown in each of the software applications. A viewport is the region of the screen where objects are projected. The limit to the number of viewports that can be opened varies between different software. However, the area allocated to each viewport becomes smaller as more viewports are opened. Therefore, modelers often have to tradeoff between the working area available in each viewport and the amount of information provided by having additional viewports open.

Each of the viewports shown in Figure 2.4 shows the model being viewed from one of the four different orientations. In this example, the top left viewport shows the model

from top view, the bottom left viewport is for the side view, while the bottom right is for the front view, and the top right viewport shows the perspective view (see the next section). Modelers may close any of the viewport or change the orientation of the model within them.

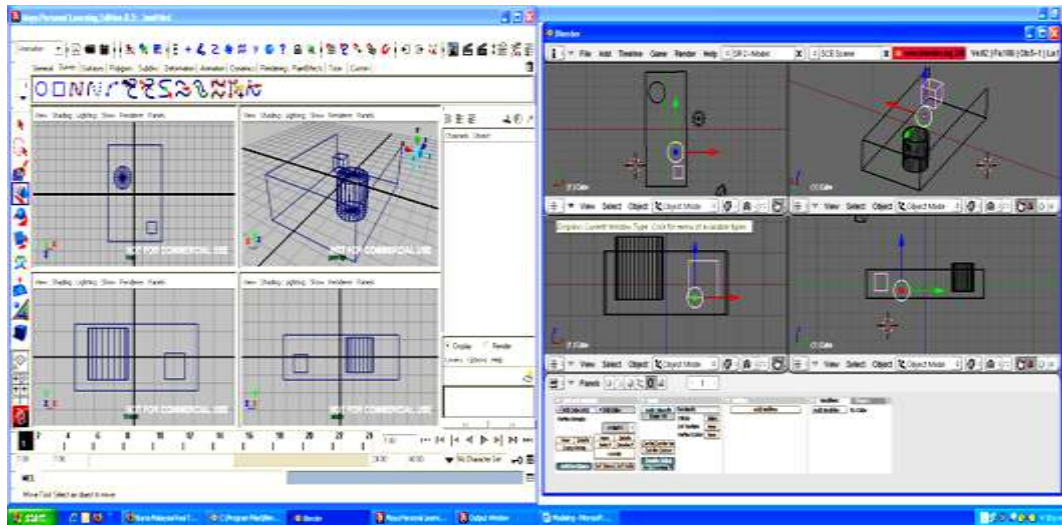


Figure 2.4: (left) Sample 3D modeling interface from MAYA and (right) Blender

2.2.2 Orthographic and Perspective View

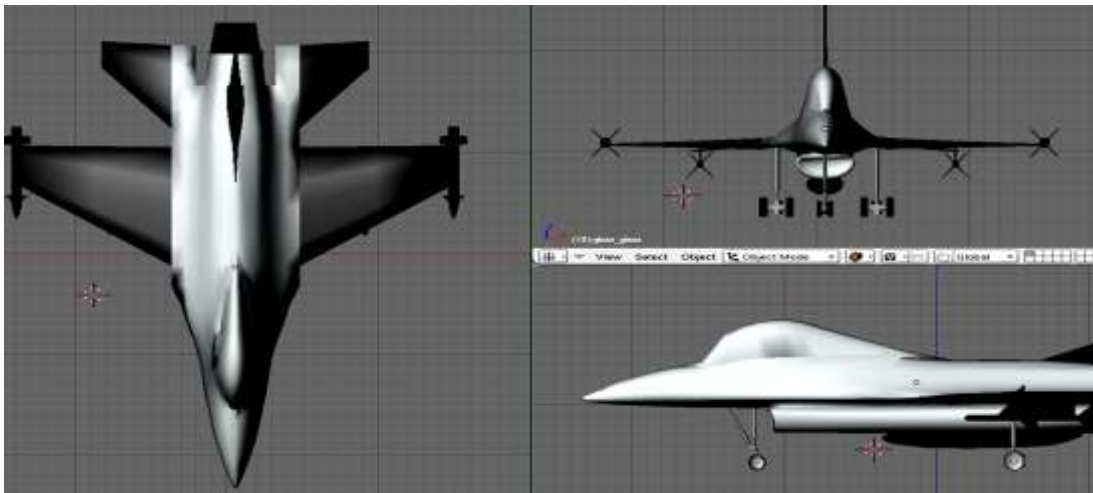


Figure 2.5: A plane is viewed from top, front and side in orthographic mode

In 3D modeling tasks, models are often shown or displayed in one of two different views: orthographic and perspective. An orthographic view is defined as one whereby all parallel lines remain parallel and do not converge from any direction (Hulsey 2008). In orthographic view, objects or models are often viewed from front, top, bottom and side. For instance as in Figure 2.5 the display area is divided into three viewports. A screen shot of a plane shows views of this model from top, front and side orthographically.

In perspective view, a point of view gives different dimensional effects from each viewing where the parallel lines are no longer parallel. Instead, “the lines will merge at a point called the vanishing point that appears to create a natural effect whereby the distances between two objects are simulated” (Hulsey 2008). In 3D modeling tasks, the illusion of distance provides modelers with some sense of position between near and far objects.

2.2.3 Solid Mode versus Wireframe Mode

A 3D model can also be shown in various drawing modes, for instance shaded, textured, bounding box, solid, and wireframe or boundary (Hearn and Baker, 1997). The solid and wireframe modes are usually used throughout the modeling processes. In a solid mode, models define the volume of the objects they represent. Solid mode works hand in hand with the selected view type. When orthographic view and solid mode are active simultaneously, the model can be seen only from the outmost level of the model.

On the other hand, when perspective view and solid mode are active simultaneously, the viewer is able to see the internal components of the objects. In Figure 2.6, the engine is actually located inside the car. However, the combinations of perspective view, solid mode and zooming process enable the engine to be seen by the viewer.

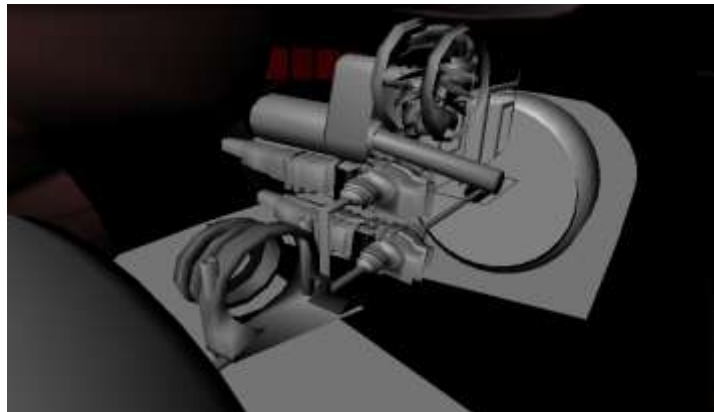


Figure 2.6: Model is in solid mode with perspective view

In a wireframe mode, the model represents the surface of an object by showing the object's boundary. In this mode, the boundaries of all objects including boundaries of internal objects are visible to the modeler. In essence, there are no hidden objects in this display mode. However, the actual locations within the overlapping boundaries cannot be estimated easily. Figure 2.7 shows a snapshot of a model in solid mode on

the left, and in wireframe mode on the right.

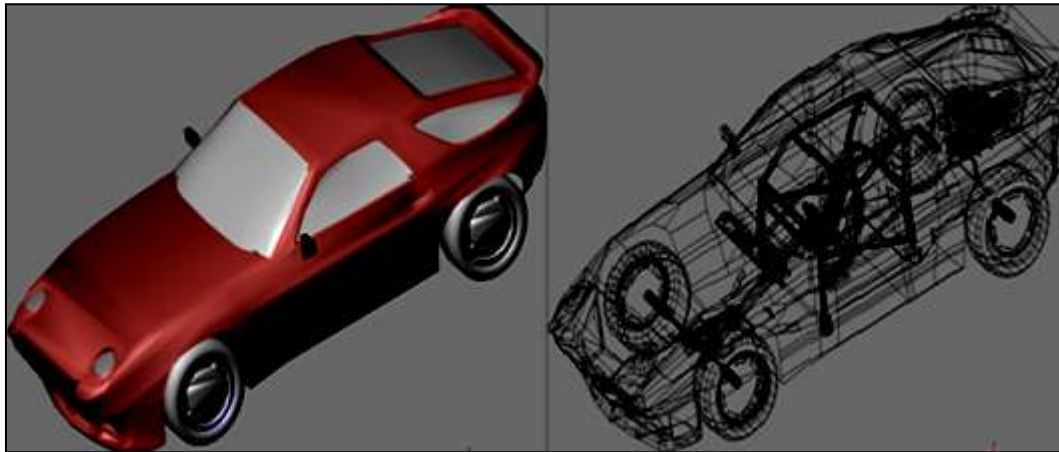


Figure 2.7: (left) A model in solid and (right) in wireframe modes

2.3 Usage of 3D Models

Modeling software can be categorized according to their primary emphasis and intent in creation of the 3D models. There are three primary categories pertaining to the usage of 3D models which these modeling software support: models for rendering (static), models for animation, and models used in simulation. In the first category, rendered models are similar to still pictures used in a slide presentation, or printed on paper as described earlier.

In the second category, the use of models in animation involves the process of generating and displaying still images, one after another (Potmesil and Hoffert, 1987). Besides displaying still images, one after the other, there are three other elements, namely motion, time and distance, that need to be considered (Pell, 1997). They play an important role in making it possible to create a smooth and meaningful transition in the animation.

A technique called ‘keyframing’ is popular in generating high quality animations. In ‘keyframing’, strategic points are set up, where these points are used during the rendering process for capturing different stages or locations of the model, and also to determine poses of the character in between these points (Finkelstein, 2009).

Another popular technique used for creating animations is by using a motion capture equipment. In motion capture, the movement of a 3D model is synchronized with the movement of a live object such as a human or an animal. Dyer et al. (1995) define motion capture as a process that "involves measuring an object's position and

orientation in physical space, then recording that information in a computer-usable form. Objects of interest include human and non-human bodies, facial expressions, camera or light positions, and other elements in a scene".

In the third category, where models are to be used in simulation, models are not only animated, but also integrated with mathematical formula to assist calculations and predictions (Oxford, 2012). Use of models for simulation is popular in the manufacturing industry, where 3D models play an important role in enabling prototype development prior to mass production. The model simulation process is more challenging because in this case modelers not only need to have good modeling skills but also animation and simulation skills.

Therefore it is clear that some 3D modeling is required regardless of the use of the model in either of the three categories. For this reason, the ability to master the modeling process is essential for any 3D modeler. In the course of mastering the modeling process, modelers need to be aware of the most appropriate modeling techniques that they should employ. In general, each technique can be used for creating the curves, 3D surfaces, vertices and polygons that represent a model. The next section describes some of the most commonly used modeling techniques.

2.4 Modeling Techniques

Creating 3D models in the past was not easy. The Bresenham algorithm, which is capable of plotting lines, and is required for generating a 3D model, was published in 1965 (Bresenham, 1965). It wasn't until 1975, that the well known Utah teapot (also known as Newell teapot) was produced (Crow, 1987). This model is popular in the computer graphics community even though its mathematical model of an ordinary teapot is a fairly simple shape (Torrence, 2006). Since then, 3D modeling has grown rapidly and so has the quality and complexity of the generated 3D models.

These days there are a range of techniques that modelers can use for creating 3D models. These can be divided into two groups: implicit and explicit techniques. This categorization is based on the data structures used to represent 3D models by each of these techniques. In the implicit group, techniques that will be discussed in this chapter include:

- Constructive Solid Geometry

- B-spline
- NURBS

While in the second group, the following techniques will be described.

- Polygon Modeling.
- Freehand 2D to 3D sketching
- Still image conversion
- 3D scanner technology
- Video tracing.

2.4.1 Constructive Solid Geometry

Constructive Solid geometry (CSG) is the process of constructing a 3D object by using a combination of 3D primitive solid objects. Using this technique, two or more primitives objects are combined with each other, using Boolean operations. Primitive objects used in this type of operation can be sphere, cylinder, cone, cube, and etc., while the Boolean operations can be union, intersection and difference. This technique enables the creation of a more complex object from two or more simple objects. As an example, a solid block with a few holes can be created through a combination of a cube and several cylinders.

CSG is defined by Hearn and Baker(1997) as a technique “to combine the volume occupied by overlapping 3D objects using set operations”. Similarly, Goldman (2009) describes CSG as a process of building up more complicated solids from a small collection of simple primitive solids, by applying Boolean operations.

Figure 2.8 demonstrates the process of creating a model using the CSG technique. The image on the left shows two separate solid objects. The image in the middle shows a snapshot of the two object being merged, while the image on the right shows the new solid object after the Boolean operation “difference” has been applied.

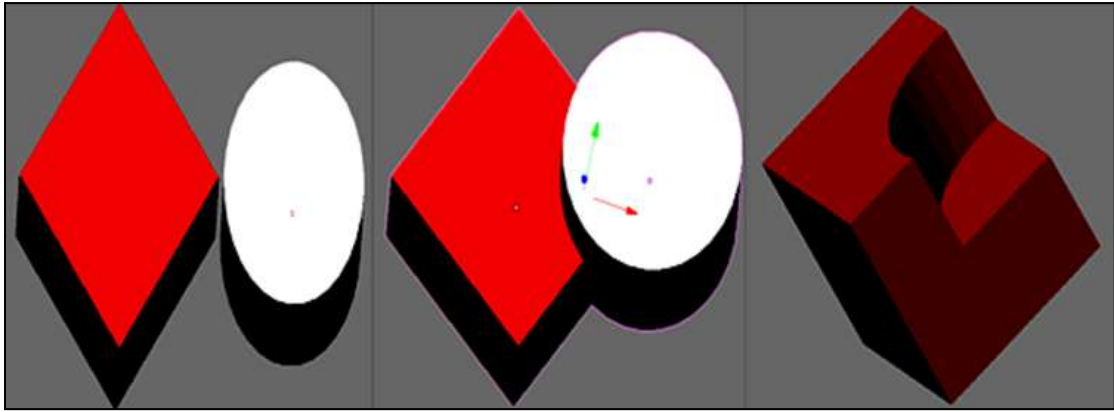


Figure 2.8: Applying Boolean operation "difference" to two primitives objects

Using this technique, modelers pass two implicit parameters to the 3D modeling software being used; a Boolean expression and the location of the two objects, as well as the objects themselves. Through mathematical calculations which use these parameters, a Boolean operation is calculated or processed to generate the new solid object.

The process of constructing a 3D model using the CSG technique is rather easy to carry out. This technique can also produce 3D objects which are relatively accurate (Kerbrat et al., 2010). However, the key problem with the CSG approach is that it is computationally expensive to represent models with irregular surfaces (Tarnig and Chang, 1993).

2.4.2 B-spline Modeling

In the real world, a spline is usually a thin and flexible wood or rubber strip used for drawing large curves. Mathematically, however, a spline is a function used for defining a curve.

In 3D modeling, a spline requires two or more points to create a curve. All the other points which are between the specified points are created through an interpolation process (i.e. generated by using a mathematical formula). Anand (1993) defines spline as a general piecewise parametric representation of geometry with continuity at the common joints between segments. A similar definition is given by Salomon (2006) where spline is defined as a set of polynomials that are smoothly connected at certain data points.

There are several types of spline curves that have been adopted by 3D modeling software. Among these are linear spline, cardinal spline, B-spline, Bezier curve and

NURBS (Kerlov, 2004). However, B-spline and NURBS are the most widely used method for approximating splines (Zang and Qin 2001, Henderson 2003, and Sarfraz 2008).

B-spline refers to a Basis spline (Boor 1978, Meyer, 2005, and Salomon, 2006). B-spline contains the start and end points of the curve together with a set of local control points. However, in B-spline, the curved line rarely passes through its control points. B-spline approximates middle points between two control points and it can be thought of as a method for defining a sequence of degree of curves that join automatically (Pfenning, 2005). Local control point is a point that determines the area that will be affected or influenced when it is being moved (Sulkimo and Vuoskoski, 1995, Sederberg 2005, and McConell 2006).

The B-spline technique is particularly useful for creating organic objects that often consist of complex curves. This is achieved through automatic smoothing of the curve between two consecutive controls using mathematical calculations.

Figure 2.9 illustrates how the B-spline technique works. In this example, the B-spline circle contains 8 control points as shown in Figure 2.9 (left). One of the control points (control point 2) is manipulated by extruding it to the right, as far as point A. As shown in Figure 2.9 (right), when the control point 2 is extruded, the part of the curve that is affected is minimized to the curve between controls points 1 to 3 only. Furthermore, a smooth curve is still maintained even when the curve is modified.

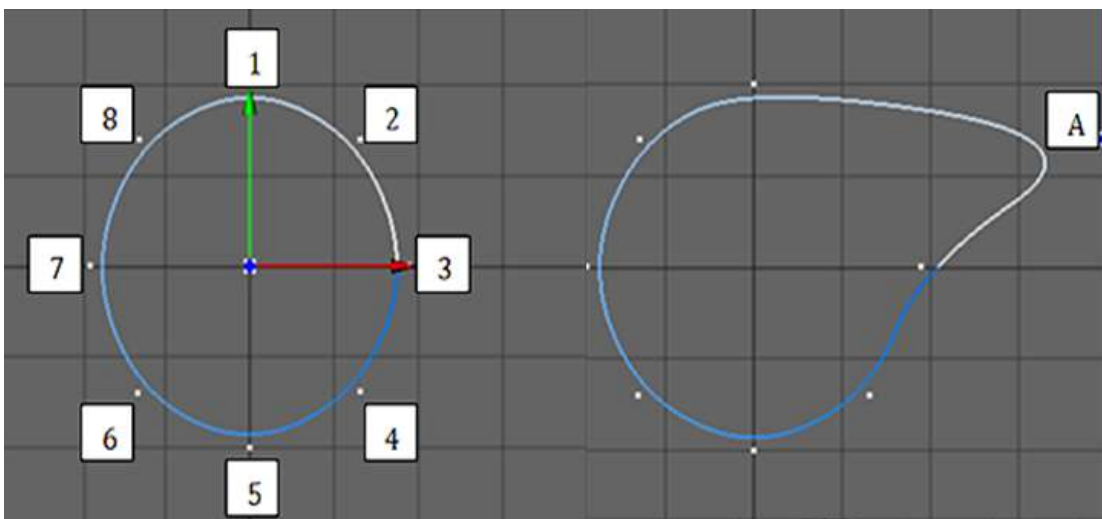


Figure 2.9: B-spline circle before and after extruding control point 2

This concept which is applied to the B-spline curve is adopted in 3D modeling. In 3D modeling, the changes that take place are also confined within the two nearest curves

of the manipulated control point. Figure 2.10 (left), shows an example of a 3D B-spline model. This model is created by using an extrusion technique which is applied to the whole B-spline circle. This technique increases the thickness of the circle to generate a 3D model. After this conversion, the model is further extruded at point A, and the result is shown in Figure 2.10 (right). This example shows that the B-spline concept applied in this process is able to produce a smooth curve on the modified object, and the effect to the neighborhood of the altered point A is minimized.

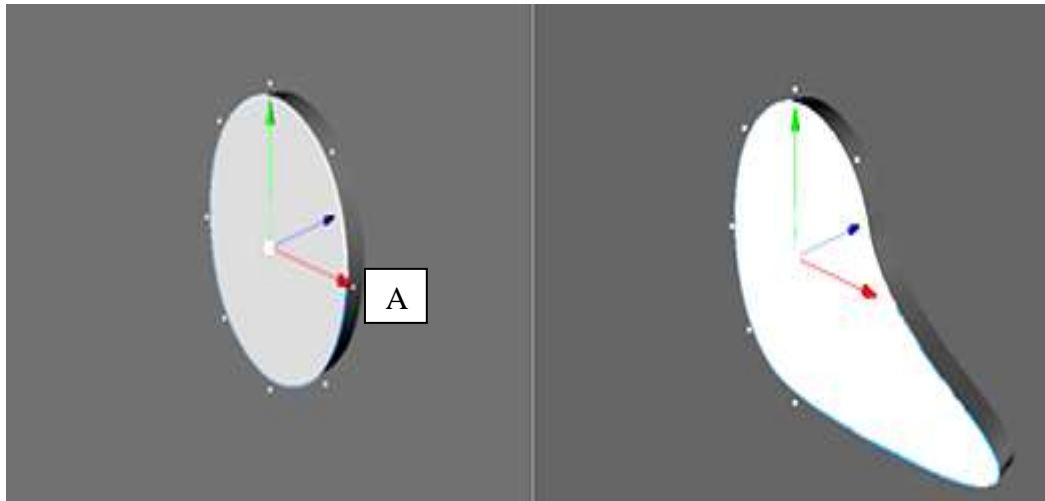


Figure 2.10: (left) Example of the model before and (right) after extruded at point A

Although the B-spline technique is able to generate smooth curves, it is difficult to create complex models using B-splines only. Pourazady and Xu (2000) point out that interactive design of 3D models using this technique “is often cumbersome where in many cases, a large number of control points must be manipulated in order to modify even a small piece of a curve segment”. They also state that it is often not clear which control points should be manipulated, and how the manipulation should occur. This is in contrast to the 3D modeling requirements where modelers need to have full control over what they need to change in order to create 3D models. Modelers also need to be able to determine where and to what degree the changes need to be made.

2.4.3 NURBS Modeling

As mentioned earlier, the NURBS technique is one of the most widely used methods of approximating splines. It is available in many commercial 3D modeling software because of its power of representing free-form shapes. Although NURBS is similar to B-spline, and they both generate smooth curves, there are some differences between them.

NURBS, or Non-Uniform Rational B-Spline (Hearn and Baker 1997, Salomon 2006, and Hardy and Steeb 2008) is a generalization of B-spline. The main difference between NURBS and B-spline, however, is that in NURBS a weight is associated with each control point (Wilkins and Billawala, 1992, and Zlatanova, 2008). The value of a weight is calculated using the distance between each control point and the apex of the curve. The weight also contributes to the shape of a curve or surface by providing extra control for modeling it.

Pourazady and Xu (2000) point out that the weight associated with each control point in NURBS offers a “unified mathematical form not only for representation of free-form curves and surfaces, but also for the precise representation of close-form shapes such as lines, conics, quadrics”. For this reason, NURBS is a very useful method not only for creating organic objects but also for modeling complex real-world surfaces such as terrain.

The following example illustrates the difference between a NURBS and a B-spline. A NURBS-based circle similar to the B-spline circle described earlier (Figure 2.9) is shown in Figure 2.11. This circle has 8 control points, as with the previous example. Figure 2.11 (right) shows the result of extruding point 2 to point A on the right. As mentioned earlier, the distance between the control point and the apex of the curve determines the value of the weight. So in this case, the distance between the control point 2 to the apex of the curve is larger than the distance between a control point 2 to the apex of the curve in Figure 2.9. Due to this weight factor, the changes that take place when control point 2 is extruded is less compared to the B-spline example of Figure 2.9.

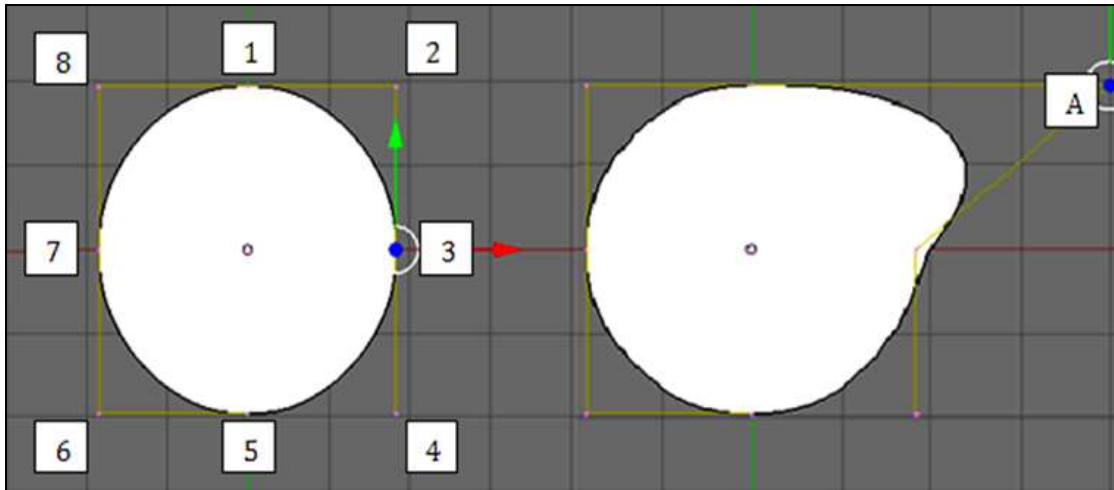


Figure 2.11: NURBS circle before and after extruding at control point 2

Curves and surfaces created by both NURBS and B-spline techniques are smooth. However, as with B-spline, the NURBS technique also relies on the use of control points, except that NURBS control points also have weights associated with them. The two parameters of control points and weights used by the mathematical formula in the NUBRS technique have an impact on the final curves or surfaces of the model. Therefore, making a minor modification to a small part of a model is even more difficult using NURBS than when using B-spline.

2.4.4 Polygonal Modeling

3D polygonal modeling is the process of building a 3D object by explicitly specifying the coordinate position of polygons that eventually shape the curves or surfaces of the objects (Russo 2006, and Goldman 2009). This technique is different in comparison to the last three techniques because in this technique modelers are able to directly control every part of the model.

With polygon modeling, modelers often begin their modeling tasks by starting with one or more primitive objects that are available in most 3D modeling software. Figure 2.12 shows four examples of primitive objects: a plane, cube, cone, and cylinder. The primitive objects used as the basis of polygon modeling usually consists of a small number of polygons. A polygon, as described in Section 2.1, consists of vertices, edges, and faces. These three are also known as the key components of a polygon-based model. For example, a cube is likely to be made of 8 vertices, 12 edges and 4 faces, while a cylinder might consist of 66 vertices, 160 edges and 66 faces.

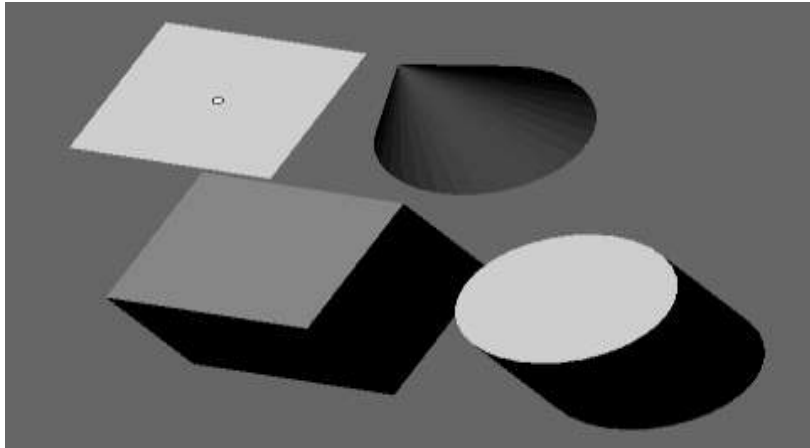


Figure 2.12: Examples of primitive objects that are included in most 3D modeling software

In this type of modeling, modelers would mold a ready-made primitive object by manipulating its key components. Key components can be added, deleted, subdivided, altered and extruded as necessary. The addition or subdivision processes, which can be done repetitively, generate new key components and polygons. In general, the number of key components and polygons grow in relation to the complexity of the model.

Figure 2.13 shows the model of a human consisting of two objects: the body and the skeleton. In this example, the skeleton (colored pink) is made of 27,584 vertices, 81,484 edges and 54,218 faces. A cylinder is likely to have been used initially for creating the model of the skeleton. So in this case the number of the polygons has increased from around 66 to more than 50,000. This example illustrates how the large number of polygons and key components can often get overcrowded and overlapping in a reasonably complex 3D model.

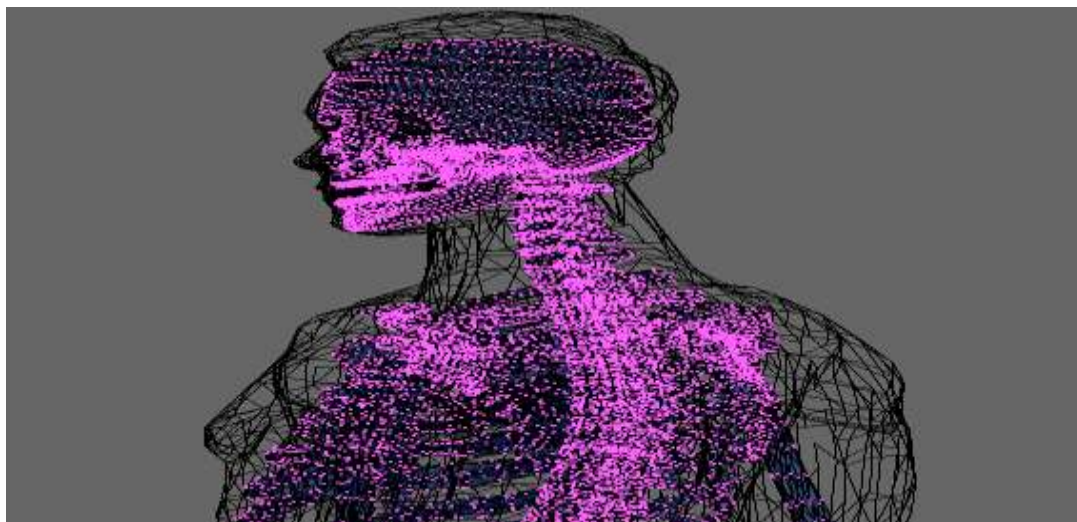


Figure 2.13: A human model consists of two objects, the body and the skeleton

One of the advantages of the polygonal modeling technique is that the impact of any manipulation to vertices is limited to the immediate edges that are connected to the manipulated vertex. For example, extruding a vertex at point A of the model as shown in Figure 2.14 (left) will generate the result shown in Figure 2.14 (right). In this example extruding the vertex A has had no impact on the other areas of the model away from it.

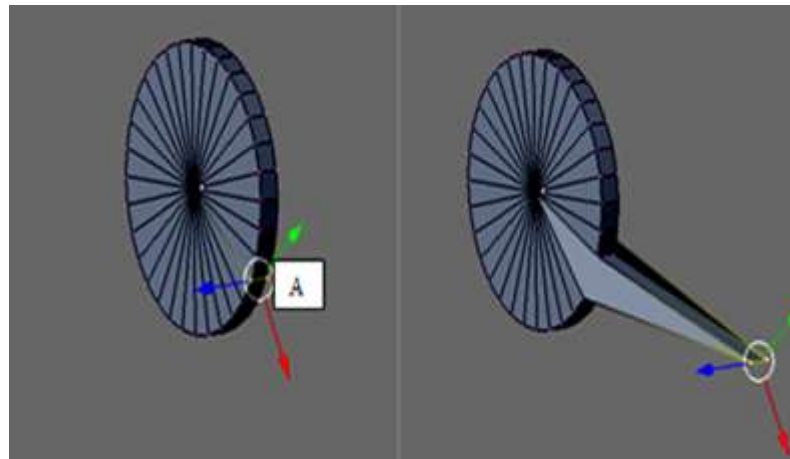


Figure 2.14: (left) Polygonal model before and (right) after extruding at point A

In polygonal modeling method there is no weight associated with a vertex. Therefore, the changes to the curve are only determined by the position of the edges and the location of the manipulated vertex. The number of vertices are normally higher in polygonal models compared to the number of control points in B-spline or NURBS models. This higher number of vertices in polygonal modeling is required to generate smooth curves.

All the techniques discussed above involve the manipulation of one of two types of components (i.e. vertices or control points). These two types of components have to be manipulated by the modeling software being used either explicitly or implicitly to create 3D models. While the models created by these techniques can be made to appear photo-realistic and high quality, it is known that the processes involved for creating and maintaining the models are very tedious and time consuming (Ono et al. 2004, El-Hakimi et al. 2005). Therefore a few other techniques have been developed in order to simplify the modeling process. The techniques that will be discussed in the next few sections provide a starting point to polygonal modeling, where the generated models are usually incomplete and not very detailed. For this reason, models generated using these methods often need to be manipulated further to create the final

model required.

2.4.5 Freehand 2D to 3D Sketching

Typically in sketch-based modeling, the user enters a series of strokes and the computer interprets them to accomplish some tasks. The idea of using sketching for interacting with computers is not new. This concept was first proposed in the early 1960s, and has evolved since then. Freehand 2D to 3D sketching is defined as the "process of communicating ideas through pencil and paper that approximate visual images with low overhead where there is no need for precision or specialized knowledge" (Zelevnik et al., 1996). With this technique, modelers are able to enter information into a computer using a stylus or mouse with digital ink strokes. The basic goal of sketching is to make a hasty or un-detailed drawing prior to further precise manipulations for improving the model.

Ivan Sutherland in his seminal work on SketchPad used a light pen to make drawings and create geometric primitives (Sutherland, 1963). Many years later Zelevnik et al. (1996) introduced a system called SKETCH. While functional, SKETCH is limited to standard 3D geometric primitives such as cubes, cylinders, and pyramids for conceptual modeling.

In 1999 Igarashi et al. introduced a prototype system called Teddy which improved the usefulness of sketching technique by allowing free-form modeling. Based on Teddy, another system was then developed, called Vteddy (Owada et al., 2003). Vteddy provides a "temporary cutting" operation for editing internal structures. Since then, the sketching techniques have improved progressively.

Freehand 2D to 3D sketching has been categorized here as an explicit technique, similar to polygon modeling. However, this technique is only able to approximate a 3D model, and the lack of detail and precision in the drawing is likely to require further refinements to be made to the generated model. In most cases, the created models can be edited to add the missing components. This is done by using editing functions available in the polygon modeling technique.

2.4.6 Still Image Conversion

Still Image Conversion (SIC) is a technique used to generate 3D models by making use of the depth information of different areas of 2D images, which can be determined

by their contrast and sharpness (Wei, 2005). In many cases, multiple shots of images are used to produce a 3D model. For example, a model of a human head can be created by taking pictures of the head from three different angles (e.g. from the front, side and back). Various techniques are then used to detect the depth differences between far and near objects of the 2D image.

When using this technique, the quality of the original 2D images play an important role in generating the 3D model. Therefore, any missing information, especially the depth information related to each separated area, can often generate an incomplete model which then requires further improvements. When this occurs, the polygon modeling technique can be used for adding the missing components.

2.4.7 3D Scanner

A 3D scanner is a device that analyzes a real-world object or environment to collect data on its shape and possibly its appearance (Georgopoulos et al., 2010). There are a variety of technologies used for digitally acquiring the shape of a 3D object, and most of them require multiple scans in order to generate a complete model. A set of vertices are determined from the scanned object, that are then used as input to the modeling software to generate the surfaces and polygons of the 3D model.

Using this technique, the quality of the generated 3D model is determined by the accuracy and precision of data collected from the scanning process. Therefore, the generated 3D model may not contain all the necessary polygons due to missing data arising from imprecise scanning function. Once again the polygon modeling technique is often used for adding missing details, or for manipulating the created polygons.

2.4.8 Video Tracing

In this technique, a 3D model is created by tracing the shape of the object being modeled across different frames of images captured by video (Pollefeys et al., 2004). An example of this technique is provided by Anton et al. (2007) in their system called VidoeTrace, which enables users to trace the shape of the object to be modeled over one or more frames of the recorded video. This application also support functions such as sweeping, extruding, and mirroring.

As with to the 3D scanner technique described earlier, a model generated using the

video tracing technique can also be edited by manipulating its "point clouds". During the manipulation process of the point clouds, modelers would undertake the same activities used in the polygonal modeling technique, where points are added, deleted, or transformed for reshaping the model.

2.5 Common Elements of Various Modeling Techniques

In the previous sections various implicit and explicit modeling techniques were discussed. While these techniques differ in their individual approaches, they nevertheless share one common element in that they all require some level of editing. This means that each 3D model, whether it is created automatically or not, needs to be shaped and perfected through further editing. Automatic creation of models refers to 2D to 3D sketching, still image conversion, 3D scanner, and video tracing techniques, while the non-automatic creation of a model refers to CSG, B-spline, NURBS, and polygonal modeling techniques. What is important to note is that regardless of how the initial models are produced, modelers often need to edit these models further by manipulating their control points and vertices. In most cases, this editing is done by some employing polygonal modeling.

Based on the rationale that the polygon modeling technique is generally used for refining models created using various methods, it is reasonable to assume that this technique is the most commonly used method for creating or refining 3D models. Therefore it is important to better understand the process of polygonal 3D modeling. This is discussed in the next section.

2.6 3D Modeling Processes

Selection of the most suitable modeling process is generally dependent on two factors. The first pertains to the specific purpose for which the model will be used. Applications of 3D models span across a wide range of industries including the movies, computer games, and manufacturing. The second factor relates to the model category being created. The three primary modeling categories are character modeling, scene modeling, and terrain modeling.

Each modeling category is usually applied across multiple industries. For example, two or more modeling categories may be used in creating special effects for movies. Movies normally include models of both characters and scenes, and sometimes they

may even include terrain as well. Some computer games, such as a flight simulation, would contain models from all three categories.

Based on these examples, it is clear that there are some differences and commonalities between the three modeling categories. These differences and commonalities will be discussed in depth in the next few sections.

2.6.1 Character Modeling

Character modeling, as its name suggests, is creating a graphical representation of an entity with specific characteristics. The objective of character modeling is to create a model that is similar to, or is closely related to, something that physically exists or virtually appears in the imagination. Examples of character models include humans, animals, robots, toys, aliens, etc.

The Webster dictionary defines a character as “a symbol that represents information”, where in 3D modeling a symbol is the 3D model created on the computer to represent the intended object. Kerlov (2004) describes character modeling as the process of creating something that has the look or personality of the represented model. As an example, model of a human should have both the look and personality of a human. A more detail definition is given by Seegmiller (2008), defining character modeling as the "process of creating something that, taken in the context of its environment, will elicit a belief, a reaction, or expectation from the audience about the physical makeup, disposition, and personality of the creation". This definition clearly indicates that good character modeling is not only to satisfy the designer but also the audience or viewers of the character. For this reason, characters that are created are often very detailed, and the process of creating them can be a rather complex one.

In character modeling, the modeler usually starts with a basic primitive object such as a cube or cylinder. Alternatively, the process may start with an existing model previously created (e.g. acquired from a 3D model library) which is then edited further.

Another common method for creating a basic 3D object in character modeling is by starting with a 2D shape or curve and then using methods such as spinning or lathe to create 3D shapes. This method is commonly used for creating symmetrical objects. Figure 2.15 illustrates the condition before and after such a process. In many cases,

the created object would require further improvements in order to shape the object to its final form.

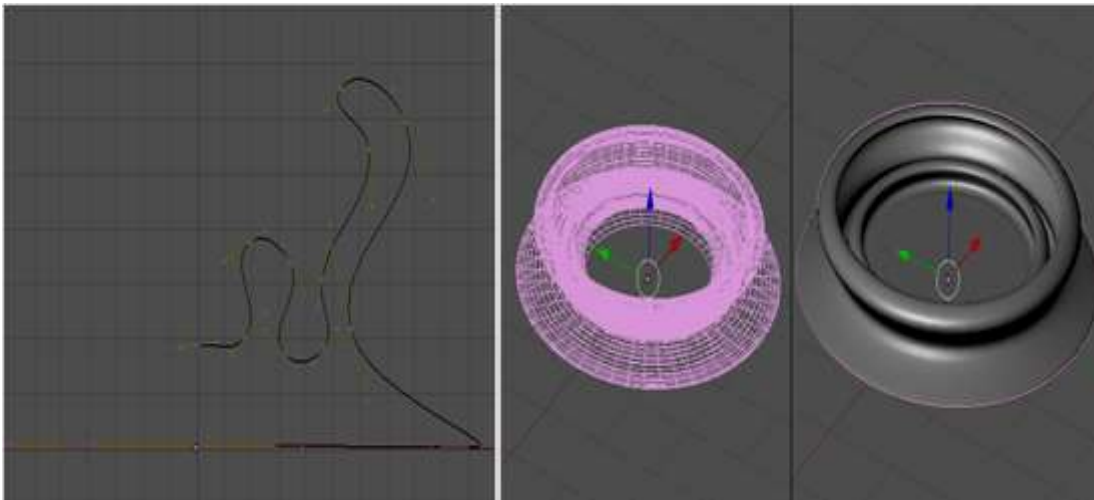


Figure 2.15: (left) A curve used to represent the boundary of the object, and (right) the resulting 3D object after the spinning process

There are several common methods used during the shaping process. Some of those methods are:

- addition and deletion of polygons
- extrusion
- deformation
- welding
- alignment
- transformations (rotation, scaling and translation).

These techniques are discussed further below.

Addition and deletion of polygons

Adding and deleting polygons are perhaps the two most common activities that take place while shaping a 3D character model. In both these activities, the ability to have a high level of accuracy is critically important. Modelers need to know where polygons have to be added or deleted, and what the effects of these additions and deletions will be.

In both cases, it is important to be able to select specific polygons accurately. The main problem, however, is that the target polygon may be hidden or obstructed by

others. Furthermore modelers also need to be aware of the impact of adding or deleting a polygon on its surrounding areas. For instance, when deleting a polygon, an unwanted hole may be created during the deletion process. When this problem is not immediately noticed, a model could be corrupted. Figure 2.16 (left) illustrates an example of where a single vertex is being deleted, and how difficult it is to notice its deletion in Figure 2.16 (right).

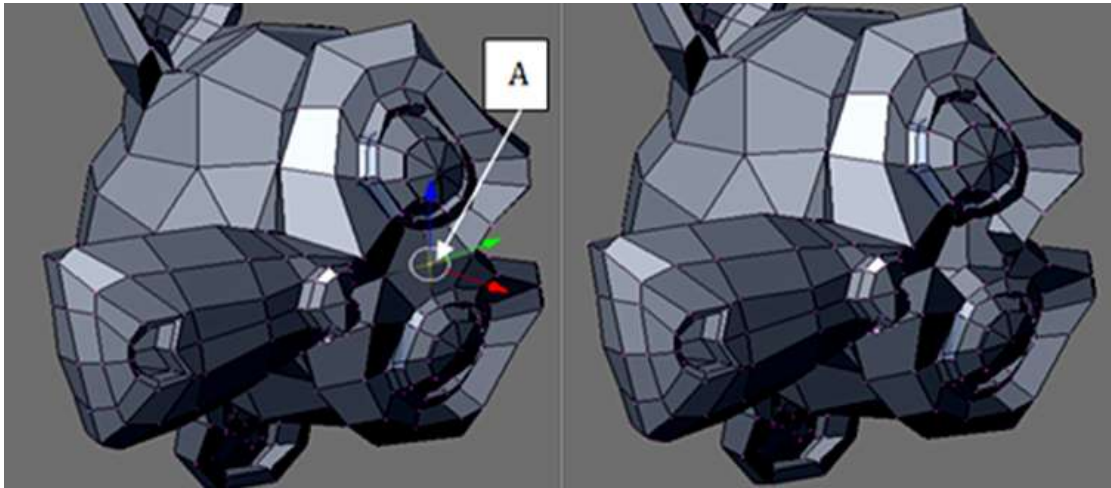


Figure 2.16: Deleting a vertex at point A (left) before and (right) after

Extrusion

As well as addition and deletion, polygons can also be moved or shifted around during the shaping process. As mentioned earlier, polygon models consist of vertices, edges and faces, each of which can be moved. This shifting process is called extrusion (Russo, 2006). As with the process of addition or deletion, the correct polygon or one of its key components must be selected prior to extrusion. This can, however, be a challenging task when there are too many polygons, which may not only be overcrowded but also overlapping. Earlier in this chapter, Figure 2.10 illustrated an example of the extrusion process, while Figure 2.13 gave an example of a model with overcrowded and overlapping polygons.

Deformation

Deformation can be divided into two categories, global and non-global (local) deformation (Russo, 2006). Extrusion of a particular polygon is an example of a non-global deformation. In a non-global deformation, only the selected polygon, or polygons, are affected. In this case where a particular polygon is extruded, the problem of working with a specific polygon remains.

In a global deformation, on the other hand, the whole of a selected object is affected. Twist and taper are two examples of global deformation. Twist is the process of winding an object around an axis in a particular direction, while taper is changing an object by compressing or expanding it (Giambruno 2002). Figure 2.17 illustrates the original model of a cylinder, and its condition after it has been twisted and tapered. In global deformation, modelers need to be aware of the larger implications of changes that are made.

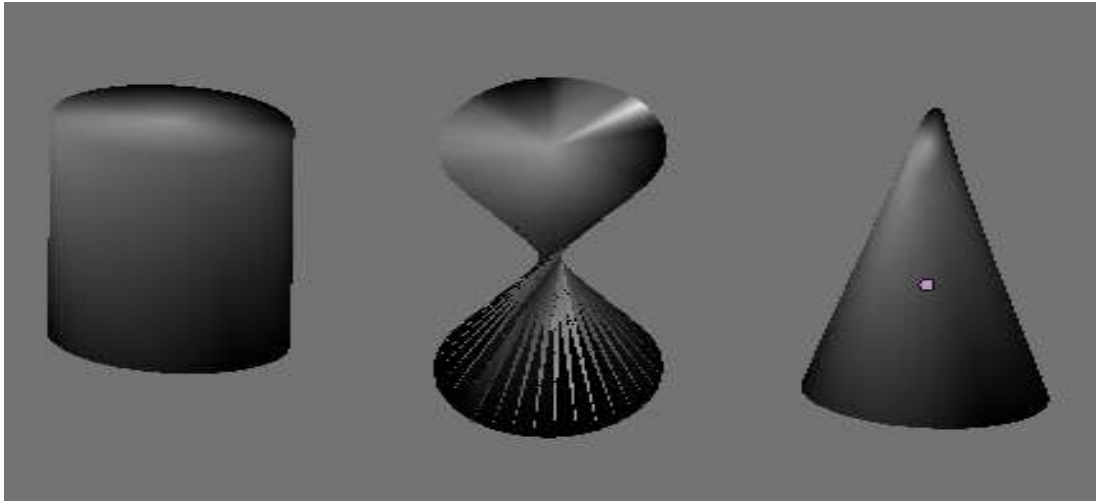


Figure 2.17: (left) Original model of a cylinder, (middle) after it has been twisted, and (right) tapered

Welding

Many models are made up of several individual objects or parts. For example, a model of a human would consist of hands, legs, head, and many other parts. Often these different parts of a model are created separately and then welded or stitched together (Giambruno 2002). This process of welding requires modelers to select the vertices that need to be welded. Once again the ability to select the targeted vertices correctly is crucial to the welding process. Figure 2.18 (left) shows two separate objects, the head and the ear of a human model. During the process of welding the two objects, the vertices are paired, and then a vertex from each object are welded together. Figure 2.18 (right), shows the model after a pair of vertices are welded. In this task, determining the pair of vertices to be welded can be difficult when vertices are hidden behind other vertices, or even other objects.

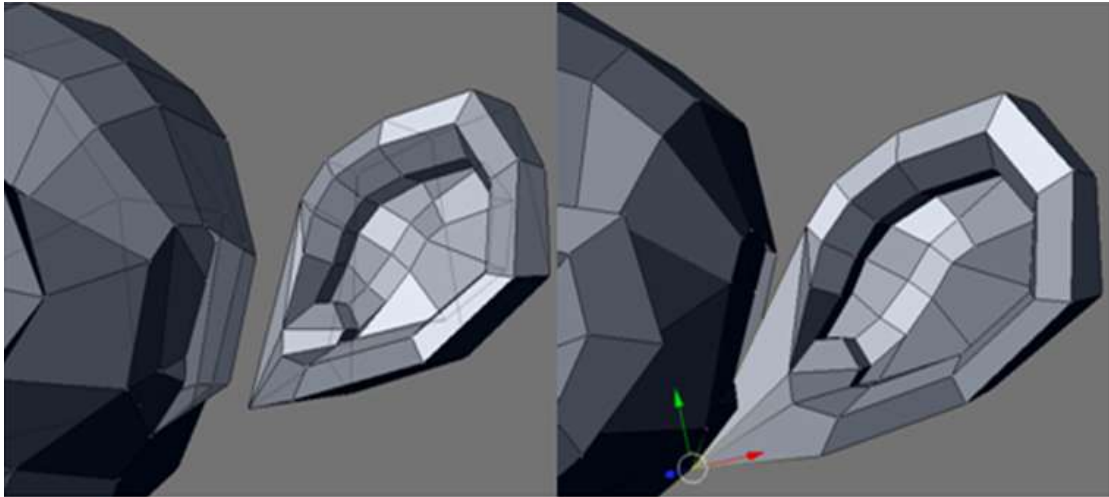


Figure 2.18: (left) Models of the separated head and ear, and (right) as they are being welded

Alignment

Alignment is the process of placing an object in relation to others (Russo, 2006). To be able to do this, both objects involved in the process must be visible during the process. It is also important that during this process the distance between the objects can be effectively viewed. This often requires viewing the model from different angles. This can, however, be difficult in 3D modeling environments where it is not easy to always visualize the physical depth. Without the depth information, modelers would need to estimate the distance between objects when they try to align them. Alignment is clearly an important activity in character modeling, where often different parts of a model are created independently and then aligned and stitched, or placed in relation to one another. For example, the head and the body of a human model would need to be aligned if they are created separately, before being stitched together.

Transformation

Another operation regularly performed during the modeling process is to change the size, location, or orientation of 3D objects. This is done through a transformation process. In order to change the size of the object, the intended object is first selected, and then its size is reduced or increased. Similarly an object's location can be changed by first selecting it and then moving or dragging it to a new position. An object's orientation can also be transformed through a rotation process, where the targeted object is selected before it is rotated.

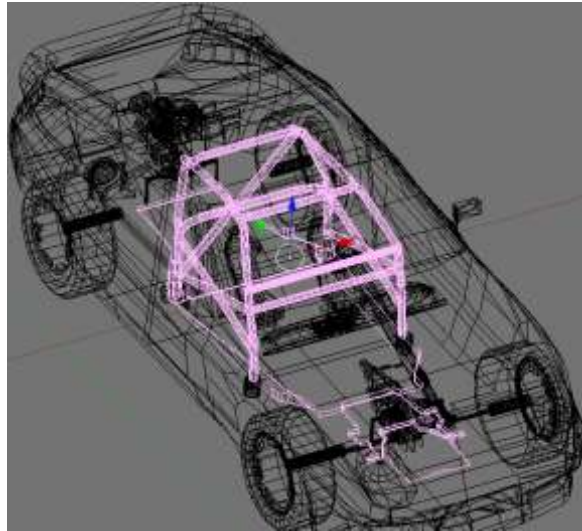


Figure 2.19: Challenge of transforming the object under constrain of others

For all these three transformation operations, modelers need to have a good overview of the entire model, so that they are able to recognize the effects caused by the operations they perform. For instance, when moving or resizing an object it is important to know whether the modified object overlaps other objects or not. This example is illustrated in Figure 2.19, where the main chassis (in pink) is located inside the body of the car, and any transformation to the chassis has to be in relation to the body of the car and its other internal parts. In this case however, the overlapping edges of different parts would make it difficult to know whether the objects are crossing each other or not.

2.6.2 Scene Modeling

Scene modeling is the process of creating a scene, where various objects related to the scene are placed within it and in relation to one another. A scene model of a beach, for example, could include model of a person, the seashore, sea, sky, trees, etc. Similarly, a scene of a town might include buildings, cars, roads, traffic-lights, and so forth.

Hence, scene modeling usually involves two processes. The first process is to create the individual objects required in the scene, while the second process involves the placement of related objects at the appropriate locations within the scene.

During the first process, modelers must undertake various operations, as previously described in character modeling. These operations may include adding, deleting, extruding, aligning and transforming objects. Each of these operations are dependent

on the modelers' ability to select the targeted objects or the polygons correctly.

The second process, on the other hand, involves the placement of objects in different parts of the scene. The placement process would naturally be constrained by the orientation, distance, landscaping, and placement of other objects in the scene. Modelers therefore would need to be aware of all the objects contained in a scene when creating it. This requires them to constantly view the entire scene model when they perform transformation operations.

In this type of modeling, it is also common to align objects in relation to others. The same process of alignment as described in character modeling is also practiced in scene modeling.

2.6.3 Terrain Modeling

Natural terrains in the real-world usually consist of mountains, lakes, rivers, vegetation, etc. In a computer 3D modeling context, terrain modeling is used for creating models that convey visual information to give a direct impression of an area being modeled.

There are several techniques available for creating terrain models. One of the first techniques used for terrain modeling was introduced by Kaneda et al. (1989) based on the use of contour lines. This technique allows drawing contour lines, and then filling the area between contours lines with triangular meshes automatically.

Until a few years ago using this type of standard polygonal mesh was the most popular technique for creating terrain models (Watanabe and Igarashi, 2004). More recently, however, methods that utilize 2D images to create terrain models automatically have gradually been gaining popularity (Da Silveira and Musse 2006, and Belhadj 2007). In these techniques the level of brightness in 2D images is used to detect changes in terrain elevation. These changes are expressed as dictum points above sea level. The main disadvantage of these techniques however is that some areas of the terrain being modeled could be hidden and not captured in 2D images being used. For example, the changes in elevation could be blocked by trees or buildings. As a result, the created model can be incomplete and often require further modifications.

Models created using contour lines or 2D images are often converted to polygons.

This means that the shape of the terrain is determined by the number of polygons. Increasing the number of polygons increases the smoothness of the terrain. Figure 2.20 shows an example of a terrain using 1024 polygons, while Figure 2.21 shows the terrain with 4096 polygons, which looks much smoother, and therefore much more realistic.

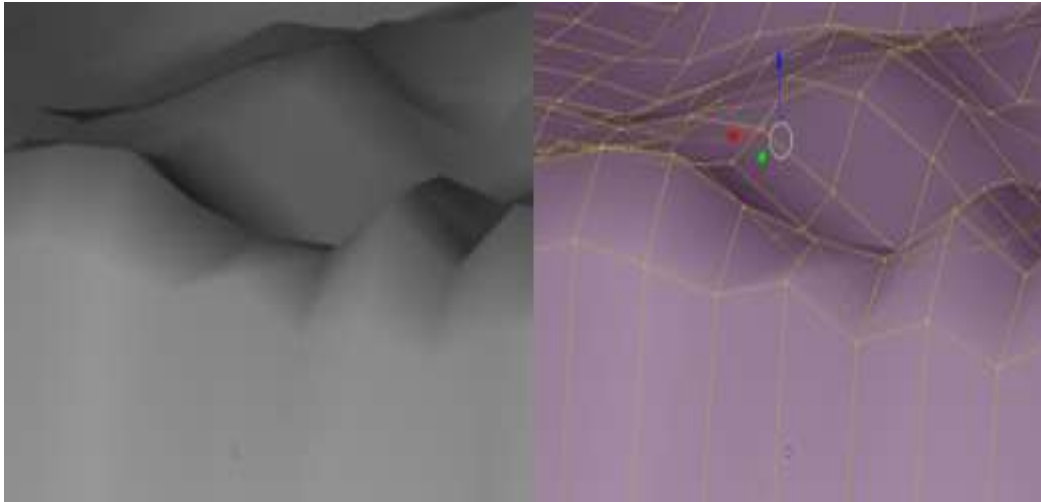


Figure 2.20: Terrain with 1024 polygons

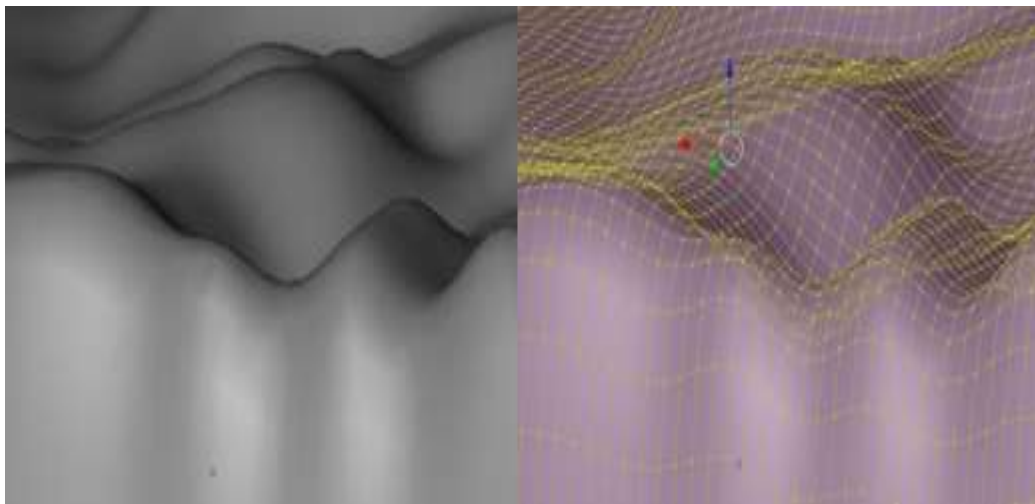


Figure 2.21: Terrain with 4096 polygons

Besides changing the smoothness of the terrain, in this type of 3D modeling it is often necessary to change the elevations of different parts of the model. Examples could include modifying the height of a hill, or the depth of a valley. As in character and scene modeling, terrain modeling requires performing a similar range of operations. Operations performed can include: selecting a single or a group of polygons, changing the relationship between different parts of the model in terms of their relative height, etc. In order to change the relationship between the parts being modified, the modelers need to have an overview of the entire terrain. This is important because

modelers need to recognize correctly the effects of the changes they make in relation to the overall shape of the terrain.

Furthermore, in terrain modeling many parts of the model, for instance the hills and mountains, are usually very similar to one another in their appearance. For the modelers to recognize which part of the terrain they are working on they often require to perform additional tasks such as zooming in and out, seeing the model from different angles, and referencing it to other information such as physical sketches or drawings.

2.7 Navigation and Manipulation

From what has been discussed in relation to character, scene, and terrain modeling, it is clear that all three categories of modeling have two factors in common. The first is that all of them usually involve to some extent shaping the 3D model that is being created. This shaping process requires modelers to work with detailed objects. The second factor is that modelers often need to be aware of other objects while working on a particular object. This requires them to have an overview of the entire model being created.

The type of activities that modelers perform during the shaping process, or when working on individual parts of the model in relation to other parts, can be further broken down to the following tasks:

- Navigating through the model to get to the location where the changes will take place.
- Recognizing the parts of the model being viewed at any given time while navigating through the model.
- Awareness of the relationship between the parts of the model being changed and the rest of the model.
- Being able to select parts of the model that are being changed.

These four basic types of activities can be categorized into two groups: those that deal with navigation and those that are related to manipulation. Both groups can be rather complex in nature and will be discussed further next.

2.7.1 Navigation

Navigation refers to the process of getting from one place to another, or moving through an environment. In both real-world and virtual 3D worlds³, navigation requires some means of getting from an original location to a final destination. Driving, walking or running are examples of how one moves around in the real world. In the virtual world the only means of navigation is by using an input mechanism such as a mouse or keyboard.

Darken and Sibert (1993) define navigation as the process of wayfinding, that is to determine a path to be traveled. They formally describe navigation as “the process by which people control their movement using environmental cues and artificial aids such as maps so that they can achieve their goals without getting lost”. Ferwerda (1994) defines navigation as “planning and execution of travel through space, real or virtual, carried out with reference to external and internal representation of the space being traveled”. It is clear from these definitions that navigation not only requires traveling but also needs cues or references to assist it.

Ferwerda (1994) observes that the navigation process in a virtual world is a lot more difficult compared to navigation in the real world. This observation is supported by Vinson (1999) who claims that navigation in a virtual world is generally more difficult due to the unfamiliar environment in which navigation takes place compared to the real world. In many cases, an environment in the virtual world is created based on the imagination of the modeler and therefore is artificial in nature, which makes navigation in such a world a new experience to its viewers.

Navigation in a virtual world is required in many situations. For example, this type of navigation is carried out in 3D modeling tasks, playing computer games, virtual tours, etc. In 3D modeling tasks, navigation is performed for a number of reasons. For instance it might be necessary to get to a target component or object, or to view the model from different orientations or perspectives. In computer games, navigation is frequently required in almost all games. For example, in fighting games navigation is needed to chase the enemies, or in driving games navigation is a part of the crucial

³ Throughout this chapter, the terms 'virtual world' and 'virtual 3D world' refer to any 3D computer environment

task of getting to the final destination by following the race track.

Darken and Sibert (1996) classify navigation into three categories: exploration, naïve search, and primed search. Exploration is defined as a wayfinding task without a target, while naïve search is described as getting to the targeted location without having a priori knowledge of the target's location. A primed search, on the other hand, is a goal-oriented process where the location of the target is known in advance.

Bowman et al. (2001) state that navigation is comprised of traveling and wayfinding and that these two components are strongly interconnected. They further explained that travel is a motor component of navigation, whereas wayfinding is its cognitive component. They found that a good travelling technique will integrate navigation aids. These definitions can also be applied in 3D modeling tasks whereby modelers often need to apply navigation aids so that mistakes can be avoided.

In 3D modeling tasks, all these types of navigation are undertaken regularly depending on the task being performed. Exploration is carried out when modelers do not know in advance which object or its parts need to be modified. In this case, modelers would explore the model, looking for the parts that are to be changed. A naïve search is often carried out when the targeted object is hidden or obstructed by other objects. In 3D modeling tasks, it is often the case that modelers know in advance what they are looking for but may not know where it is. The reason for this is that the targeted object could be hidden by others. A primed search type navigation is done when the targeted object is partially visible behind overlapping parts.

Regardless of which type of navigation being carried out, effective navigation relies on two distinct processes. The first process involves the actual movement to a target's location. This process relies on the actual ability to move by using some kind of an input device. The second process involves the ability to know the path or direction to be taken, and at the same time, to be aware of the current position and the orientation. This second process relies on an output device where the visual feedback would be displayed in accordance to the current position and orientation of the viewer.

Navigation problems can arise due to the limitations of either the input device being used to provide the movement, or the output device used for viewing the 3D virtual world. These two distinct processes involving input and output devices are discussed in depth in Section 2.8.

2.7.2 Manipulation

Similar to navigation, manipulation processes are also carried out in both the real world and a virtual 3D world. In general, the objective of manipulation is to alter the shape of objects, to move them to a new location, or to rotate them, etc. using some kind of tool or device. In the real world, machineries and human hands are used for manipulating objects. In the virtual world, however input devices such as a mouse and keyboard are commonly used for manipulation.

Hand (1997) points out that manipulation in the virtual world often corresponds directly to actions performed in the real world, which include scaling, rotating, translating, creating, deleting, editing, etc. Prior to each of these actions, modelers' initial task is to select the target object, and this relies on the precision provided by the input devices being used.

Chen et al. (1988) describe manipulation as the processes of translating, rotating and resizing the objects. They also highlight that in 3D manipulation, simple direct manipulation controllers are important. This type of manipulation controller enables users to concentrate on their tasks without having to pay much attention to the input device being used, so that the manipulation of objects in virtual worlds can be done effectively.

Subramaniam and Ijsselstein (2000) give a more detailed definition of manipulation. They describe manipulation as the process of selecting or grabbing objects, and further explain that selecting or grabbing is "the action that secures a firm interaction with surrounding objects for comfortable manipulation; positioning or displacing objects by movement from one position to another and finally deforming where the shape and size of objects are modified". From this definition, it is clear that selecting the correct object is an essential part of the manipulation process. Thus, input devices of high precision are required in order to perform this selection process prior to performing other processes such as positioning or deforming of objects.

Bowman et al. (2001) give a similar definition by defining manipulation as the process of selecting, positioning and sizing objects. They also highlight that users' ability to manipulate the correct objects has a profound effect on their performances while in virtual worlds.

However, manipulation of objects in virtual worlds is not an easy process. Mackinlay and Kettner (1994) identify that performing object selection can be problematic when there are many objects in a scene, because 3D objects would occlude one another. They further describe that the use of some input devices such as a mouse, tablet, trackball, etc. decreases the accuracy of selecting objects because correlating 2D hand movements in the real world to object movement in virtual worlds can be difficult.

Frees and Kessler (2004) have also observed that users are often frustrated and make some mistakes when performing manipulation tasks. They describe that one of the common problems contributing to mistakes is due to the missing force feedback by input devices in virtual world, which naturally exists in the real world. Furthermore in the absence of force feedback, it is generally difficult for users to move to precise positions in the virtual world. Currently there are only a limited range of input devices that provide offers force feedback. An example of input device with force feedback will be discussed in Section 2.8.1.

In 3D modeling tasks, manipulation tasks are performed frequently on target objects, polygons, or key components of the model. As described earlier, these targeted objects have to be selected correctly prior to manipulation. This however is not always a trivial task, as the targeted objects can be overlapping or too close to many other. Thus, the success of the manipulation process once again relies on the accuracy of input devices being used.

Users performance during the manipulation is not only determined by input devices' capability, but also by the effectiveness of the output devices being used where the visual feedback is displayed. A less effective output device can also cause users difficulties in understanding the visual feedback, and this can lead them to making wrong decisions.

In the next section, the role of input and output devices in assisting users during the navigation and manipulation processes will be discussed.

2.8 Input and Output Devices

2.8.1 Input Devices

An input device generally involves a hardware that allows the user to communicate location information to the computer system. In relation to the process of navigation

and manipulation, input devices can be categorized into two groups. The first group includes input devices used for navigation and manipulation of 2D environments, while the second group includes devices specifically designed for navigation and manipulation of 3D environments. However, some input devices are designed for either navigation or manipulation only and not both.

Input devices used for navigation and manipulation in 2D environments include keyboard, mouse, joystick, trackball, touchpad, etc. These devices offer only 2 Degree of Freedom (DOF). DOF is referred to the ability of an input device to control the position and orientation of an object. Adam (2010) describes DOF as the number of possible dimension that input devices can move through. For example, 2 DOF is referred to an input device that can control the position along only the X (horizontal) and Y (vertical) axes. Similarly 6 DOF refers to the ability of an input device to control the position and orientation of an object along the X, Y and Z axes, where orientation is expressed as pitch, roll and yaw, or degrees of movement around them. These axes of X, Y and Z are often used to define width, height and depth of 3D models respectively.

Keyboard is the most commonly used input device to enter textual information into a computer. It can be used for navigation and manipulation. A keyboard allows for much greater interaction (i.e. navigation and manipulation) than 2DOF devices. However keyboards often involve a combination of multiple actions and activities. For example, a user may need to press on a shortcut key, click on a menu and use an arrow key to emulate a specific movement.

For navigation and manipulation, other input devices such as a mouse is rather more popular than a keyboard. A mouse is often used on a flat surface to generate X and Y coordinate values, and can be easily moved in any direction with one hand. Having user's hand resting on a flat surface while operating a mouse stops the user from getting fatigue, and this leads to more steady hand movements. Perhaps the main reason for the widespread use of a mouse is because of its effectiveness in terms of precision and speed (Subramaniam et al. 2003).

A joystick is an input device that is usually spring-loaded so that it returns to its center position when released. With some joysticks, users may manipulate additional buttons and throttles located on the base of the device. Joysticks are very useful for direct

pointing, such as in navigation and manipulation, and are widely used by players of computer games.

Similar to a mouse or joystick, a trackball can be used to generate precise X and Y input values, and allow cumulative travel in any 2D direction (Ahlstrom and Longo, 2003). Other 2D input devices such as touchpads also have similar capabilities.

Although these input devices only offer 2 DOF, they can however be used to provide input to navigation and manipulation in virtual 3D worlds as well. Except for some hand-held joysticks, 2D input devices allow users' hands to rest on a flat surface, which enables them to maintain their accuracy and precision while navigating in 3D space without getting tired (Kettner 1995, and Ahlstrom and Longo 2003). However, when navigating and manipulating in 3D worlds, 2D input devices often require an extra input command (e.g. using a keyboard) to allow users to navigate and manipulate in the depth direction (e.g. Z axes). The reason for this is that 2D input devices can only navigate and manipulate in a 2D plane (e.g. along the X and Y axes).

The need to match the DOF between an input device and the computer environment with which the user is interacting has been highlighted in several research. For instance, Ferwerda (1994) observes that when the task space has more degrees of freedom than what is offered by the input device being used, the task becomes more complex where extra steps or handling are often required. These extra steps include opening menus, executing commands, or other functions, etc.

Similarly, Bowman et al. (2001) discusses how users require input devices that enable them to navigate and manipulate comfortably in the 3D worlds. For this reason, the DOF between an input device and the computer environment with which the user is interacting need to be matched. Nash et al. (2000) highlight that the difficulty in navigation and manipulation can lead to "dissatisfaction, frustration and eventually discontinued use of that environment". It is therefore clear that matching the DOF between the input device and the environment in which it is used is essential. In order to overcome this mismatch between 2D input devices and 3D spaces, a number of alternative 3D input devices have been developed.

The 3D Mouse (Venolia 1993) is an expanded version of a conventional 2D mouse. It comes with a roller that provides an additional degree of freedom, thus allowing the user to rotate in the depth dimension. Similar to the 2D mouse, the movement to the

body of the roller mouse enables navigation and manipulation in the familiar plane up, down, left and right. Moving the wheel of the roller allows users to navigate and manipulate towards or away from a 3D position. Recently, the 3D mouse has been modified to accommodate both “in-air” (3D) and “on-desk” (2D) mouse motion. The mode button mounted on the mouse is used to differentiate between the two distinct modes of operation (Mercier et al., 2011).

In 1996, Poupyrev et al. introduced a novel technique called Go-Go that integrates with 6DOF. This allows a more natural manipulation process, similar to the real world. In addition, this technique allows both nearby and distant objects in a 3D computer world to be reached and manipulated.

The Rockin’ Mouse was developed by Balakrishnan et al. (1997), to be an input device with 4 DOF. Like a regular 2D mouse, the Rockin’ Mouse requires a flat surface and can perform all the usual functions of the 2D mouse. However, the bottom of the Rockin’ Mouse is rounded so that it can be tilted. This tilting is used to control two extra degrees of freedom. This feature allows for more directions of navigation and manipulation while using the normal functions of the 2D mouse.

The SpaceBall (Labtech 2000) is a 6 DOF device, which measures simultaneously the movement and rotation along the X, Y, and Z axes. The navigation and manipulation are done by holding the ball and pulling or pushing it in the desired direction. The SpaceBall can be used both to perform precise movements, as well as large movements and rotations (Noris 2005).

The Cubic Mouse (Frohlich and Plate, 2000) allows users to specify three-dimensional coordinates in graphics applications. This device consists of a box with three perpendicular movable rods passing through the center of the case that represents the X, Y, and Z axes of a coordinate system. These features enable user to navigate and manipulate objects in 3D spaces effectively. The disadvantage of this device is that it causes arm fatigue with prolonged use, because the user needs to continuously hold the device in the mid-air.

The 3D Treadmill (Cyberwalk 2008) is different from the other 3D input devices discussed so far, because it requires the user to stand and “walk in place” instead of using a hand-controlled input device. Although this device is used for navigation only, it has the advantages of a 6 DOF input device, while freeing the hands to perform

other tasks. However, 3D Treadmill is a bulky equipment and requires the user to stand for the duration of interaction. As a result, users can become fatigued, and maintaining good precision can be difficult (Broudet et al., 1999). Also in relation to 3D modeling tasks, which usually require good precision, a foot-controlled device may not provide the same level of precision as hand-held devices.

The Virtual Balance (Fleischmann et al., 1999) is similar to the 3D Treadmill, and is also used for navigation only. It contains a platform made of weight sensor discs that react to the body movements of the user standing on it. The navigation activities are determined by movements such as stepping forward or leaning backward, which in turn control the position and orientation of user's viewpoint in the virtual environment. The drawback of using Virtual Balance is the same as the 3D Treadmill, where body-controlled movements in standing position can be tiring. Consequently, tasks which require consistency and good precision, such as in 3D modeling, can be difficult to perform.

The Cyberwheel (Geng et al., 2001) is yet another novel input device used for navigation which is like a motorcycle, where the speed of virtual motion and the direction of movement are controlled by the handles. The Cyberwheel comes with a throttle, used for controlling the movement speed. Releasing the throttle stops the motion. The navigation angle can be changed by raising and lowering the upper part of the device. Cyberwheel is more suitable for navigation in large virtual spaces, such as in a museum virtual tour. This device is also operated in a standing position, and therefore suffers from the limitations of such devices.

The Bodysuit is another type of input device, which was developed by Patrice Pierrot (Goto 2006). It is a wired garment consisting of multiple sensors, which are placed on each of the body joints (e.g. wrists, elbows, shoulders, ankles, etc.). With a body suit it is possible to move and interact with a 3D environment in much the same way that people interact with the real 3D world. This technique enables the bodysuit to be used for both navigation and manipulation. The disadvantage of a body suit as mentioned by Hedmn (2001) is that body suits are generally uncomfortable to wear.

The Wiimote is a wireless 3D input device developed by Nintendo (2012). It contains a number of buttons, including a 3-axis accelerometer and infrared camera that communicate with a game console remotely. The device is designed such that the

interaction between a user and the device is more natural (MacArthur et al., 2009, and Sko et al., 2009). For example, in a shooter game, the player can hit the target by pointing the device directly at the screen and pulling the device trigger. In sports games such as tennis and badminton, the player can return a serve by swinging the Wiimote in mid-air. However, a study conducted by Kiefer et al. (2008) where Wiimote was used as a musical controller, demonstrated that Wiimote lacks precision, and does not provide absolute positioning capability.

Another type of input device is called Kinect (Xbox, 2012). It was introduced in 2010 as a peripheral for the Xbox 360 gaming console. The Kinect device is a horizontal bar housing a microphone array, an RGB camera, and a depth sensor that tracks players' entire body at a frame rate of up to 30 fps (Khoshelham and Elberink, 2012). In their study on Kinect's depth accuracy, however they found out that error of depth measurements increases drastically with increasing distance from the sensor. This means that this device also fails to provide a continuous precision similar to Wiimote. Consequently, tasks which require consistency and good precision, such as in 3D modeling, can be difficult to perform.

Another group of 3D input devices are head-tracking devices (i.e. tracker). There are several such devices currently available, including head-trackers from Polhemus (Polhemus 2012) and the Ascension Technology Corp (Ascension 2012). These devices are often mounted to a display device such as HMD. This enables users to look at a virtual 3D world from different viewpoints just by moving their head. They work by estimating the user's head position and orientation where this estimation is used for creating a perspective image of the 3D world being viewed. This allows for the user's position and orientation to be matched with the viewpoint in the virtual environment. Trackers are often mounted on devices such as data gloves, flying mice, and wands that enable users to navigate and manipulate objects in a 3D environment. This is facilitated by providing users' navigation position and orientation to the processing engine, which is determined by the tracker's initial reference point.

The Phantom (Sensable 2011) is a 6 DOF input device which provides force feedback when selecting and positioning objects. This force feedback gives users a similar experience to the real world when touching or moving an object where resistance is sensed. However, the usability of the Phantom to deal with precise manipulation of

key components and polygons in 3D modeling tasks has not yet been tested.

Another group of devices used for manipulating 3D world objects is DataGlove. There are several data gloves currently available, including the 5DT (5DT 2012) and CyberGlove (2012). Datagloves can be used for selecting and repositioning virtual objects. However, most data gloves lack sufficient precision to allow manipulation of vertices and edges in 3D modeling tasks.

Most of the input devices described above aim to improve users' efficiency and precision while navigating and manipulating in a 3D world. However, in relation to navigation, despite the efforts, users of such devices still find them inherently difficult to use for navigating in 3D environments (Hand 1997, and McConkie et al., 2001).

Hand (1997) has identified the lack of "constraints" as one of the factors that causes the difficulty of navigating in 3D environments. The idea of a "constraint" or "helped navigation" is to modify the user's direction of view in order to allow the user to track a specific object in the scene. This idea has been found to be useful in computer games and virtual tours. For example, in a car racing game, the car is stopped from getting off the track by objects placed along the track, which work using the collision detection engine of the game. Similarly in a virtual tour, the movement is constrained by the location of the users in the virtual space. In this case, the virtual walls and passageways of buildings help the navigator to reach their destination.

However, this idea of "helped navigation" is not so practical in 3D modeling environments. In 3D modeling, objects or components of the models can be located anywhere in the 3D space. They can also be surrounded or hidden by other objects. As such, modelers need to be able to navigate freely within the model. In other words, moving through a solid object is allowed in 3D modeling, which is of course not possible in the real world. Because of not having this constraint, modelers are able to get to hidden or obstructed objects. Of course the setback of this type of navigation without constraints is that modelers can sometimes unintentionally move to a wrong position in 3D space and get lost.

McConkie et al. (2001) have outlined three other factors related to input devices that cause some difficulty in navigating in 3D environments. These three factors are due to:

- the relative mode of control of the input device,
- the non-ego-centric calibration control of the input device, and
- the concept of “space-constant“ nature of the input device.

According to McConkie et al. (2001) the “relative mode of control” means that when an input device is moved, its momentum and current position only indicate the speed and direction of navigation. It cannot in any way indicate the viewing orientation that is changed in the course of the navigation. Therefore, this causes a mismatch between the movement of the input device and the resulting location of the viewport relative to the observer. In other words, viewing orientation cannot be predicted simply by looking at the input device’s current movement and orientation.

The “non-ego-centric calibration control” is the opposite of the “ego-centric control” in which “the viewports goes to the position to which head is directed” (McConkie et al., 2001). In the non-ego-centric control often only the navigator’s hands or legs are moving, while the head and the direction of the eyes are static. As such, in the non-ego-centric control, the relationship between the control movement and the resulting viewport orientation is generally not natural.

The third factor as mentioned by McConkie et al. is called “space-constant”. In space-constant navigation “the viewport itself is at a fixed position in space that navigation occurs by rotating the virtual world and bringing different regions of the space to be viewed to the location of viewport”. This is different to how navigation is carried out in real world. In real world, navigation often involves the movement of the entire body, while in a virtual world navigation generally involves a hand movement only. This makes it difficult to establish a direct mapping between the position of an input device and the current viewport location.

From what has been discussed above, it is clear that navigating and manipulating problems related to input devices continue to exist in 3D environments. This is despite the fact that there are various 3D input devices with 6 DOF available. Although such 3D devices offer some sense of natural navigation and manipulation, a study conducted by Berard et al. (2009) indicates that 2D input devices such as the conventional mouse, outperforms 3D devices. In this study, object placement (including both translation and rotation) is used as the benchmark. Findings from this

experiment showed that the performance and accuracy of moving a 3D object is greater than when using a 2D mouse compared to other 3D devices. Factors such as cost, physical sizes, familiarity, and fatigues are some of the other reasons why 3D devices are not being fully utilized for navigation and manipulation in 3D environments.

Furthermore, in relation to 3D modeling tasks where modelers often work at a very detailed level (e.g. with polygons and key components) a high level of accuracy and precision is essential. These requirements cannot be offered by most of the 3D input devices mentioned above. As a result, conventional 2D input devices such as mice are still the most widely used input devices by 3D modelers.

2.8.2 Output Devices

An output device is the hardware used for communicating with user by displaying data or information. This visible data or information comes in various forms including text, graphics, images, etc. As with input devices, output devices are categorized into two groups. The first group includes devices used for displaying 2D information, while the second group includes devices specifically designed for displaying 3D information.

Conventional 2D output displays such as a computer monitor is mainly used for displaying 2D information. However, their usage is not limited to this only, and they can be used for displaying 3D information as well. For example, 2D display devices are commonly used for 3D modeling tasks and for playing 3D computer games.

However, 2D displays have a major disadvantage in their lack of support for displaying along the depth dimension. Without this depth perspective, it becomes difficult for users to understand the relationships and the distances between objects in a 3D world when it is viewed on a 2D monitor (Woods et al., 2002 and Hayes et al., 2006).

Furthermore, without a depth perspective a parallax effect is also not possible. Parallax is defined by Gibson et al. (1959) as "optical change of the visual field of an observer which results from a change of user's viewing position". They also assert that parallax is a cue for perceiving the depth of the objects. Due to the absence of the depth perspective and parallax effect, users often experience some difficulties in visualizing their orientation and position when navigating in a virtual 3D world which

is being viewed on a 2D display (Gibson et al., 1959).

Because of these limitations of 2D output devices for displaying 3D information a number of output devices have been developed to support viewing 3D environments. These output devices can generally be divided into two groups. The first group are standalone displays that do not incorporate any input mechanisms, while the second group are combined with an integrated input mechanism to determine the viewing orientation of the virtual world.

- **Stand alone output devices**

In a Stereoscopic Display (Stereo3D 2012) slightly different images are presented to the viewer's two eyes to create an illusion of a 3D space. In this technique, each of the two eyes receives alternative frames of the video image by synchronizing shutters incorporated into a pair of viewing glasses. However these types of stereoscopic display can cause eye fatigue (Ware 1996). In 3D modeling tasks where modelers need to perform detailed operations on polygons and their key components, often for a long period of time, such negative effects need to be avoided.

The Volumetric Display (OFH 2012) is an output device that operates without requiring the users to wear hardware such as shutter glasses. In this type of display, the 3D image is created by illuminating points in 3D space shown inside a volumetric display, enclosed by a protective transparent enclosure. The Volumetric Display enables the 3D image to be seen by many users from different perspectives depending on their position around the display. The Volumetric Display has a 360° field of view, and it provides viewers with an actual sense of depth perceptible. However, due to the difficulty of interaction between an input device with the image inside the transparent enclosure, Volumetric Display is often used as a non-interactive output-only display device (Grossman et al., 2004). This means that Volumetric Display would be more suitable for displaying a completed model, rather than being useful for creating 3D models, where interactivity is crucial.

The Alioscopy (Alioscopy 2012) is a display device that has a typical look of a conventional flat display, but is integrated with stereoscopic technology. It has some similarity to the Volumetric Display in that the users do not need to rely on special eyewear to be able to view the depth dimension. In this technology, 8 discrete images are multiplexed into one single image that enables the images to be viewed from 8

slightly different angles (Barkowskya et al., 2010). The limited number of predefined angles makes this device less than useful for 3D modeling tasks where viewing models from different angles is generally required.

- **Output devices integrated with input mechanism**

The Chamelon system was developed by Fitzmaurice in 1993 (referenced from, Buxton 1998). The images are displayed on a moveable display, where the image being displayed is determined by tracking the position and orientation of the display itself. The user therefore needs to drag the display around the virtual 3D object when navigating. Buxton claims that the movement of the display actually assists human visual perception (1998). Although Chameleon allows each user to have their own view, moving a physical object in hand for navigation is likely to cause fatigue.

The BOOM (Fakespace 2012) is an output device that is mounted on an articulated arm, and mechanical tracking technology is used to detect position and orientation. The advantages of this device are that users do not have to wear it, it is easy to operate, and several users can operate it by simply holding and controlling it. However, since the BOOM is physically attached to a large stand, the user's movements are limited. Another disadvantage of BOOM is that the user has to have at least one hand on the device which can limit various types of two-handed interaction. Furthermore, the BOOM is operated in a fashion similar to Chameleon where users need to physically move when navigating in the virtual world, and therefore require a large work area. In a task such as 3D modeling where modelers are often stationed in a fix office area, the BOOM does not offer a good alternative solution.

The head mounted device (HMD) is another type of display often used for visualizing data in a virtual world. This display device comes with a head mounted wide-view stereo-display coupled with head tracking. HMD presents a stereo binocular view of the virtual world. This type of view allows depth perception and makes it possible to recognize the position of near and far objects more effectively. The HMD is often integrated with tracking devices. These combinations of HMD and trackers allow the user's body and head orientation to be consistent with their viewing orientation. However, as well as the HMD's high cost, it has one major disadvantage. Its combination with tracker requires going through a calibration process. (Kuhl et al.

2009). Successful calibration enables the viewing orientation of the virtual world to be synchronized with the head movement, while incorrect calibration can distort perspective-related visual cues and may prevent people from properly perceiving the virtual world. Beside the issue of calibration, a latency problem has also been acknowledged as an issue with HMD (Adelstein et al., 2003, and Ellis et al., 2004). This latency can reduce the precision and degrade users' task performance (Watson et al., 2003). In 3D modeling tasks the lack of precision caused by latency could be a problem with the use of HMD.

Another specialized 3D display is the Cave (Cruz et al., 1992) which consists of a room where the surfaces of the floor, ceiling, and the walls act as displays. The Cave setup provides users with a seamless continuous view of the virtual scene. The displays are often stereo, and the outputs are viewed through a set of shutter glasses. The user's head position is tracked within the Cave. As a result, what is displayed to each user preserves viewing orientation in adapting to movements and change of location of gaze (Buxton and Fitzmaurice 1998). This device has similar advantage to HMD by allowing users to act in a more natural manner, so that they can concentrate on their actual tasks. However, as pointed out by Buxton and Fitzmaurice (1998), a major reason for the limited use of the Cave is due to its physical setup and cost.

The 3D output display devices described above have all aimed to improve users' ability to navigate effectively in 3D worlds. While some of the solutions offered by these output devices have a good potential for viewing 3D data, other issues including cost and logistic have not been addressed (Moritz et al., 2007). In addition, some of these output devices such as BOOM, HMD and Cave are often supported by integrated input devices such as head tracking system which tend to lack the precision required for 3D modeling tasks. In addition to their integration with tracking device, these output devices also often require specific input devices such as data gloves (Abaci et al., 2004). However as discussed earlier, the use of data glove may not be effective in 3D modeling tasks, because they also lack precision required for operations such as dealing with polygons and key components.

2.8.3 Multi Layer Display

A rather different type of display, developed several years ago, is Multi Layer Display (MLD) (Puredepth 2012). As shown in Figure 2.22, MLD has two LCD display

layers, separated by a 10 mm thick transparent layer. It is designed to enable data presented on the rear LCD to be visible through the front LCD. Even though the term MLD stands for Multi Layer Display, to the best of the author's knowledge, no MLD with more than two layers is currently available. The main characteristic of an MLD is that it allows the content shown on both layers to be seen simultaneously.

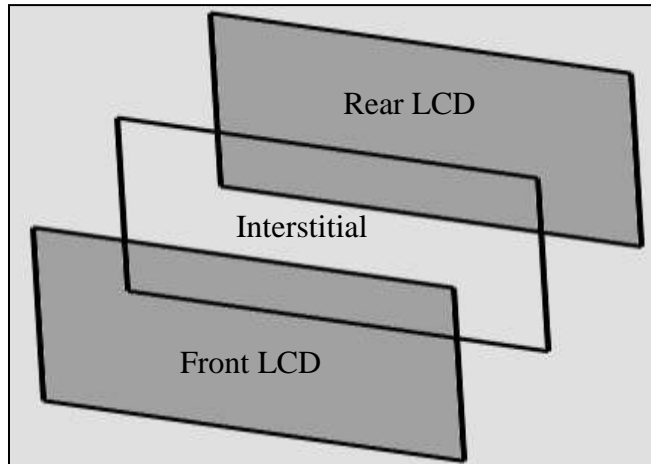


Figure 2.22: The architecture of MLD

Each LCD is connected to a separate graphics card, making it possible for the two LCDs to be spanned horizontally or vertically. It is also possible for MLD to emulate a single layer display, by cloning the front and back layers to display the same image.



Figure 2.23: Background of both layers are set to white

When viewing information on MLD, it is better to set the background of both LCDs to white to ensure that their color do not interfere with each other (Bishop, 2006). This also makes the white areas appear transparent on the front layer so that the back layer can be viewed clearly. Likewise, white areas on the back layer allow all the light from the backlight to shine through and illuminate the front layer. Figure 2.23 shows a

photograph of MLD with background of both layers set to white.

The mouse pointer can move between the two layers by moving the mouse pointer to the far left and far right of the LCDs. MLD comes with a utility that allows the user to move the cursor between the layers by clicking the middle mouse button.

A number of studies have been conducted in order to investigate the potential benefits of MLD. Aboelsaadat et al. (2004) present an empirical study which compares the performance of a conventional 2D display against MLD when used to view two virtual layers of potentially interfering information. The aim of the study was to determine whether physical separation, provided by MLD, changes the amount of interference between foreground and background layers. The experiment showed that MLD is not generally better than a single layer display. However, this study was only concerned with issues related interference between the layers, and did not aim to find any benefits gained by having the physical layer, or by the proper placement of data into the two layers.

A related study by Dunser et al (2008) investigated whether the actual separation of layers of information afforded by MLD may affect visual search task performance. The objective of this experiment was to determine subjects' performance when searching for particular targets, where the distracters and targets were displayed on different layers of MLD. Their finding indicates that in complex search tasks, the MLD significantly improves subjects' searching performance. They summarize their finding by suggesting that "depth information helps users to visually distinguish the target from the distracting stimuli" and the depth afforded by MLD "can support users in visually complex environments".

Despite its potential for displaying 3D information, all the research related to MLD have been confined to 2D information. However, the use of MLD can be extended to include 3D data as well, for example, in 3D modeling tasks. The physical separation of the layers in MLD can be used for displaying 3D information on different layers.

2.9 Discussion

This chapter has described a number of techniques currently used for generating 3D models. The techniques used by modelers often depend on the expected quality of the final model produced. Techniques such as freehand sketching 2D to 3D, still image

conversion, 3D scanning and video trace are sometimes used as a starting point for creation of 3D models. These techniques minimize the modeler's involvement with polygons and key components at an early stage of the modeling process. When no further enhancement is required to a model created using these modeling techniques, any direct manipulation of polygons can be avoided.

However, it is often the case that some of the details of the models created using these techniques would be missing because of not being fully captured or omitted from the initial sources used to generate the models (e.g. sketch, photograph). In these cases further modifications to the 3D models are necessary in order to shape them to their final form. These types of modifications are usually done using the conventional polygonal modeling technique.

When using polygonal modeling, or B-spline and NURBS modeling techniques, modelers are often confronted with the cumbersome, but unavoidable, task of working with overcrowded and overlapping details of models. Therefore, it is critical for modelers using these techniques to have an effective and accurate way of handling tasks while working in this kind of environment. Without proper tools, modelers are likely to make mistakes, or face difficulties during their 3D modeling tasks, which in turn degrades their performance.

Some of the problems faced by 3D modelers is also caused by the input and output devices they have to rely on for their tasks. This chapter has in particular focused on some of the currently available output devices used by 3D modelers. Most modeling tasks are still performed using conventional 2D displays. Even though some 3D output devices are found to be effective to display 3D data, factors such their cost, physical size, and more importantly their low precision, are among the drawbacks that limit their use in 3D modeling. As a result, modelers have to face the challenges of dealing with overcrowded and overlapping 3D data while using 2D output devices.

Several input and output devices pertaining to interaction with virtual 3D worlds that address issues related to navigation and manipulation have been discussed in this chapter. These studies, however, have not focused specifically on 3D modeling tasks, and therefore have failed to address issues of navigation and manipulation which 3D modeler who use conventional polygonal modeling techniques with 2D input and output devices. This thesis aims to address this important shortfall in current research.

2.10 Summary

This chapter has presented a summary of various 3D modeling techniques commonly used by 3D modeler, and has identified their strengths and weaknesses. This has highlighted the need to address the problems of navigation and manipulation in polygonal modeling environments. Addressing these problem however requires a better understanding of the underlying concepts of focus and context awareness. In the next chapter, these related issues of focus and context awareness in 3D modeling tasks will be discussed in detail.

CHAPTER 3

Focus and Context Awareness

The previous chapter focused on 3D modeling, the techniques and devices used by 3D modelers, and the resulting difficulties faced by them when dealing with navigation and manipulation in a 3D environment using conventional 2D input and output devices. Two issues were identified in particular:

- 3D modeling tasks often involve shaping processes where modelers work at a very detailed level (e.g. with polygons and key components), and
- 3D modeling tasks require high precision input and output devices for navigation and manipulation purposes.

This chapter presents a review of the related literature on existing methods and techniques that could be used to overcome some of the problem identified in the previous chapter. More specifically this chapter provides an overview of focus and context awareness issues and their implications for 3D modeling tasks.

This chapter begins with a discussion of the three main components of focus and context awareness (Section 3.1 to 3.3). This is followed by a discussion of focus and context awareness as a whole (Section 3.4). Workspace awareness which is concerned with providing members of collaborative groups with an appropriate level of awareness when working in a shared workspace is briefly introduced in Section 3.5. This is followed by the most important section of this chapter (Section 3.6) which provides an in-depth review of the methods used for maintaining focus and context awareness in 2D and 3D environments. The chapter concludes with a discussion in Section 3.7 and a summary in Section 3.8.

3.1 Focus

In all environments, including the real world and 2D and 3D computer environments, focus normally refers to a specific object of interest that is visible among others. For example, on a 2D map, a road or city name can be the centre of focus, while it is surrounded by other information such as building signs, terrain, etc. Similarly in a 3D modeling environment, for example, model of the nose can be the focus of interest in

a 3D human model. In this case, the nose would not be on its own but would appear with other parts of the model.

Nunnari and Simone (2004) define focus as a center of interest or activity, and note that focus is “characterized by a high degree of user involvement to govern the flow of tasks, and is devoted to supporting users in accomplishing their individual or shared tasks”. Thus, the success of a task is dependent on users’ ability to recognize their center of interest throughout the task (Kosara et al., 2002). They further explain that the users’ ability to isolate the center of interest from the rest of the non-focus area can increase their efficiency in performing their tasks.

Daurish (2003) points out that focus is task oriented. This means that focus arises from undertaking the activity and the orientation and visibility of focus can be affected by the activity. In all environments, as stated earlier, any navigation and manipulation processes will interactively change the orientation and visibility of the focus. Daurish suggests that the ability to recognize the new information that is produced by the navigation and manipulation processes is useful for supporting users in accomplishing their tasks.

In a 3D modeling environment, modelers may focus on the whole model that consists of several objects as one entity, on a single or group of objects out of many others, or on one unit or group of components. For example, in the 3D model of a car, the focus may be on a group of components that make up the steering wheel, the steering wheel as a single object, or the whole car. This suggests that the size of a focus area is not fixed but dependent on the object or objects of interest.

Furthermore, in 3D modeling, the complexity of a model is often in proportion to its quality. A high quality model often consists of a large number of components, such as polygons and their key components. For this reason, focusing on the center of interest within the correspondingly dense data is not always a trivial task. Fogal and Kruger (2009) describe that in this type of data density and complexity, viewers will face some difficulty locating or recognizing their point of interest in the sea of data. This difficulty eventually degrades modelers’ performance during their modeling tasks.

It is, therefore, clear that the ability to identify the center of interest or activity is important in order to enable users to work effectively on their targeted point of interest. A high degree of user involvement in their activity requires them to instantly

recognize their center of interest whenever changes to the viewing orientation take place.

3.2 Context

Context, as a concept, is almost the opposite of focus. Context refers to information other than the object of interest that is visible within the viewable area. It often acts as supporting information to users while they are working on the area of focus. Context is generally perceived as the extra information, which is not directly relevant to most of the action being carried out on the point of interest. Context is generally referred to by users in an indirect and occasional manner.

The Oxford dictionary defines context as interrelated conditions in which something exists or occurs. This means that context is the mutual relationship between the many conditions that exist in a given situation in which the activities or events occur, and often generate new knowledge to users.

Schilit et al. (1994) note that context is more than just knowledge, because it often involves other things that are of interest to the user which may constantly change. Things that are of interest to the users refer to “focus” as discussed in the previous section. Therefore context and focus go hand in hand and are directly related to each other.

Another description of context has been given by Schmidt et al. (1999) where they describe context as “knowledge about the user’s and device’s state, including surroundings, situation, and to a lesser extent, location”. In general, both of the descriptions by Schilit et al. and Schmidt et al. highlight that context is part of the information that is visible to the user. However, neither of them state how the information generated by context should be shown to users along with focus. Nor do they explain how information that is not useful should be filtered out, and what the effect of doing so would be.

Alternatively, Dey et al. (2001) define context as “any information that can be used to characterize the situation of an entity”. An entity is “a person, place or object that is considered relevant to the interaction between a user and an application, including the user and the application themselves”. In relation to 3D modeling process, modelers are normally aware of the relationship between different pieces of information that are

visible within the viewing area. However, due to the limitations caused by the size of the display area on top of overlapping data of a 3D model, the relevant data are often subjected to trade-offs. For example, a 3D model of an engine can be relevant to the model of the car that a modeler is working on. However, the engine would be obstructed if it is placed inside the car, and the task of shaping it would become difficult. As a result, the model of the car in this case would be removed or hidden from the screen while the engine is being shaped.

Daurish (2003) explains that context and activity go hand in hand, and argues that context arises from the navigation and manipulation activities. However, in certain conditions the context that arises from the activity being performed may not be relevant to it. Therefore, in this case, the un-relevant context is often hidden or removed. This situation can apply to 3D modeling where the processes of navigation and manipulation of the model often change the viewing orientation, resulting in a new context being produced. However due to the large amount of visible data, in some cases context may no longer be helpful to the task in progress. Instead, this context may actually become an obstacle to performing the current task.

In a computer environment, Shankar (2006) defines context as “any information regarding a user’s presence (or absence) in the vicinity of a computer”. He further expands his definition by describing that the presence of context is created by the user’s activities. Based on these definitions, he introduces the term “user-context” that can be divided into two categories: external and internal user-context.

External user-context refers to the situation “where computer senses from the external environment” (Shankar 2006). This external environment includes the movements of the user in the immediate vicinity of the computer and the presence or absence of speech. In general, this type of context is not relevant to a 3D modeling environment. In 3D modeling, modelers often rely on the information that is shown to them on a computer, and as such, do not rely on external information.

Internal user-context, on the other hand, is defined as “any information that a computer senses from its internal environment that generally relates to keyboard activity, mouse usage and the activity of different processes within a user's computer”. This second category is very much in line with the activities that take place during 3D modeling tasks. In these tasks, context is interactively built based on navigation and

manipulation of objects that are in the 3D computer environment.

3.3 Awareness

In the real physical world and the computer environments, awareness can be described as self consciousness or knowledge gained from the activities that take place around us. Awareness exists conceptually and is interactively created as a result of user's consciousness of the ever-changing context. However, in some situations awareness is referred to as the ability of the computer device to react according to context, such as the time and location where the device is being operated. This is generally known as "context-awareness", and since it is not relevant to the topic of this thesis, it will not be covered here.

The term 'awareness' often appears in literatures related to Computer Supported Cooperative Work (CSCW). A well-known definition in relation to awareness in CSCW has been given by Dourish and Bellotti (1992). They define awareness as an understanding of the activities of others, which provides a context for individual activities of the participants in a cooperative type of work. In this type of work environment, awareness of other collaborators' contributions to the group's activity plays an important role in supporting the shared group work. Clearly without such awareness there won't be an actual joint work, but an incoherent set of isolated pieces of work.

Another definition of awareness has been given by Endsley (1995) who defines it as information which is task-relevant and is created during the interaction between user and the computer environment by using some form of an input device. This task-relevant information usually changes during the interaction and it is used by the user to know what is going on. This definition can be applied to both CSCW and non-CSCW types of work.

Abowd et al. (1999) includes the term 'context' as a part of the definition where 'context-awareness' is described as "the use of context to provide task-relevant information and/or services to a user". However, the task-relevant information provided by the context is not always useful. Thus, users need to know and to decide on the relevancy of the information.

Correa and Marsic (2003) discuss that awareness can be divided into two groups:

explicit or implicit. An example of explicit awareness is where a question is asked of someone and the response helps in creating awareness. Implicit awareness, on the other hand, is where a conclusion is made by gathering information from the surroundings. The information can be in terms of sound, image or any other sources that can be detected by human senses such as touch, smell, and taste.

3.4 Focus and Context Awareness

The issues related to focus and context awareness are also important and have been investigated by a number of researchers. Yeh and Wickens (2001) conducted an experiment that determined how focus and context can be used to create user awareness. In a map reading experiment, the participants were asked to answer questions about information displayed to them. Participants were initially asked to answer questions with less visible information (i.e. context) being displayed. In this experiment, participants were able to view the context whenever necessary.

The results showed that participants often re-displayed or turned on the hidden information, even though it was not directly related to the tasks they were performing. The study also demonstrated that the participants felt less comfortable when less information was displayed, and this affected the participants' ability to give correct answers. This finding indicates that a better awareness can be established when both object of interest (i.e. focus) and context are visible. However, problems that can be caused by showing unrelated information were not investigated in this experiment.

Another comprehensive study of focus and context awareness was carried out by Khedr (2004). Khedr mentions that, in relation to focus and context awareness, the awareness created from task-relevant information is helpful and universally needed when it has certain qualities. He further characterizes the quality of awareness into two groups, which he calls "relevancy" and "information overload". Relevancy is described as "the timeliness and the availability of information", which determines the usefulness of the information. The information is not useful when it is not related to the activity, or when it is related but arrives too late to be of any effect.

In relation to 3D modeling tasks, these two types of information generally exist. Information which is far from the center of interest is often not useful. For example, when a modeler is shaping the model of an eye, information such as a remote part of the model (e.g. hand or a leg) may not be relevant at all, and can be ignored.

Information that is related, but arrives too late, may also occur while performing modeling tasks, for instance when a related object is hidden or obstructed by others.

Regarding the second type of awareness, Khedr explains that information overload refers to a situation where there is too much information, which can be “a hindrance as well since not all of it may be necessary, and the overhead of processing the inputs may be detrimental to other necessary activities and may cause unnecessary distraction”.

In 3D modeling tasks, the amount of information increases as the complexity of the model increases and some of the increased information can in turn cause distraction. To overcome this problem, some of the information can be temporarily hidden or removed using various tools provided by modeling software.

3.5 Workspace Awareness

Another form of awareness, considered important in CSCW literature, is workspace awareness (Greenberg et al., 1996). Workspace awareness is concerned with providing members of collaborative groups with an appropriate level of awareness when working in a shared workspace. This awareness is often related to users’ ability to know the identity of the group members, their location, and what they are doing when they are working in different areas of the workspace.

Gutwin et al. (1996) note that workspace awareness should cover not only the knowledge of other group members’ interactions with the workspace but also include the knowledge of the state of the workspace and its artifacts, as well as the individual’s own actions in the shared workspace. Furthermore they highlight that the “awareness information must be easily interpretable regardless of where it is presented”. This suggests that awareness can be established not only when interacting with other group members in a real physical world but also in a computer environment.

To date, the focus of the research on workspace awareness has been on providing useful information for collaborators to coordinate their actions, to anticipate others’ actions, and to find opportunities to assist one another (Gutwin and Greenberg, 1998). This type of workspace awareness information not only helps collaborators to anticipate and avoid conflicting actions, but also assists them to rapidly detect and

repair conflicts when they do occur. This is achieved by maintaining awareness which requires knowledge about where people are working, what they are doing, and what they might do next.

It is therefore clear that workspace awareness is generally about issues related to group members' ability to know what other members are doing within the shared workspace. As such, this concept is not directly relevant to this thesis and will not be discussed further.

3.6 Current Methods of Maintaining Focus and Context Awareness

In a computer environment, the tasks and scenarios that give rise to the problem of maintaining focus and context awareness are varied, and such problem occur in both 2D and 3D settings. Most of the techniques developed to deal with issues related to focus and context awareness have been designed for a specific task or specific environment, and as such may not be effective in other environments or for other tasks. For example, a particular technique designed to help users to maintain their focus and context awareness when looking at 2D maps may not necessarily be useful for viewing 3D models.

However, the fundamental principle behind all of these techniques is the same in that they aim to balance providing enough detailed information about focus of interest while still maintaining information about the context in which the focus exists. In order for a user to successfully explore and navigate a large information space, it is necessary for the techniques to strive to provide both local detail and global context that allow the user to focus in on particular items of interest and understand how those items fit into the hierarchy as a whole (Furnas 1986, Leung and Apperly 1994, and Bartram et al., 1995).

Focus and context awareness techniques can be divided into two categories, those for 2D environments and those for 3D environments. These will be discussed in the next few sections.

3.6.1 2D Environments

Even though information in 2D environments is represented only along the X and Y axes, some times a large amount of overcrowded information is displayed in a 2D surface. For example, a 2D city map may contain a considerable amount of

information. This overcrowded information can cause some difficulties to users when trying to relate what they are focusing on against the other information being displayed to them. In relation to these difficulties, Bederson and Hollan (1994) state that one challenge in viewing any large information space is maintaining a sense of the relationship between what users are looking at and where it is with respect to the rest of the information. The ability to know the relationship between information of interest with others has also been highlighted by Farrand (1973), who identifies that "an effective transformation must somehow maintain global awareness while providing detail".

A number of techniques have therefore been developed to support focus and context awareness in 2D spaces. The use of each of these technique is dependent on a number of factors, such as the type of information being displayed, the nature and level of difficulty to understand the visible information, the tasks being performed (e.g. visual search, browsing, and comparing), and the fraction of screen real-estate allocated to context and focus regions (Nekrasovski, 2006).

In the following sections, a number of techniques which can be used to provide focus and context awareness in 2D environments will be discussed.

3.6.1.1 Zooming

Zooming is a technique which is used for changing the scale of the detail area by using an input device. It is applicable to both non-computer and the computer-based environments. In a non-computer environment, this technique is employed for example in conventional photographic cameras and binoculars to increase the clarity of the objects of interest being viewed. In a computer environment, zooming is generally used for detailed viewing of graphical information on a 2D display device. It enables users to change the scale at which the graphical information on the region of interest is viewed at a greater or lesser level of detail. Viewing in greater detail reduces the area of interest being displayed, while viewing in lesser detail increases the area of context being displayed.

The Oxford dictionary defines zooming as a technique for "changing smoothly from a long shot to a close-up or vice versa". However, Hornbaek et al. (2002) point out that zooming is not always a smooth process, but rather the smoothness of the zooming is dependent on the technique being used. For instance in a jump zooming technique, the

change in scale occurs instantly, without a smooth transition. Hornbaek et al. (2002) and Bederson and Hollan (1994) claim that this type of technique can be disorienting, and may not provide the most effective support for the cognitive and perceptual processing required for understanding the interactive information created during the zooming process. In contrast to this, in animated zooming the transition from the old to the new scale is smooth, and therefore more useful to users (Bederson and Hollan 1994, and Pook et al. 2000)

Zooming can be carried out in two different directions, zooming in and out. Zooming in increases the apparent size of objects of interest, and decreases at the same rate when zooming out. In other words, zooming in is the process of virtually enlarging the parts of interest, whereas zooming out reverses the effect. The zooming technique is widely used when there is only one window per display area (Hornbaek et al., 2002).

In an attempt to improve the process of zooming, Igarashi and Hinkley (2000) have proposed speed-dependent automatic zooming, where zooming level is automatically varied depending on the scroll rate. This technique allows zooming out when the 2D space is scrolled quickly, while scrolling slowly or remaining stationary causes zooming in. In an experiment using this speed-dependent automatic zooming, participants were asked to carry out map browsing tasks. Findings from this experiment showed that using speed-dependent automatic zooming the task efficiency remained the same or got slightly worse than when using traditional scrolling methods of zooming.

In another study conducted by Pook et al. (2000), they noticed that zooming was difficult to use on large information spaces because zooming does not provide sufficient context information. They observed that when zooming, even after a short period of time, users no longer know where they are in the information space, nor where they can find the information they are looking for. A similar problem is also mentioned by Cockburn and Savage (2003) who noted that zooming in on the objects being displayed can cause the areas outside the selected region of interest to move off-screen, and this temporal separation of zooming demands assimilation between pre- and post-zoom states. In their evaluations, Cockburn and Savage conclude that zooming causes the abrupt transitions between discrete zooming levels, requiring

users to re-orient themselves after each zooming action.

In summary zooming technique trades-off between the visibility of the focus of interest and the overview of the context. This means that maintaining focus and context awareness can be difficult when using a zooming technique.

3.6.1.2 Fisheye View

Fisheye view is another technique developed to support users in maintaining their focus and context awareness in 2D spaces (Furnas et al., 1995). In this technique, only the region of interest is enlarged while the area outside the region of interest remains without any magnification. A Degree of Interest (DOI) function is employed to assign a value to each location in the viewing space area. This value represents the relative interest in that location based on the currently selected location being viewed in detail. Fish-eye view provides a balance between detail at the focus of the user's attention and context at a global level. At points further away from the user's centre of attention, the level of detail decreases, with only important features of the context being evident (Schaffer et al., 1996). The changes between the centre of attention and the surrounding area are managed dynamically.

Compared to zooming, this technique is different in that it offers guaranteed visibility, a property which ensures that the region of interest remains visible independent of user's navigation actions (Munzner et al., 2003). The Fisheye technique allows the user to view a large region at once, while revealing low-level details in the single area of focus. However, in this technique image of the region being viewed is distorted to display parts of the region in great detail while also showing the context that contains the area of focus. Figure 3.1 shows an example of fisheye technique. The left figure shows the original 3D model of a head prior to the fisheye technique being used. The two other figures (middle and right) show two areas of the model being "fisheyed", where the two areas (mouth, and nose and eyes) are enlarged while the scale for the rest of the model remains unchanged. These three figures also illustrate a property of guaranteed visibility where both focus and context remain visible all the time.

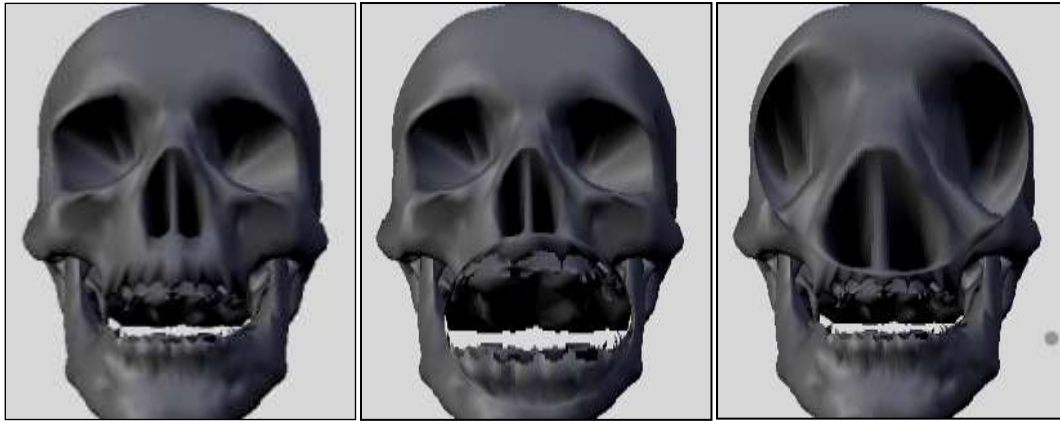


Figure 3.1: Effect of fisheye technique on a 3D model

Schaffer et al. (1996) have used the fisheye technique to conduct an experiment to compare its effectiveness against conventional zooming technique for diagnosing a fault in a power distribution network. The outcome of this experiment demonstrated that fish-eye view enabled users to find the faults much faster than when using the zooming technique.

Another experiment comparing the efficiency of the fisheye technique with conventional zooming was conducted by Gutwin and Fedak (2004). In this experiment participants were asked to create a presentation document and add objects to presentation slides, which required them to find and select icons and menus, draw shapes, select data objects on slides, etc. The findings showed that the fisheye technique outperformed the zooming technique in most of the cases of the study. Gutwin and Fedak claim that switching back and forth between the overview and the zoomed-in view incurs costs that are not present in the use of the fisheye technique. The more switching that is required, the more time will be needed by the zoom technique. As a result, fisheye was found to be more efficient than zooming.

Although these research suggest that the fisheye technique generally performs better than the zooming technique, Mackinlay et al. (1991) point out that the fisheye technique, which uses Degree of Interest functions and a threshold to determine the contents of the display, often causes the visualization to have gaps between the focus and context areas that might be confusing to the viewers. Furthermore, they explain that “the desired destination might be in one of the gaps, or the transition from one view to another might be confusing as familiar parts of the visualization suddenly disappear into gaps”. Similarly, Baudisch et al. (2002) discuss how the fisheye technique introduces distortions and makes it difficult for viewers to integrate all the

information being presented into a single mental model.

Gutwin (2002) has identified another weakness of the fisheye technique whereby the distortion effect caused by non-linear magnification makes certain interactions more difficult. This can for example cause overshoot when attempting to select a target or focus point.

3.6.1.3 Bifocal Display

The Bifocal Display is an information presentation technique where the supporting information or items are compressed uniformly (Spence and Apperley, 1982). This technique enables a large data space to be viewed as a whole, while simultaneously a portion is seen in full detail. It has some similarity to the fisheye technique in that the detailed area is seen in the context of the overview. However, the Bifocal Display aims to preserve the continuity across the boundaries between the area of focus and context.

A well-known use of the Bifocal Display technique is in the stretchable dock of application icons associated with the Mac OS X (Modine 2008) operating system. Figures 3.2 shows an example of this technique being used, where the sizes of the icons are different depending on their distance from the icon of interest.



Figure 3.2: Icon of interest is on Safari (above) and Skype (below)

Although Bifocal Display provides spatial continuity between the focus and context regions (Spence and Apperley, 2011), Mackinlay et al. (1991) discuss the fact that it does not integrate detail and context completely smoothly or intuitively. As a result, the relationship between these two regions may not be obvious. They also note that in this technique, when the focus moves, items suddenly expand or shrink, which may be confusing to the viewer. A similar concern has been mentioned by Leung and

Apperley (1994). They observed that there is a discontinuity of magnification at the boundary between the detailed and context views which distorts the view. This distortion can reduce the smoothness of continuity across the boundaries. Similarly, Smith (1997) states that because of the magnification discontinuity between the focal and context regions, “as items move from one to another or from being the context to the focal region, the item can suddenly expand which may surprise the user and require some time to mentally absorb” the changes.

3.6.1.4 Perspective Wall

The Perspective Wall technique by Mackinlay et al. (1991) is a conceptual descendent of the Bifocal Display. In this technique, a 2D surface is folded to create a 3D perspective view. Similar to Bifocal Display, it consists of two side panels which show a distorted view of the out-of-focus regions. The two side panels used for displaying the context are shaded to enhance the perspective effect. Perspective Wall attempts to smoothly integrate detailed (focus) and context view to enable users to visualize linear information. A representation of the Perspective Wall is shown in Figure 3.3.



Figure 3.3: A representation of the Perspective Wall

The main distinction between this technique and the Bifocal Display is that in the Perspective Wall the context region is zoomed out at an increasing rate, in comparison with the constant demagnification of the Bifocal Display. In addition to this, the view generated by the Perspective Wall is dependent on a larger number of parameters, including the length of the wall, the width of the viewport, the angle and size of the central focus region, etc. Therefore the information displayed to the viewers can be reduced directly proportional to their distance from the focus region, which provides smoother transition when moving the area from the context to the focus region.

Fiers et al. (2005) report on their use of the Perspective Walls for viewing DNA data

in their medical lab. They note that the Perspective Walls provides an effective technique for realizing the relationship between context of a substantially larger area and the current area of interest. This observation is not, however, based on any empirical comparison between Perspective Wall and other techniques such as Bifocal Display or conventional zooming.

3.6.1.5 Multiple Windows on a Single Display

The previous techniques discussed above have been developed to utilize a single window for display of information. It is, however, possible to have several windows each displaying different views of the space being viewed.

The most common setup used with multiple windows is to use one of the windows to provide an overview that shows the entire data space in miniature, and one or more windows to give detailed views showing portions of the data space at other sizes (Gutwin and Fedak 2004). In this case, the miniature provides the overall context of information while the detail view represents the focus area. This combination of views that uses a spatial separation between focused and contextual views is often called an overview+detail interface (Plaisant et al. 1995). Categorically, fisheye, Bifocal Display and Perspective Wall are in focus+context group, where focus is displayed within the context (Cockburn et al., 2008).

An example of multiple windows setup where a detailed map is being displayed is shown in Figure 3.4. In this example, the top left window provides an overview of the map of Hamilton city area in a smaller scale, while larger images of the map at different scales are shown in the other three windows.



Figure 3.4: Multiple windows on a single display

Several studies have been conducted to compare the effectiveness of multiple

windows against other techniques such as zooming, fisheye, etc. In a study by Hornbaek et al. (2002) participants were asked to locate objects on a map shown to them. This study which compared multiple windows and zooming techniques showed that 80% of the participants preferred multiple windows. They stated that the overview shown in one of the windows supported navigation and helped viewer to keep track of their position on the map. However, the study also showed that switching between the focus and context windows required mental effort and this assimilation process hindered interaction and caused the participants to take a longer time to complete their tasks.

Another related study (Plumlee and Ware, 2006) compared the use of multiple windows with the zooming technique for a multi-scale pattern matching task. The findings of this study showed that when a large number of items per set were used, participants were able to complete their jobs faster using multiple windows. They also observed that when using multiple windows the study participants made more visits back and forth between pattern locations, but they made fewer errors than when using the zooming technique.

A more comprehensive study by Cockburn et al. (2008) investigated issues related to focus and context interfaces to identify effectiveness of different viewing techniques. The study included three categories of techniques. The first category, called overview+detail, included multiple windows technique which uses a spatial separation between focused and contextual views. The second category included techniques that use a temporal separation between focus and context, for example zooming. The third category, called focus+context, included techniques such as the fisheye and Perspective Wall which minimize the seam between views by displaying the focus within the context. Findings from this study showed that none of these approaches is ideal for maintaining focus and context awareness. This is because spatial separation between views require users to assimilate the relationship between the concurrent views of focus and context information.

3.6.1.6 Radar View

The Radar View is another technique aimed at improving users' ability to maintain focus and context awareness in 2D spaces. This technique provides an overview of the entire data space in miniature with radar in it, while a focus region is displayed at

different size by using the zooming technique. The Radar View can be implemented on a single or multiple windows. Figure 3.5 shows the Radar View technique using a single window, where the region of interest is represented by the rectangle drawn on the miniature view of the map, while the focus area is enlarged using the zooming technique.



Figure 3.5: The Radar View with both the radar and zoom in the same window

Figure 3.6 illustrates an example of the Radar View using two windows. A rectangle radar region is shown on the left window to indicate the region of interest, defining the focus area displayed on the right window.



Figure 3.6: The Radar View using two windows

The Radar View technique can be used in a single user or multiple users work setting. Gutwin et al. (1996) and Schafer and Bowman (2003) claim that this technique is useful in CSCW environments where it provides group awareness by allowing the users to see the location and activities of the group members regardless of where they are in the shared workspace.

Schafer and Bowman (2003) have conducted an empirical study to compare the Radar View and fisheye techniques. In this study, participants were asked to work together in pairs to position traffic lights and road signs on a city map based on a set of criteria given to them. The results of the study however indicated that there was no significant difference between the two techniques. The participants did not find either of techniques easier than the other for collaboration, and they did not prefer one technique to the other.

Despite the claims that the Radar View provides support for maintaining workspace awareness (Gutwin et al, 1996), Greenberg et al. (1996) point out that the Radar View has its limitations where a physical and contextual gap between the focus area and the global context causes users to make abrupt contextual shifts back and forth between them. They describe further that when using this technique, users often need to mentally integrate the information from the windows in order to match their detailed view with the radar area in the overview.

3.6.1.7 Multiple Displays Setup

Multiple displays setup is where more than one physical display is used to show the 2D information space. The physical displays used in this case can be organized in a number of ways to include multiple monitors, a combination of a projector and a monitor, a combination of multiple projectors, etc. In this type of setup, one of the displays may be used for viewing the region of interest (i.e. focus) while the others show the context or the overview of the 2D information space. This setup is similar to multiple windows except that in multiple displays, the physical 2D space available is larger. There is also a physical separation between different displays being used.

A number of studies have found that users' productivity increases when they use multiple displays setups. For instance, in a study conducted by Norton (2003) the number of lines of code generated and defect levels were measured with an in-house bug-tracking system. The study demonstrated that the use of multiple displays increased the productivity in terms of the line of code generated per day by 10%, and defect levels decreased by 26%.

The same pattern was shown in a study commissioned by the Nippon Electric Company (Manjoo, 2009). In this study, office workers were asked to perform several common tasks using various display configurations. The results showed that people

who used two 20-inch computer monitors were 44% more productive at certain text-editing operations than people using a single 18-inch monitor.

However due to the physical setup, multiple displays often take up a lot of desk space. In addition Cox et al. (1998) note that physical separation between the displays creates another problem in that the overview is normally neglected. The same observation is made by Grudin (2000) who claims that the constraint with multiple displays is caused by the fact that displays do not connect seamlessly. The monitor bezels or cases separate surfaces when the content of a window straddles across multiple displays. Grudin also mentions that this separation causes users to treat multiple displays as a non-continuous space.

3.6.1.8 Resolution Contrast Display Setup

In a resolution contrast display setup two types of displays with different viewing resolution are used in combination. Even though this setup involves displays of different resolutions, it is however designed to preserve the scaling of the geometries of images, including their ratio and lengths in the image.

Baudisch et al. (2001, 2002) have conducted an experiment using a wall-sized low-resolution display with an embedded high-resolution display region. In this experiment participants were asked to refer to the two display screens to extract information from a large static map. They had to perform two tasks: task one was to find the shortest path between marked locations on a map of London, and task two was to verify connections on a circuit board. The goal of this study was to determine the usefulness of this setup against multiple windows and the conventional zooming technique. Findings from the experiment showed that the participants took 39% longer when using the conventional zooming technique. When comparing this setup with the multiple windows technique, it was discovered that the participants took 27% longer when using multiple windows to complete the task.

It should however be noted that this type of setup may suffer from the same problem of physical separation that other multiple displays setups suffer from.

3.6.1.9 Alpha Blending

In a standard display environment, users may open multiple windows which could be overlapping, or placed side-by-side. This causes the information of the background

window in an overlapping case to be hidden from the viewer. As a result, users need to either physically switch between windows when they are overlapping in order to see the information on different window or visually switch between windows that are visible side-by-side. The Alpha Blending is a technique designed to solve these types of problem. The Alpha Blending technique adopts the concept of semitransparent layers that can be superimposed to allow the contents of the windows to be viewed simultaneously on top of each other in the same window. This reduces the need to switch back and forth between windows, especially overlapping windows which occlude each other (Harrison et al., 1995). Figure 3.7 shows jet fighters using this Alpha Blending technique, in which the contents of the windows can be viewed simultaneously in a single window.



Figure 3.7: A 3D Model of jet fighters is shown using the Alpha Blending technique

The method employed in Alpha Blending has evolved since it was developed by Porter and Duff (1984). In the original version of Alpha Blending, the overlapping information blended by computing a weighted sum of pixel colors of the front and background windows. This computation generates new colors that allow content from the overlapping windows to remain visible to the viewer.

This type of blending has some limitations, because it often causes all the colors to get diluted by the respective contribution of the overlapping pixels (Gutwin, 2004). In addition, original Alpha Blending is subject to interference effects which can consequently cause visual ambiguity (Gutwin, 2004). Because of this visual ambiguity, users tend to have some difficulties in making a correct judgment on the actual location of the information being viewed (i.e. in which layer the information exists).

Due to these limitations, Baudish and Gutwin (2004) have introduced an improved version of the Alpha Blending, called multi blending. Multi blending blends the individual colors, texture features, and windows separately, using a range of image processing techniques. As a result, it provides higher visibility to the features most relevant to the user's task at hand. At the same time, it also better preserve the visibility of both the background and foreground windows. Baudish and Gutwin have conducted an experiment to compare the usability of the original Alpha Blending and multi blending. In this experiment, participants were given the task of clicking on matching icons displayed on the screen as quickly as possible. Findings from the experiment showed that multi blending performed significantly better than the Alpha Blending. However, Baudish and Gutwin point out that multi blending is computationally more expensive.

3.6.1.10 Multi Layer Display (MLD)

As mentioned above, Alpha Blending and its variations have the problem of making it difficult for users to separate information present in different layers. Multi Layer Display (see Chapter 2) can be seen as an extension to the Alpha Blending technique using a hardware setup which physically separates the information layers. This separation not only enables the contents of multiple windows to be viewed simultaneously but also provides a physical gap between them. MLD seems to offer a sense of depth perspective which does not exist in the Alpha Blending technique.

In MLD, there are two factors that contribute to improving the visibility of information shown on both layers. The first factor is the color combination of the two layers, as described in Chapter 2. Bishop (2006) identifies that MLD works best when the background of both layers are set to white, to ensure that their colors would not interfere with the each other.

The second factor is the level of transparency between the two layers (Wong et al., 2005). Wong et al. have conducted an experiment to determine the level of transparency that works best between the front and rear LCD layers. In this experiment, participants are asked to read texts shown on the rear LCD layer with the transparency of the front LCD layer set to 0, 30 and 70 percents. Participants' performance was compared with reading on a conventional 2D display. The findings of the study suggest that the participants performance was poor at the transparency

level of 0% and 30%. At the 70% transparency, however, their performance was at the similar levels to reading on a conventional 2D display.

It is possible to use the two layers of MLD to provide focus and context information in a manner similar to Alpha Blending. Masoodian et al. (2004) have developed an application called DeepDocument which attempt to provide focus and context awareness environment for editing Microsoft Word TM documents. It presents the main document page view on the front layer of MLD while the overview of the entire document is displayed on the rear layer. The system attempts to use the physical separation of the layers to allow users to work on the main document at the page level while looking at its overview. The transparency of the front layer supported by the MLD makes the task of viewing the overview of the document on the back layer possible. There is no empirical study of this system to demonstrate its effectiveness.

Hayes et al. (2006) have however, compared the usability of a conventional 2D display and MLD in relation to decision making process. In this study participants were asked to make decisions on dispatching ambulances to accident incidents based on the location of the accident and its severity. A 2D map was displayed in both display setups during the experiment. In the MLD setup, the street map was shown on the front layer while the ambulance stations were displayed on the rear layer. The findings of the study showed that participants made better decisions when using MLD compared to those made while using a conventional 2D display.

There is, therefore, some evidence that MLD enables users to maintain their focus and context awareness. This, however, needs to be investigated further and will be discussed later in this chapter.

3.6.2 3D Environments

3D information often tends to be more complex than 2D information. The existence of the depth factor in 3D spaces can lead to overlapping data. This is particularly true of 3D models, as discussed in Chapter 2. Various techniques have been developed specifically for dealing with issues of focus and context awareness in 3D environments. These will be discussed in the next few sections.

3.6.2.1 Zooming

The zooming technique is applicable to both 2D and 3D environments. In a 3D

environment, similar concepts to the 2D environment are applied where the zooming technique will scale up or down the visibility of the objects' characteristics.

Figure 3.8 illustrates an example of using the zooming technique for viewing a 3D model. In Figure 3.8 (left), three objects appear in the viewport prior to zooming in. At a certain stage during the zooming in process, the model of the cone is scaled up to a level where two of the objects in the model disappear from the viewport. This causes a zooming problem similar to that described in 2D environments, where the zooming in causes the areas outside the region of interest to move off-screen. This visual separation requires users to re-orient themselves after each zooming action.

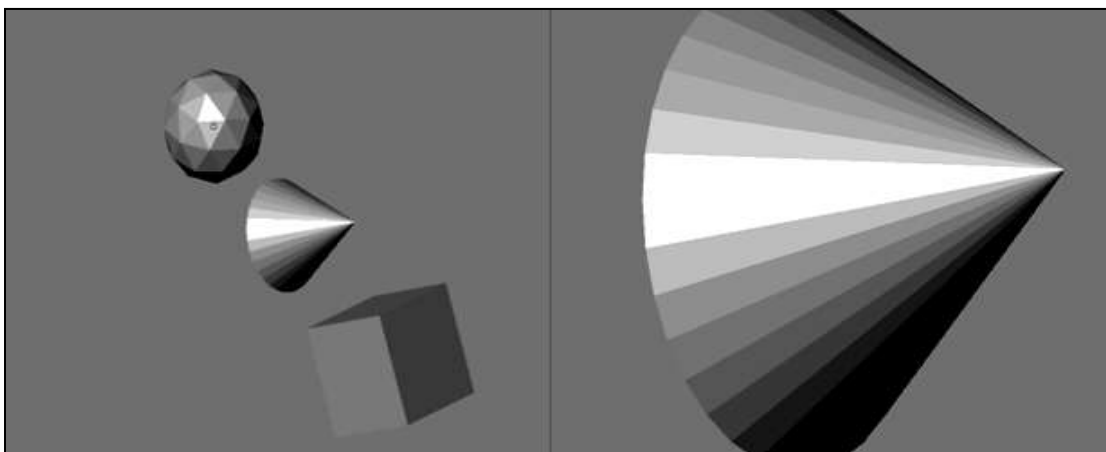


Figure 3.8: (left) 3D Model prior to zooming in where three objects of the model are visible. (right) Shows the model after it is zoomed in where the other two objects are no longer visible

3.6.2.2 Multiple Viewports

The technique of using multiple viewports in 3D environments is also similar to the use of multiple windows in a 2D environment, where the display area is divided into a number of sub-areas. Using multiple viewports in a 3D environment has its own advantages and disadvantages. The key advantage of using multiple viewports is that it makes it possible to see different views of a 3D model in each of the viewports. By combining various information available from different viewports, it is then possible to them get an understanding of the relationship between different parts of the model to create a sense of context while viewing details of parts of the model in one of the viewports.

The disadvantages of this technique are that it causes the working area in each viewport to become smaller, and the separation of information into multiple viewports causes information discontinuity which requires the user to constantly switch between

the detail and overview viewports (Hornbaek et al., 2002). Both these problems are similar to those discussed in relation to multiple windows in 2D environments.

3.6.2.3 Object and Component Editing Modes

Most 3D modeling environments provide two different modes of editing models: object and component modes. In the object editing mode, the manipulation process affects the entire part of the selected object, while in the component editing mode, manipulation can be applied to the individual components (i.e. vertex, edge, and face) of the selected object. Besides their intended use for editing the model, these modes can also be used for helping modelers to realize the orientation of a model being displayed. In other words, they can help users to maintain their focus and context awareness when viewing 3D models.

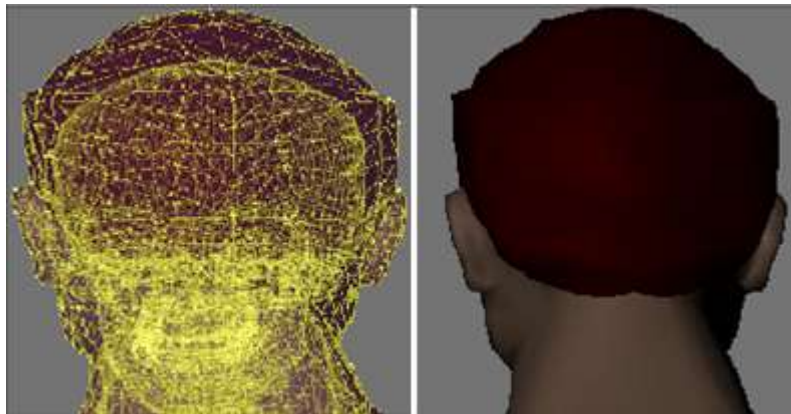


Figure 3.9: (left) Model in component edit mode, and (right) model in object editing mode

For example, the 3D model of a human head shown in Figure 3.9 (left) is in the component editing mode. However, due to the large number of overlapping vertices, edges, etc., the actual orientation of the model cannot be detected easily. In order to determine the orientation of this model the display mode can be changed to the object editing mode as shown in Figure 3.9 (right), making the orientation of the model clearly visible. However, this switching process between the two modes is likely to cause the viewers to lose their focus of the individual component of interest.

3.6.2.4 Hiding and Un-hiding

Another technique commonly available in 3D modeling environments is to allow selected object(s) of a model to be hidden or revealed. The hiding technique is often used when the object of interest is blocked by other objects or when the targeted object is overlapping with others. Un-hiding on the other hand is used for revealing a

hidden object. For instance, the model shown in Figure 3.10 (left) consists of three objects: the body, skeleton, and the heart which are overlapping each other. In this case, focusing on and modifying the skeleton for instance would be difficult. It is however possible to hide all other object, except the skeleton, to produce the result shown in Figure 3.10 (right), making it easier to work on the skeleton.

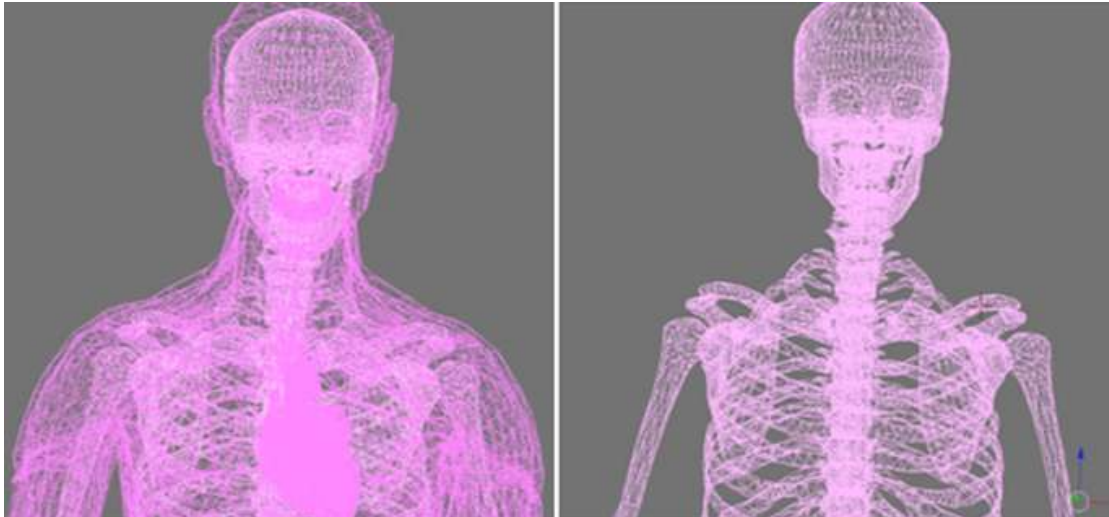


Figure 3.10: (left) Before hiding technique is applied to the model, and (right) after hiding technique is applied

While this hiding technique is able to reduce the clutter, it in turn creates another problem. To illustrate, consider scenario which requires the user to increase the size of the skeleton based on the dimensions of the human body while the visibility of the skeleton is obscured by other components of the model. One of the choices available to the modeler is to hide all other components (i.e. the human body and heart). The advantage of doing this is that the skeleton can now be seen easily. However, due to the missing context (i.e. the human body), the enlarged skeleton may accidentally increase beyond the size of the body.

Without the visibility of the context, users are faced with either the cognitive challenge of remembering context whilst working on detail, or having to reactivate it when the situation arises (Masoodian, et al., 2004). In many instances, users are required to remember or visualize their context while working on any specific attribute of data. So without the concurrent visibility of both focus and context, users may not be aware that enhancements made to an object of focus might go against the limitation set by the context.

3.6.2.5 Back Surface Removal

The back surface removal is similar to the hiding technique in that it allows hiding certain parts of the 3D model. However, in most 3D modeling environments the back surface removal can only be used in the component edit mode. This technique is used to hide or reveal the components of the model (i.e. vertices, edges, and faces) by determining which lines or surfaces are visible from specific viewing point (Humphrey, 2004).

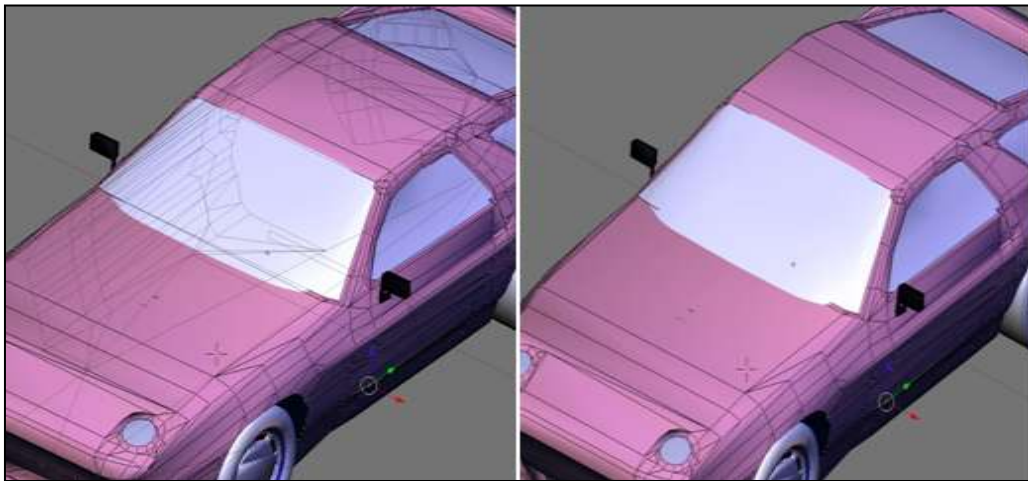


Figure 3.11: (left) Hidden surface removal function is off, and (right) hidden surface removal is on

Figure 3.11 (left) shows the 3D model of a car with all its surfaces visible, while Figure 3.11 (right) illustrates the same model with back surface removed from viewing. Although this technique can reduce cluttering of data caused by overcrowded information, it also can remove the overall perspective of a 3D model.

In the component edit mode, without the back surface removal, the components of the near and back faces of a 3D model are always visible to viewer. Naturally, this situation causes some challenges for a modeler when performing editing activities such as picking, extruding, etc. In the case that the point of interest is located on the near side of the model, the back surface removal technique is useful for removing the components of the other side of the model. By doing so, the modeler can avoid the distraction caused by components of the back faces. However, in other modeling scenarios, shaping processes may involve both side of the model, in which, this technique may not very useful as it would cause some of the point of interest to disappear from the view.

3.6.2.6 Magic Lens

Another technique that was developed specifically for dealing with issues of focus and context awareness in the 3D world is called the Magic Lens (Looser, 2007). Magic Lenses are 2D interface components that provide alternative representations of viewed objects that can be used to provide focus and context - especially when visualizing layered information. In a study Looser asked participants to select and manipulate a 3D object. It was found that users strongly preferred the lens-based interaction technique to other methods, largely because it reduced the effort of interaction. However, no comparative study has been conducted to determine its effectiveness in terms of visualizing tiny objects such as edges, faces, and vertices.

3.7 Discussion

In previous sections, a number of techniques developed to solve some of the problems associated with focus and context awareness have been discussed. Although many of these techniques are commonly used in 2D environments, their use in 3D environments, for instance in 3D modeling tasks is rather limited. These limitations can be grouped into four key areas which are categorized according to each technique's functionalities, as follows:

- Distortion-based
- Multiple windows or multiple viewports
- Hide and reveal technique.
- Overlays (Alpha Blending and MLD)

In the following sections the reasons for the limited use of these techniques in 3D modeling tasks are discussed.

3.7.1 Distortion-based

Distortion-based techniques are those that alter the original scale and proportions of the information being displayed. The techniques that belong to this category are zooming, Fisheye view, Bifocal Display, Perspective Wall, and Radar view. In the zooming technique, the entire information space being displayed is scaled up or down uniformly, whereas the other techniques apply different scales to different regions being displayed.

When performing 3D modeling tasks, modelers need to reshape objects, which

requires their precise viewing and gauging of the scale. Thus, modelers need to know the exact proportions and distances between the objects or components of the 3D model involved. For example, the task of scaling up the 3D model of a windscreen of a car requires the same scale to be applied to both the windscreen and car. This visible information is used by modelers to make a correct judgment in terms of size and placement. So, in the case where objects are displayed using different scales, modelers would find it difficult to determine whether the enlarged object is in proportion to the constrained object. Consequently, this limitation would adversely impact the model being shaped.

It is therefore reasonable to assume that the distortion-based techniques are unlikely to be useful in 3D modeling tasks, particularly during the manipulation phases.

3.7.2 Multiple Windows or Multiple Viewports

As discussed earlier the studies conducted by Hornbaek et al. (2002), Baudisch et al. (2002), Plumlee and Ware's (2006), and Cockburn et al. (2008) have provided sufficient evidence that the use of multiple windows or viewports requires users to switch their attention between the detail and overview windows. This involves some mental effort, which can be costly in term of time, and can therefore reduce user performance.

In 3D modeling tasks, modelers are not only dealing with overcrowded information as in 2D tasks, but also with overlapping information caused by the depth or Z axis information that appears in the 3D space. Besides overlapping information, modelers also need to work with precise components (e.g. vertices and edges) of the model. For this reason, the complexity of dealing with 3D information is often greater than that of 2D, because the relationship between the components of 3D model requires more mental effort and precision.

Using multiple window or viewport techniques that divide the information into non-continuous windows or viewports can disrupt the flow of information between the windows and viewports. As well as this, modelers have to switch back and forth between these windows or viewports. This is likely to distract modelers attention from the tasks being performed. Added to these challenges, the modeler is required to go through the same ordeal of regaining focus and context awareness that has been shown to exist in 2D environments.

3.7.3 Hide and Reveal Technique

As discussed earlier, these techniques remove or show the selected parts of a 3D model. They offer the flexibility of hiding or revealing the context information. The two popular techniques that give these effects of hiding and revealing are the back face removal, and the hiding and un-hiding techniques. The back face removal technique hides or reveals the component of the back faces of the model, while hiding and un-hiding can be applied to any part of a model.

To date, these techniques have often been used in 3D modeling tasks for a number of reasons. Among these are to view an object which is obstructed by other objects, and to reduce clutter caused by overcrowded information. In 3D modeling tasks, modelers usually need to modify parts of the model that may be dependent on other parts. Often, the objects involved may be blocking each other. To solve this problem, one of the objects involved can be removed from view in order to see the obstructed object. While these techniques are able to achieve this objective, they do in turn create a new problem where modelers would face the challenge of remembering the context whilst working on detail.

It is, therefore, reasonable to assume that these technique would not always useful in 3D modeling tasks, particularly when the tasks being performed on different parts of the model are dependent on each other.

3.7.4 Overlays (MLD and Alpha Blending)

Overlays techniques, which consist of the use of layers in MLD and Alpha Blending, enable the contents of multiple windows to be viewed together as layers. MLD allows physical overlapping of information on two layers, while Alpha Blending allows contents of multiple layers to be shown within a single window.

In 3D modeling tasks, the ability to recognize the distance between near and far objects is important. For example, when aligning the objects of a model, modelers need to determine which object is near to their view and which one is behind it. Without this depth perceptible, alignment and positioning tasks can be difficult. The same problem can occur when modelers attempt to select components such as vertices and edges. As mentioned earlier, these components shown on a 2D display are often overlapping. Therefore without a depth perspective, selecting correct components is

not generally an easy task.

The overlays technique employed in Alpha Blending is aimed at 2D tasks, where depth perspective is not an issue that needs to be considered. Features offered by Alpha Blending are only helpful for viewing the information provided by overlapping 2D windows, and would not necessarily help modelers to recognize the location of the objects in a 3D space.

MLD, on the other hand offers physical separations between the two LCD layers, which may be used to overcome the limitations of Alpha Blending. Even though MLD is not designed for viewing 3D information, its features, including the transparency of the two LCD layers and the physical gap between them, may provide a potential solution for more effective viewing of 3D models. This is an area of research that has not been investigated previously and forms the basis of this thesis.

3.8 Summary

This chapter has discussed the concept of focus and context awareness, and provided a summary of techniques developed to support focus and context awareness in both 2D and 3D work environments. This has demonstrated that most existing techniques are not sufficient for effective focus and context awareness in 3D modeling tasks. To provide more effective techniques however, it is important to better understand the role of focus and context awareness in terms of 3D modeling tasks that are commonly performed by modelers.

In order to understand the types of difficulties faced by 3D modelers, and eventually address them, a pilot study involving 3D modelers was conducted. A detailed discussion on this pilot study and its findings are presented in the next chapter.

CHAPTER 4

Pilot Study of 3D Modelers

The previous chapter presented existing research related to focus and context awareness. Several techniques and technologies designed to assist users with maintaining focus and context awareness were also discussed. It was however noted that most of these methods and technologies were primarily for 2D environments and did not focus on 3D modeling tasks.

Although 3D modeling software have evolved considerably since their early days, it is not clear whether existing tools are sufficient or effective in supporting modelers to maintain focus and context awareness while performing their modeling tasks. A pilot study has therefore been carried out to better understand how modelers create 3D models using existing software and what difficulties and challenges they may face during their modeling tasks.

This chapter begins with an outline of the purpose of the pilot study (Section 4.1), followed by a discussion of the methodology used during the study (Section 4.2) and the tasks carried out by the study participants (Section 4.3). The questionnaires used in this study are presented in Section 4.4, and the demographic of the participants are given in Section 4.5. The findings of the study are discussed in Section 4.6. and the chapter concludes with a discussion in Section 4.7 and a summary in Section 4.7.

4.1 Purpose of the Study

The purpose of the study was to broadly identify any problems faced by 3D modelers while performing their modeling tasks. The main questions that this study aimed to answer were:

- What are any potential problems faced by modelers while performing 3D modeling tasks?
- What are the modeling situations that may cause these potential problems to occur?
- How do modelers overcome these problems when they occur using existing 3D modeling software tools?

4.2 Methodology

The coverage of this study is rather broad since it was not initially clear what the range of potential problems faced by 3D modelers were. Thus, the objective of conducting this broad preliminary study was to identify any possible problems faced by modelers while performing 3D modeling tasks. For this reason, a comprehensive questionnaire method used to gather information from users of 3D modeling software in terms of their experience. The study participants were computer science students doing a course in 3D modeling. They were invited to fill out a questionnaire after they had completed a 3D modeling assignment.

The study discussed in this chapter was conducted with the approval of the Ethics Committee of the Faculty of Computing and Mathematical Sciences, University of Waikato. A copy of the approval letter is attached in Appendix A.

4.3 3D Modeling Task

The study participants had to create a fully textured skinned character of their own design as part of their 3D modeling coursework. This modeling task was completed over several weeks using the Blender 3D modeling software version 2.49 (Blender, 2012). The study participants were not videotaped or observed while they carried out their modeling tasks, as they did this in their own time using private or laboratory computers. The students were asked to create a 3D model of a character that could then be used for animation (e.g. walking or running). In addition to this, they were required to apply texturing and skinning to the model they created. It was also stated in their instruction sheet that the model created should not have more than 3000 triangles, or 1500 quad, polygons. The models created as part of the assignment were therefore not very detailed. The assignment sheet (i.e. handout) specifying the requirements is included in Appendix B.

4.4 Questionnaire

The aim of the questionnaire was to collect information about the participants' experience of using conventional 3D modeling software for performing their modeling tasks. The questionnaire used in this study is presented in Table 4.1. Questions 1-3 collected demographic data, including the participants' age, sex and their level of 3D modeling experience. Questions 4-15 focused on the participants'

experience of using Blender to create their 3D models. Questions 7-15 used a five-point scale to get the participants' ratings of different aspects of the 3D modeling process.

The design of the questionnaire was guided by the findings of the literature review discussed in chapter 2. As highlighted in Section 2.4, 3D modeling usually involves some level of shaping of the 3D model being generated. Modeling technique such as B-spline, NURBS, and polygon modeling involve the manipulation of two types of components, namely vertices or control points. In most models with some level of complexity the vertices or control points tend to overlap, and models can end up being overcrowded. It was therefore important to find how difficult it is to manipulate vertices in such a cluttered environment, and what are some of the likely problems associated with this process. It was also determined from the literature review, as stated in Section 2.6, that 3D modeling tasks often require modelers to add or delete polygons, extrude, deform, align, and perform some kind of transformation (rotation, scaling and translation). Performing these tasks requires precision in terms of selection and manipulations of polygons and other components of 3D models. This questionnaire therefore aimed to gauge the difficulty of performing these tasks.

Table 4.1: Questions of the questionnaire

1-	Age Range:	<input type="checkbox"/> Below 20	<input type="checkbox"/> 20-25	<input type="checkbox"/> Above 25
2-	Gender:	<input type="checkbox"/> Male	<input type="checkbox"/> Female	
3-	3D Modeling Experience			
	Please indicate the 3D modeling software that you have used or are familiar with and your expertise level for each of the selected software. You may answer more than one.			
	3D Studio Max	<input type="checkbox"/> Beginner	<input type="checkbox"/> Intermediate	<input type="checkbox"/> Expert
	Blender	<input type="checkbox"/> Beginner	<input type="checkbox"/> Intermediate	<input type="checkbox"/> Expert
	Cinema 4D	<input type="checkbox"/> Beginner	<input type="checkbox"/> Intermediate	<input type="checkbox"/> Expert
	Light wave	<input type="checkbox"/> Beginner	<input type="checkbox"/> Intermediate	<input type="checkbox"/> Expert
	Maya	<input type="checkbox"/> Beginner	<input type="checkbox"/> Intermediate	<input type="checkbox"/> Expert
	Wing 3D	<input type="checkbox"/> Beginner	<input type="checkbox"/> Intermediate	<input type="checkbox"/> Expert
4-	Do you feel that you successfully completed the assignment?			
	<input type="checkbox"/> Yes	<input type="checkbox"/> No		
5-	How often did you delete a 3D object you were working on and started with a new object?			
	<input type="checkbox"/> Never	<input type="checkbox"/> One or more time, why?		
6-	How regularly did you use/view each of the following viewport options?			
	In Orthogonal Mode:			
a.	Camera View			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
b.	Front View			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
c.	Side View			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
d.	Top View			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
e.	View all			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
	In Perspective Mode			
a.	Camera View			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
b.	Front View			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
c.	Side View			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
d.	Top View			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time
e.	View all			
	<input type="checkbox"/> Never	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Regularly	<input type="checkbox"/> Most of the time

Table 4.1: Continued from the previous page

Rate your agreement or disagreement with each of the following statements.

- 7-** If you have used the “view all” windows, how important was it to see all the objects you had created?

 Not Important Very Important
 Explain why?
- 8-** Blender does not have an indicator for the eye location in its various views, how problematic was this when finding your location in the 3D world?

 Not Problematic Very Problematic
 Explain why?
- 9-** How easy was it to select a single vertex when there are many vertices in your model?

 Not Difficult Very Difficult
 Explain why?
- 10-** How easy was it to select a group of several vertices (e.g. an edge or face) together when there are many edges or faces in your model?

 Not Difficult Very Difficult
 Explain why?
- 11-** How easy was it to align objects in perspective view (e.g. when putting an object on top of another object)?

 Not Easy Very Easy
 Explain why?
- 12-** How useful would it be to show object names (labels) in perspective view?

 Not Useful Very Useful
 Explain why?
- 13-** Do you know what an occlusion effect is? Yes No
 If yes, how useful do you think it will be?

 Not Useful Very Useful
- 14-** Do you know what parallax effect is? Yes No
 If yes, how useful do you think it will be?

 Not Useful Very Useful
- 15-** Do you know what depth perception is? Yes No
 If yes, how useful do you think it will be?

 Not Useful Very Useful

4.5 Participants

As mentioned earlier, the participants who that took part in this study were undergraduate computer science students taking a course in graphics and multimedia. This group of students was chosen because they had some knowledge of 3D modeling but were not considered to be experts. It was also assumed that they would have an interest in 3D modeling because they had chosen to enrol in a graphics and multimedia course. Thus having them in this study should be in line with the objective of the study. It is also expected that due to their limited practical exposure to 3D modeling, their bias toward a particular modeling tool or modeling software would be minimal.

Their participation in the study was on a voluntarily basis and did not contribute to their coursework. The ages of the participants ranged from 20 to 25 years old. The group consisted of 13 men and 12 women. Based on the feedback from the participants none of them considered themselves to be an expert in 3D modeling. 13 of the participants considered themselves to be at an intermediate level in using the Blender 3D modeling software, while the others considered themselves to be beginners. Besides Blender, 16 of them had some experience using MAYA, of these 6 considered themselves to be at the intermediate level and 10 were beginners. Eight of the participants had also some experience using 3D Studio Max, and considered themselves to be at an intermediate level.

4.6 Results of the Study

The result of the study identified a range of issues related to the participants' experience of using 3D modeling software when performing their modeling tasks and the main problems they faced in doing so.

Questions 7 to 15 were analyzed using descriptive statistics, where mean and mode are used for interpreting the results. Descriptive statistics was used instead of inferential statistics because this study involves only one sample, and the data does not imply anything about a larger population. As stated by Tullis and Albert (2008), descriptive statistics is more appropriate than inferential for analyzing data when the conclusion does not apply to a larger population beyond the sample. These findings are presented in the following sections.

4.6.1 Task Completion

Question 4 asked the participants if they felt they had completed their assignment successfully. Of the 25 respondents, 15 (60%) said that they had not successfully completed their assignment. This is a high percentage considering that the participants' grade depended on this 3D modeling tasks. One of the reasons for the participants' failure to successfully complete their work may be due to the difficulty they had in using the Blender 3D modeling software, and the tools it provides. This is reflected in their responses to the other questions of the questionnaire.

4.6.2 Deleting the Model and Starting Over

In Question 5, the participants were asked whether they have intentionally deleted the model they were working on at some point and start over again the process of shaping their 3D model. The objective of this question was to determine the causes and the consequences of the problems that the study participants faced while performing their modeling tasks. Of the 25 respondents, 16 (68%) acknowledged that they had deleted their model and started over one or more times with a new primitive object.

One of the reasons for deleting an object that was mentioned by one of the participants is *"because the shape became complex and the vertices were not moving properly to form a shape, and when I only select[ed] one vertex to move, a whole lot of deselected vertices of the other side has moved too and ruined the shape"*. Here, the respondent claims that several unselected vertices were moved, and this ruined the shape of their model. However, in the Blender software used for the assignment, an unselected vertex will not be affected when other selected vertices are moved or transformed. Therefore, the most likely reason for the respondent's claim is that he was not fully aware of the status of the selected vertices. In this case the respondent may not have realized that vertices on the other side of the object were selected unintentionally due to the fact that vertices were overlapping, or were too close to each other. As a result, the model was wrongly shaped. As discussed in Chapter 3, the amount of information increases as the complexity of a model increases, such that the details of a model (e.g. its vertices and edges) eventually become overcrowded. This in turn leads to an increase in the difficulty of the modeling process as demonstrated by this example.

Another reason that was given for deleting a model and starting over was that *"I got*

so lost that I didn't know where I was going and decided to start fresh". In this case, the respondent simply gets lost while performing their 3D modeling tasks. This has been identified as an issue by Russo et al. (2000) who state that when users get lost in a 3D space, they usually try to restart from the beginning. Russo et al. further explain that when users are interacting with a 3D virtual world, they need to have easy access to information to allow for judicious decision making when solving eventual problems. For the user's movements to be efficient, it is important for the modeler to have a spatial knowledge of the environment and a clear understanding of their location. So in this example case, the respondent's reason for getting lost in the 3D space may have been caused by their lack of easy access to information and/or not having a clear understanding of their location.

4.6.3 Use of Multiple Viewports

In answer to Question 6 all the respondents noted that they often had two or more viewports open while performing their 3D modeling tasks. Generally, the purpose of having more than one viewport open is to enable modelers to view and work on details of the 3D model in one viewport while having an overview or different views of the 3D model in the others. The respondents' feedback showed that their most commonly used views were the front, top and side views. While in orthographic mode, 15 (80%) of the respondents noted that they regularly used the front view, 18 (72%) used the top view, and 21 (84%) used the side view. In the perspective mode, the numbers are very similar, with 18 (72%) of the respondents regularly using the front view, 15 (60%) using the top view, and 15 (60%) using the side view. Even though, the questionnaire did not ask for the reason for using these view types, it maybe the case that these views were used in order to support the participants in understanding the relationship between the objects they were working on and the rest of their 3D model.

4.6.4 Viewing All Objects of the Model

Question 7 asked the participants whether they had used the "view all" function or not, and how useful they had found it if they had used it. The "view all" function in Blender makes all objects of the 3D model visible to the viewer.

In 3D modeling tasks often parts of the model may disappear from the view as the result of a navigation or manipulation process. For example, Figure 4.1 (left) shows a

3D model of a jet fighter. At this stage, only one jet fighter appears on the screen, and it is not possible to know whether there are any other objects in the model. In order to have a view of the entire model, the modeler can either zoom out or use the “view all” function. The “view all” function automatically resets the view so that all the objects of the model are visible, as shown in Figure 4.1 (right). However, in this case the size of the objects on the screen is also altered in order to accommodate them in the viewport.



Figure 4.1: (left) Model of a jet fighter zoomed in, (right) all the objects of the model are made visible using the “view all” function

The analysis of the participants’ responses shows that the mode is 4, which implies that the ability of to see all the objects was important to most of the participants. As shown in Figure 4.2, 9 of the participants noted the importance of viewing all the objects above average. This is supported by the mean of 3.24.

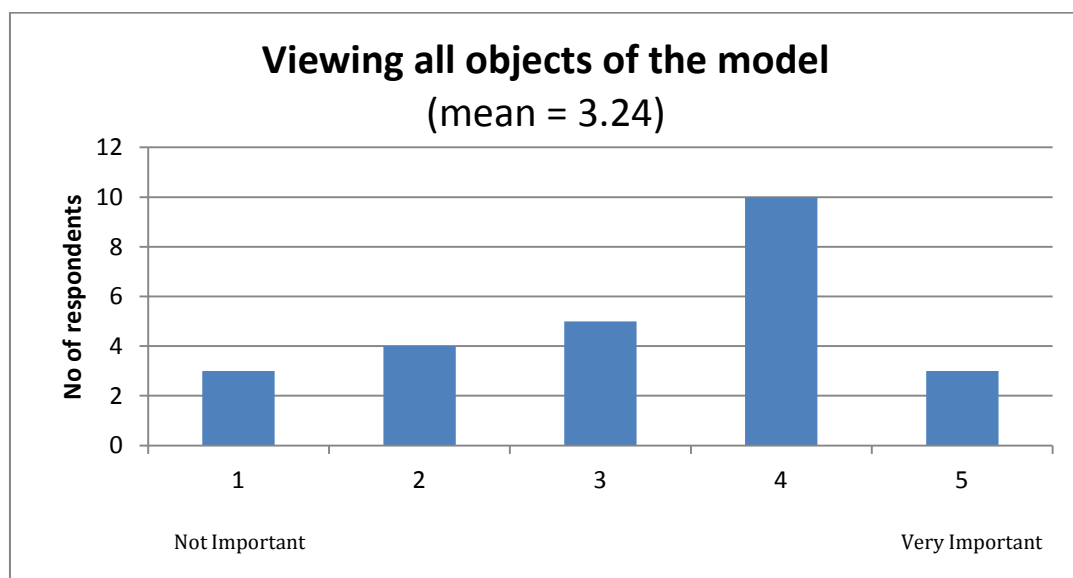


Figure 4.2: Responses to a Question 7

4.6.5 Realizing the Viewer's Location

Question 8 concerned the need for having a virtual eye location indicator on the screen. The eye location indicator, as shown in Figure 4.3, is used in some 3D modeling software to show where the model is being viewed from. An example of a 3D modeling application with such a tool is Doga (2012), which uses a red dot to indicate the position of the eye, and blue lines to represent the viewing direction.

This virtual eye location indicator provides extra information to enable the viewer to determine why the model appears in a given orientation. However, displaying an eye indicator on top of the 3D model tends to make the viewport even more crowded with information, particularly when viewing a complex 3D model.

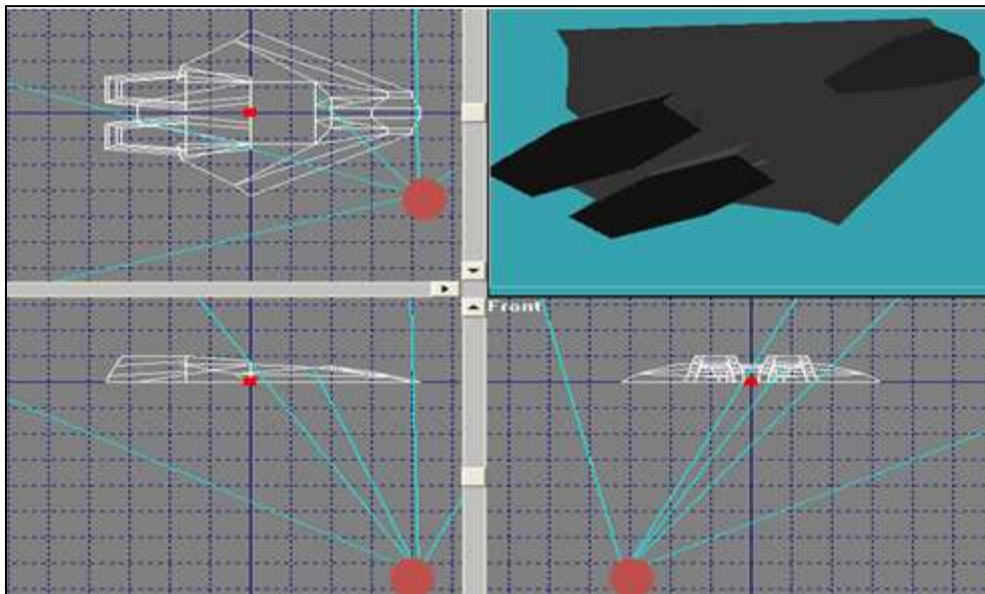


Figure 4.3: Eye location (red dot with blue lines) in Doga 3D modeling software

The result of the analysis, as shown in Figure 4.4, shows that many participants found the lack of information about the eye location in Blender problematic when performing 3D modeling tasks. The mean value for the difficulty rating in this question is 3.36.

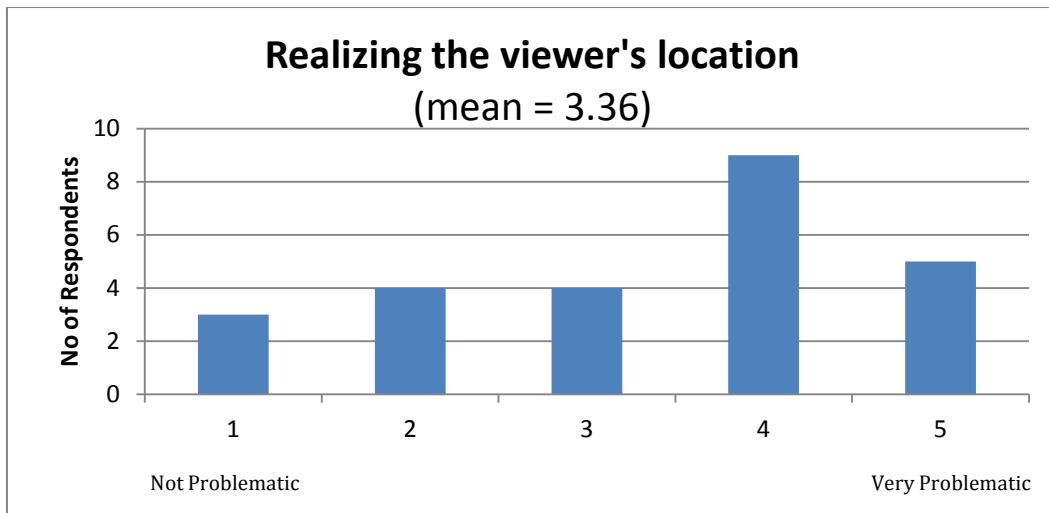


Figure 4.4: Responses to a Question 8

4.6.6 Selecting a Vertex or a Group of Vertices

The participants were asked whether or not selecting a single vertex (Question 9) or a group of vertices (Question 10) was a difficult task. The mode for the frequency of responses for Question 9 is 4 (see Figure 4.5) resulting a mean value of 3.32.

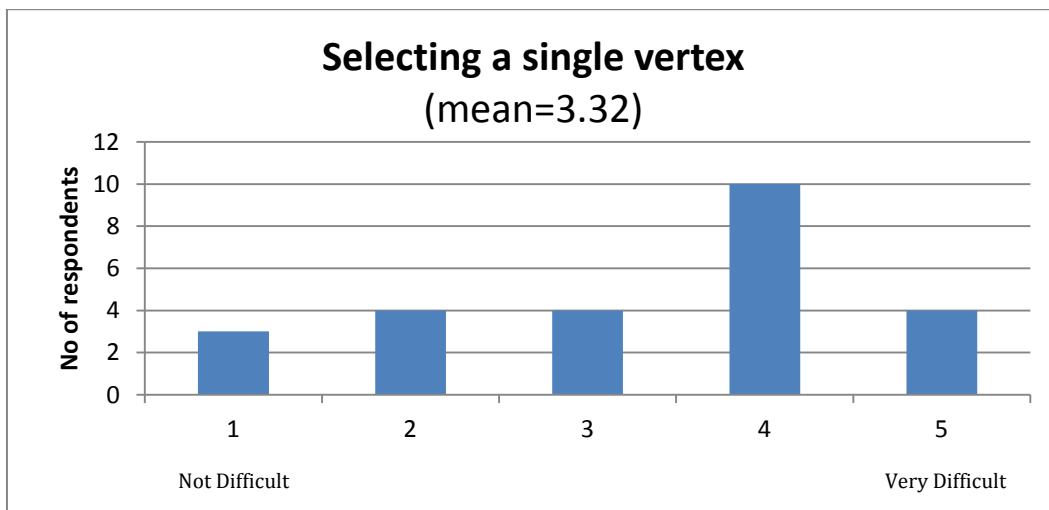


Figure 4.5: Responses to a Question 9

For Question 10 (i.e. whether or not selecting a group of vertices was a difficult task), the result of the analysis, as shown in Figure 4.6, shows that many participants found selecting a group of vertices to be difficult (i.e. mode = 5). The mean value for the difficulty rating in this question is 3.32.

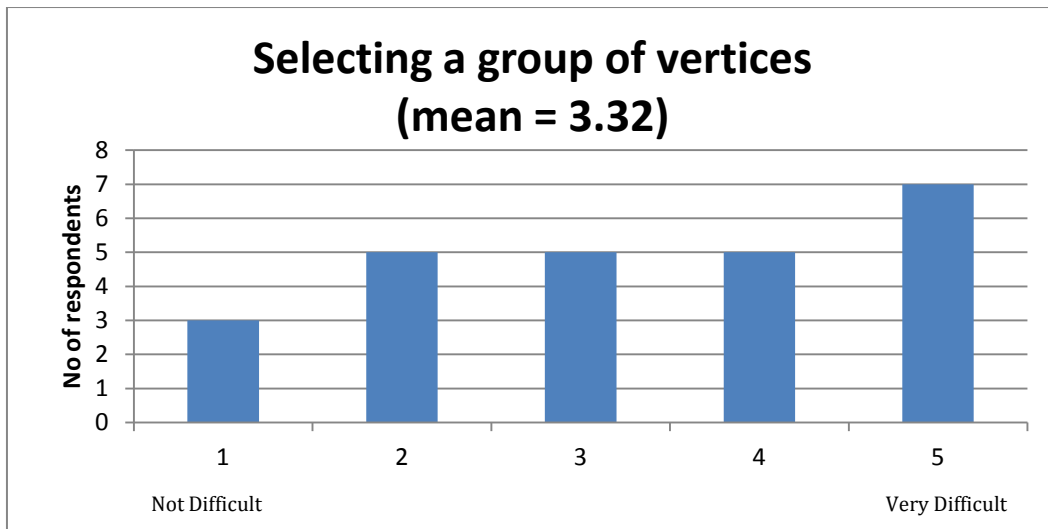


Figure 4.6: Responses to a Question 10

The task of selecting a single vertex or a group of vertices is frequently repeated throughout the 3D modeling process. Selecting correct vertices is therefore critically important in 3D modeling. However the results of the study show that the selection of a vertex or a group of vertices is not always easy. As pointed out by the respondents, one of the reasons why selection of vertices is such a tedious process is because of the overlapping components in 3D models. Three situations in which selecting vertices can be problematic are highlighted by the respondents, and are discussed below.

The first situation is highlighted by one of the respondent, who points out that “[I] often need to zoom in and zoom out to understand the model better. In some views it was very hard to see where a particular vertex was, and it took some time to select the correct one because the vertices can be close to each other”. This respondent used the zoom in technique to increase the visibility of the targeted vertex by showing a larger gap between the vertices. Figure 4.7 illustrates examples of this zooming technique and how it can be helpful. In Figure 4.7 (left), vertices A and B are too close to each other such that the distance between them is not easily recognized. The distance between them becomes more clear after the model is zoomed in, as shown in Figure 4.7 (right). However, this technique causes some of the model to move off the viewport.

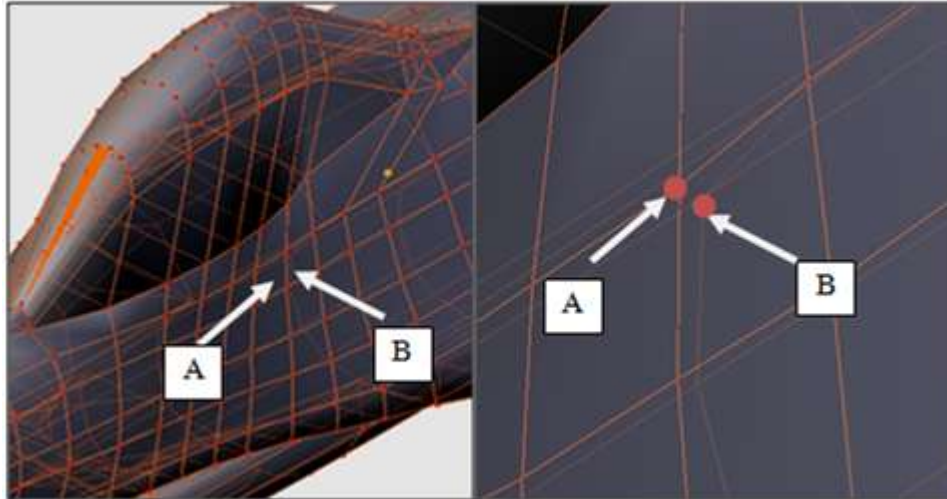


Figure 4.7: (left) Prior to zooming in, and (right) after zooming in

The second situation related to the difficulty of selecting a vertex is highlighted by another respondent: “[I] wasn’t sure how to select group of vertices. In many instances, I often selected the one I didn’t want. You would assume the one in front would be selected but it would choose the one behind. It was irritating”.

The problem of not being able to select a group of vertices accurately is often caused by the lack of accuracy of the selection tool being used. Group selection tools are provided by 3D modeling software to allow selection of more than one vertex at a time. In Blender, group selection is done by interactively drawing a rectangle around the vertices. However, this tool is not very accurate because it is not able to identify whether the location of the vertices within the rectangle are on the front or back surface of the objects within it.

Figure 4.8 illustrates how the rectangle selection tool is used in Blender. In this example a 3D model is shown in the wireframe mode, with the vertices of both the front and back faces of the model visible. In Figure 4.8 (left), a yellow rectangle is drawn, with the aim of selecting vertices of interest A, B, and C. Figure 4.8 (right) shows a snapshot of the vertices after they are selected using the rectangle selection tools. A fourth vertex D which belongs to the back face of the model is also selected unintentionally. This result shows that the rectangle tool has a problem with not discriminating between the front and back vertices.

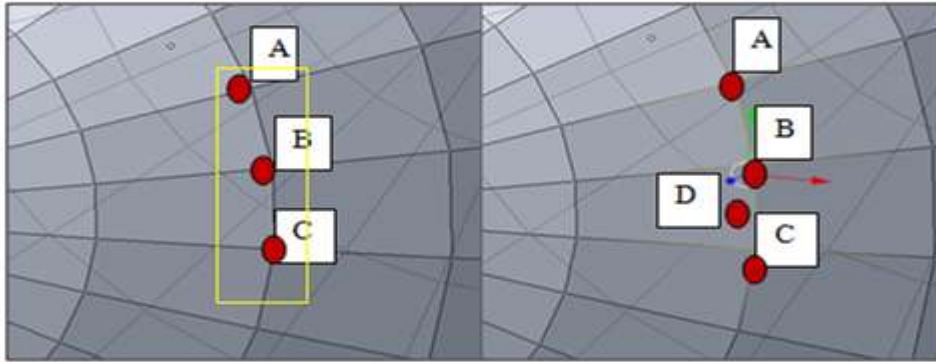


Figure 4.8: (left) Selecting a group of vertices, and (right) result after a group of vertices are selected using block selection

The third situation relating to the difficulty of selecting vertices is highlighted by one of the respondent who had to “*move around the model [navigate] in order to be sure that the correct component is selected*”. Figure 4.9 illustrates an example of this situation, where the vertices and edges of the front and back faces of the model are visible. Vertices A and B” look near each other when viewed from the direction in Figure 4.9 (left). In this example, several vertices are selected (shown in yellow), including vertices A and B. However, the status of vertex B because of its location on the back face cannot be identified easily. In this case the modeler may not be able to see whether vertex B has been selected correctly or not, when viewed from this particular orientation. In order to verify the status of the selection, the modeler would need to navigate around the model. Figure 4.9 (right) verifies that in this example, vertex B is actually selected. Although this technique of navigating in the 3D space can be used to verify the status of the selected vertices, it can also cause the modeler to lose their focus on the point of interest as they move around the model.

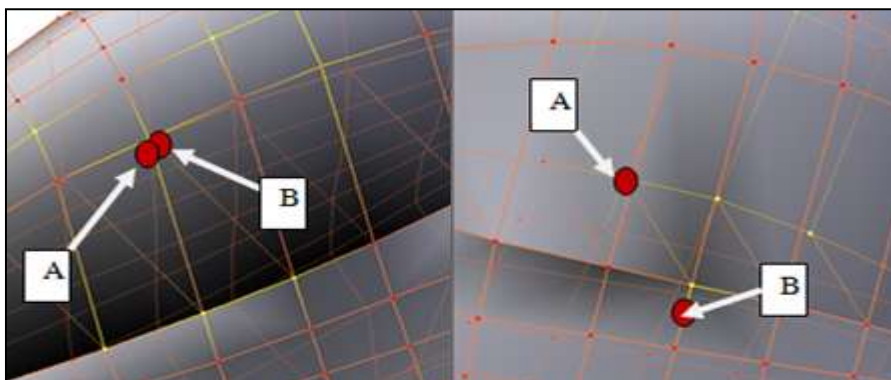


Figure 4.9: (left) Model and the selected components viewed from one perspective, and (right) viewed from another perspective

4.6.7 Aligning Objects of the Model

In Question 11 the respondents were asked to rate the difficulty level of aligning

objects, for example putting an object on top of another. The result, as shown in Figure 4.10, suggests that aligning objects is not an easy task. Three of the reasons given by the participants for the difficulty of aligning objects are discussed below.

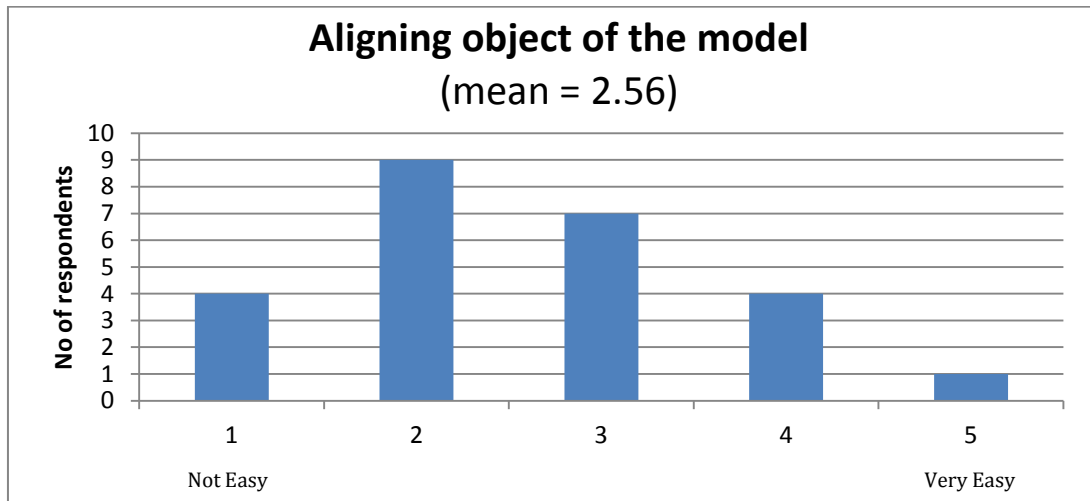


Figure 4.10: Responses to a Question 11

One of the respondent refers to a case where *“the objects were perfectly aligned but then [I] realized that they were completely wrong when the model was viewed in another viewport”*. Similarly another respondent gives an example of when *“in one viewport the objects looked nicely aligned, but they were not true when seeing from another viewport. So I realigned them again but then realized that they were wrong in another viewport”*.

These examples demonstrate that alignment of object requires modelers to navigate in the 3D space and view the objects using different viewports in order to validate the status of the aligned objects. Although multiple viewports are useful for providing modelers with different viewing orientation, having multiple viewports open reduces the size of the working area. Furthermore, using multiple viewports requires modelers to re-orient their focus back and forth between different viewports.

Another respondent points out that *“moving objects for aligning purpose often results [in] the objects being moved far away from the targeted location... it is confusing as you think that they are closed or aligned to each other”*

The case referred to by this respondent demonstrates the need for having a depth perspective while performing 3D modeling tasks. Without depth perspective, recognizing the distance between objects can be rather difficult. Figures 4.11 and 4.12 illustrate an example of an alignment process, and how the view provided by a

viewport can be misleading. In Figure 4.11 (left), both objects are clearly apart and not aligned with each other. When the objects are viewed using the side view, as shown in Figure 4.11 (right), the objects are again identified as being far apart from each other but at the same depth. When object A is dragged along the X axis and placed above object B, as shown in Figure 4.12 (left), object A looks to be aligned with object B. However, when the viewing orientation is again changed, as shown in Figure 4.12 (right), it is clear that the assumption that the objects have been aligned was wrong.

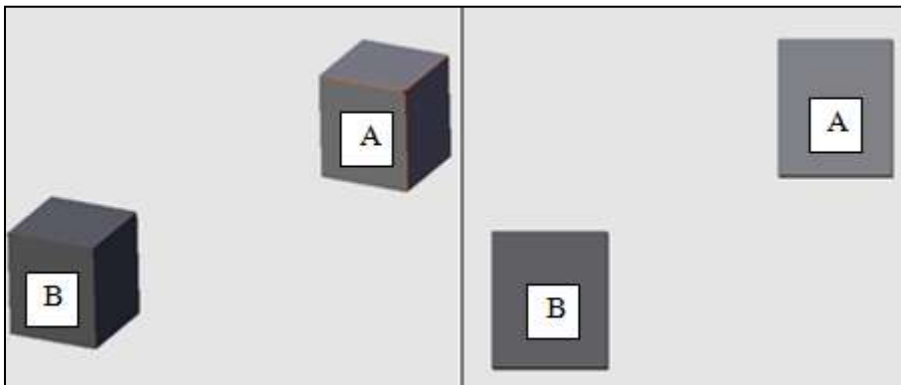


Figure 4.11: (left) Initial orientations of the two 3D objects, and (right) the objects are viewed from the side

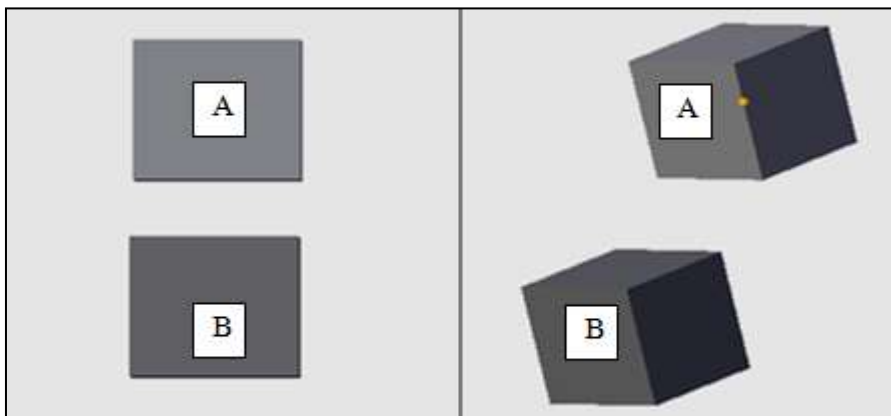


Figure 4.12: (left) Object A is dragged to the left to be aligned with object B, and (right) the viewing orientation is changed, showing that the objects are not aligned on all axis

4.6.8 Displaying Objects' Name on the Screen

Question 12 asked the participants to give their rating of the usefulness of displaying the name of the objects on the screen, as provide by some 3D modeling software. The general idea of displaying the name of the objects is to help modelers to know which objects they are working on, and enable them to identify the object of interest accurately. The results, as shown in Figure 4.13, suggests that displaying objects' name on the screen is not considered very useful by the respondents. The main reason

given by the respondents for these ratings is that displaying the object names would further clutter the 3D model.

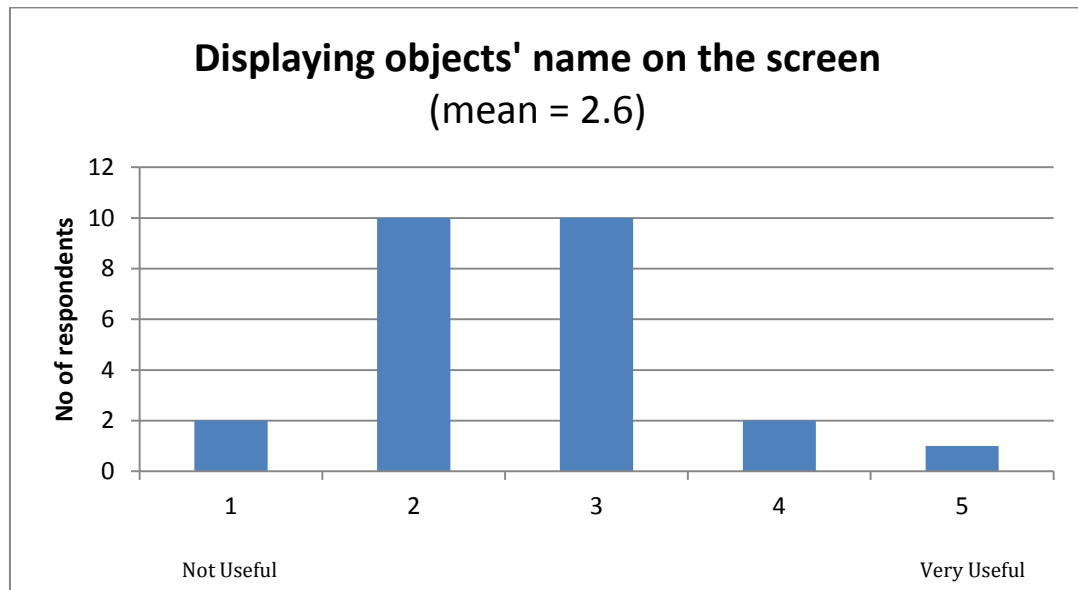


Figure 4.13: Responses to a Question 12

4.6.9 Understanding of Occlusion, Parallax Effect and Depth Perception

In Question 13, 14, and 15, respondents were asked about their understanding of the following three terms: occlusion, parallax effect and depth perception. For the first two terms, more than 90% of the participants had no understanding of the meanings of the terms. The third term, depth perspective, was not understood by 60% of the respondents. These reflect the respondents' lack of experience in 3D modeling tasks.

4.7 Discussion

The results of this pilot study demonstrated that most of the respondents faced a number of difficulties while performing their 3D modeling tasks. These difficulties may have contributed to the 60% of the respondents' inability to complete their 3D modeling tasks successfully. As novice modelers, any difficulties in the use of the software may have become an obstacle to performing their tasks and eventually degraded their performance.

Even though most of these novice modellers' experiences are based on Blender, as discussed earlier, Blender is a typical example of 3D modeling software. It provides reasonably similar functions to other 3D applications. Thus, the use of Blender should not have any distortive influence on the results of this study. Further analysis in relation to Blender and non-Blender users can be found in Chapter 7.

In general, the difficulties identified in this study can be divided into four categories:

1. Maintaining position awareness.

Respondents have highlighted that they sometimes get lost while performing their modeling tasks in the 3D space. This is evidenced from the participants' responses to Question 6, which shows that more than 85% of the participants rely on more than one viewport while performing their 3D modeling tasks. Further evidence is observed from the participants' responses to Question 7, where the rating of "viewing all" objects indicates that the ability to view all is important to the participant. This suggests that maintaining position awareness can be difficult when some of the information is not visible, which tends to happen as a result of navigation and manipulation. A high difficulty rating given to Question 8 also shows that the lack of information about the eye location is problematic, which further suggests that maintaining position awareness in the 3D space is indeed difficult.

2. Identifying and selecting objects or components of interest.

The participants' responses to Question 6, as described above, shows that multiple viewports are often used by the participants to guide them in identifying and selecting objects of interest. As discussed in Section 4.6.6, it was found that selecting a particular vertex or a group of vertices is a difficult process.

3. Recognizing the distance between objects or components.

As discussed in Section 4.6.2. in response to Question 5, 16 of the participants acknowledged that they had deleted their model and started over once or more times with new primitives object. As described by many of the participants, one of the reasons for this was that they had selected the vertex of the wrong side of the object when reshaping their model which ruined the shape their model. This problem can be avoided if the distance between components or objects is easily recognizable.

4. Realizing the relative position of objects or components.

Understanding objects' relative position is considered as a problem based

on the findings discussed in Section 4.6.7, which identifies that the task of aligning object is not an easy task. This mainly caused by the difficulty experienced by the modelers in identifying objects' relative position.

4.8 Summary

This chapter has described a pilot study that was conducted in order to better understand potential problems faced by 3D modelers. Although the findings of the study are more relevant to novice 3D modelers and may not always apply to 3D modelers in general, the study has shown some interesting results which need to be investigated further.

The next chapter presents a more comprehensive study of professional 3D modelers, which aims to better understand more specifically issues faced by them in terms of maintaining focus and context awareness when performing 3D modeling tasks.

CHAPTER 5

Study of Professional 3D Modelers

The previous chapter presented a pilot study conducted with novice 3D modelers. The results of this study showed that the participants often faced difficulties performing their modeling tasks. These problems were then summarized and divided into four categories:

- Maintaining position awareness.
- Identifying and selecting object or components of interest.
- Recognizing the distance between objects or components.
- Realizing the relative position of objects or components.

Due to the limited experience of novice 3D modeler in terms of dealing with complex modeling tasks, a more in-depth study of professional modelers was conducted. This study focused more specifically on the four categories of problems identified in the previous pilot study. These problems are all related to maintaining focus and context awareness in 3D modeling tasks.

The study discussed in this chapter was conducted with the approval of the Ethics Committee of the Faculty of Computing and Mathematical Sciences, University of Waikato. A copy of the approval letter is attached in Appendix C.

This chapter begins with an outline of the purpose of this study (Section 5.1), followed by a discussion of the methodology used for it (Section 5.2). Details of the study are then provided in terms of the interview questions used (Section 5.3), the study participants (Section 5.4), data collection and analysis (Section 5.5), and the findings (Section 5.6). The chapter concludes with a discussion (Section 5.7) and summary (Section 5.8).

5.1 Purpose of the Study

As mentioned earlier the aim of this study was to understand issues related to focus and context awareness particularly in terms of the four categories of problems identified during the pilot study presented in the previous chapters. To do this, the

study was conducted with professional 3D modelers who have more experience of working with complex 3D models in a range of areas.

The more specific questions that the study aimed to answer are:

- What preparatory tasks are undertaken by professional modelers prior to performing their modeling tasks?
- What techniques do modelers use to avoid focus and context awareness problems from taking place?
- Under what conditions do these problems occur?
- How do modelers attempt to solve these problems when they occur?

5.2 Methodology

This study consisted of a series of interviews, during which structured but open-ended questions were asked. Interviews provide an opportunity for getting more in-depth information from the participants. Furthermore, the use of open-ended questions during the interviews provided a better flexibility for adding or removing questions depending on the circumstances and feedback given by the participants, which often varied due to their modeling experience. Beside the interviews, the participants were also observed while performing 3D modeling tasks in their workplace. Some of the interview and observation sessions were video-taped, when permission was granted to do so. The duration of the sessions ranged from one to two hours.

During the interviews, images of 3D models relevant to the questions were shown to the participants. The images were used for illustrating modeling situations or scenarios which may involve focus and context awareness problems as identified in the previous pilot study. The images used in the interviews will be presented in related sections of this chapter.

In order to better understand the participants' explanation, they were also sometimes asked to demonstrate the relevant modeling issues using their own examples. These demonstrations included when and how the difficulties would normally occur and how they were resolved. In the course of these demonstrations, the participants were observed, questions were asked for clarification, and audio or video-recordings were made when permitted.

5.3 Interview Questions

As mentioned, the participants were interviewed using a set of open-ended questions. Some questions were omitted or modified depending on the participants' responses to previous questions. A summary of the interview questions is given in Table 5.1. The questions posed in the interviews are divided into four groups:

- Modeling experience (Questions 1 to 7)

The purpose of these questions was to learn about the participant's background in 3D modeling. These questions probed participant's level of experience with 3D modeling tasks and their software preferences.

- Methods of modeling and preparation (Questions 8 to 15)

The aim of these questions was to determine the participant's methods of modeling and preparation when undertaking 3D modeling tasks.

- Focus and context awareness problems (Question 16 to 28)

This set of questions focused on the main aim of the study, which was to identify the issues related to focus and context awareness problems faced by 3D modelers. These questions are divided into four categories identified earlier.

- a. Maintaining position awareness (Questions 16 to 21).

- b. Identifying and selecting objects or components of interest (Questions 22 to 23).

- c. Recognizing the distance between objects or components (Questions 24 and 25).

- d. Realizing the relative position of objects or components (Questions 26 to 28).

The participants were also prompted to highlight any other difficulties that they have previously experienced. For each difficulty that they identified, the participants were asked to explain in detail those situations that cause the problems to occur, and discuss how they overcome these problems using existing 3D modeling techniques provided by their conventional modeling software.

- Group projects and collaborative work (Questions 29 to 38)

The aim of these interview questions was to identify whether or not the four categories of problem mentioned earlier exist in the context of group projects, and if so, how such problems occur.

Table 5.1: Questions used during the structured, open-ended interviews

Modeling experiences

- Q1: Can you tell me a bit about yourself and your experience with 3D modeling?
Q2: What are the 3D modeling software that you commonly use to create 3D models?
Q3: What is one of the most challenging projects you've ever worked on?
Q4: What is the average time required to complete a project?
Q5: Do you do computer animation as well?
Q6: How much time (in percentage terms) do you spend on modeling or animation?
Q7: How do you compare the difficulty level of 3D modeling versus animation?

Method of modeling and preparation

- Q8: Do you recycle or reuse your own existing models for new models or do you always start from scratch?
Q9: Have you ever used or improved someone else's model?
Q10: If yes, what has been your experience when working with or improving someone else's model?
Q11: When you start a model, do you have everything clear in your mind or does it develop as you progress?
Q12: For other elements such as lights, textures, color, etc., do you have everything clear in your mind when you start a model or does it develop as you progress?
Q13: For texturing, do you generally draw your textures from scratch or do you start with existing textures or reference photos?
Q14: What is the most common type of viewport you use when performing 3D modeling tasks?
Q15: When editing objects, do you prefer to work in orthographic or perspective mode?

Focus and context awareness problem

Maintaining position awareness

- Q16: How do you maintain position awareness when navigating in the 3D modeling scene; that is do you know what object you are looking at and from which angle?
Q17: Have you encountered a situation in which you are not sure what object you are looking at and from which angle?
Q18: If yes, what caused it to happen and how did you resolve it?
Q19: When manipulating or transforming objects, what are the approaches that you take?
Q20: Have you encountered any situation or condition in which you have not been sure what you have done or the extent of manipulation that you applied to an object?
Q21: Have you had any experience of not knowing which side of an object you are looking at after manipulating or transforming the object?
-

Table 5.1: Continued from the previous page

Identifying and selecting objects or components of interest

Q22: How do you manage selecting objects, vertices, edges or faces of a model?

Q23: When editing a model (e.g. extruding, adding, deleting and grouping vertices, edges or faces) how do you make sure that you are selecting the correct component?

Q24: Have you encountered a situation in which you selected and edited the wrong object or component?

Recognizing the distance between objects or components

Q25: Do you have any difficulties recognizing the distance between front, internal or back parts of the model?

Q26: How do you verify which components are nearer to you?

Realizing the relative position of objects or components

Q27: For a single model, do you model several parts and then assemble them, or do you add patches to the edges of existing patches?

If several parts are modeled,

Q28: When assembling different parts, have you encountered any problems in realizing objects' relative position.

Q29: What are the methods that you use for assembling different parts?

Group projects and collaborative work

Q30: What types of models or scenes require you to work in groups?

Q31: When working in a group, how many team members are involved in a single project and how are they classified?

Q32: Based on your experience, how is collaboration managed?

Q33: For all members in the group, how are the scale and texture of different objects determined? Is it determined by an individual?

Q34: What is the most common problem faced by members when working in a group?

Q35: Is there an individual team member assigned to do the final arrangement of objects in a 3D scene?

If yes, Q36: Does that particular individual have any rights to amend or modify different objects?

Q37: Is the process of placing 3D objects and stitching undertaken by that particular individual?

Q38: What are the most common problems faced by that particular individual?

5.4 Participants

The target group of this study was professional 3D modelers in New Zealand. Open invitations were made by email to companies and individuals offering 3D modeling services. No preliminary filtering of the participants was undertaken in terms of software preference. However whenever possible, total years of working experience was taken into consideration before issuing invitations.

Out of 30 invitations, 13 agreed to be observed and interviewed. These participants were professional 3D modelers who worked in either a 3D modeling company or were free lance 3D modelers. The participants were mainly involved in the film or computer gaming industries.

Of the thirteen participants, 10 imposed a condition prior to the interviews that video-taping the sessions or viewing of the 3D models that they were working on was not allowed due to confidentiality or copyright issues. However, all the participants agreed to have their interviews audio-taped.

5.5 Data collection and analysis

While conducting the study, the main methods of data collection were audio and video recording. All the participants were audio recorded during their interviews, and when explanations were given while demonstrating their modeling tasks. However as stated above, 10 of the participants were not video-taped while demonstrating their 3D models. Beside these two methods of data collection, hand-written notes were also made during the study. The length of the audio recording varied depending on the time taken to demonstrate modeling tasks, and the actual interviews.

Analysis of the recorded data involved listening to the audio recordings, watching the video, transcribing the conversations, taking notes of any noteworthy observations, and looking at the hand-written notes. The length of the transcription for each interview is given in Table 5.2.

Table 5.2: Summary of the audio recording for each interview session

Participant No.	Audio Length (mm:ss)	Transcription Word Count
1	37:31	2427
2	45:47	3432
3	31:10	1455
4	41:38	3542
5	28:46	2321
6	29:31	1976
7	35:41	2872
8	31:24	1987
9	32:48	1876
10	46:16	2982
11	49:38	3102
12	29:42	1987
13	43:31	2582

5.6 Findings

In the following sections, findings from the interviews and observations are discussed in depth. The results are categorized according to the four groups of questions mentioned earlier: modeling experience, methods of modeling and preparation, focus and context awareness, group projects and collaborative work.

5.6.1 Modeling Experience

In this part of the interviews, the study participants were asked about their level of experience in 3D modeling and the use of modeling software that they were familiar with. A summary of the participants' replies to these questions is given in Table 5.3. As can be seen, 85% of the participants had five years or more of 3D modeling experience. In terms of the use of 3D modeling software, MAYA and 3D Studio Max were the two most commonly used 3D modeling software. Even though the interfaces of these two software are different, their functionalities are very similar. Hence the differences, advantages and disadvantages of the individual 3D modeling software are not considered in terms of the analysis of the results of the study.

Table 5.3: Responses to questions 1 and 2

Participant No.	Years of Experience	3D Modeling Software Used
1	2 yrs	MAYA, Blender, 3D Studio Max
2	7 yrs	MAYA, 3D Studio Max
3	8 yrs	MAYA
4	11 yrs	MAYA, ZBrush
5	6 yrs	MAYA, 3D Studio Max, Zbrush, Blender
6	5 yrs	MAYA
7	5 yrs	MAYA, 3D Studio Max, Blender
8	10 yrs	MAYA, Zbrush
9	5 yrs	MAYA, 3D Studio Max, Lightwave, Zbrush
10	6 yrs	MAYA, 3D Studio Max
11	4 yrs	MAYA, 3D Studio Max
12	8 yrs	MAYA, 3D Studio Max, Soft Image
13	5 yrs	MAYA, 3D Studio Max, Zbrush

In Question 3, the participants were asked to describe the most challenging project they had worked on. Based on the participants' responses it is clear that 3D modeling tasks can be divided into two categories. The first category is referred to as “a well planned and structured 3D modeling” where the expected finished 3D model is well-defined. The second category is an “ad hoc type of modeling” where the target output is not well-defined. Majority of the participants (9 of them) noted that working on the second type of modeling tasks is often the most challenging type of projects. Three situations in which working on ad hoc modeling tasks can be problematic are highlighted by the participants, and are discussed below.

The first situation is highlighted by one of the participants, who points out that “[I] have created a 3D logo for a company... however the client [company] does not provide a sample of how the finished product should look like. Therefore I have to create a logo without a proper reference or guideline. It is even worse than that, the client often requests for changes or improvement”.

The second situation is very similar to the one mentioned above. One of the participants pointed out that *“interpreting someone else’s idea where the client did not have specific target on what they want is a very difficult process”*. The third situation which supports the above statements is that *“converting a mascot’s 2D images into 3D model where the client can freely access or view the product for comment and further improvements have caused him a lot of difficulty of completing the project”*.

These comments suggest that modelers’ tasks would be easier if they have something to refer to when creating their models. As noted by a few of the participants a reference can give them a good guideline towards achieving their modeling goal. Question 4 asked the participants to estimate the average time modelers usually take to complete their 3D modeling tasks. The aim of this question was to estimate the complexity of the projects the study participants work on. Clearly the time taken to complete a project varies between 3D modeling tasks, and each task may take a few days to a few months, depending on the size and the complexity of the project. Of the 13 participants, 8 of them noted that they have been involved in 3D modeling tasks that taken between one to three months to complete.

In Question 5, the participants were asked whether they do computer animation as well as 3D modeling. Of the 13 participants, 9 of them work on computer animation as well. In the related Question 6, those who did computer animation were asked to estimate how much time (in percentage) they spend on each of the modeling and animation tasks. Seven of the respondents said that they spend more than 50% of their time on modeling, while the other 2 participants said that they spend more than 50% of their time on animations. In answer to Question 7 where they were asked to rank the difficulty level of modeling versus animation tasks, 6 of the participants ranked the modeling task as being more difficult than animation, while 3 suggested that animation was more difficult than modeling.

5.6.2 Methods of Modeling and Preparation

Table 5.4: Methods of modeling and preparation

Participant No.	Reusing model from scratch	Experience of someone else's model	of using	Design is clear from beginning or develops gradually
1	Both	Yes	Easy	Clear from beginning
2	Scratch	No		Clear from beginning
3	Both	Yes	Easy	Clear from beginning
4	Both	Yes	Easy	Clear from beginning
5	Scratch	Yes	Difficult	Develops gradually
6	Scratch	No		Clear from beginning
7	Scratch	No		Clear from beginning
8	Scratch	Yes	Difficult	Clear from beginning
9	Both	Yes	Difficult	Clear from beginning
10	Scratch	No		Clear from beginning
11	Both	Yes	Easy	Clear from beginning
12	Scratch	No		Clear from beginning
13	Scratch	Yes	Difficult	Clear from beginning

In terms of the methods of modeling and preparation, the participants were asked in Question 8 whether they recycle existing 3D models. As shown in Table 5.4, 8 (62%) of the participants preferred to create their 3D models from scratch instead of recycling existing models. As mentioned by one of the participants, breach of copyrights was a key reason why existing models were not recycled. The uniqueness of a model was another reason why recycling existing models was not favored by the study participants. However, the participants said that whenever possible, using existing models they could reduce their work by 50%.

Question 9 asked the participants whether they have ever worked on, or improved, someone else's model. Eight of the participants noted that they have used someone else's model. Of these eight, four described recycling someone else's model as being both easy and practical, while the other four claimed that further enhancement to someone else's model was a difficult task. These four participants, not in favor of

using someone else's model, claimed that they normally did not have enough information, such as the overall structure of the model, when using this method. They also claimed that often some of the components of the model would be missing due to compatibility problems with the 3D modeling software originally used to create the model.

In response to Question 11, as shown in Table 5.4, 12 (92%) of the participants said that they prefer to do their modeling when they have everything clear in their mind. Most of them prefer to work in the environment where references such as blueprints or sketches are available to them to refer to. As mentioned by a few of the participants, a well-defined output or reference is very useful for guiding them towards their goal. Without any reference material, the participants claimed that they were not able to determine whether they were in the right track or not.

The same number of participant (12) also prefer to have other elements such as lights, textures, and colors well defined before they start their modeling tasks (Question 12). In a related question (Question 13), 8 (62%) of the participants said that they generally draw the textures from scratch rather using existing textures.

In Question 14, the participants were asked about the type of viewports that they most commonly open while performing 3D modeling tasks. Eight of the participants said that they prefer to perform their tasks using an orthographic view. Three of the participants preferred a perspective view, while the other two noted that they often did their modeling tasks in both orthographic and perspective views.

Similar responses were obtained from the participants when they were asked in Question 15 to describe their viewing preference when editing objects. In the edit mode, 9 of the participants preferred to work in orthographic view, 2 preferred perspective view, and the other 2 preferred to use a combination of both orthographic and perspective views.

5.6.3 Focus and Context Awareness Problems

It is important to note that before interviewing the study participants about the kinds of focus and context awareness problem they may have faced in their modeling tasks, the participants were given a detailed explanation of what is meant by focus and context awareness. This was necessary because the participants were generally

unaware of the relationship between focus and context awareness and 3D modeling tasks. Based on these detailed explanations and examples given to them, the participants were able to relate their modeling experiences to the four categories of focus and context awareness problems that this study aimed to investigate.

Table 5.5: Summary of whether the study participants face focus and context awareness when performing 3D modeling tasks

Participant No.	Maintaining position awareness	Identifying selecting component	and objects of	Recognizing distance between objects components	the or position of objects or components
1	Yes	Yes		Yes	Yes
2	Yes	Yes		Yes	Yes
3	Yes	Yes		Yes	Yes
4	Yes	Yes		Yes	No
5	Yes	Yes		Yes	No
6	Yes	Yes		Yes	Yes
7	Yes	Yes		Yes	Yes
8	Yes	No		Yes	Yes
9	No	No		Yes	No
10	Yes	Yes		Yes	Yes
11	Yes	Yes		Yes	Yes
12	No	No		No	Yes
13	Yes	No		Yes	No

Table 5.5 provides a summary of the participants' responses indicating whether or not they faced such difficulties while performing 3D modeling tasks. Detailed explanations of issues related to these categories are provided in the following sections.

5.6.3.1 Maintaining Position Awareness

Regarding the issue of maintaining position awareness while performing 3D modeling tasks, the participants were asked in Question 16 to discuss how they know what objects they are looking at, and from which angle the objects are being viewed when navigating in a 3D scene. Eleven (84%) of the participants said that they relied on extra viewports to display multiple viewing angles of objects to guide them during the navigation process. The other two participants, however, relied on reference drawings or sketches of objects instead of opening extra viewports. These two pointed out that opening extra viewports reduced the size of their screen workspace.

Question 17 asked the participants whether they have experienced any difficulties recognizing the orientation of objects in 3D scenes. Once again, 11 of the participants acknowledged that they often fail to recognize the orientation of objects, particularly in wireframe mode. When asked in Question 18 to describe solutions to this particular problem when it occurs, the participants said that they often rely on one of three different solutions to this problem. The first solution is to look at the objects in other viewports or printed reference material. The second solution is to zoom out of the scene being viewed, and the final solution is to change the mode of the objects being displayed (e.g. the mode is changed from wireframe to solid).

A very similar pattern is also observed during the manipulation process. In questions 19, 20, and 21, the participants were asked about the approaches they take during the manipulation process, and whether they have encountered any problems realizing the extent of their manipulation, or recognizing objects' position and orientation as the result of manipulation. In response to Question 19, 11 (84%) of the participants stated that they rely on extra viewports to guide the manipulation process. For both Question 20 and 21, the same number of participants claimed that they had sometimes experienced problems understanding what they have done during the manipulation process, as well as not recognizing objects' position and orientation.

Figure 5.1 illustrates the difficulty that modelers may have faced when navigating in a 3D space. In this example, a 3D car model (Figure 5.1a) is shown in a wireframe mode. From this viewing angle, the viewer should be able to identify the orientation of the displayed model. However, when navigating, the model may be seen in a different orientation as illustrated in Figure 5.1b. In this case, due to the overlapping

edges, it would be difficult to recognize the orientation of the car. In Figure 5.1c the display mode is changed from wireframe to solid, thereby, rectifying this confusion and making it clear that the model in Figure 5.1b is being viewed from underneath.

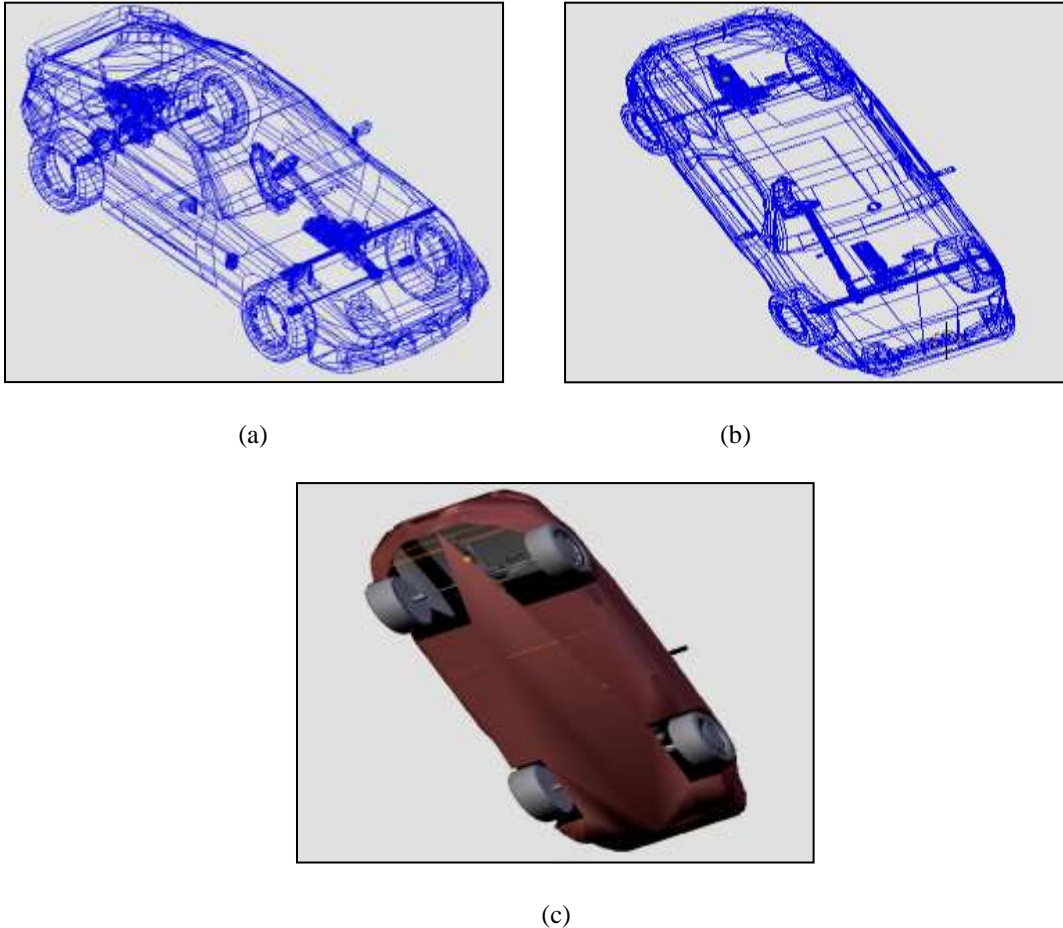


Figure 5.1: An example of navigation and model orientation problem

In this example, although the wireframe mode aids with displaying all the objects comprising the model, it creates a problem in terms of showing the orientation of the model. Although changing the display mode to solid would solve this problem, switching from one mode to another may also cause the viewers to lose their focus on the region of interest as displayed in the wireframe mode.

A common solution for maintaining position awareness, as pointed out by a few of the participants, is to open a second viewport in which the model is continuously shown in solid mode. Figure 5.2 illustrates the benefit of using multiple viewports while performing modeling tasks. Figure 5.2 (left) shows the orientation of the model before navigation. In this figure, a solid model is shown in the right viewport to give the modeler a better perspective view. Figure 5.2 (right) on the other hand, shows the orientation of the model after the navigation process. The differences between these

two orientations are not so noticeable in the wireframe views. However, a solid model (shown on the right for each case) provides a better perspective of the model's orientation. The two key limitations of this approach (i.e. opening another viewport) are decreasing the size of the working area, and requiring the modeler to change their focus back and forth between one viewport and another.

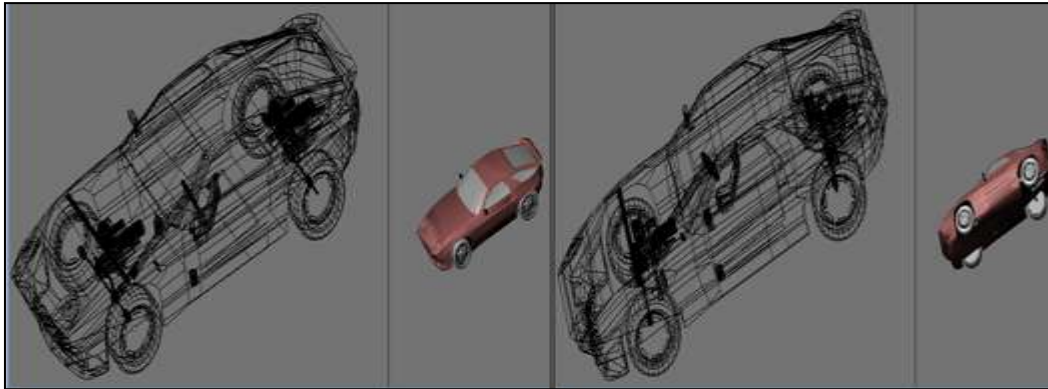


Figure 5.2: (left) Orientation of the model prior to navigation, and (right) after navigation

Furthermore, in most existing 3D modeling software there is no link between multiple viewports. This means that the orientation of the model being viewed in two viewports will not remain the same when navigation is performed in one of the viewports. One of the ways of achieving the linked display effect, as shown in Figure 5.2 , where wireframe and solid objects are viewed from the same orientation, is by splitting a single viewport into two. When a viewport is split, the orientation of the model in the newly created viewport is the duplicate of the original viewport..

However, in some cases displaying the model in solid and wireframe modes may not solve the problem of focus and context awareness during navigation and manipulation. For instance, the problem would persist when the selected objects are internal components of the model and cannot be seen in the solid mode. For example, Figure 5.3 shows the two front seats of the model of a car that are internal components. In this case the seats will not be visible when the car is viewed in solid mode, as shown in the two right viewports.

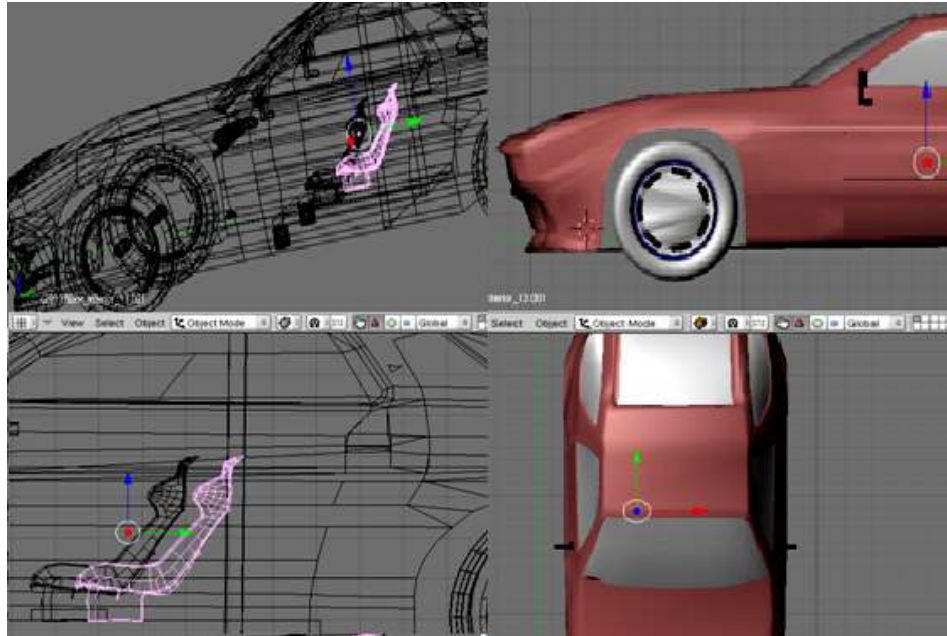


Figure 5.3: Multiple viewports opened simultaneously, showing wireframe and solid views of a car

It should also be noted that although two of the participants claimed that they did not experience any difficulties maintaining their focus and context awareness during the navigation process, they mentioned that they often refer to sketches when such an ambiguity occurs. However, this method of changing eye focus from a display device to sketches is actually similar to the process of changing eye focus from one viewport to another. Both methods have the same consequence whereby modelers may lose their focus and context awareness. In fact looking at sketches is actually worse, since the model and sketches are not even in the same space (i.e. screen and paper). So, it is reasonable to say that all the study participants have experienced some difficulties in terms of maintaining their focus and context awareness during the navigation and manipulation processes of their 3D modeling tasks.

5.6.3.2 Identifying and Selecting Objects or Components of Interest

Selecting objects or components of interest in a 3D space requires the modeler to identify the object or component precisely. However, due to overlapping objects and components, this task is often a tedious process. In relation to this issue, the participants were asked to describe how they manage selection of objects and components of 3D models (Question 22), how they make sure that they are selecting the correct one (Question 23), and whether they have encountered any problems when performing this type of tasks (Question 24). In response to these three related questions, 10 (77%) of the participants mentioned that they have encountered

problems when performing such an operation. Findings show that the participants rely on several methods for managing the object or component selection process.

One of the participants mentioned that he *“often uses a hiding technique to reduce the number of objects being displayed”*. This technique reduces the amount of information being displayed, and improves the visibility of the object or component of interest. In addition to this, the participants mentioned that they also perform navigation, zooming in and out, and doing some trial and error to determine the status of the selected objects or components. For instance, one of the participants mentioned that *“during a selection process, combination of techniques are used to help reduce the wrong selection being made by rotating or navigating around the objects”*. Another participant noted that he relies on multiple viewports to assist him with selecting correct objects or component of interest.

To investigate this issue further, the participants were asked to look at a model (as shown in Figure 5.4) and to identify the location of the selected tyre. In this figure, the left rear tyre of the 3D car model is selected. All the participants were able to identify the location of the selected tyre correctly without the aid of other tools such as using a second viewport or displaying the model in solid mode.

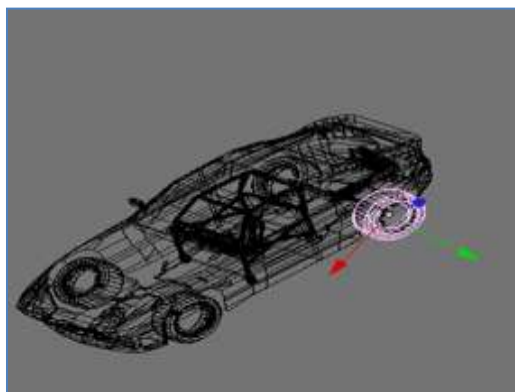


Figure 5.4: Initial view of a model in which the left rear tyre is selected

The participants were then presented with a slightly rotated image of the same model in wireframe mode, as shown in Figure 5.5. The participants were asked to identify whether the selected tyre was the rear left or right tyre. More than 80% of participants gave the wrong answer to this question. This is because they were tricked by the orientation of the model, believing that the selected object was the rear right tyre instead of the rear left.

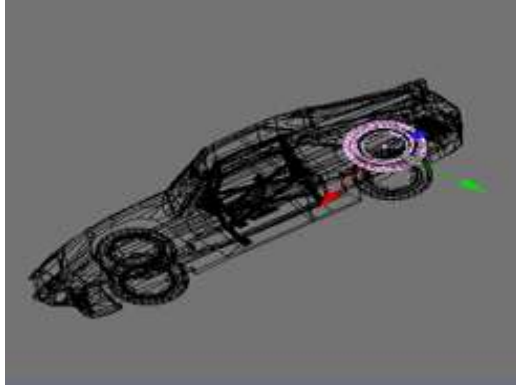


Figure 5.5: Rotated view of the model shown in wireframe mode

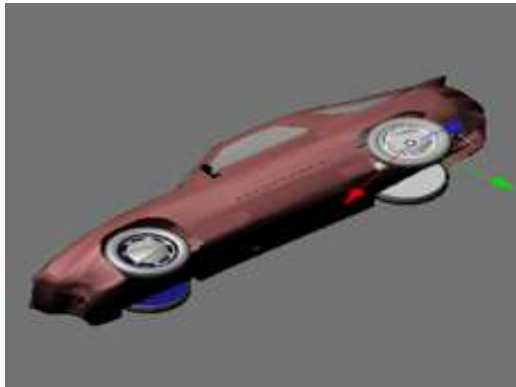


Figure 5.6: Rotated view of the model shown in solid mode

However, when the model was shown in solid mode (Figure 5.6), the participants were able to correct their mistake. This demonstrates that having multiple viewports and displaying a model in different mode can help the viewer to more easily recognize the orientation of the model after a manipulation process.

Unfortunately this is not always the case though, as demonstrated by another example, in which the entire car is rotated even further, as shown in Figure 5.7. Both solid and wireframe modes are available at the same time, and are viewed from the same angle. When the participants were asked to guess the actual location of the selected tyre (i.e. right or left) in this example, they admitted that they found it difficult to identify the location of the selected tyre even with the support of the solid model.

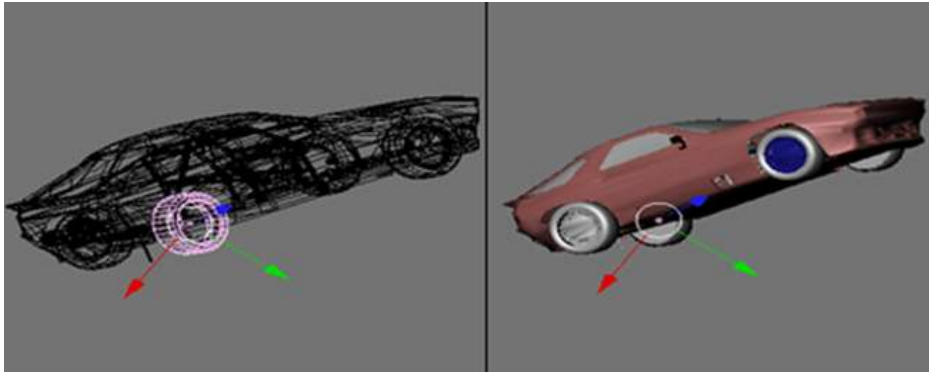


Figure 5.7: Model of the car after further rotation

In this second test, more than 80% of the participants gave the wrong answer because they were tricked into believing that the selected tyre was the rear right tyre instead of rear left tyre. This confusion is caused by the fact that the selected object is highlighted and looks closer to the viewer. The participants were also rather confused when comparing the wireframe and solid views of the model which seemed to contradict each other. As demonstrated by this example, having more than one viewport and displaying a model in both solid and wireframe is not always useful.

5.6.3.3 Recognizing the Distance Between Objects or Components

The participants were asked whether they had any difficulties recognizing the distance between components or objects of a model (Question 25), and how they would verify which components are nearer to them (Question 26). Twelve (92%) of the participants admitted that they sometimes find it difficult to recognize the distance between components or objects. Due to this difficulty, they often select the wrong component, and this causes them to either repeat or perform unnecessary steps to correct their mistakes, which should be avoidable from the outset. The participants also pointed out that they rely on various techniques to assist them with solving their mistakes. These techniques include zooming, moving around the objects (navigation), opening multiple orthographic viewports, changing the model editing mode from wireframe to solid, and using back surface removal. The technique of back surface removal is effective for reducing the amount of information being displayed, but it removes the components of the rear or far side of the selected object, and consequently, the relationship between near and far components is lost (see Section 3.6.2.5 for details).



Figure 5.8: The model of a car: (left) without back surface removal and (right) with back surface removal

5.6.3.4 Realizing the Relative Position of Objects or Components

Question 27 asked the participants about their preferred style of modeling, and whether they prefer to create a model as a single object or to model individual objects separately and then combine them together. Almost all of the participants (12 out of 13) said that they prefer to create individual objects separately and then assemble them together into a single model. The aim of this question was to identify any problems encountered during the process of assembling objects.

In response to Question 28, 8 of the 12 participants considered the process of assembling different objects together to be a difficult process, during which they encounter some problems. In an example similar to the one mentioned in the Chapter 4, one of the participants referred to a case where *“the objects were perfectly aligned when viewed in a certain orientation but then realized that they were completely wrong when they were viewed in another viewport”*.

In another case, a participant stated that he often needs to *“realign the objects because their relative position cannot be determined easily in wireframe mode”*. A wireframe displaying mode is usually used when the objects are being manipulated on an internal part of the model.

In Question 29, the participants were asked to describe the methods that they use to reduce the difficulty of recognizing objects' relative position when assembling them. Their responses showed that more than 90% of them rely on multiple viewports in one way or another to ease their tasks when assembling objects.

5.6.4 Group project or collaborative work

The participants were also asked to share their experiences relating to group projects or collaborative type of work (questions 30 to 38). The purpose of these questions was

to find out any problems which may occur specifically in this type of collaborative work, that may not be related to performing modeling tasks in a single user environment.

In response to Question 30, the participants generally agreed that the size of the project and the quality of 3D models required are often the main reasons for working in a team. The number of team members varies depending on the scope of the project, and may range from 2 to 20 members. It was also noted by one of the participants that the completion time may influence the size of the team, with larger teams needed when the project has to be completed in a short period of time. In response to Question 32 on how to manage team work, the participants said that they generally believe good communication and well structured and organized teams with disciplined members are important for success of a project.

One of the participants noted that teamwork requires members of the team to strictly follow the “entire project’ schedule and timeline”. She also acknowledged that a “proper pipeline must be well-defined that communication breakdown between team members can be avoided”. A similar point was mentioned by another participant who stated that “cooperation and good communication are very essential, or else the project might fail”.

In a related question (Question 33), all the participants who had experienced group work noted that there is often no single individual who decides on the scale or textures of the model. Any proposals or ideas are generally discussed and agreed by the team members.

In Question 34, the participants were asked to describe some of the most common problems when working in a group. Several cases were identified during the interviews in response to this question. A case was highlighted by one of the participants who pointed out that he often faces “both human (e.g. communication) and technical problems” when working in a group. A similar point was mentioned by another participant who claimed that “bad communication may cause a duplicate task or job not being done at all”. He further explained that “different visual preferences among project members have also caused an unexpected outcome that increases the cost”. The same concern was stated by another participant “for a group project, arguments are always happening because some people cannot agree with someone

else's ideas". These clearly show that good communication plays an important role in managing group projects.

The results of the interviews in response to Question 35 show that usually an individual team member is assigned the task of the final arrangement of objects in a model or scene. However all the participants pointed out in response to Question 36, that this particular individual usually has no right to modify or amend the objects. The task of improving the objects is undertaken by the owner or creator of the object. The objective of this question was to understand the difficulties (if any) that were faced by an individual when modifying someone else's model.

Furthermore, in a related question (Question 37), all the participants stated that the individual responsible for assembling the final scene performs the task of placing the 3D objects at their designated locations in the 3D space. While performing this task, the individual involved often faces problems caused by the quality of the 3D models failing to meet the scale or standard of the project. For instance one participant highlighted that the difficulty of placing objects at the designated area occurs "if any of the submitted or completed models do not follow the measure (scale) specified at a very early stage of the development". Similarly another participant mentioned that "a problem happens when a finished product placed in the library does not meet the specified standard such as the scale is not been followed by modeler".

Study participants also noted that they often experience some difficulties in placing individual objects in a 3D space due to the problem of recognizing the relative position of objects as discussed earlier.

5.7 Discussion

The results of this study have further highlighted and clarified issues related to the four categories of problem associated with maintaining focus and context awareness in 3D modeling tasks, as identified in the pilot study of Chapter 4. These issues are summarized as below.

1. Maintaining position awareness.

This category of problems refers to modelers' difficulty in maintaining awareness of the position and orientation of objects of a model when performing manipulation and navigation tasks. Findings from the study

show that modelers often rely on techniques such as opening multiple viewports, hiding, and changing model display mode to solid or wireframe when performing these tasks. These techniques enable modelers to maintain their understanding of context and recognize what they are looking at in terms of their focus. However, none of these techniques is able to fully support maintaining position awareness. For instance when using multiple viewports, the area of focus and context are separated, which requires modelers to switch their attention from one viewport to another. In addition to this problem of discontinuity, the objects being viewed in each viewport are often displayed in different zooming scale or from different viewing orientation. These two problems occur because in most 3D modeling software viewports are treated independently of each other. Furthermore, using multiple viewports also divides screen real estate into a series of smaller section which reduces the amount of information that can be displayed in each of them and condenses the size of the graphical data (i.e. model) on the screen. Consequently, modeling tasks tend to become more complicated because the objects and components of the model overlap each other even more.

2. Identifying and selecting object or components of interest.

This category of problems refers to situations where modelers face some difficulties in selecting objects or components of interest correctly. As discussed earlier, overlapping objects and components is a factor that causes this type of problems to occur. In a cluttered 3D model viewing situation, modelers have to rely on different techniques such as hiding to overcome this problem. The hiding technique reduces the amount of clutter and therefore increases the accuracy of selecting objects or components of interest. However, the hiding technique tends to eliminate modelers' ability to maintain their awareness of the relationship between the objects or components of interest with the others (i.e. context). As a result, modeling tasks which are constrained by these hidden objects can become difficult. Therefore the hiding on its own is not very effective in facilitating focus and context awareness while performing 3D modeling

tasks.

3. Recognizing the distance between objects or components.

This third category of problems relate to recognizing the location of objects or components in a virtual 3D modeling space. It includes the difficulty of recognizing the near and far objects or components. This type of problem often takes place when models are displayed in the wireframe mode. As discussed earlier, modelers often use multiple viewports to overcome this problem by viewing objects or components of interest from different angles or orientations. This reliance on multiple viewports, however, leads to break down of focus and context awareness as discussed before. The discontinuity of information between multiple viewports distracts modelers' attention from objects or components of interest. This forces modelers to take other extra steps to regain their focus.

4. Realizing the relative position of objects or components.

This category of problem is related to the difficulty of placing or aligning objects in a virtual 3D space. Findings of the study, as discussed earlier, indicate that modelers often have difficulties in performing this type of tasks using conventional 3D modeling software. The study showed that modelers usually need to view the model being manipulated from various angles (e.g. as top, side, and front) in multiple viewports. This, once again, leads to problems associated with relying on multiple viewports.

5.8 Summary

This chapter has presented an interview type study of professional 3D modeler, with the aim of better understanding issue related to the four categories of problems caused by the lack of focus and context awareness in 3D modeling tasks. Findings from this study suggest that modelers often rely on using multiple viewports and hiding techniques to deal with these problems. It is however also clear from the study that these techniques are not sufficient on their own, and that other new tools and techniques are needed. The next chapter introduces a new set of techniques designed to assist with maintaining focus and context awareness in 3D modeling environments.

CHAPTER 6

Design and Implementation of a Set of Focus and Context Awareness Techniques

Review of the existing literature, technologies and techniques, as well as the studies conducted as a part of the thesis with novice and professional modelers, have demonstrated that even with the support of the latest modeling software, creating 3D models remains a difficult task. The difficulties are not only caused by the complexity of the models being created but also by the ineffectiveness of input and output devices, and existing software in helping 3D modelers to maintain their focus and context awareness while performing their modeling tasks. As discussed in the previous chapter, most modelers face four key difficulties while performing 3D modeling tasks:

- Maintaining position awareness
- Identifying and selecting objects or components of interest
- Recognizing the distance between objects or components
- Realizing the relative position of objects or components

In order to address these problems, a set of focus and context awareness techniques have been developed.

This chapter begins with a summary of existing software tools for exposing internal objects or components of 3D models (Section 6.1). This is followed by a discussion of the hardware and software technology used for the development of the focus and context awareness technique as part of this thesis. Sections 6.3 to 6.7 introduce the five focus and context awareness techniques that have been developed (i.e. object isolation, component segregation, peeling focus, slicing, and peeling focus and context). Section 6.8 elaborates on some the technical issues addressed during the development of these techniques. The chapter concludes with summary in Section 6.9.

6.1 Current Methods of Exposing Internal Objects or Components

In most 3D modeling situations, some of the objects or components of a model may be obscured from the viewer depending on the position of the model and the orientation from which it is being viewed. For this reason, understanding the relationship between objects, such as their relative position to one another, can often be difficult. Most modeling software provide a number of tools to assist modelers with viewing objects regardless of their position in the model. Among the techniques that are available for this purpose are hiding, zooming in perspective mode, and viewing the model in wireframe mode. These techniques are briefly reviewed below.

- **Hiding**

As discussed in Chapter 3, hiding is a popular technique used by modelers when they are trying to view or locate objects that are hidden or obscured by other objects. Using this technique allows the selected object(s) to be removed temporarily from the viewport to reveal other objects obscured by them. The major advantage of this technique is that the shapes of the objects are not distorted, and their sizes remain the same. However, when one or more objects are hidden, the overall context of the model is no longer visible. Hiding an object temporarily removes the relationship between that objects and the rest of the model. Therefore, this technique generally fails to provide continuous support for maintaining focus and context awareness.

- **Zooming in perspective mode**

The zooming technique in perspective mode also allows modelers to see objects hidden behind other objects. However, this technique changes the visual size of the objects, distorts the appearances of the model, and removes some parts of the model from the viewport as the object of interest gets closer to the focus region. As a result, some information that is relevant to the modeling task being done may no longer be visible. As with the hiding technique, zooming does not provide continuous support for displaying the relationship between the objects of interest (i.e. focus) and the rest of the model (i.e. context).

- **Displaying the model in wireframe mode**

Although displaying a model in wireframe mode does not distort or remove

any parts of the model being displayed, it can, however, result in a clutter of information in the viewport. In this mode, the skin of the model is removed to reveal all its internal objects and components, making the viewport overcrowded with visual information. Because of this, tasks such as distinguishing distance between near and far components or objects can become difficult in wireframe mode.

Another useful technique, which is not generally provided by most 3D modeling software, is the cutaway technique. Cutaway is a technique which allows users to penetrate layers of skin in order to see the internal objects of a model. This technique has, for instance, been used in the medical field for studying the internal organs of 3D human models (Viola, et al. 2005). Figure 6.1 shows an example of the cutaway technique. The left most image shows a 3D model of a human body prior to the cutaway technique being used, while the middle and right-most images show two stages of the technique in progress.



Figure 6.1: Using the cutaway technique

Cutaway techniques have been implemented in three interactive modes. The first is where the cutting is done interactively based on a location specified by a user (Bruyns et al., 2002). The second is through automatic cutting such that the shape of the cutout is dictated automatically by the placement of the objects of interest in the scene (Diepstraten et al., 2003). The third which has been developed by Li et al. (2007) is based on the hierarchy of the objects of a model. These three cutaway techniques, however, have been used mainly for visualization of models and not in 3D modeling software. As such, they have only been used for viewing 3D models in solid mode and not in wireframe mode. The cutaway technique also suffers from the problem of removing parts of the model, which is similar to hiding and zooming techniques, in its lack of support for maintaining focus and context awareness.

6.2 Design of a Set of Focus and Context Awareness Techniques

The techniques provided by conventional 3D modeling software, as discussed in the previous section, fail to provide a continuous support for awareness of the relationship between the objects of interest and the rest of the model. The hiding technique temporarily removes the relationship between different objects of a model, and therefore also hides overall context of the model. Displaying a model in the wireframe mode, on the other hand, results in a clutter of information in the viewport, causing tasks such as distinguishing distance between near and far components or objects to become difficult. Zooming in perspective mode distorts the appearances of the model, and removes some parts of the model from the viewport, which in turn result in the relevant information to the modeling task becoming no longer visible.

Although the use of multiple viewports along with these techniques provides modelers with some support, the use of multiple viewports causes the working area in each viewport to become smaller, and the separation of information into multiple viewports causes information discontinuity which requires the user to constantly switch their attention between the detail and overview viewports.

A potential solution to the problem of multiple viewports is to overlay information being displayed on different viewports in a single viewport. As discussed in Chapter 3, the Alpha Blending technique offers some possibilities toward achieving the goal of overlaying focus and context information. The Alpha Blending technique overlays the information of different windows by adopting the concept of semitransparent layers that can be superimposed to allow the contents of the windows to be viewed simultaneously on top of each other in the same window. Baudish and Gutwin (2004) have, however, identified a major problem with the alpha blending technique. The problem is that viewers of information being displayed on a windows generated using alpha blending often have difficulty in identifying the actual location of the information on different layers. This show that the Alpha Blending technique causes visual ambiguity which can be problematic when applied to 3D modeling tasks.

6.2.1 Hardware Platform

Due to the visual ambiguity problem associated with the Alpha Blending technique, the MLD hardware display technology was adopted as a suitable platform for the development of the new focus and context awareness techniques in this thesis. As previously mentioned (see Chapter 2), MLD hardware consists of two physically separated front and back display layers. The transparency of the front layer makes the task of viewing the information on the back layer possible. This physical separation and transparency of the two layers not only enables the contents of the two layers to be viewed simultaneously but also provides a physical gap between them that creates a sense of depth perspective. In addition to these features, MLD also enables dual layer images to be transformed and manipulated simultaneously. This is important because users can view the object of interest and the rest of the model from the same orientation at all times during the navigation and manipulation process.

Findings from a number of studies, as previously discussed in Chapter 3, indicate that the two physically separated display panels of MLD can be useful in separating overlapping information. In addition, MLD also supports the effect of motion parallax, where what is displayed on the front layer moves relative to what is displayed on the back layer when a viewer moves their head (Prema et al., 2006).

Furthermore, as highlighted by Wong et al. (2005), MLD allows users to conveniently switch their attention between the information presented at different depth planes within the same visual field of view, reducing the strain on their working memory. It affords a viewer the ability to focus on details presented on the front layer, while still retaining the context for the details on the back layer in the same field of view. This allows viewer to maintain an overview of the content of a large amount of information while providing swift access to details.

6.2.2 Software Platform

The Blender 3D modeling software (Blender, 2012) was chosen as a platform for the development of the set of focus and context awareness techniques because it is an open source software and offers all the standard tools required in 3D modeling tasks. The development of the new techniques was done in the Microsoft Windows™ environment using the Visual Studio™ .Net 2003. The code has been written in C++ and uses the OpenGL graphic library for display.

Blender has two interactive modes known as the *object* and *edit* modes. In the object mode, an object is treated as a single entity, and the manipulation applied to it affect it as a whole. Object mode is often used when the entire object needs to be deformed or transformed. Edit mode, on the other hand, is used when each component (i.e. vertex, edge, and face) of the selected object needs to be treated independently. Due to the fact that manipulation and shaping of a model can be done in both object and edit modes, the terms *object editing mode* and *component editing mode* will often be used in this thesis instead of the original terms of *object* and *edit* modes. However, whenever appropriate, the original terms are also used in their relevant context.

6.2.3 Five Focus and Context Awareness Techniques

A set of five focus and context awareness techniques were developed to deal with the four groups of problems identified through the users studies described in the previous chapters. These five techniques utilize the two layers of MLD to display different types focus and context awareness information on top of one another. Even though the focus and context information can be displayed on both the front and back layers or interchangeably between them, it was decided to use the front layer of MLD to display information related to the objects of interest (i.e. focus) and the back layer to display information related to the context. This was decided based on the work by Masoodian et al. (2004) who have used MLD to provide a focus and context awareness environment for editing Microsoft Word™ documents. In this application, the main document page view (i.e. focus) is presented on the front layer of MLD while the overview (i.e. context) of the entire document is displayed on the back layer. The transparency of the front layer supported by the MLD makes the task of viewing the overview of the document on the back layer possible.

The five new focus and context awareness techniques that have been developed here using MLD are:

- Object Isolation
- Component Segregation
- Peeling Focus
- Slicing
- Peeling Focus and Context

As will be discussed in the following sections, the object isolation technique is designed to be used in both object and component editing modes, the component segregation is intended to be used in component editing mode, and the peeling focus, slicing, and peeling focus and context are intended to be used in object editing mode.

6.3 Object Isolation

The object isolation is a technique used for separating the object of interest from the rest of the model. It is intended to be used when modelers need to shape an object which is overlapping with other objects within a model. For example, in a 3D human model, an internal organ such as the heart is hidden within the skin and skeleton, and therefore shaping it with the other objects around it can be difficult. In this case object isolation can be used to separate the heart from the rest of the model.

The object isolation technique works by presenting the selected object (i.e. the object of interest) and the non-selected objects on different layers of MLD. The object of interest is shown on the front layer while the other objects are displayed on the back layer. By separating objects into two layers, modelers can perform tasks on the object of interest in a less crowded environment. The transparency of the front layer permits the overall context of the model relevant to the task being performed to be seen. This technique is designed such that the same panning and zooming effects are applied to objects on both layers. It should therefore be possible for the viewer to establish a continuous relationship between the object of interest and its context as the object moves during the navigation and manipulation processes.

Figures 6.2 to 6.5 illustrate⁴ the use of the object isolation technique in object editing mode. Figure 6.2 shows the initial view of a 3D car model, where the car body (in brown) and its internal parts are visible to the viewer. As shown in this figure, the outmost parts of the model including the main body, side mirrors, tires and rims are engine, seats, etc. are shown on the back layer. The objects shown on the front layer are displayed in solid mode, and the objects on the back layer are in wireframe mode with edges colored in blue.

⁴ Throughout this chapter, screen shots will be presented to illustrate how a model is displayed on the MLD using its two layers. In most cases, the screen shots consist of a set of three images. The two on the top show the separate images displayed on the front and back layers of MLD side by side. The figure on the bottom is the actual photograph of the model being displayed on MLD. A demonstration of the individual technique has been provided in the enclosed videos.

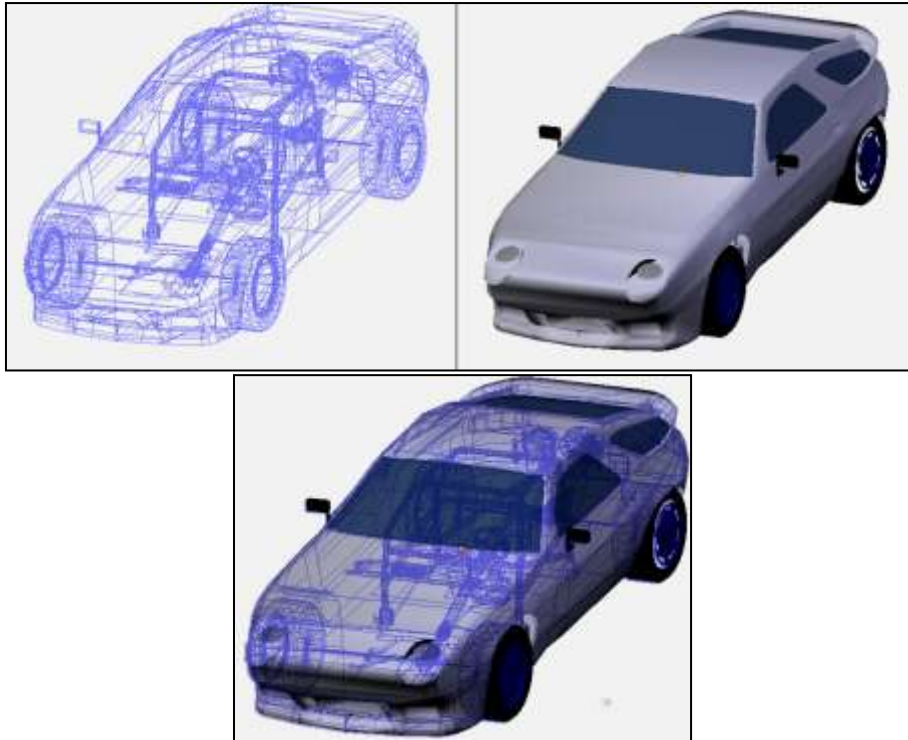


Figure 6.2: The initial condition of the model before the object isolation technique is applied

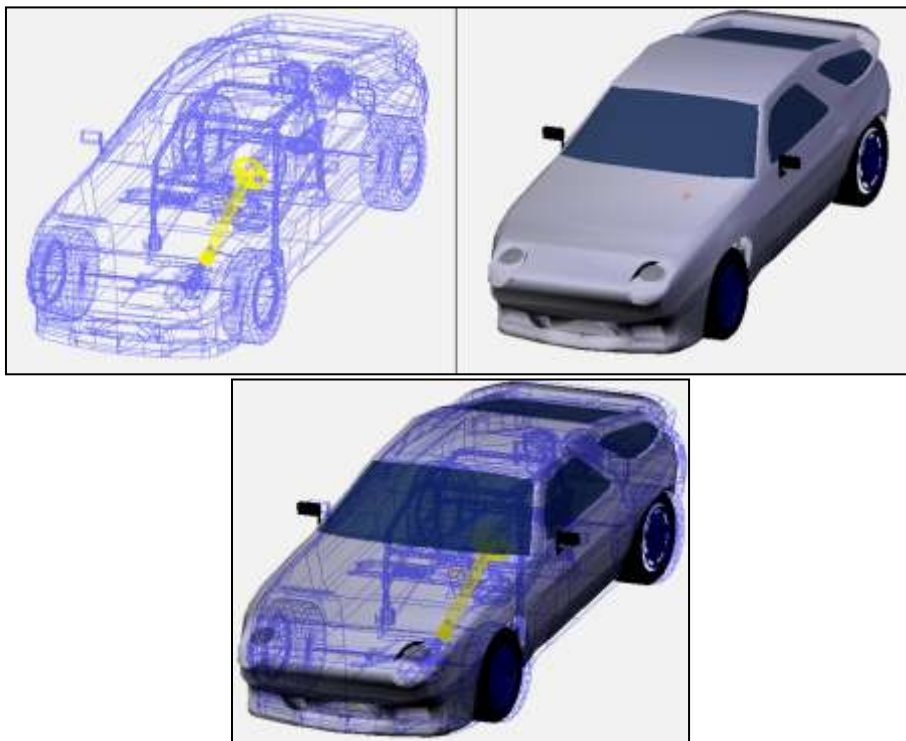


Figure 6.3: The steering set is selected on the back layer, and colored yellow

Figure 6.3 shows the steering set, which is comprised of the steering wheel, rods, and a wheel joint, is selected. The color of the selected objects change to yellow while the non-selected objects remain in blue. Once the object of interest (i.e. focus) is selected it can be isolated from the rest of the model (i.e. context) by using the object isolation

technique. As the result of this, the steering set is transferred to the front layer, as shown in Figure 6.4.

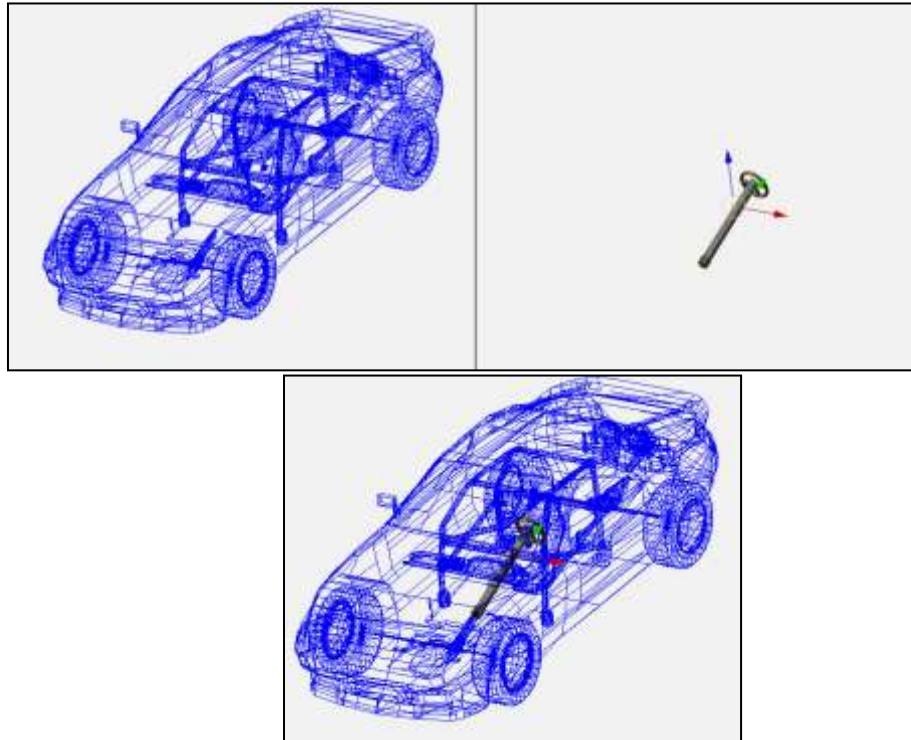


Figure 6.4: The steering set which was initially displayed on the back layer is transferred to the front layer after object isolation technique is applied

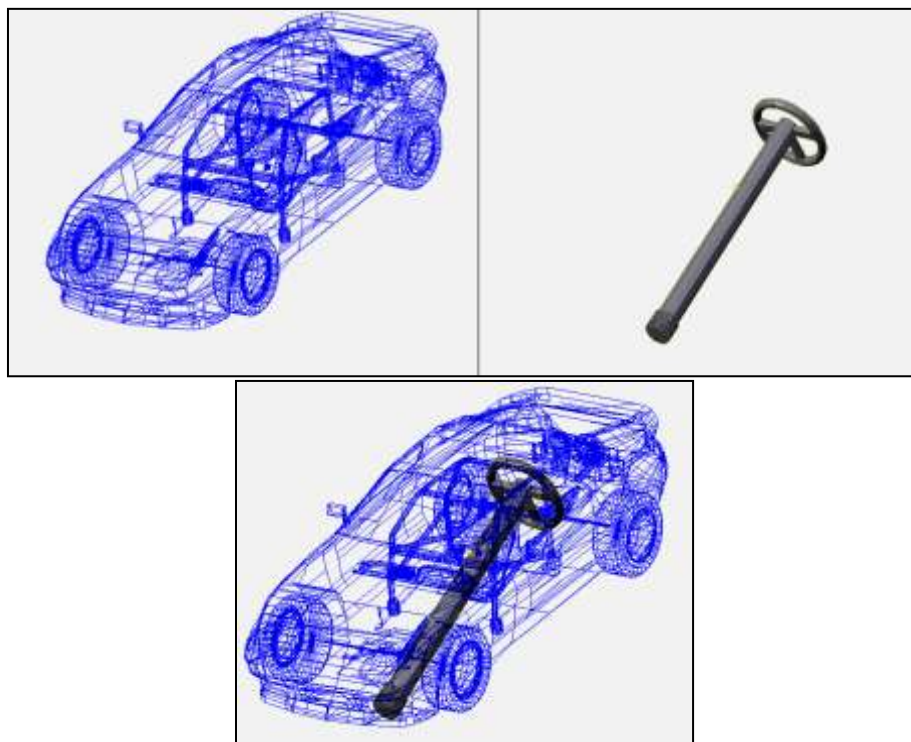


Figure 6.5: The steering set shown on the front layer is edited in object editing mode

Once the object of interest is transferred to the front layer, the user can manipulate it

in either the object or component editing modes. Figure 6.5 shows the object of interest on the front layer in object mode, and Figure 6.6 shows it in component editing model, where its edges and vertices are shown in red.

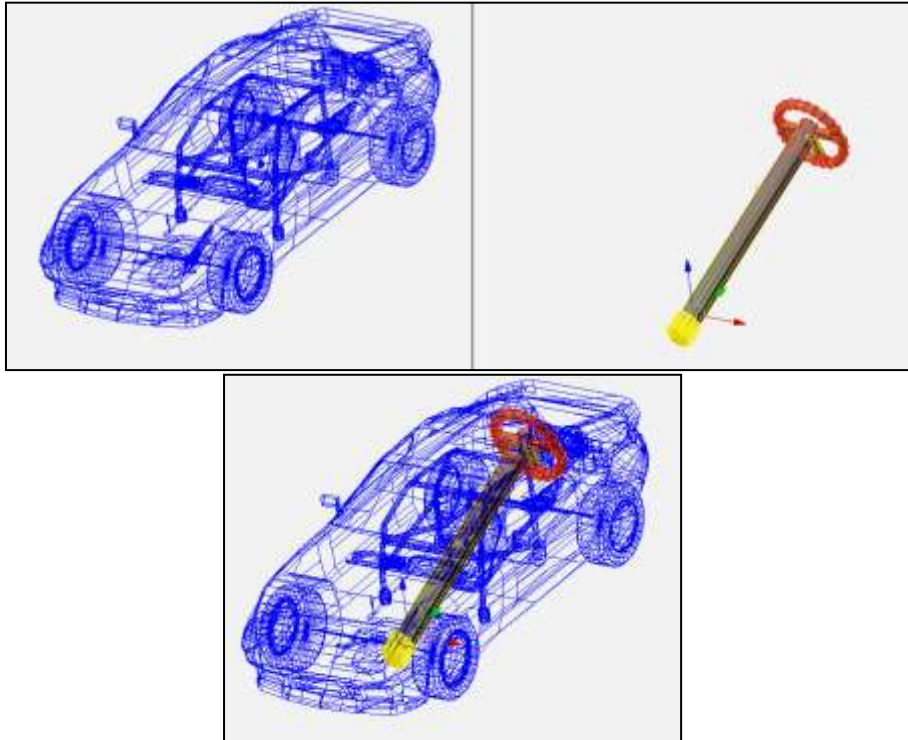


Figure 6.6: The object of interest is being edited on the front layer while context of the model is shown on the back layer

6.4 Component Segregation

This second technique is aimed at addressing the problem of manipulating a model at the component level (e.g. vertices, edges, and faces). This technique is similar to object isolation in the sense that no object is hidden or removed from the display area, and that the context is shown on the back layer in wireframe mode. Using this technique, modelers should be able to realize the relationships between all the objects and components of the model without requiring them to move their attention between multiple viewports, as previously discussed.

The main difference between the component segregation and the object isolation techniques is that the components of the selected object are split between the two layers of MLD when in the component editing mode. Components that are closer to the viewer are shown on the front layer, while the components that are on the far side of the selected object are displayed on the back layer.

When using this technique, the location of the mouse cursor, either on the front or

back layer, determines which components are available for manipulation. For example, the mouse cursor needs to be moved to the back layer when the user intends to select components shown on that layer. Similarly, the mouse cursor has to be brought to the front layer in order to have access to components displayed on the front layer. This eliminates the possibility of selecting components on the wrong side of the model. The physical separation between the front and back layers' components would allow users to select the targeted components more accurately without having to hide some components or perform any navigation which might change the model's orientation.

Even though various components of a selected object are separated onto different layers, the transparency of the front layer of MLD makes all the components visible to viewer at all time. This feature would be useful when the task being performed requires the modeler to compare the shapes or alignments of components on the opposite sides of the object being edited. In certain conditions, small head movements by the viewer may also improve clarity of their view. Such movements are natural when looking at real 3D objects, and require little conscious thought.

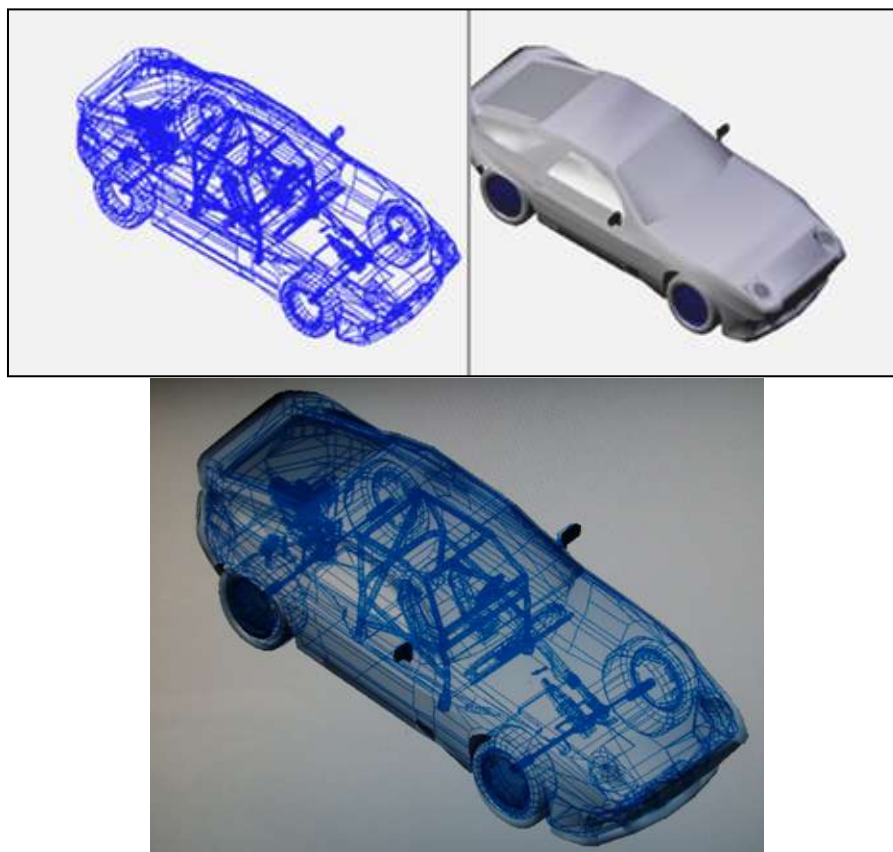


Figure 6.7: The model of the car before the object of interest is selected

Figures 6.7 to 6.9 illustrate how the component segregation technique can be used by 3D modelers. In Figure 6.7, the model is in object editing mode, and no object has been selected.

Figure 6.8 shows the main body of the car is selected and the model is in component editing mode. At this stage, the edges and vertices that are closer to the viewer are shown in red on the front layer. Those components on the other side of the model are shown with blue edges and red vertices on the back layer. In MLD as shown on Figure 6.8 (right), components that belong to the near and far sides of the body of the car are visible. In addition, other objects inside the car body are visible on the back layer.

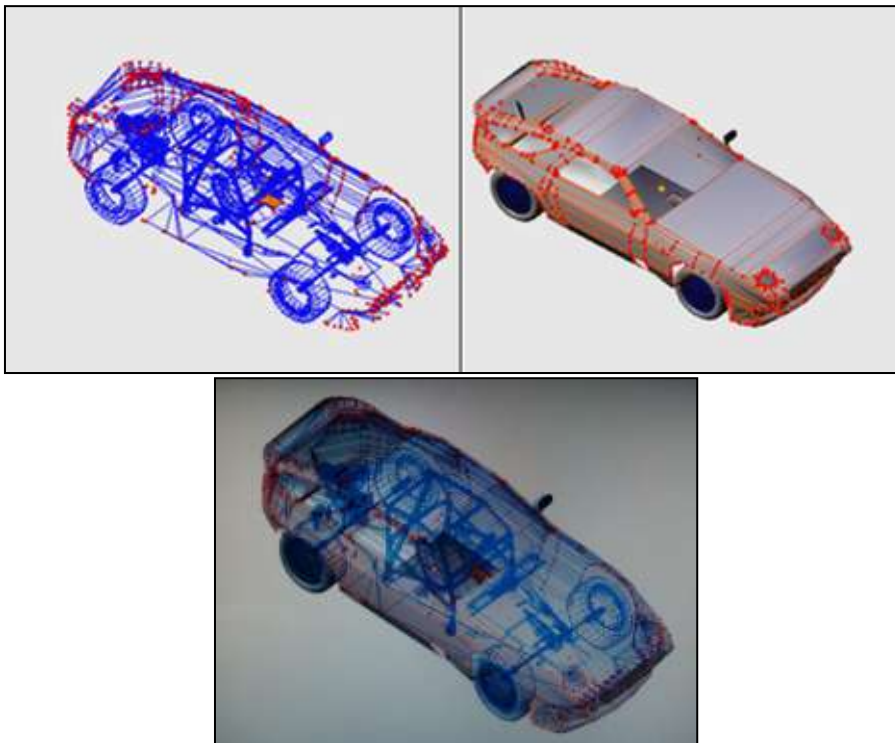


Figure 6.8: The body of the car is selected and changed to edit mode

Comparing the two sides of an object can be accomplished by setting the viewing orientation to side, top, or front views as appropriate. Figure 6.9 shows a 3D car model viewed from the side. This allows the differences between the two sides of the car body to be identified. A direct comparison is therefore possible because the components of both layers appear within the same viewing orientation. They are not directly overlapping as would be the case on a single layer display. As mentioned earlier, the physical gap between the two MLD layers makes it clear to the user which components are on the front and back layers.

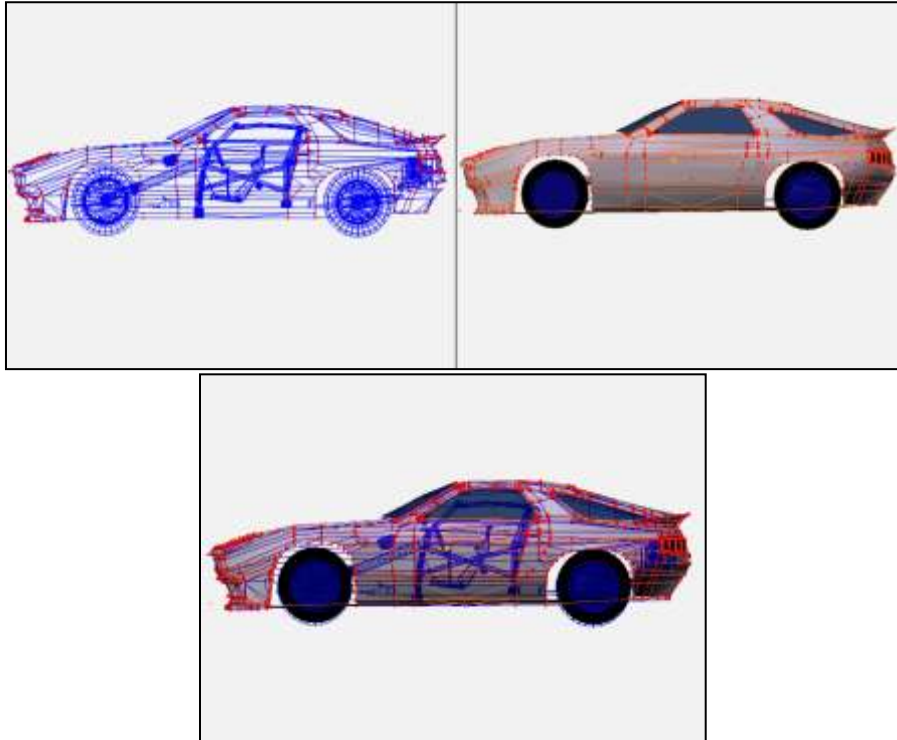


Figure 6.9: The model is viewed in side view

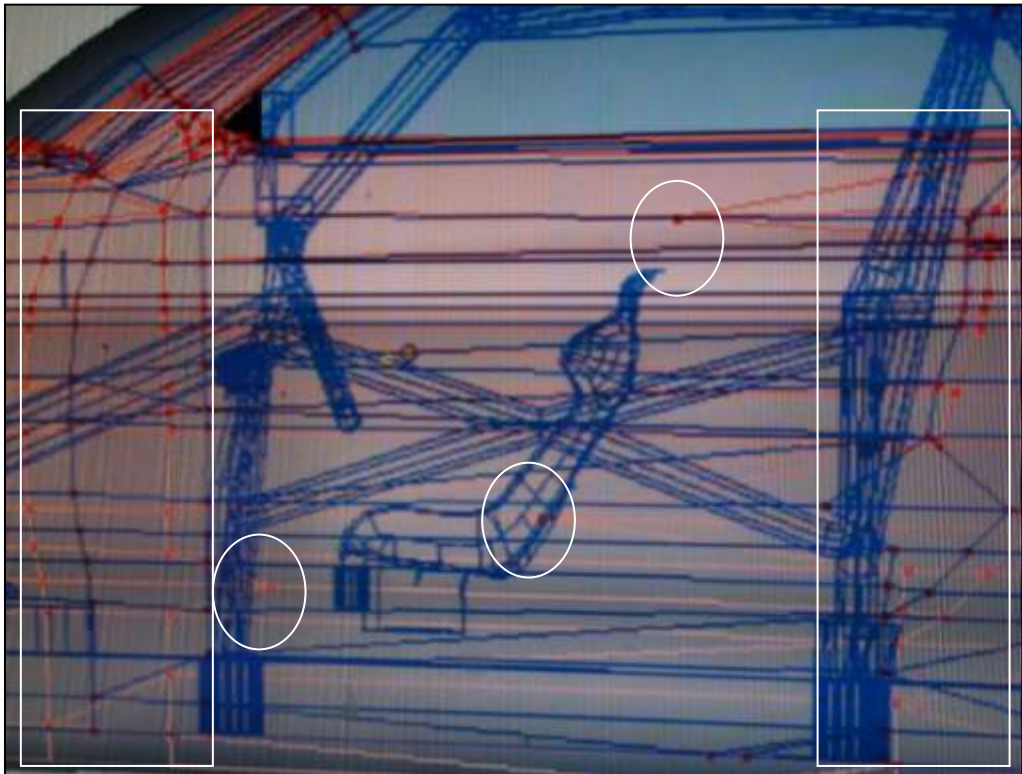


Figure 6.10: Close up of the model where the actual differences, and the parallax effect are visible

Figure 6.10 shows a close up of the model viewed from the side on the actual MLD screen. The three white circles indicate the differences between the positions of the

components of both layers. In this example, a number of vertices are misaligned. A few other differences also identified in this figure are marked by the white rectangles. However, these differences are caused by parallax effect that exists in MLD depending on the viewer's head position. In this close up, the image is captured from the center of the model, causing the parallax effect to the leftmost and rightmost of the model.

6.5 Peeling Focus

Peeling focus is a technique that is designed for two purposes. The first is to ease the modelers' task of finding an object of interest in the model where it might be hidden or obscured by other objects. The second is to enable modelers to realize the relative position of objects in a model.

The peeling focus is needed mainly because in object editing mode objects on the front layer of MLD are shown in solid, and therefore only the outmost skin of the model is displayed to the viewer, and the internal objects are hidden from the view. On the back layer, on the other hand, objects are displayed in wireframe mode. However, in this mode locating an object of interest and realizing the relative position of objects is often difficult because the edges of objects tend to overlap each other.

The peeling focus technique only affects the model displayed on the front layer of MLD. When this technique is used, portions of the model on the front layer are incrementally removed or shown depending on the action being applied, while the context, of the model shown on the back layer of the MLD remains the same at all time. Thus, this technique enables modeler to expose objects of interest on the front layer and to work in a less cluttered environment. This technique works by moving a clipping plane towards or away from the viewer to incrementally expose what is previously hidden or obscured by other objects.

Figures 6.11 to 6.14 demonstrate the steps taken and the results of using this technique. Figure 6.11 shows the initial condition of a model before the peeling focus technique is applied. As mentioned before, this technique is intended to be used in object editing mode, and therefore the images shown here are in this mode.

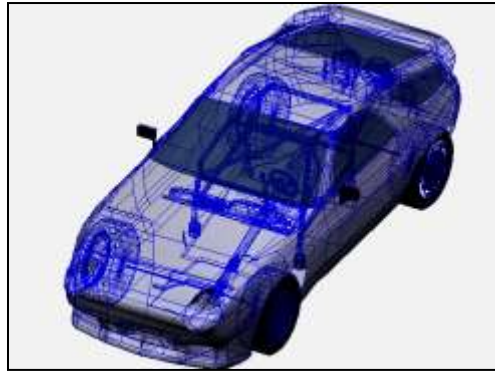


Figure 6.11: Initial condition of the model

When this technique is applied a portion of the model that is visually closer to the viewer and in the path of the Z axis is incrementally removed from the front layer. This process steadily exposes interior objects, as illustrated in Figure 6.12, allowing the viewer to locate the objects of interest inside the model.

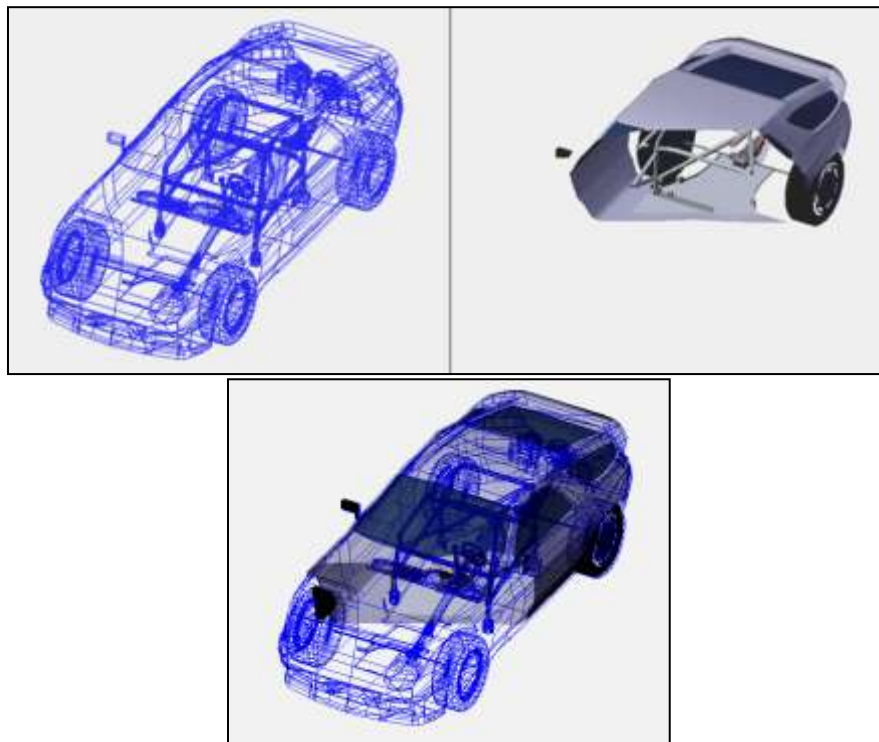


Figure 6.12: The peeling focus technique is used to reveal a portion of the model on the front layer

As peeling focus is applied incrementally, more objects from the front layer are removed (as shown in Figure 6.13), exposing any hidden internal objects. It is important to note that throughout the peeling process only the segments of the model shown on the front layer are affected, while context displayed on the back layer remains unaffected.

The portion of the model which is peeled on the front layer (i.e. focus) is determined

by the orientation of the model with respect to the clipping plane. Therefore any changes to the model's orientation as the result of navigation by the user will alter the visibility of the model and the segments being peeled. For example in Figure 6.14, a different segment of the model is shown on the front layer because the model has been rotated. The orientation of the overview (i.e. context) shown on the back layer has also changed accordingly.

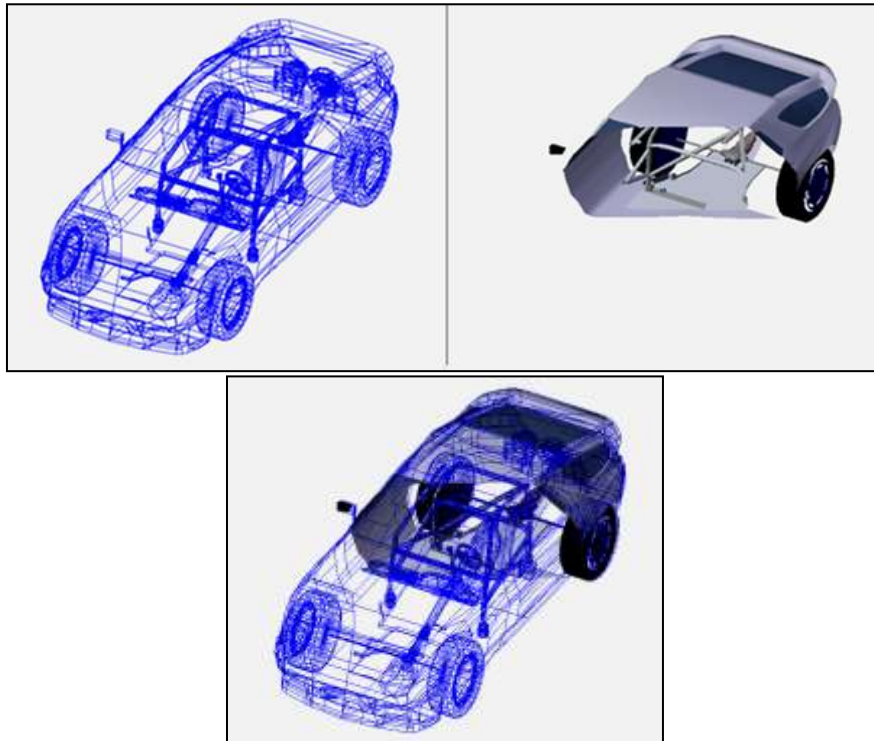


Figure 6.13: Further peeling of focus reveals deeper internal objects

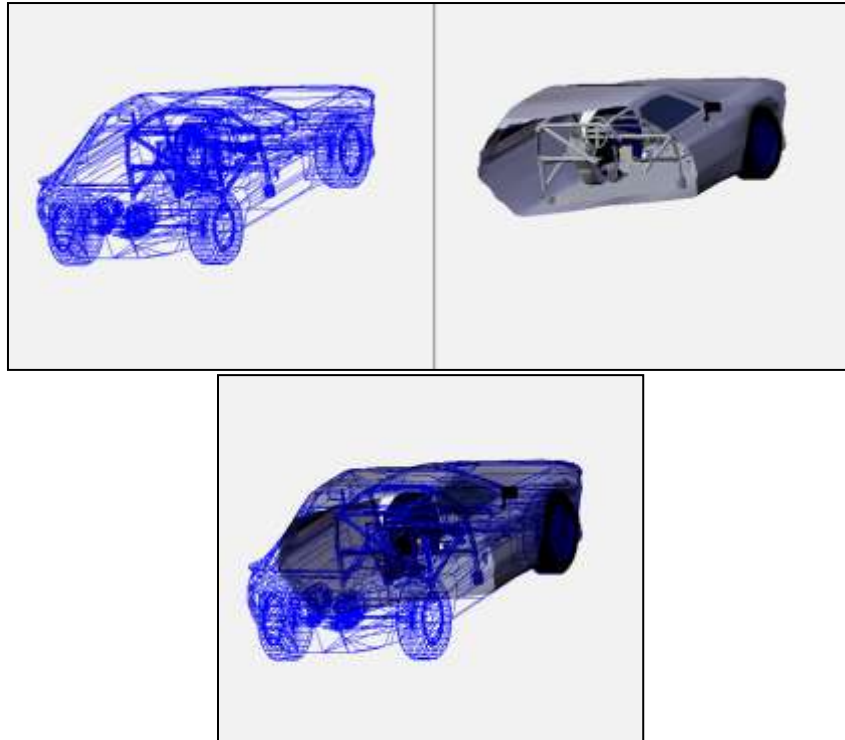


Figure 6.14: The model displayed in a different orientation

Even though peeling focus removes portions of the model shown on the front layer, the viewer can still view the overview of the model shown on the back layer. This allows the viewer to see the relationship between the object of interest and the rest of the model, even after parts of the object of interest have been peeled from the front layer. The proportions and scaling of the model remain the same while allowing the modeler to work on the front layer in a less crowded environment. The application of this technique aims to eliminate the unnecessary steps required in the hiding and un-hiding techniques.

6.6 Slicing

The slicing technique operates by removing portions of an object which is on the back layer of MLD. This technique removes part of the model from the back and makes it visible on the front layer. Parts of the model that appear on the front layer are displayed in solid mode while the remainder of the model on the back layer remains in wireframe. This technique aims to enable modelers to remove what is not relevant to their modeling tasks, while allowing them to focus on parts of the object of interest.

As previously described, each of the five techniques described in this chapter is designed to be used in a certain 3D modeling situation. The slicing technique, as well as the peeling focus and context technique which is discussed in the next section,

operate in a different manner to the peeling focus technique. In these two new techniques the overall context of the model is no longer visible at all times, and therefore, they are more suitable for cases where the modeling tasks being performed do not require modelers to refer to the entire model. In any other circumstances where a more complete context overview is required, the previous three techniques may be more suitable. In the slicing, and also peeling focus and context techniques, focus and context do not necessarily involve two separate objects but may be of a single object where context can be the rest of the same object. For example, when performing a modeling task on the body of a plane, focus may be on the middle of the plane while the context that is relevant to the tasks is part of the body at the back of the plane.

Figures 6.15 to 6.20 demonstrate six stages of the slicing technique being applied. Figure 6.15 shows the initial view of a 3D car model where all the objects of the model are visible in the solid mode on the front layer, and the wireframe mode on the back layer.

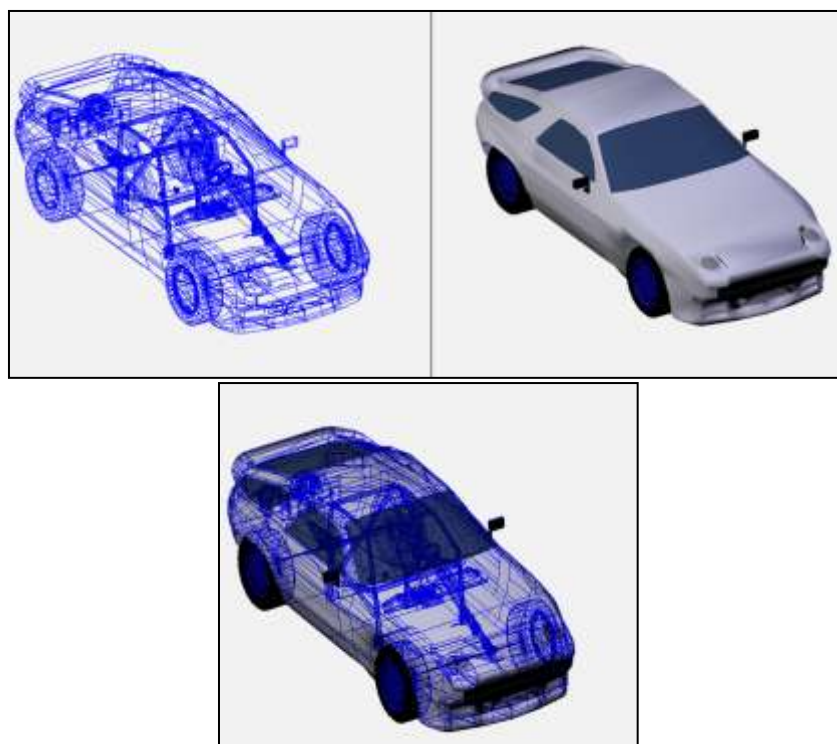


Figure 6.15: The initial view of the model before the slicing technique is applied

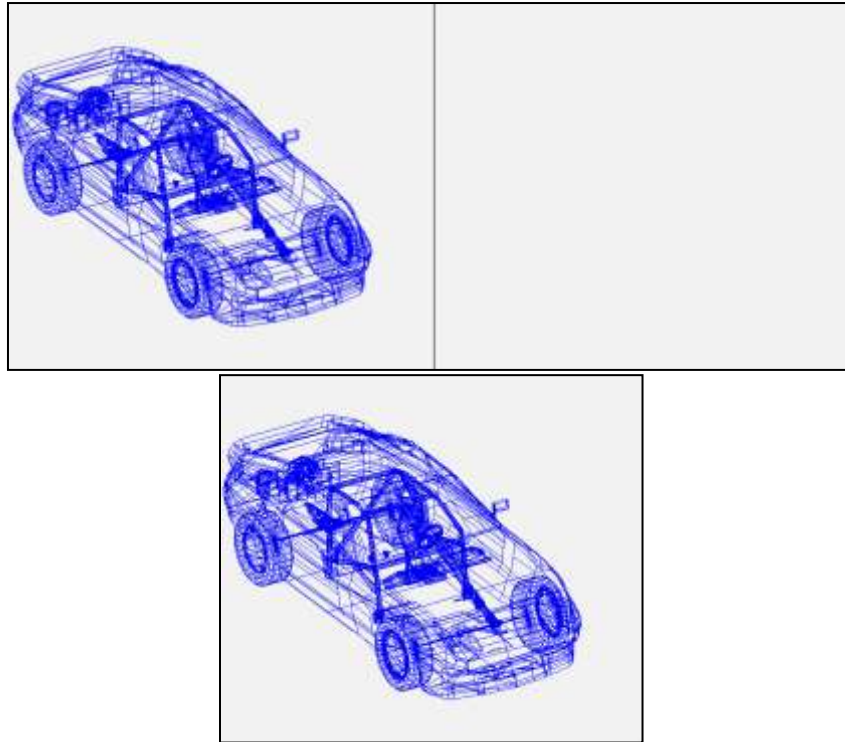


Figure 6.16: The view of the mode when slicing is started

When the slicing is started, objects shown on the front layer of MLD are removed, and what is shown to the viewer is the model of the entire car in the wireframe mode on the back layer, as can be seen in Figure 6.16.

When the slicing technique is applied, it incrementally removes portions of the model from the back layer and moves them to the front layer, as shown in Figure 6.17.

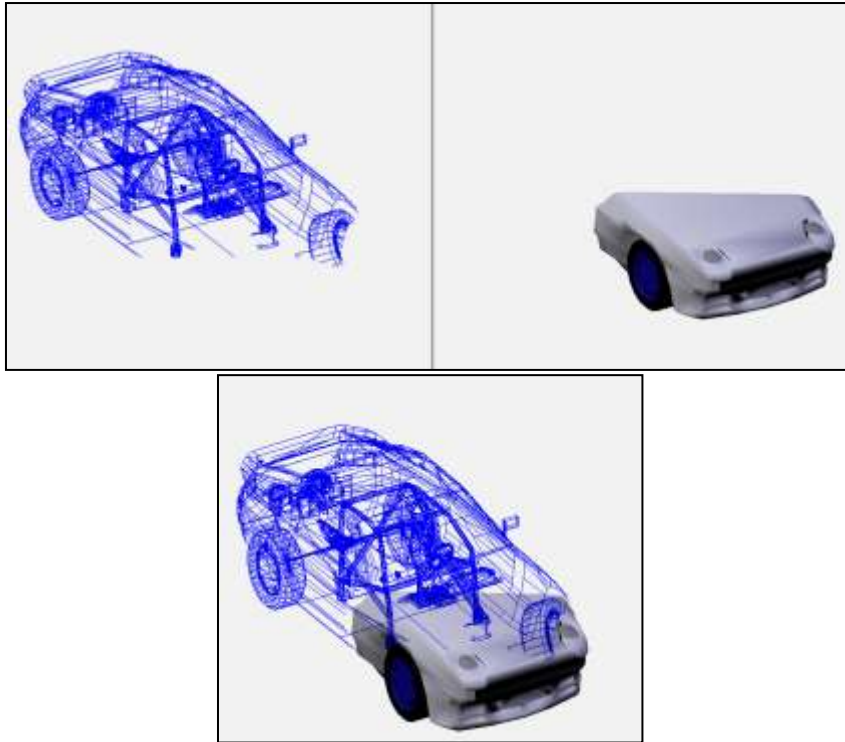


Figure 6.17: Portions of the model are removed from the back layer and concurrently appear on the front layer

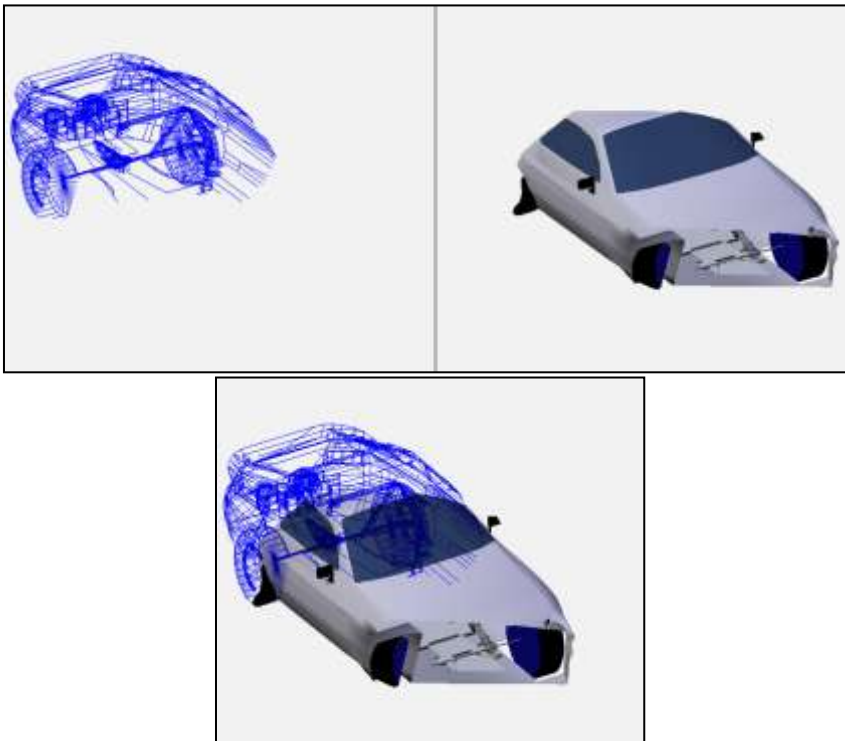


Figure 6.18: The front part of the model is no longer visible on either of the layers

As further slicing is performed, subsequent portions of the model are affected. The front portion of the sliced part of the model shown on the front layer is eventually removed as slicing continues through the model (see Figure 6.18).

As with the peeling focus technique, the portions of the model that are sliced can be interactively changed, depending on the orientation of the model to the clipping plane. Figure 6.19 shows the effect of rotating the viewport where the portions of the model that are sliced are changed.

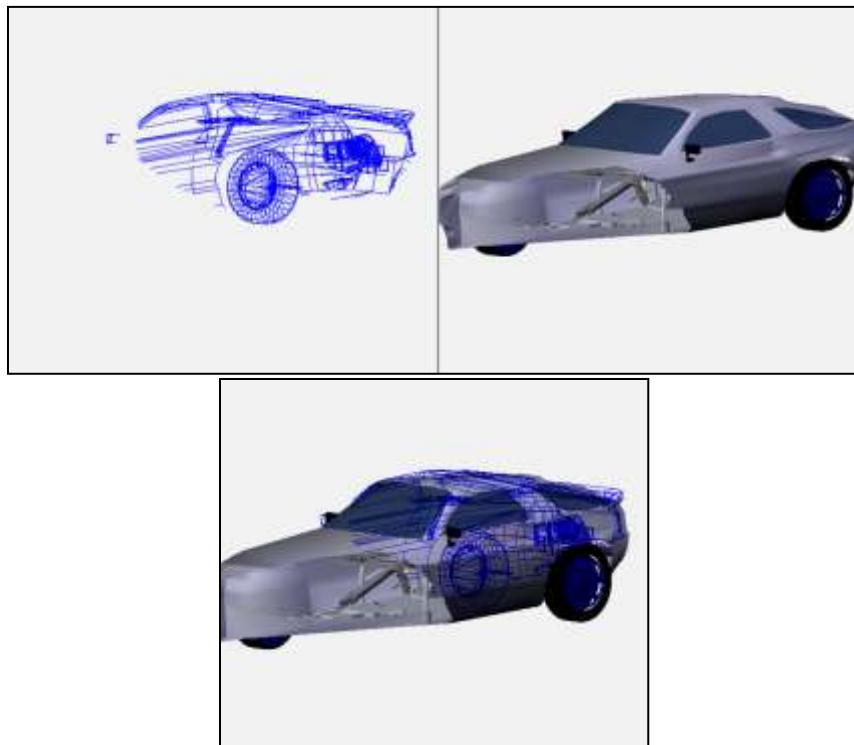


Figure 6.19: Different portions of the model are shown when the orientation of the model is changed

6.7 Peeling Focus and Context

As with the slicing technique, the peeling focus and context technique removes parts of the model from both layers of MLD. The difference between these two techniques, however, is that in the peeling focus and context, the same portions of the model (i.e. objects of interest and context) are shown on both the front and back layers of MLD, where as in the slicing technique different portions of the model are displayed.

When the peeling focus and context is applied parts of the model are concurrently removed from both the front and back layers of MLD. Figure 6.20 demonstrates the initial stage of the process of peeling focus and context where a small portion of the 3D car model is removed from both layers. Figures 6.21 and 6.22 show further peeling of focus and context.

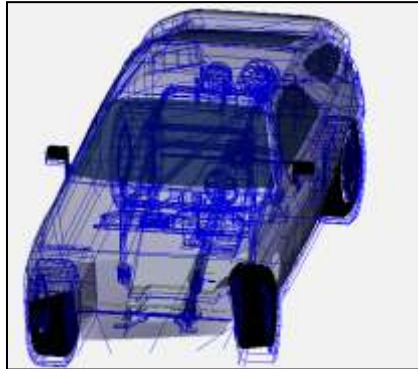
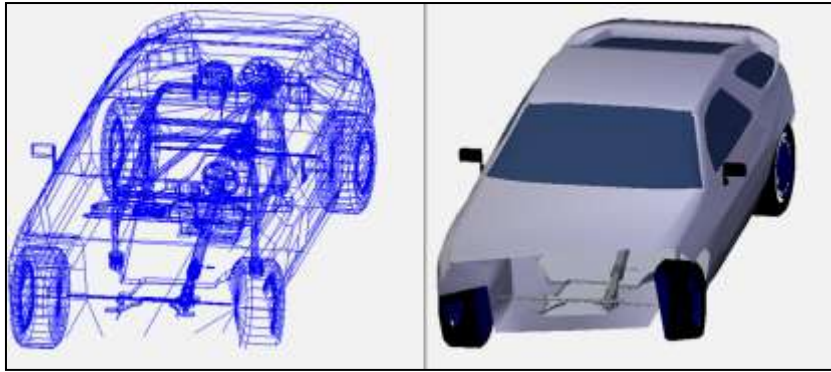


Figure 6.20: Part of the model is peeled from both layers

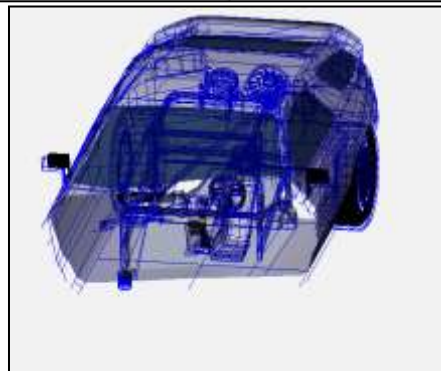
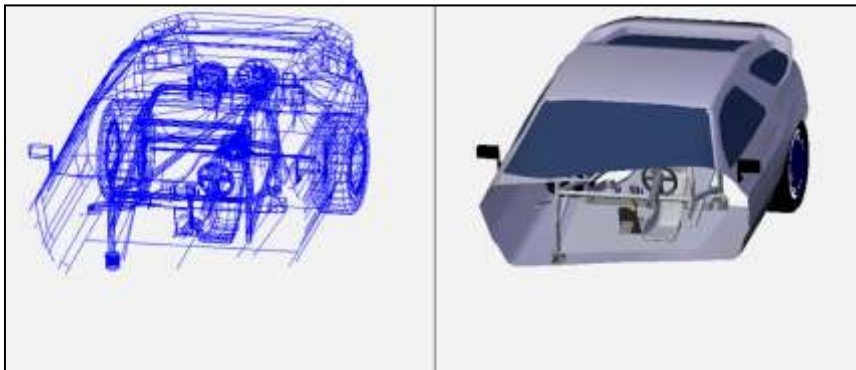


Figure 6.21: Further peeling of the focus and context

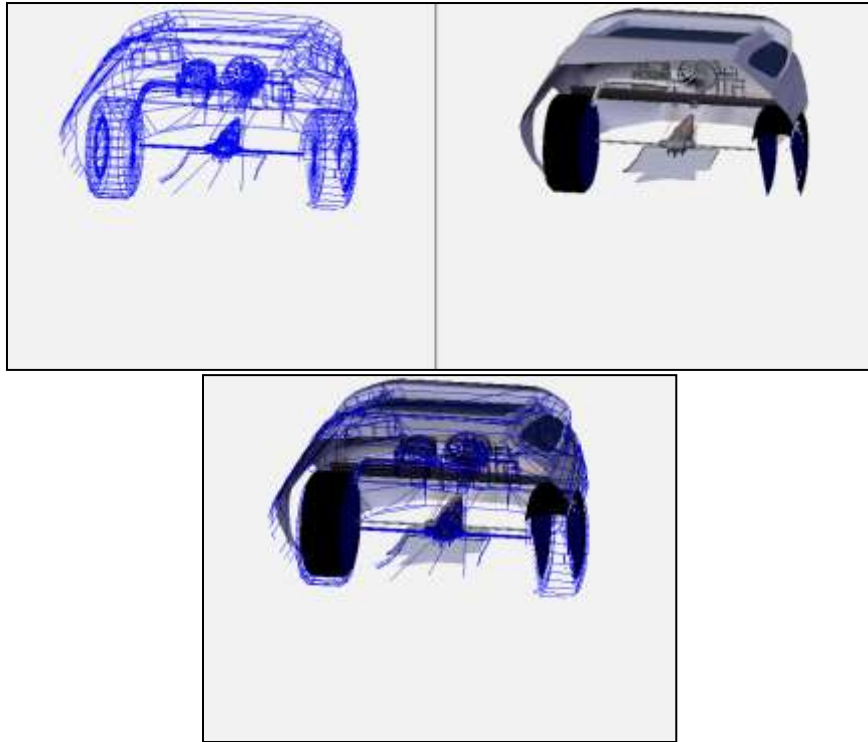


Figure 6.22: Even further peeling of the focus and context

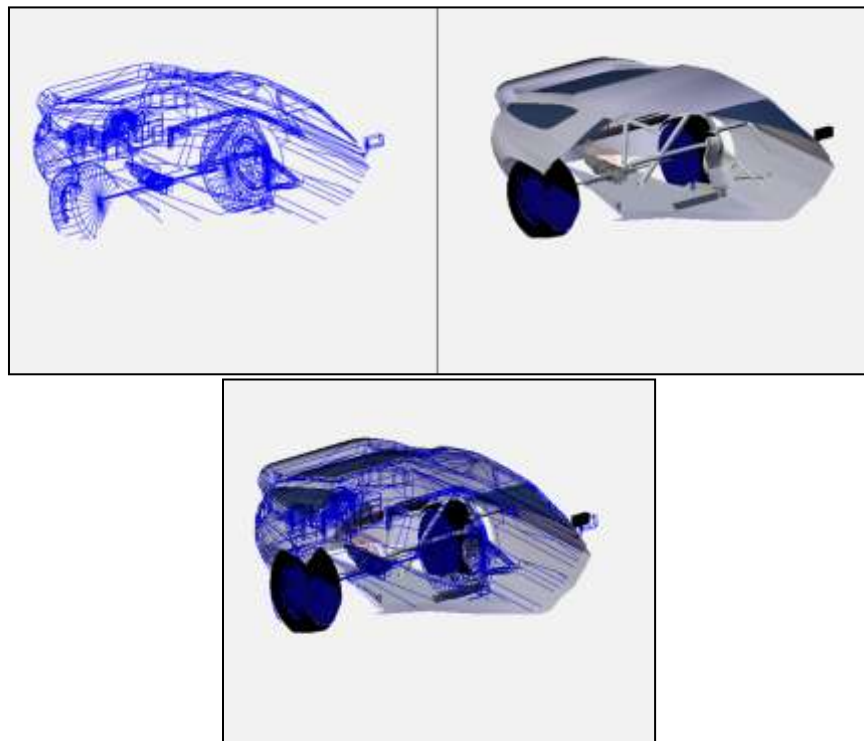


Figure 6.23: View of the peeled model from a different angle

Similar to the last two techniques, parts of the model that are peeled change interactively depending on the orientation of the model to the clipping plane. Figure 6.23 illustrates the effect of moving the view of Figure 6.22 around.

6.8 Implementation

Implementation of the techniques described in this chapter involved resolving a number of issues related to MLD. There are:

- Color combinations of the front and back layers
- Transparency of data presented on the front and back layers
- Types of information to overlay
- Clipping planes of the front and back layers
- Component segregation

Each of these is discussed in the following sections.

6.8.1 Color Combinations of the Front and Back Layers

Wong et al. (2005) have conducted an experiment to determine the effects of different combinations of foreground text colors and background colors and textures on MLD. In this experiment 12 combination of pairs of colors were tested, with one color used on the front and one on the back layer. The choices of 12 color combinations for foreground text and background color used in the experiment were based on the findings of Lalomia and Happ (1987) who categorized color combination into three groups of good, poor, and inconclusive, as listed in Table 6.1.

Wong et al. in their experiment narrowed the scope of their study to examine the task of reading text and tested the following readability factors:

- Reading speed: how quickly a textual passage is read.
- Error detection: how efficiently simple spelling errors are recognized.
- Comprehension speed: how quickly text can be comprehended and recalled.
- Comprehension accuracy: how accurately text can be comprehended and recalled.

Table 6.1: Color combinations categorized by Lalomia and Happ (1987)

Category	Group #	Background Color	Text Color
Good Combination	1	White	Black
	2	Black	Magenta
	3	Black	Green
	4	Blue	Yellow
Poor Combination	1	White	Green
	2	Red	Blue
	3	Black	Blue
	4	Green	Red
Inconclusive	1	Green	Light Magenta
	2	Magenta	Yellow
	3	Red	Green
	4	Cyan	Yellow

The findings from this experiment showed that for none of the readability aspects tested, there was any apparent correlation between the determined effectiveness of the color combinations tested and their associated performance on MLD. This suggested the need to reassess the color combination recommendations for MLD, rather than applying the same rules as recommended for conventional single layer.

In another study of MLD Prema et al. (2006) observed that color combinations with dark foreground colors and light background colors were more effective. They further point out that if the background is dark then the foreground objects become difficult to see. Also, if the foreground object is in light color it appears transparent and the background color shines through.

In a 3D modeling setting, determining the best color combinations is even more complex than the text-based scenarios addressed by Wong et al. because of the many unique situations that are present in 3D modeling tasks. For example, the color of selected objects has to be different from the color of non selected objects, and the color of the components of selected object (i.e. edges, vertices and faces) needs to be different from the components of non selected objects. This in itself means that at any one time, up to 4 color combinations may appear on the display.

In addition, 3D models can be displayed in different modes (e.g. solid mode, wireframe mode, object editing mode, and component editing mode). These settings are not even mutually exclusive and can be turned-on at the same time. For example, a model can be edited while in solid or wireframe mode.

Table 6.2: Combinations of colors used on the front and back layers of MLD

Set	Action	Back layer		Front layer	
		Components or Objects	Color	Components or Objects	Color
1	Object is selected	Selected object	Yellow	Selected object	Yellow
		Non selected objects	Blue	Non selected objects	
2	Component is selected	Selected components of the selected object	Yellow edges and red vertices	Selected components of the selected object	Yellow edges and red Vertices
		Non selected component of the selected object	Blue edges and red Vertices	Non Selected component of the selected object	Yellow edges and red vertices

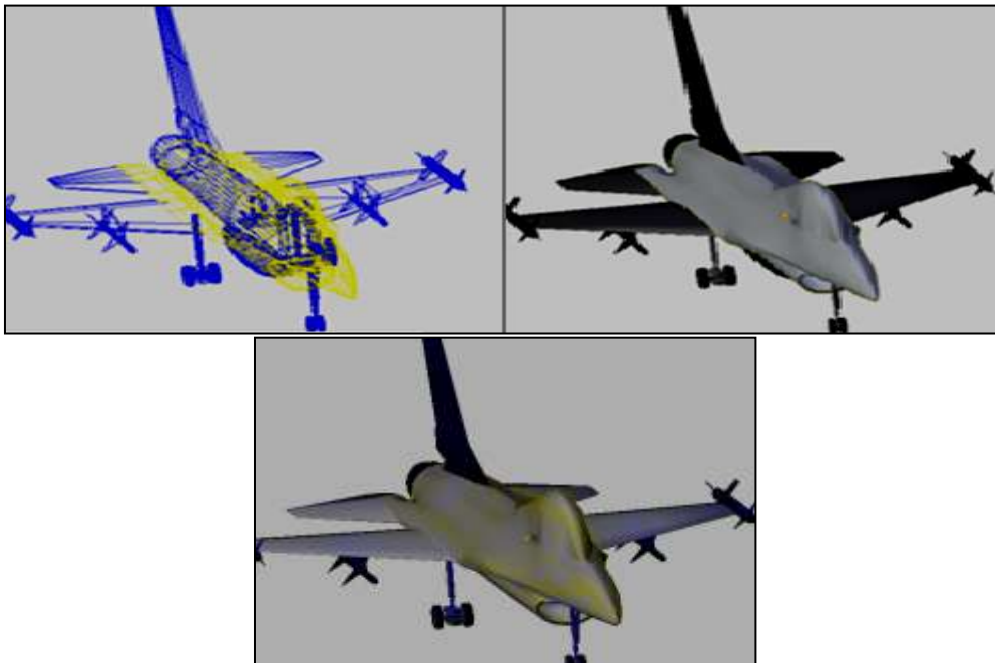


Figure 6.24: Model of an airplane with objects selected, using the color combinations of Set 1

After comparing a number of color combinations, it was decided to use the color combinations shown in Table 6.2 in implementing the techniques described in this chapter. These color combinations seemed to provide the best contrast between the two layers of MLD when working on a 3D model. Figures 6.24 and 6.25 show these color combinations using an example 3D model.

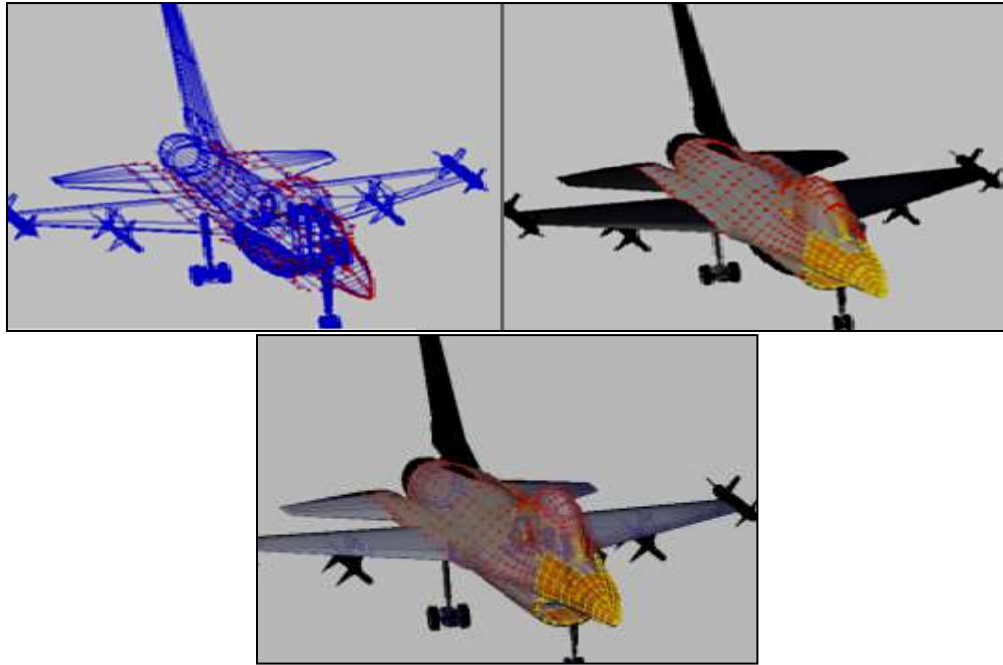


Figure 6.25: Model of an airplane with some components selected, using the color combinations of Set 2

6.8.2 Transparency of the Front and Back Layers

Another issue that needed to be resolved was finding the best transparency levels for the two layers of MLD. Wong et al. (2005) have suggested that a transparency level of 70% applied to the front layer of MLD maximizes the ability of the viewer to distinguish objects on both layers of MLD. In their study, by providing this level of transparency on the front layer the viewers were able to effectively see the information displayed on the back layer while focusing on the objects of interest shown on the front layer.

The implementation of the focus and context awareness techniques described in this chapter do not set the transparency levels suggested by Wong et al. The reason for this is that the transparency levels tested by Wong et al. were for text only, where the visual setting is less complicated than a 3D modeling scenario to differentiate the object of interest from the context, but also allow the objects displayed on the back layer to be seen through from the front layer. Instead of setting transparency levels, the methods described here use the color combinations described in the previous section.

6.8.3 Types of Information to Overlay

The third issue highlighted by Wong et al. (2005) is how to decide what objects to be shown and where they should be displayed. They suggest that the objects should be

displayed in accordance to their relevancy. This means that objects shown on the back layer should be determined by the objects that appear on the front layer. However, this suggestion cannot be implemented fully in a 3D modeling environment because the location of each object of a model is fixed according to the final form of the model being created. In the techniques described here, the choice of how the objects are displayed between the two layers depends on the 3D tasks being performed and the specific technique being applied.

6.8.4 Clipping Planes of the Front and Back Layers

In the techniques described in this chapter 3D models are displayed on both layers of the MLD. As such, two independent sets of clipping planes are used, one on each layer. In Figure 6.26 the left image shows the clipping planes of the back layer while the right image shows the clipping planes of the front layer. Initially the depth assigned to the near and far clipping planes of both layers are set to 0.1 and 500 respectively, which represent the near and far planes in the viewing volume set by the Blender modeling software. This means that the segments of the model being viewed which exceed these values of 0.1 and 500 are not displayed to the viewer. The two values guarantee the visibility of the entire model before any of the techniques are applied.

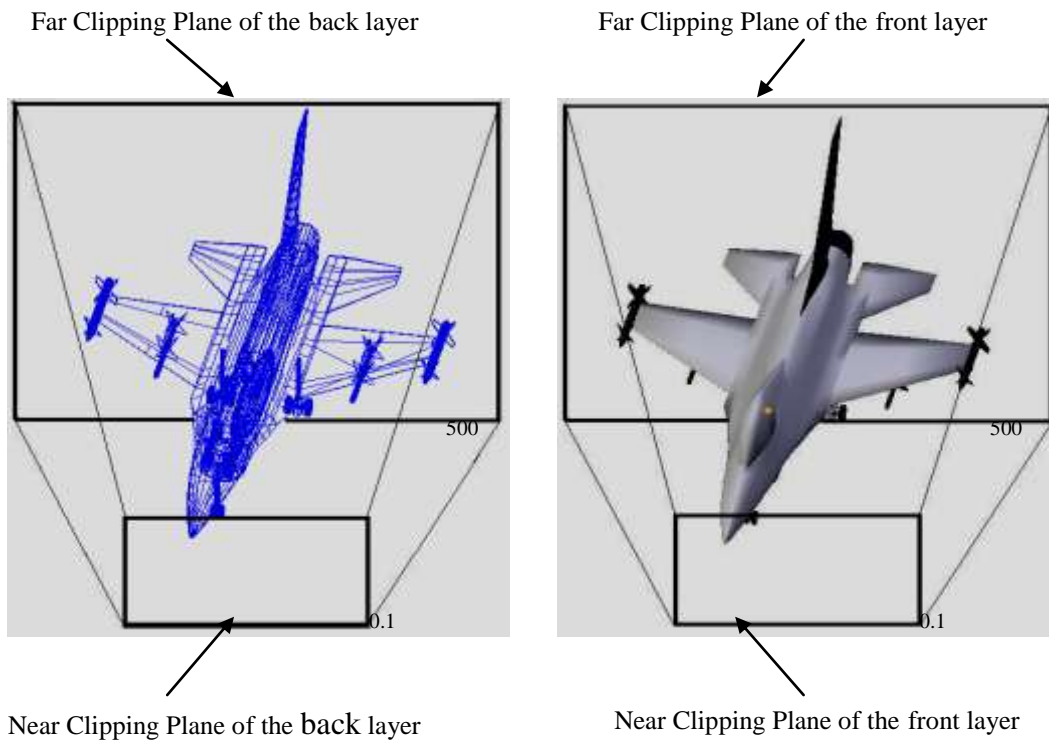


Figure 6.26: Clipping planes of the front and back layers of MLD

The clipping planes work differently depending on the type of focus and context awareness techniques being used. In the slicing technique, three clipping planes are active at all times. On the front layer, the gap between near and far clipping plane is set to 3 units where these units represent the thickness of the “slicer”. The gap of 3 units was selected based on some initial tests to provide a good view of the neighborhood of the object of interest and context that is relevant to the tasks. The gap between near and far clipping plane of the back layer was however set to 500 units. When the slicing method is used, the depths assigned to the near and far clipping planes of the front layers are increased by 0.5. The depth is increased by 0.5 because it seems reasonable enough that portions of the object which are steadily removed from the back layer and are made visible on the front layer. On the back layer, a different rule is applied, in which the near clipping plane is increased by 0.5 but the far clipping plane of the back layer remain the same (i.e. 500).

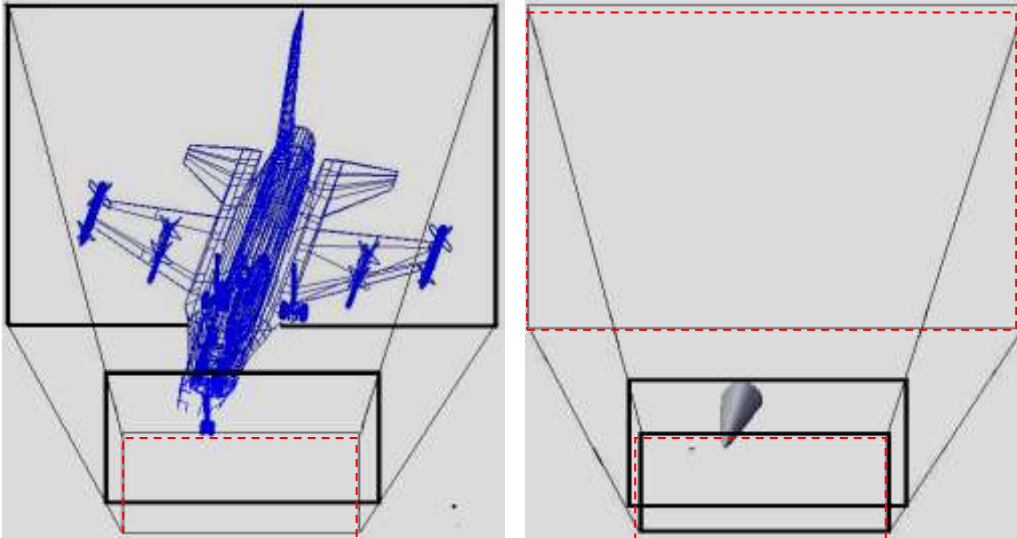


Figure 6.27: Three clipping planes (i.e. two of the front layer and one of the back layer) are moving in order to give the slicing effect. The red dotted rectangles are the initial positions of the clipping planes and the black rectangles are the clipping planes as they move

Figure 6.27 demonstrates the changes to the three clipping planes that take place when using the slicing technique. In these examples, only a small portion of the model appears on the front layer because the distance between near and far clipping plane is small (i.e. 3 units), and on the back layer, only the near clipping plane is moved while far clipping plane remains the same.

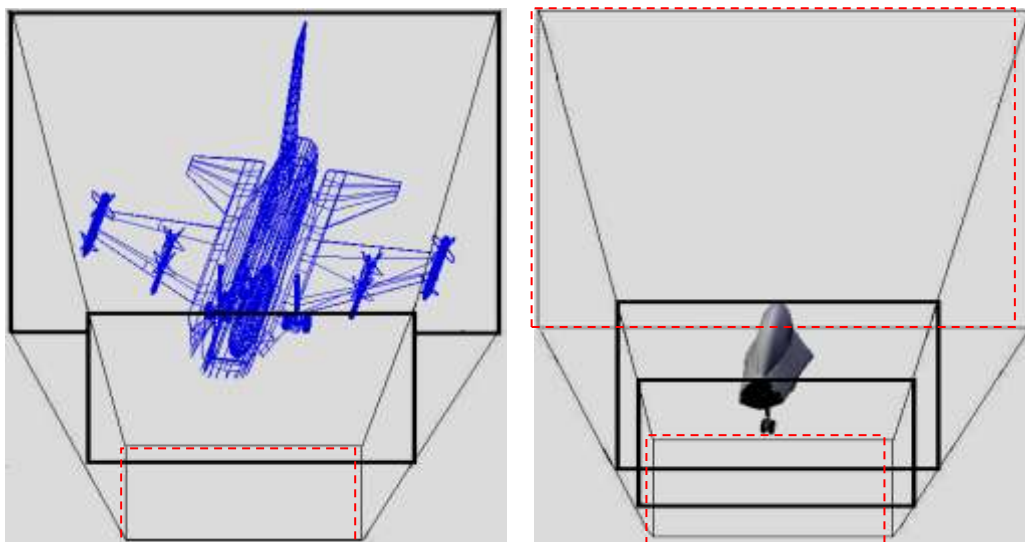


Figure 6.28: Different portions of the model shown on the front and back layers

As further slicing is performed, the three clipping planes (e.g. the near and far clipping planes of the front layer, and the near clipping plane of the back layer) are steadily moved, causing the subsequent portions of the model to be affected as shown in Figure 6.28.

In the peeling focus technique, only the near clipping plane of the front layer is

moved. When the near clipping plane is moved beyond the location of an object that object is removed from the front layer. On the back layer the values assigned to the near and far clipping planes are unchanged. As a result, the overview of the model remains visible at all times. In this technique, the near clipping plane of the front layer changes by 0.5 each time the technique is applied. Figure 6.29 illustrates an example of moving the near clipping plane away from the viewer, gradually removing the front part of the 3D model.

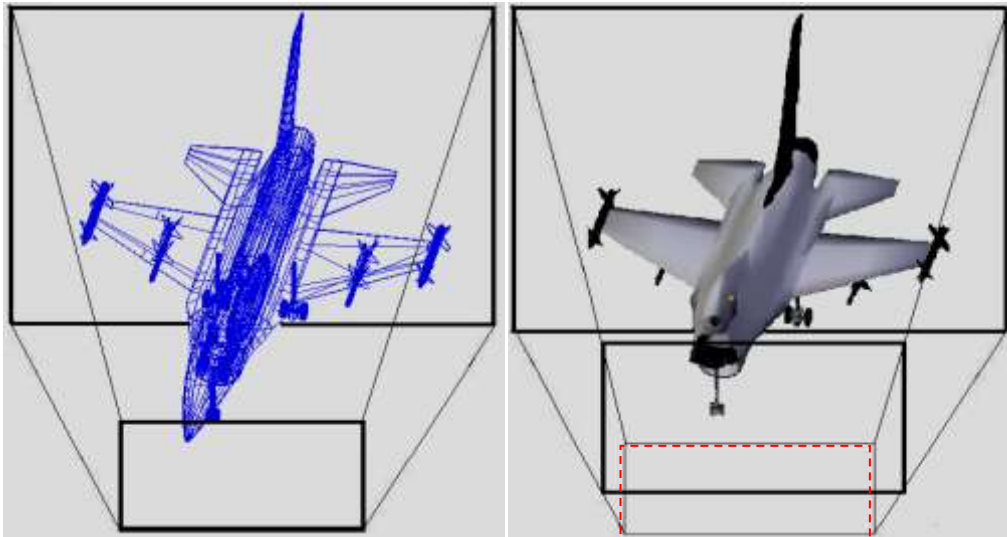


Figure 6.29: During the peeling focus process only the near clipping plane of the front layer is moved

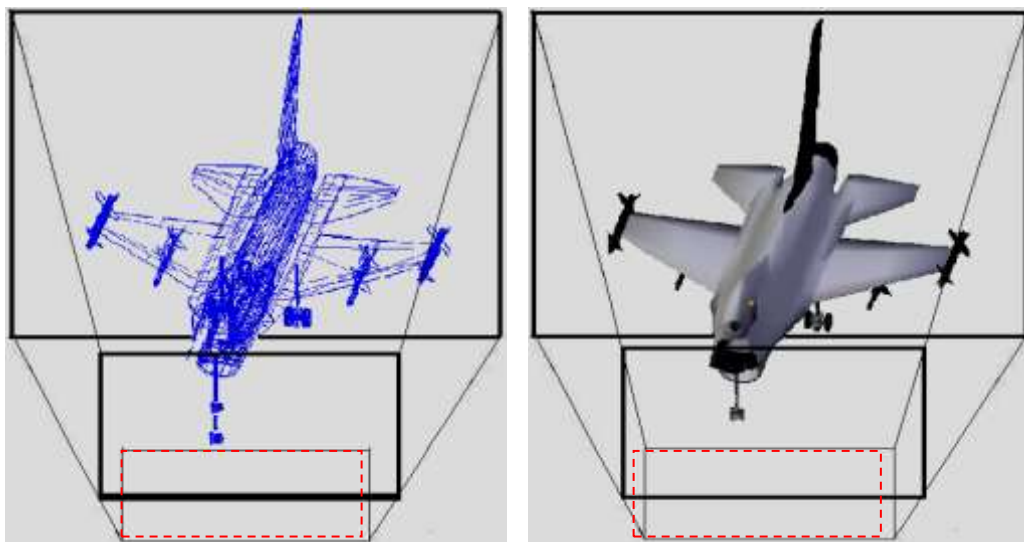


Figure 6.30: The peeling and focus technique moves the near clipping planes of both layers

The peeling focus and context technique applies a similar method of moving the clipping planes to the peeling focus technique. However, in the peeling focus and context technique the near clipping planes of both layers are moved forward or backward at the same rate. The far clipping planes of both layers are unchanged. As a

result, the same portions of the model are either removed or revealed from both layers, as shown in Figure 6.30.

6.8.5 Component segregation

As previously discussed in Section 6.2.2, the component segregation technique is used for splitting the components of the selected object between the two layers of MLD when working in edit mode.

The Back surface removal (see Section 3.6.2.5) was tested as a possible method for implementing the component segregation technique. However, it was decided that a more advanced method is needed because the visibility of the components on the front and back layers of MLD are opposite to each other in component segregation. On the front layer the components of the back face need to be removed, while on the back layer, the component of the front face need to be removed. So, using the back surface removal technique could only solve part of the requirement, which led to the conclusion that this technique was not particularly useful here.

A different method was therefore developed to implement the component segregation technique. In this method, the visibility of the surfaces to appear, either on the front or back layer, are determined by calculating the normal values of polygon using their dot products. The two vectors required in the dot product calculation are determined by three continuous vertices of each polygon in the clockwise rotation. An example is shown in Figure 6.31.

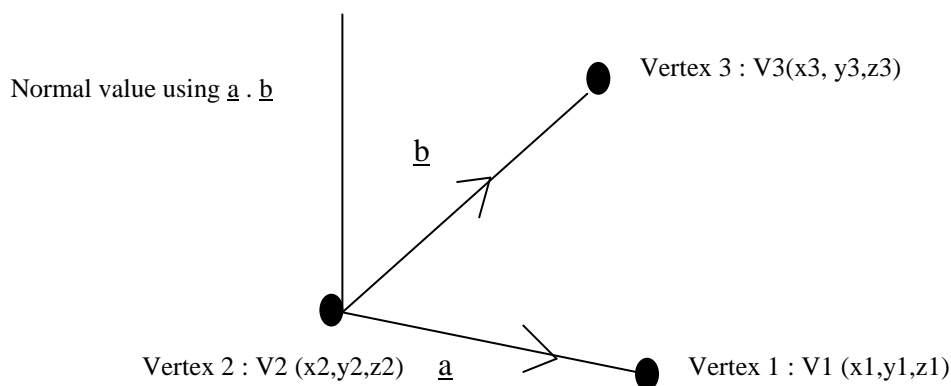


Figure 6.31: Representations of the vertices of polygon

$$\underline{a} = (x1 - x2, y1 - y2, z1 - z2)$$

$$\underline{b} = (x3 - x2, y3 - y2, z3 - z2)$$

where \underline{a} and \underline{b} can be rewritten as

$$\underline{a} = a_1 \underline{i} + a_2 \underline{j} + a_3 \underline{k}$$

$$\underline{b} = b_1 \underline{i} + b_2 \underline{j} + b_3 \underline{k}$$

The dot product of \underline{a} and \underline{b} is calculated as follow:

$$\underline{a} \cdot \underline{b} = (a_1 * b_1 + a_2 * b_2 + a_3 * b_3)$$

If the dot product resulting from these calculations is greater than or equal to zero, the coordinates (i.e. X, Y, and Z) of the relevant vertices are stored in the array. This implies that these vertices of the polygon are facing the viewer and need to be displayed on the front layer. The other vertices, for which the result of the dot product is less than zero, are not stored in the array. This array is used by the system immediately before displaying the vertices and edges of each polygon. Vertices which are found in the array are displayed on the front layer while others not found in the array are shown on the back layer. During the manipulation or navigation process, the dot product of each polygon is calculated again to reflect the object's new orientation. Codes used for calculating the dot products (i.e. normal values) of the polygons and those for determining the visibility of the components to be displayed (i.e. either on the front or back layers) are included in Appendix D.

6.9 Summary

In this chapter a set of focus and context awareness techniques has been discussed. These techniques are object isolation, component segregation, peeling focus, slicing, and peeling focus and context. The aim of these techniques is to enable modelers to maintain focus and context awareness while performing 3D modeling tasks, with the hope of addressing problems they regularly face, as identified in the previous chapter. However, it is important to evaluate these techniques in order to examine their effectiveness over existing methods provided by conventional 3D modeling software. The next chapter presents a user study of the techniques proposed in this chapter.

CHAPTER 7

Evaluation of the Focus and Context Awareness Techniques

The previous chapter described the design and implementation of a set of focus and context awareness techniques. These techniques were: object isolation, component segregation, peeling focus, slicing, and peeling focus and context. This chapter describes a user study conducted to evaluate these techniques. The aim of this study was to compare the effectiveness of the developed focus and context awareness techniques with several conventional techniques provided by existing 3D modeling software. The study analyzed the task completion time, the quality of the models created during the study tasks, and the participants' opinion about the techniques they used.

The study discussed in this chapter was conducted with the approval of the Ethics Committee of the Faculty of Computing and Mathematical Sciences, University of Waikato. A copy of the approval letter is attached in Appendix E.

This chapter begins with an outline of the proposed research questions (Section 7.1). This is followed by a description of the two controlled experiment conditions (Section 7.2). An overview of the study participants is given in Section 7.3. Setup and study methodology are described in sections 7.4 and 7.5 respectively. A detailed discussion of the tasks assigned to the study participants and the four types of data gathered during the study are provided in sections 7.6 and 7.7. The results of the study are presented in Section 7.8. The chapter concludes with a discussion (Section 7.9) and summary (Section 7.10).

7.1 Evaluation Research Questions

The goal of this study was to identify whether there are any significant differences between the participants' performance in completing the tasks using the focus and context awareness techniques developed for MLD and existing modeling techniques provided by conventional software. To do this, two experimental conditions were

used in this study, where participants were asked to perform a number of tasks using specific modeling techniques in each of the two experiment environments. A range of data were collected and analyzed to answer a number of research questions. These evaluation questions were:

1. Does object isolation used with MLD improves focus and context awareness in comparison to using the hiding technique with conventional displays?
2. Does component segregation technique used with MLD improve focus and context awareness in comparison to using the hidden surface removal technique with conventional displays?
3. Does peeling focus technique used with MLD improve focus and context awareness in comparison to using the zooming technique with conventional displays?
4. Does slicing technique used with MLD improve focus and context awareness in comparison to using the hiding technique with conventional displays?
5. Does peeling focus and context technique used with MLD improve focus and context awareness in comparison to displaying the model in wireframe display mode with conventional displays?

7.2 Experiment Conditions

This study was conducted using two controlled experiment conditions, as presented in Table 7.1. They will be referred to in this chapter as: SLD, using existing modeling techniques, and MLD using the new focus and context awareness techniques.

Table 7.1: Overview of the two experimental conditions

SLD (Single Layered Display)	MLD (Multi Layered Displays)
<ul style="list-style-type: none"> • original Blender software 	<ul style="list-style-type: none"> • Blender software with the five new techniques (see Chapter 6)
<ul style="list-style-type: none"> • conventional 2D display 	<ul style="list-style-type: none"> • multi-layer display
<ul style="list-style-type: none"> • two viewports opened side by side. 	<ul style="list-style-type: none"> • two viewports on the front and back layer of MLD

Note that in this chapter the terms V1 and V2 are used to refer to two side-by-side viewports 1 and 2 used in SLD, where V1 refers to the left viewport and V2 to the

right viewport. In MLD the two viewports are displayed on the two layers and the terms front and back layers are used to refer to these two viewports in MLD.

7.3 Participants

An open invitation was sent to undergraduate computer science students taking a course in graphics and multimedia⁵ at the University of Waikato. The minimum requirement for taking part in this experiment was that the participants must have some experience in 3D modeling tasks. The reason for selecting students (i.e. novice modelers) as participants was because the previous studies (see chapters 4 and 5) established that novice and expert 3D modelers had similar difficulties with respect to focus and context awareness issues. Novice users however do not tend to have bias toward any specific software or functionality. Having the participants of the same background (i.e. graphics and multimedia) can avoid from having a participant(s) that are different from others known as "sample selection bias" (Cuddeback, et al. (2004).

Sixteen participants took part in this study 8 of whom had previous modeling experience in Blender, and the other 8 had no experience in Blender but had used other modeling software such Maya (Autodesk, 2012) and 3Ds Studio Max (Autodesk, 2012). Fourteen of the participants were male and 2 were female. None of the participants had any previous working or modeling experience using MLD.

7.4 Setup

Two types of display devices were used during the study. In SLD, a conventional 17 inch flat monitor was used, while in MLD a Deep Video™ (Puredepth, 2012) 17 inch flat monitor with dual front and back layers was used. In both conditions a Pentium 4 CPU, running Microsoft Windows XP, with a speed of 3GHz and the RAM size of 1GB was used to run the modified or unmodified versions of Blender modeling software. The hardware used in the experiment came with two graphic cards that were required for MLD.

The experiment was conducted in the Usability Laboratory of the Department of Computer Science at the University of Waikato. The participants were observed from

⁵ This was the same course used for finding participants as the pilot study presented in Chapter 4, but a year later and with new students.

a control room through a one-way mirror. A screen-capture device was used for recording the participant's computer screen. An extra video camera was also placed behind the participant in order to capture the activities that took place on their monitor screen, including the mouse cursor position, (i.e. whether it was on the front or back layer of MLD). The participants' faces were not video recorded in this study.

7.5 Methodology

In this experiment each participant was asked to perform 10 modeling tasks: a set of five tasks in SLD and another set of five tasks in MLD. The tasks and their level of difficulty were comparable between the two sets. Before conducting the experiment several experts performed the tasks to make sure that they were comparable.

In SLD, two viewports of the same size were opened side-by-side. Different panning and zooming techniques could be used in the two viewports of SLD. Participants were also free to close the viewports at their own discretion. The two viewports could be used for viewing the focus and context area interchangeably during the modeling tasks.

In MLD, however, focus and context were shown on two viewports on top of one another. As described in Chapter 6, even though focus and context information can be displayed on both the front and back layers of MLD, or interchangeably between them, it was decided to use the front layer for displaying focus and the back layer for displaying context information. Unlike SLD, the same panning and zooming effects were applied to both focus and context viewports. This allowed the objects on both layers to be shown in the same orientation at all times during the modeling tasks.

The order of the use of SLD and MLD was counterbalanced to reduce any possible learning effects across the two conditions. The experiment had a within-subjects design, where each participant was required to experience both conditions. Half of the participants completed the first set of tasks in SLD followed by the second set of tasks in MLD, while the other half worked in MLD first, followed by SLD. The complete ordering of the experiments tasks and condition is given in Table 7.2.

In this experiment the order of the tasks were not changed, and all the participants experienced the new focus and context awareness techniques developed for MLD in the same order. The tasks were independent of one another and the learning effect as

not considered to be an issue.

Table 7.2: Grouping and order of the study

No of participants	SLD						MLD				
4 with, and 4 without Blender experience	Task 1a	Task 2a	Task 3a	Task 4a	Task 5a		Task 1b	Task 2b	Task 3b	Task 4b	Task 5b
	MLD						SLD				
4 with, and 4 without Blender experience	Task 1a	Task 2a	Task 3a	Task 4a	Task 5a		Task 1b	Task 2b	Task 3b	Task 4b	Task 5b

Prior to using MLD a tutorial was given to the participants to familiarize them with the five focus and context awareness techniques. There was no time limit for the tutorial session, and the participants were allowed to ask for further explanations from an observer if need.

Although no specific tutorial was given to the participants prior to using SLD, they were given a sheet of paper containing a summary of various commands, such as short-cut keys and command buttons. Participants were also given an unlimited time to acquaint themselves with the features and functions of Blender before doing the experiment in SLD. Naturally, during the SLD tutorial session, the participants who had no previous experience of using Blender took longer to familiarize themselves with Blender. In this study, the amount of time spent on the tutorial section was not recorded or analyzed.

During the actual study tasks sessions, the participants were given several printed images of the models relevant to the tasks they were performing. These images included:

- the initial condition of the model,
- a zoomed-in view of the object of interest (i.e. focus) that needed to be manipulated,
- a zoomed in view of other objects (i.e. context) relevant to the tasks, and
- the expected outcome (finished model) that needed to be produced.

In addition to these, the participants were also given detailed instructions on the requirements of each task. The detailed instructions explained the conditions that needed to be observed when manipulating the object of interest (i.e. focus) and the

rest of the model (i.e. context). The images and instructions used in the experiments are included in Appendix F. In this study, a 3D model of a car was used.

7.6 Tasks

As mentioned above, the participants were asked to complete two sets of five tasks in this study. A summary of the tasks is given below in Table 7.3.

Table 7.3: Summary of the tasks used in this experiment

Task No.	SLD	MLD
1	Increasing the size of a particular object under the constraint of other objects.	
	To maximize the size of the middle part of the floor tray of the main chassis frame to cover a bigger area of the car as shown.	To maximize the size of the back part of the floor tray of the main chassis frame to cover a bigger area of the car as shown.
2	Matching the shape of object on the opposite sides.	
	To replicate (without copying or duplicating) the design of the right side windscreen to the left side windscreen of the car, that is to edit the left side windscreen to be the same as the right side windscreen.	To replicate (without copying or duplicating) the design of the left side door to the right side door of the car, that is to edit the right side door to be the same as the left side door.
3	Relocating an object inside an obscured area.	
	To place the main chassis frame in the designated area.	To install steering wheel gears in the designated area.
4	Positioning two objects inside obscured area.	
	To place the front engine and the speedometer in its new location.	To place the steering wheel and driver's seat in their designated area.
5	Aligning two objects or components.	
	To complete making the square frame under the main chassis.	To create a link or a bar between the front and back track rods under the main chassis.

Each task was divided into two subtasks. The first subtask was to locate the object of interest (i.e. focus) and to determine its relationship with the rest of the model (i.e. context). The second subtask was to perform the actual modeling task (e.g. transforming and editing an object or component). In each task, participants were instructed to use a specific modeling technique as stated in the instruction sheet. The

following sections describe each of the tasks in detail.

7.6.1 Task 1: Increasing the Size of a Particular Object Under the Constraint of Other Objects

Findings from the background studies (see chapters 4 and 5) showed that in many instances modelers are required to shape objects which are constrained or influenced by other objects. For example, when enlarging the size of the windscreen of the model of a car, its size needs to fit in the windscreen area of the car. This type of tasks is even more challenging when the objects involved are hidden or obstructed by other objects inside the model.

Task 1 was therefore designed such that the participants were required to look for a hidden object of interest (e.g. the chassis floor tray). In addition, the participants also needed to be aware of the relationship between the object of interest and the hidden context (e.g. the internal parts of the car) before modifying the model. Once the relationship between the focus and context was identified, then the participants were required to maximize the size of the chassis floor tray, with the condition that the enlarged floor tray should not exceed the body of the car. In addition, the enlarged floor tray was not supposed to overlap with the position of the four tyres either. To enlarge the floor tray, the participants needed to select and extrude its edges.

The overall objective of this task was to determine whether the problem of recognizing object's relative position, and the distance between them, as discussed in Chapter 5, could be overcome by using the object isolation technique developed for MLD. A summary of the techniques that needed to be used in this task in both SLD and MLD is given in Table 7. 4. Task the hiding technique was used in SLD while the object isolation technique was used in MLD and can be used to locate the targeted object obscured by others. However, this technique temporarily removes some of the information (i.e. context) relevant to the tasks. Consequently, recognizing the relationship between them can be difficult. In comparison, object isolation technique used in MLD maintains the visibility of both objects of interest and context at all time.

Table 7.4: Summary of the techniques used in SLD and MLD

Condition	Technique	Visual Effects
SLD	Hiding	<ol style="list-style-type: none">i. Hide the selected objects until the object of interest appears on V1 and it is shown in solid mode.ii. All objects including the selected appear on V2 and they are displayed in wireframe mode.
MLD	Object isolation	<ol style="list-style-type: none">i. Only the object of interest appears on the front layer and it is shown in solid mode.ii. All objects including the selected object appear on the back layer and they are displayed in wireframe mode.

In this task the participants would see the model in its initial condition in SLD as shown in Figure 7.1, and in MLD as shown in Figure 7.2.

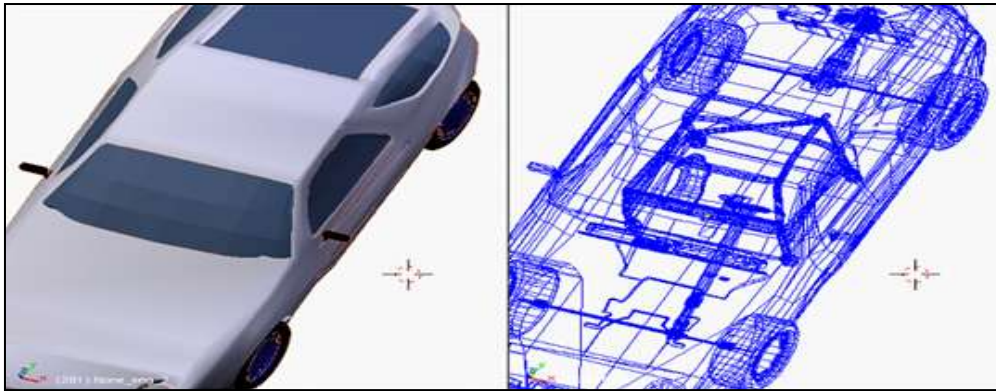


Figure 7.1: The initial view of the model in SLD

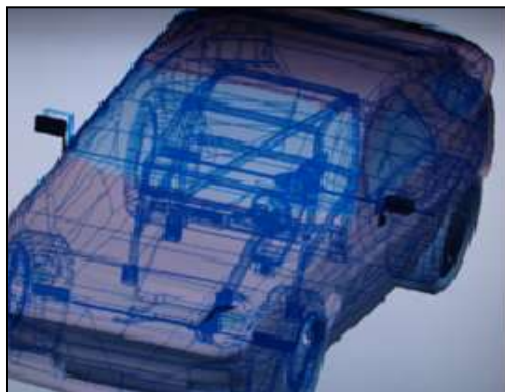


Figure 7.2: The initial view of the model in MLD

In both SLD and MLD, the participants were also told that the four legs of the chassis floor should not be moved. To better clarify this, the image shown in Figure 7.3 was given to them, in which the arrows point to the four legs.

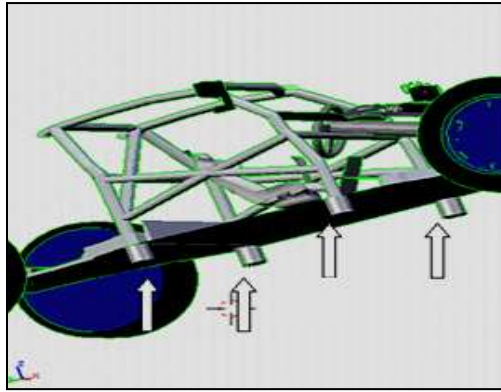


Figure 7.3: The four legs of the chassis floor that needed not be moved are indicated by the arrows

The final goal of this task in SLD was to maximize the rear part of the floor chassis, as illustrated in Figure 7.4.

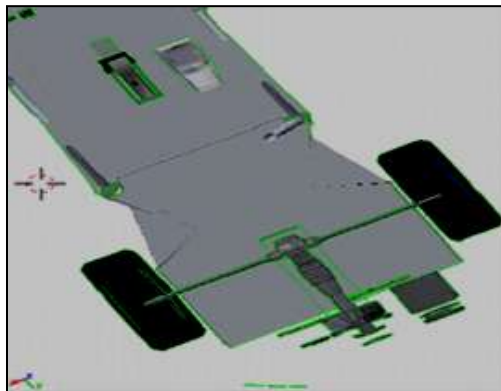


Figure 7.4: The expected finished model in SLD

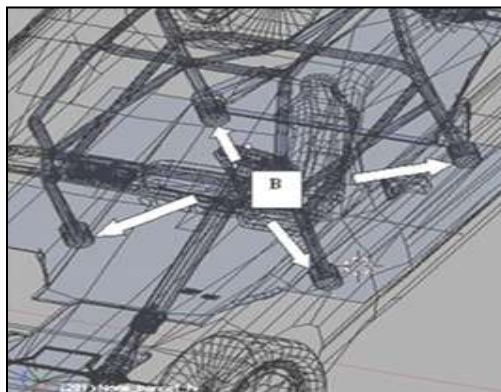


Figure 7.5: The expected finished model in MLD. The B shows the legs of the chassis floor

In MLD, the participants were asked to enlarge the right and left sides of the chassis floor. While doing so, the enlarged chassis floor was not allowed to exceed the size of the car. As such, the participants needed to realize the relationship between the object of interest (i.e. chassis floor) and the context (i.e. the body of the car) while performing this task. Figure 7.5 illustrates the expected finished model after the right and left side of the floor were enlarged.

7.6.2 Task 2: Matching the Shape of Objects on the Opposite Sides

Findings from the earlier studies showed that the absence of depth perspective in 3D modeling environments causes modelers some difficulties while performing modeling tasks, particularly when the tasks involve selecting objects or components which are overlapping, and this leads to selecting the wrong objects or components.

In Task 2, the participants were asked to perform a task that required them to select and compare a group of components on the opposite sides of the same object. The aim of the task was to identify the differences between two sides of the object and then to align them. A summary of the techniques that needed to be used in this task is given in Table 7.5. In this task, the hidden surface removal technique was used in SLD while the component segregation technique was in MLD.

Table 7.5: Summary of the techniques used in SLD and MLD

Condition	Technique	Visual Effects
SLD	Hidden surface removal	<ul style="list-style-type: none">i. Components of the object of interest that need to be changed appear on V1.ii. Components of the object of interest that need to be compared to appear on V2.
MLD	Component segregation	<ul style="list-style-type: none">i. Components of the object of interest that need to be changed appear on the front layer.ii. Components of the object of interest that need to be compared to appear on the back layer.

In SLD, the participants were first required to identify the differences between the two sides of the car's windscreen, which involved identifying the positions of the components (i.e. vertices and edges). Once the differences between the components of the two sides were identified, the participants were required to edit the right side of the windscreen to replicate the left side. The two sides of the windscreen were displayed next to each other on V1 (i.e. focus) and V2 (i.e. context) as shown in Figure 7.6.

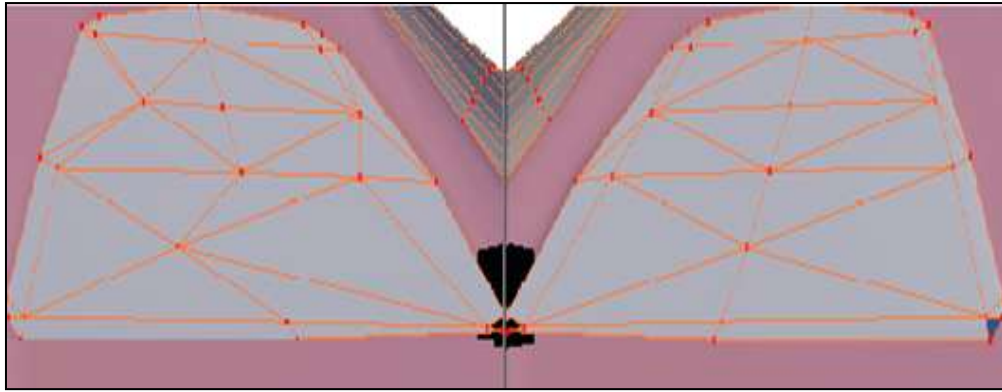


Figure 7.6: Focus and context are displayed next to each other in SLD

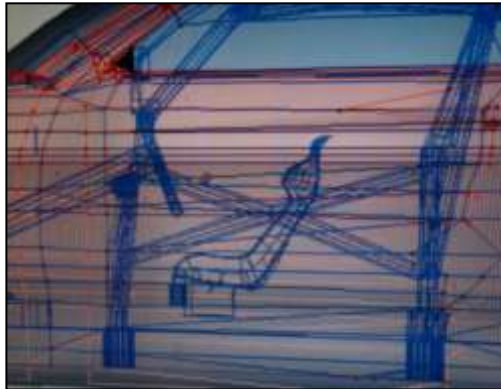


Figure 7.7: The left door is shown on the front layer while the right door is shown on the back layer of MLD

In MLD, the participants were given a similar type of task where they were first required to identify the differences between the two side doors. The participants were then asked to modify the components of the left door to replicate the right door. In this task, the object of interest (i.e. left door) was shown on the front layer while the context (i.e. right door) was shown on the back layer of MLD (see Figure 7.7). Note that the model is shown in component editing mode.

7.6.3 Task 3: Relocating an Object Inside an Obscured Area

As discussed in Chapter 5, position awareness and realizing the distance between objects or components are two common problems faced by modelers while performing 3D modeling tasks. These problems often occur when a modeler navigates around or manipulates objects in 3D space which subsequently changes the orientation of the objects. In addition, overlapping of objects on a conventional display makes it difficult for modelers to realize the distance between objects. Thus, in this task the participants were asked to perform the task that imitates this situation by using the required modeling techniques as given in Table 7.6. The zooming while in perspective view technique was used in SLD while the peeling focus technique was

in MLD.

In this task the participants were required to move an object from the outside of a car to a designated area inside the car. In SLD, the task involved moving the main chassis frame from outside the car and placing it in its location inside the car. Figure 7.8 illustrates the initial view of the model in SLD. The image on the left shows the initial condition of the model in solid mode on the left viewport, while the right image shows the model in wireframe mode on the right viewport. The arrow A and shown in this figure highlight the object of interest (i.e. main chassis frame) that needs to be relocated to its designated area. The designated area was shown in detailed in the handout given to the participants (included in Appendix F). The participants needed to realize the relationship between the object of interest and the rest of the model, particularly its designated area. Besides realizing the relationship between them, the participants needed to also realize the relative position of the objects or components involved.

Table 7.6: Summary of the techniques used in SLD and MLD

Condition	Technique	Visual Effects
SLD	Zooming while in perspective view	<ul style="list-style-type: none"> i. Going through the skin of the model until the object of interest is found on V1. The sizes of objects shown on the display change in this process. ii. The whole context of the model appears on V2 in wireframe mode.
MLD	Peeling Focus	<ul style="list-style-type: none"> i. Portions of the model are removed until the object of interest is visible on the front layer. The sizes of objects remain the same in this process. ii. The whole context of the model appears on the back layer in wireframe mode.

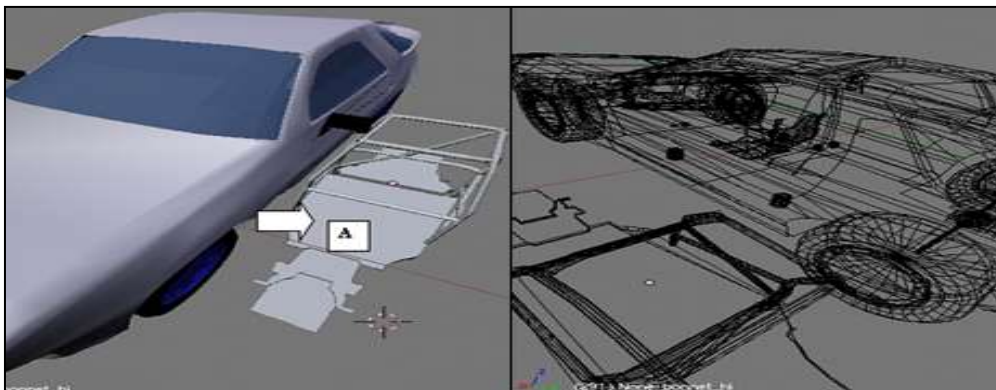


Figure 7.8: The initial view of the model in SLD

After realizing the relationship between the focus and context, the participants needed to place the object of interest inside the car, while observing the requirements stated in the task sheet (i.e. the safety bar of the chassis frame should not cross over the steering arm B, and the height of the frame must be maximized to C without going over the roof) as shown in Figure 7.9.

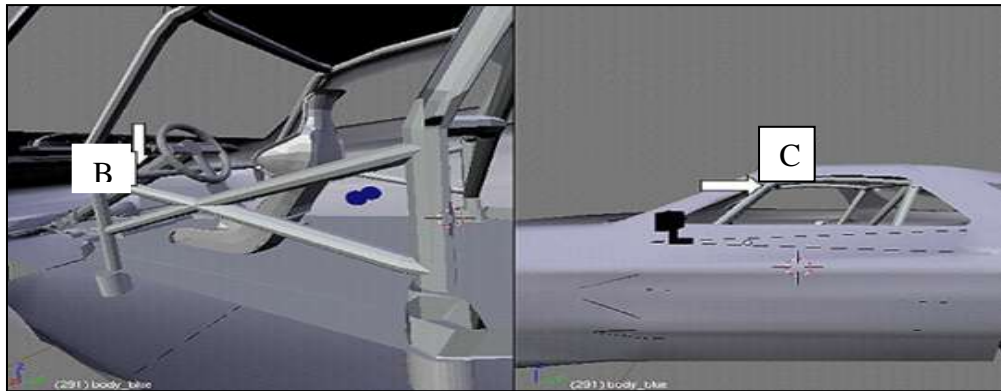


Figure 7.9: The expected finished model in SLD

In MLD, a comparable task was given to the participants, asking them to move the steering wheel set from outside the car to its designated area inside the car. As in SLD, some requirements needed to be observed, which were stated in the task sheet (see Appendix F). The participants started with the model as shown in Figure 7.10. They then needed to determine the relationship between the object of interest (i.e. steering wheel set) and the context of the model, particularly the safety bar of the main chassis frame.

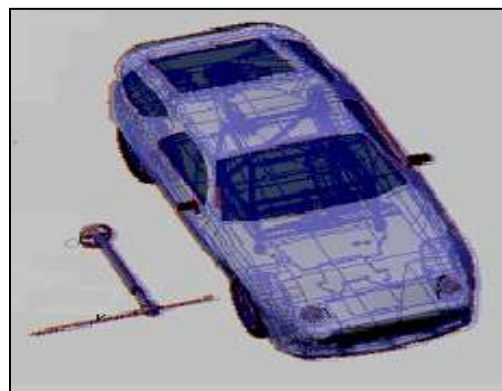


Figure 7.10: The initial condition of the model in MLD with the steering wheel set outside the car

Figure 7.11 illustrates the expected finished model where the steering arm is placed between the two safety bars of the chassis frame. It was anticipated that the visibility of the safety bars of the chassis frame was important to the modeler while completing this task so that it could be placed correctly between them.

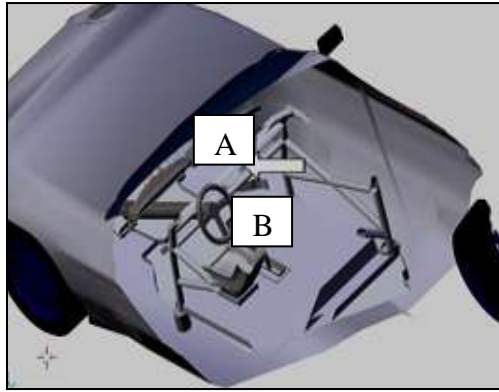


Figure 7.11: Expected finished model in MLD where the steering arm is placed between the two safety bars A and B

7.6.4 Task 4: Positioning Two Objects Inside an Obscured Area

This task was included in the study based on the findings from the previous studies which showed that maintaining position awareness and recognizing the relative position of 3D objects while performing modeling tasks are often difficult. Without a good sense of depth perspective, modelers often fail to place the object of interest in a designated area correctly. In this task the techniques listed in Table 7.7 were used. The hiding technique was used in SLD to hide all objects except the object of interest from the left viewport while keeping everything visible on the right viewport. The slicing technique was used in MLD to transfer the object of interest to the front layer while keeping the context on the back

Table 7.7: Summary of the techniques used in SLD and MLD

Condition	Technique	Visual Effects
SLD	Hiding	<ul style="list-style-type: none"> i. Hide all objects except the selected object (i.e. object of interest) in V1. ii. The whole context of the model appears in V2 in wireframe mode.
MLD	Slicing	<ul style="list-style-type: none"> i. Slicing and transferring the model until the object of interest appears on the front layer of MLD. ii. The remaining parts of the model (i.e. context) appear on the back layer

In this task, the participants were asked to move two objects which were dependent on each other to a designated area inside the car. In SLD the two objects of interest were the engine and the speedometer as shown in Figure 7.12. As with Task 3, the participants needed to realize the relative position of the objects and components involved when moving them to the designated area.

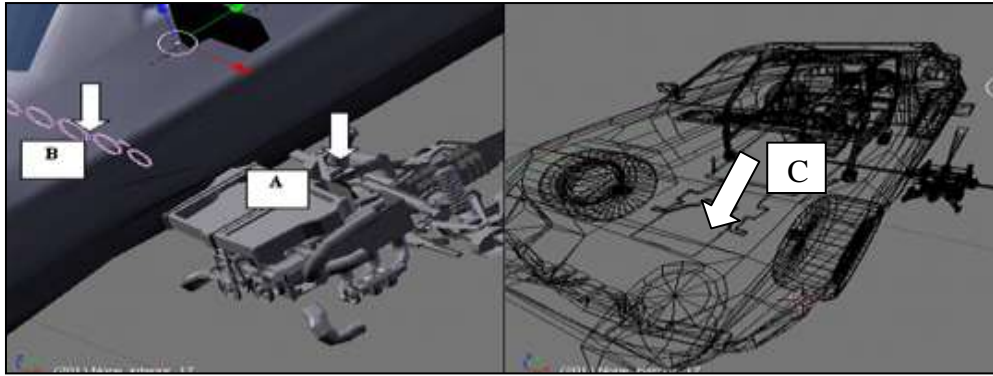


Figure 7.12: The two objects of interest marked with A and B in the left viewport and the designated area marked C in the right viewport

When placing the engine inside the car, the requirement was that it must be placed at the base marked C, and the rod of the engine must be tilted in order to be connected to the steering wheel. Figure 7.13 illustrates the expected finished model for this task in SLD.

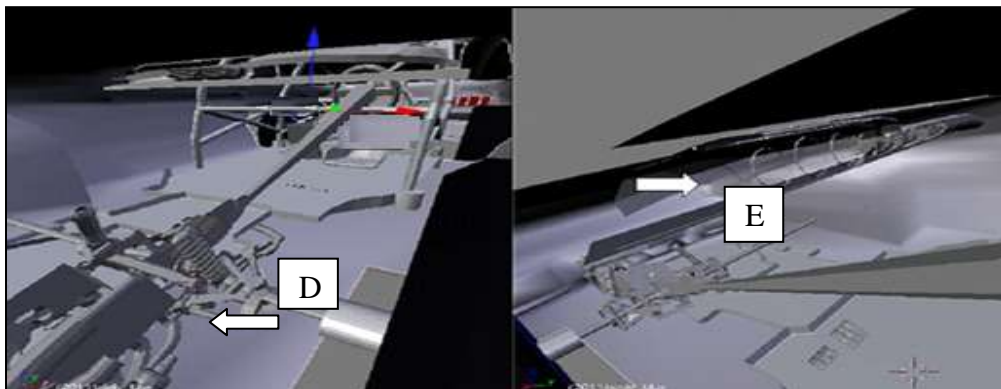


Figure 7.13: The expected finished model in SLD which shows the engine D and speedometer E at their designated locations

In MLD the participants were asked to move the driver's seat A and the steering unit B from the outside of the car to their designated position inside the car. Figure 7-14 illustrates the initial view of the model in MLD.

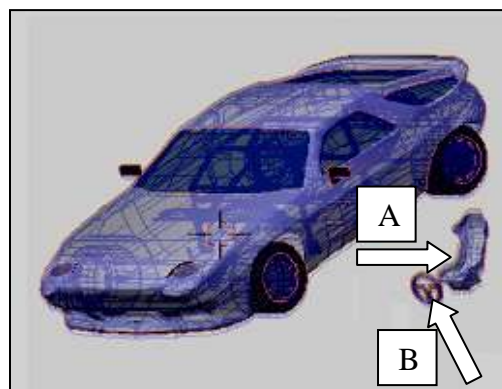


Figure 7.14: The initial view of the model in MLD showing the driver's seat A and the steering unit B outside the car

In doing this task, the driver's seat marked A needed to be placed at its base marked C, and the steering needed to be connected with the steering arm marked D (see Figure 7.15).

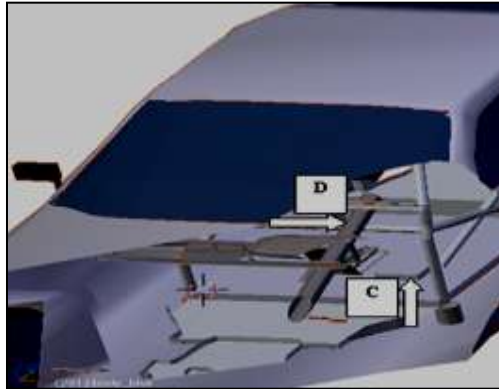


Figure 7.15: The expected finished model in MLD which shows the driver's seat C and the steering arm D at their designated locations

7.6.5 Task 5: Aligning Two Objects or Components

Findings from the earlier studies (see chapters 4 and 5) showed that modelers are often required to align two or more objects of the model. For example, the model of a town area might consist of several buildings that need to be placed and aligned accordingly. In many such cases, the objects involved are obstructed by each other which makes it difficult to align them. In addition, this task is performed on a conventional display, on which recognizing relative position of objects can be difficult due to the lack of support for depth perspective.

This task was therefore designed to require the participants to look for obstructed objects of interest in the context and align them. In this task the participants needed to be aware of the relationship between both the focus and context, in term of the distance between objects, their relative position, and alignment. Once the relationship between the focus and context was identified, then the object of interest needed to be shifted and aligned.

The overall objective of this task was to determine whether the problem of recognizing the relative position of objects, and the distance between objects or components, could be overcome by using the peeling focus and context technique. A summary of the techniques that needed to be used for this task in both SLD and MLD is given in Table 7. 8. In this task the wireframe display mode was used in SLD, while the peeling focus and context technique was in MLD.

Table 7.8: Summary of the techniques used in SLD and MLD

Setup	Technique	Visual Effects
SLD	Wireframe display mode	i. The object of interest is shown in wireframe mode in V1. ii. The overview (i.e. context) of the model appears in V2 in solid mode.
MLD	Peeling Focus and context	i. The near part of the model is peeled off until the object of interest is visible on the front and back layer. On the front layer, the model is viewed in solid mode while on the back layer the model is in wireframe mode.

In SLD the object of interest was an incomplete square frame obscured under the floor of the main chassis. The participants needed to first locate the incomplete square frame A as shown in Figure 7.16. To complete this task the participants then needed to compare the initial condition of the model with the images of the finished model, as shown in Figure 7.17, in which the completed square frame B has been laid and aligned under the floor C.

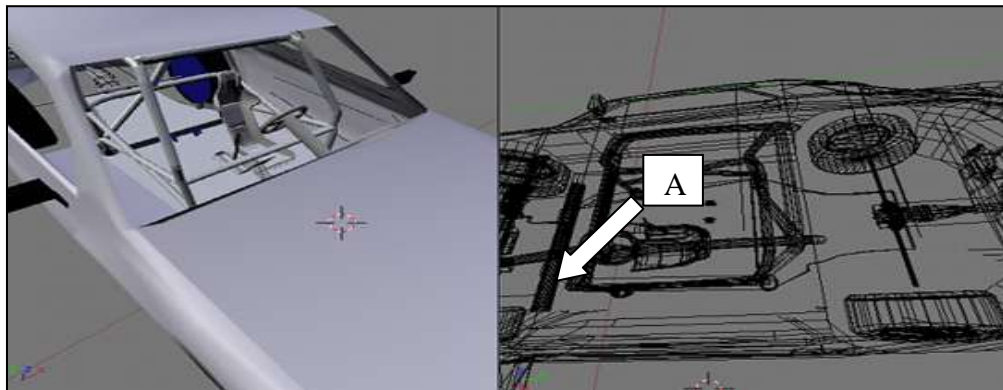


Figure 7.16: The incomplete square frame A shown on the right viewport

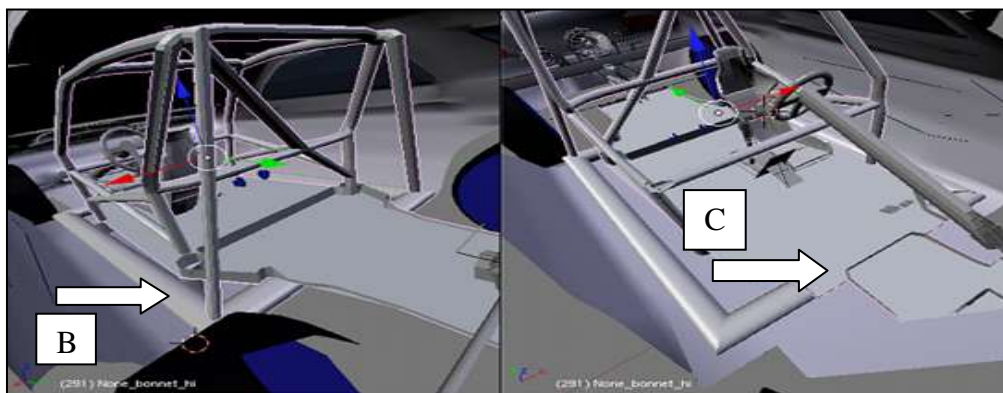


Figure 7.17: Square frame laid and aligned under the floor

In MLD the participants were required to align and create a link between the front and back track rods under the main chassis. Figure 7.18 shows the initial view of the model in MLD. In this figure, the objects of interest are not clearly visible and the

participants needed to locate the objects of interest by peeling the focus and context.

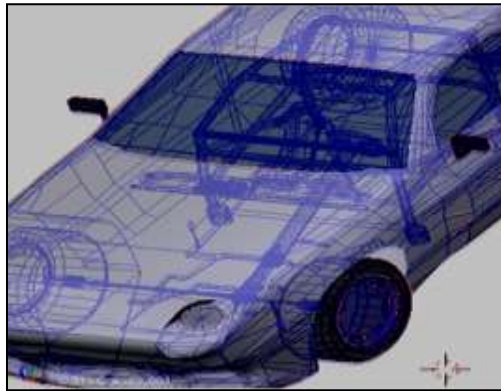


Figure 7.18: The initial view of the model in MLD showing the internal parts of the car

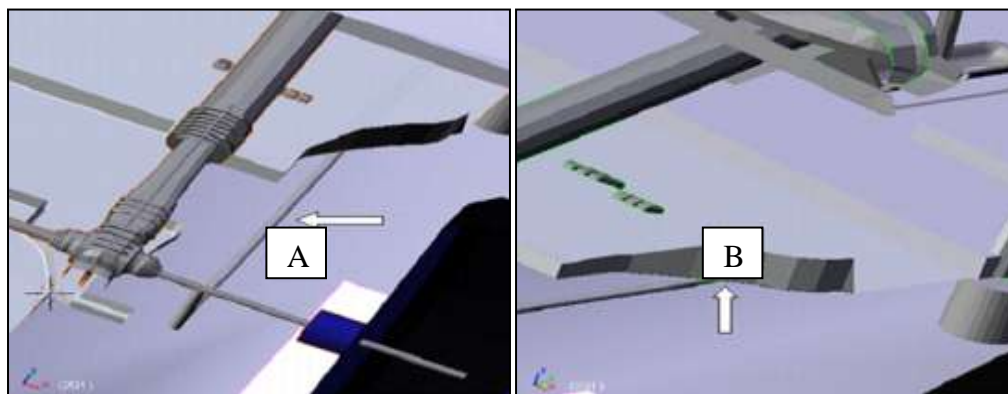


Figure 7.19: Images of the expected finished model in MLD, illustrating the connected bar under the main chassis

Figure 7.19 shows two images of the expected finished model in MLD with the connected bar A under the main chassis B.

7.7 Data Collection

Three types of data were collected during this study. These were task completion time, quality of the finished model, and the participants' opinion regarding the tasks they performed and the environments in which they completed the tasks.

7.7.1 Task Completion Time

The total time to complete each task (TC) was measured in two parts: the time taken to locate the object of interest (TL) and the time to complete the modifications required to the model (TM).

The time taken to locate the object of interest (TL) was measured because the object of interest is often obstructed or overlaps with other objects in the model. In most modeling tasks which require object manipulation and transformation, the ability to pick or to select the correct object is therefore critical.

The time to complete the required modifications (TM) was measured to see how much time was spent on doing the task rather than on finding the object of interest.

7.7.2 Quality of the Finished Model

The quality of the finished models was measured to evaluate the output of each task by each of the participants. The evaluation of the output was done by the author alone. It involved viewing the finished output produced by the participants against the expected outcome for each task as described on the task sheets. This was felt to be satisfactory because the tasks were precisely defined and the expected outcomes were clearly shown on the task sheets. A score of one to three was given to each finished model. A score of one was given for an incomplete model that was far off the expected finished model. A score of two was given to a reasonably finished model, while a score of three was given to a perfectly finished model. The quality of the models was assessed independently of the task completion time. The reason for this was that the participants were given an unlimited amount of time to complete their tasks.

7.7.3 Participant's Opinion

In this study a set of questionnaires were used to collect the participants' opinion. The participants were asked to answer a set of questionnaire upon completion of each task. These questionnaires are presented in Table 7.9. After completing all the 10 tasks, the participants were also asked to answer another set of questions to obtain their view of both experimental conditions. The final questions is given in Table 7.10.

Table 7.9: Questionnaires answered by the participants after each task was completed

Tasks	Questions	Response on a scale of 1-7	
Task 1			
1	How difficult was it to select a single vertex?	Not Difficult 1	Very Difficult 7
2	How useful was isolating a particular object from the rest of the objects in the model for editing?	Not Useful 1	Very Useful 7
3	I was able to effectively complete this task using the system.	Strongly Disagree 1	Strongly Agree 7
Task 2			
1	How difficult was it to select a single vertex?	Not Difficult 1	Very Difficult 7
2	How difficult was it to determine the differences between groups of objects or items?	Not Useful 1	Very Useful 7
3	How important was it to view all other objects while working on a particular component?	Strongly Disagree 1	Strongly Agree 7
4	I was able to effectively complete this task using the system.	Strongly Disagree 1	Strongly Agree 7
Task 3			
1	How difficult was it to locate a specific object?	Not Difficult 1	Very Difficult 7
2	How difficult was it to see the relationships between objects in term of distance and orientation?	Not Useful 1	Very Useful 7
3	I was able to effectively complete this task using the system.	Strongly Disagree 1	Strongly Agree 7
Task 4			
1	How difficult was it to locate a specific object?	Not Difficult: 1	Very Difficult 7
2	How important was it to know the relation between a particular object from rest of the objects in the model?	Not Useful 1	Very Useful 7
3	I was able to effectively complete this task using the system.	Strongly Disagree 1	Strongly Agree 7
Task 5			
1	How difficult was it to locate a specific object?	Not Difficult: 1	Very Difficult 7
2	I was able to effectively complete this task using the system?	Strongly Disagree 1	Strongly Agree 7

Table 7.10: Questionnaire answered after all the 10 tasks were completed

Questions	Response on a scale of 1 to 7				
	SLD		MLD		
1	How easy was it to align objects in SLD and MLD (e.g. when putting objects on top of another objects)?	Not Easy 1	Very Easy 7	Not Easy 1	Very Easy 7
2	How useful was the depth perception in SLD and MLD?	Not Useful 1	Very Useful 7	Not Useful 1	Very Useful 7
3	How effective was the separation of a particular object from other objects in the model in SLD and MLD systems?	Not effective 1	Very effective 7	Not Effective 1	Very Effective 7
4	Depth perception improved my work performance.		Strongly Disagree 1	Strongly Agree 7	
5	The ability to separate a particular object from others improved my work performance.		Strongly Disagree 1	Strongly Agree 7	
6	The ability to maintain focus and context awareness is important in order to avoid the confusion related to object orientation from occurring during navigation and manipulation		Strongly Disagree 1	Strongly Agree 7	
7	The ability to maintain focus and context awareness improved my work performance		Strongly Disagree 1	Strongly Agree 7	
8	In general, modeling in MLD is more effective than in SLD		Strongly Disagree 1	Strongly Agree 7	

In addition to these questionnaires a brief interview was also conducted at the end of the experiment sessions. The purpose of the interview was to get the participants' feedback on the strength, weakness, and improvements that needed to be made to the focus and context awareness techniques developed for MLD.

7.8 Results

The following sections present the results of the experiment. These have been organized into three sections: the task completion time, the quality of the finished models, and the participants' opinions.

7.8.1 Task Completion Time

The data gathered from the experiment were analyzed using the statistical software MINITAB (Minitab, 2012). The task completion time was analyzed using a general linear analysis function. Several factors were taken into consideration for this analysis. These included the experimental conditions, order of the experiment conditions, and the demographics of the participants. Therefore the analysis and the findings are divided into three groups:

- Conditions : comparing SLD versus MLD
- Order + conditions : comparing order of exposure to the experimental conditions SLD + MLD or MLD + SLD
- Demographics + conditions : comparing users with or without Blender experience

7.8.1.1 Result of Task 1: Increasing the Size of a Particular Object Under the Constraint of Other Objects

Table 7.11: Time taken to complete Task 1 in each of the environments

	SLD		MLD		F	p-value
	mean	SD	mean	SD		
TL	65.125	44.5	83.25	68.9	0.78	0.344
TM	234.4375	228.9	330.75	274.6	1.16	0.019
TC	299.5	241.7	414.1	287.6	1.48	0.09

i. TL (Time for Locating the object of interest)

Table 7.11 shows that the mean time taken for locating the objects of interest is higher in MLD than SLD. However the $F(1,30)$ value of 0.78 and p -value of 0.344 suggests that the differences between the two experiment conditions were not significant.

ii. TM (Time for Modification)

Table 7.11 also shows that the mean time taken for making the modifications is slightly higher in MLD than SLD. However the results of the analysis of $F(1,30)=1.16$ and p -value of 0.019 show that there was no significant difference between the time taken to complete the modifications using the different modeling techniques in SLD and MLD. This suggests that the separation of the object of interest from the context using the object isolation technique in MLD did not change the modification time

significantly.

iii. TC (Time for Completing the task)

The $F(1,30)=1.48$ and p -value of 0.09 shown in Table 7.11 also indicate that there was no significant difference between MLD and SLD in total time taken to complete Task 1.

7.8.1.2 Results of Task 2: Matching the Shape of the Objects on the Opposite Sides

Table 7.12: Time taken to complete Task 2 in each of the environments

	SLD		MLD		F	p-value
	mean	SD	mean	SD		
TL	82.875	27.29	62.6875	21.98	5.99	0.023
TM	478.625	257.6	301.1875	202.2	4.87	0.001
TC	561.5	269.4	363.8	208.5	5.57	0.001

i. TL (Time for Locating the object of interest)

Table 7.12 shows that the mean time taken for locating the objects of interest is higher in SLD than MLD. The $F(1,30)$ value of 5.99 and p -value of 0.023 suggests that the differences between the two experiment conditions were significant. This suggests that the participants took less time to locate the object of interest using the component segregation technique in MLD than the hiding technique in SLD.

ii. TM (Time for Modification)

Table 7.12 also shows that the mean time taken for making the modifications is higher in SLD than MLD. The results of the analysis of $F(1,30)=4.87$ and p -value of 0.001 show that there was a significant difference between the time taken to complete the modifications using the different modeling techniques in SLD and MLD. This suggests that the segregation of the object of interest from the context using the component segregation technique in MLD changed the modification time significantly.

iii. TC (Time for Completing the task)

The $F(1,30)=5.57$ and p -value of 0.001 shown in Table 7.12 also indicate that there was a significant difference between MLD and SLD in the total time taken to complete Task 2.

7.8.1.3 Results of Task 3: Relocating one Object Into the Obscured Area

Table 7.13: Time taken to complete Task 3 in each of the environments

	SLD		MLD		F	p-value
	mean	SD	mean	SD		
TL	65.1875	26	48.375	21	5.61	0.002
TM	264.375	186.6	158.6875	175	4.41	0.002
TC	329.5	188.1	207.1	168	5.55	0.001

i. TL (Time for Locating the object of interest)

Table 7.13 shows that the mean time taken for locating the objects of interest is higher in SLD than MLD. The $F(1,30)$ value of 5.61 and p -value of 0.002 suggests that the differences between the two experiment conditions were significant. This suggests that the participants took less time to locate the objects of interest using the peeling focus technique in MLD than the zooming technique in SLD.

ii. TM (Time for Modification)

Table 7.13 also shows that the mean time taken for making the modification is higher in SLD than MLD. The results of the analysis of $F(1,30)=4.41$ and p -value of 0.002 show that there was a significant difference between the time taken to complete the modifications using the different modeling techniques in SLD and MLD. This suggests that the ability to maintain focus and context awareness using the peeling focus technique in MLD changed the modification time significantly.

iii. TC (Time for Completing the task)

The $F(1,30)=5.55$ and p -value of 0.001 shown in Table 7.13 also indicate that there was a significant difference between MLD and SLD in the total time taken to complete Task 3.

7.8.1.4 Results of Task 4: Positioning Two Parts From Outside the Car Into the Specified Area Inside the Car

Table 7.14: Time taken to complete Task 4 in each of the environments

	SLD		MLD		F	p-value
	mean	SD	mean	SD		
TL	117.125	103.2	92.5	58.6	0.69	0.177
TM	485.9375	287.9	295.125	252.4	5.48	0.001
TC	630.1	343.5	384.3	301.8	4.67	0.001

i. TL (Time for Locating the object of interest)

Table 7.14 shows that the mean time taken for locating the objects of interest is higher in SLD than MLD. However the $F(1,30)$ value of 0.69 and p -value of 0.177 suggests that the differences between the two experiment conditions were not significant.

ii. TM (Time for Modification)

Table 7.14 also shows that the mean time taken for making the modifications is higher in SLD than MLD. The results of the analysis of $F(1,30)=5.48$ and p -value of 0.001 show that there was a significant difference between the time taken to complete the modifications using the different modeling techniques in SLD and MLD. This suggests that the ability to maintain focus and context awareness using the slicing technique in MLD changed the modification time significantly.

iii. TC (Time for Completing the task)

The $F(1,30)=4.67$ and p -value of 0.001 shown in Table 7.14 also indicate that there was a significant difference between MLD and SLD in the total time taken to complete Task 4.

7.8.1.5 Results of Task 5: Aligning Two Objects or Components

Table 7.15: Time taken to complete Task 5 in each of the environments

	SLD		MLD		F	p-value
	mean	SD	mean	SD		
TL	92.5625	50.2	137.6875	81	3.58	0.058
TM	747	348.6	603.75	285.7	1.67	0.114
TC	839.5	344.3	741.4	279.1	0.78	0.286

i. TL (Time for Locating the object of interest)

Table 7.15 shows that the mean time taken for locating the objects of interest is higher in MLD than SLD. However the $F(1,30)$ value of 3.58 and p -value of 0.058 suggests that the differences between the two experiment conditions were not significant.

ii. TM (Time for Modification)

Table 7.15 also shows that the mean time taken for making the modifications is slightly higher in SLD than MLD. However the results of the analysis of $F(1,30)=1.67$ and p -value of 0.114 show that there was no significant difference between the time taken to complete the modifications using the different modeling techniques in SLD

and MLD. This suggests that the ability to maintain focus and context awareness in MLD did not change the modification time significantly.

iii. TC (Time for Completing the task)

The $F(1,30)=0.78$ and p -value of 0.286 shown in Table 7.15 also indicate that there was no significant difference between MLD and SLD in the total time taken to complete Task 5.

7.8.1.6 Summary of the Results for Task Completion Time

Figures 7.20 to 7.23 show the summary of the means for TL, TM, and TC for both SLD and MLD for all the five study tasks. Figure 7.20 shows the mean time taken for TL, Figure 7.21 shows the mean time taken for TM, and Figure 7.22 shows the mean time taken for TC. These figures show that three of the techniques developed for MLD were faster than SLD. The results suggest that although the MLD techniques were new to the participants they were able to complete the tasks in MLD faster, or at least at the same speed as in SLD.

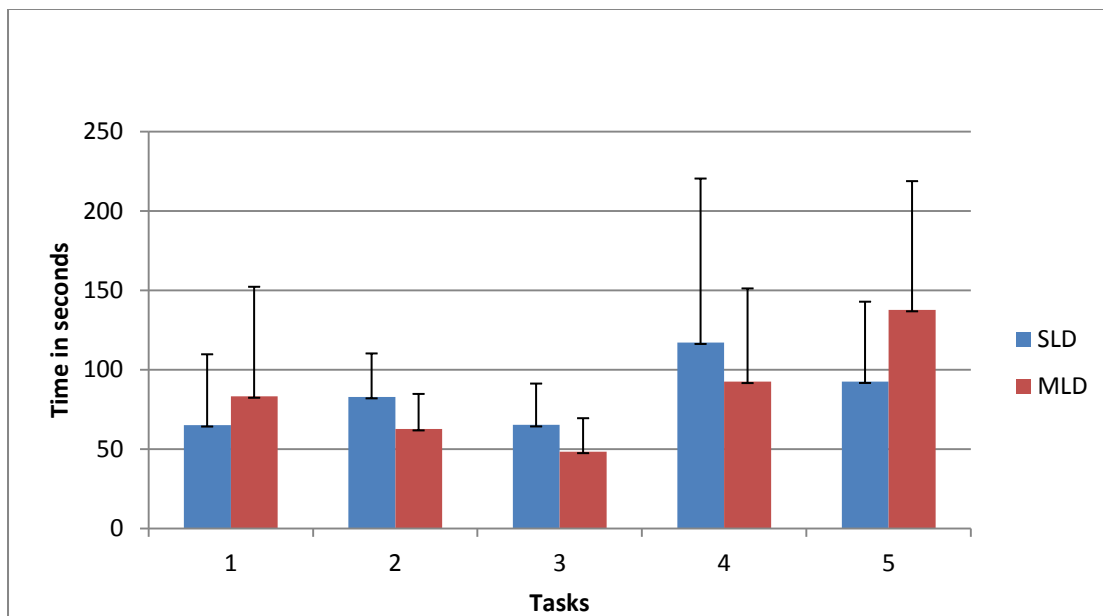


Figure 7.20: Time taken to locate the objects of interest (TL)

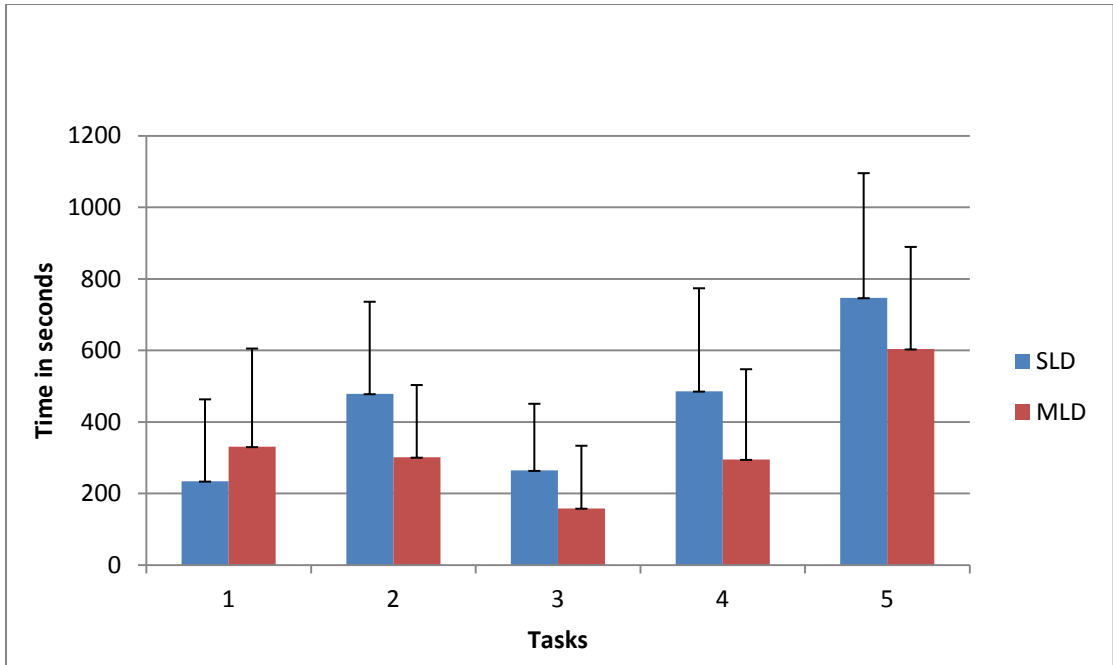


Figure 7.21: Time taken to complete the modifications (TM)

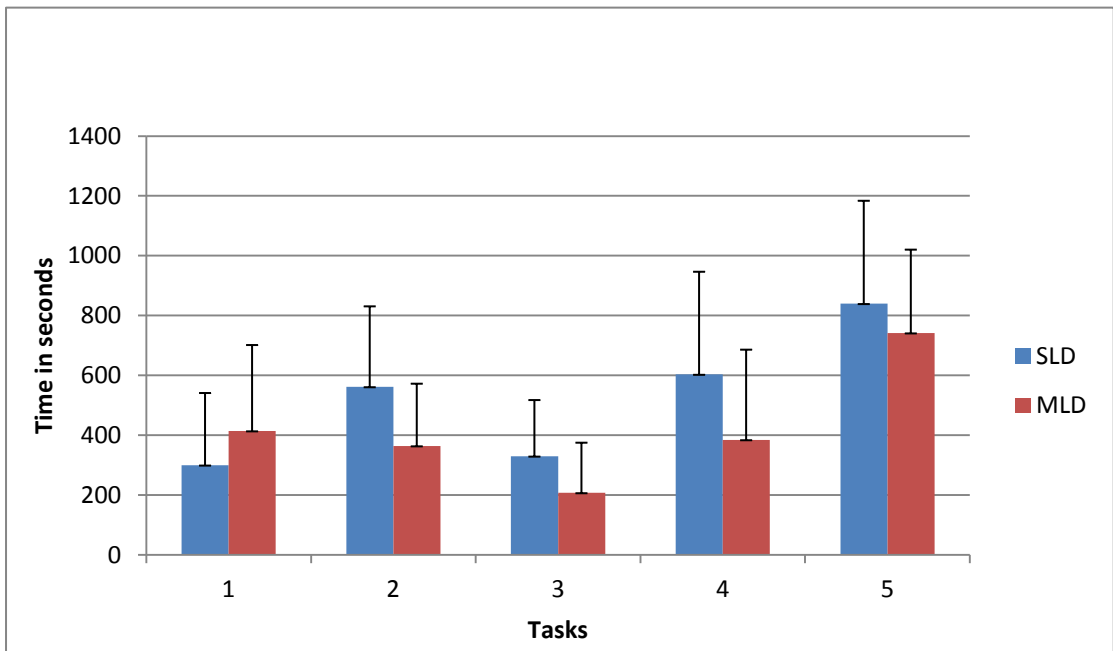


Figure 7.22: Total time taken for completing the tasks (TC)

The summary of the statistical differences between SLD and MLD in terms of the task completion time are shown in Table 7.16. This results indicate that the component segregation, peeling focus, and slicing techniques used in Task 2, 3, and 4 have changed the modeling time significantly. These three new techniques have improved the participants' ability to maintain their focus and context awareness more efficiently

than using the conventional modeling techniques. Based on these results it is possible to answer the evaluation question posed in Section 7.1, as summarized in Table 7.17.

Table 7.16: Summary of the statistical differences between SLD and MLD

Task #	Techniques				
	SLD	MLD	TL	TM	TC
1	Hiding	Object Isolation	Not significant	Not significant	Not significant
2	Hidden surface removal	Component Segregation	Significant	Significant	Significant
3	Zooming	Peeling Focus	Significant	Significant	Significant
4	Hiding	Slicing	Not significant	Significant	Significant
5	Wireframe	Peeling Focus and Context	Not significant	Not significant	Not significant

Table 7.17: The hypotheses / questions and their findings from the study

Number	Hypotheses / Questions	Yes / No
1	Does object isolation used in MLD improve focus and context awareness in comparison to using the hiding technique in SLD?	No
2	Does component segregation technique used in MLD improve focus and context awareness in comparison to using the hidden surface removal technique in SLD?	Yes
3	Does peeling focus technique used in MLD improve focus and context awareness in comparison to using the zooming technique in SLD?	Yes
4	Does slicing technique used in MLD improve focus and context awareness in comparison to using the hiding technique in SLD?	Yes
5	Does peeling focus and context technique used in MLD improve focus and context awareness in comparison to displaying the model in wireframe display mode in SLD?	No

7.8.1.7 Analysis of the effects of the order of the experiment conditions

As mentioned earlier in Section 7.5, eight of the participants worked in SLD first and then in MLD, while the other eight participants used MLD before SLD. Therefore, it was important to analyze the data to find out whether the orders of the experimental conditions had any impact on the task completion time. General linear model analysis was carried out and the order of the experimental settings used as an additional factor. The findings of this analysis are shown in Table 7.18. The p -values for tasks 1 and 5 were greater than 0.05 which suggest that there were no significant differences in task completion time between SLD and MLD. These findings confirm the earlier analysis

that the differences between SLD and MLD were not significant.

Table 7.18: Results of the effects of order of experimental conditions on task completion time

Task No	SLD to MLD (SLD)	SLD to MLD (MLD)	MLD to SLD (SLD)	MLD to SLD (MLD)	p-value
1	348.5	495	250.6	333	0.618
2	755.6	416.5	367.4	311.3	0.007
3	417.5	209.2	241.6	204.9	0.007
4	745.6	378.3	460.5	390.4	0.006
5	771.1	650	908	832.9	0.799

For tasks 2, 3, and 4, the p -values were all less than 0.05 which indicate that there were significant differences between SLD and MLD in task completion time. These results are the same as the previous analysis, confirming that the order of experiment settings did not affect task completion time.

7.8.1.8 Analysis of the Differences Between the Participants With/Without Blender Experience

As discussed in Section 7.3, eight of the participants had some experience in using the Blender software, while the other eight had no experience in using Blender, but some experience in using other modeling software (e.g. Maya or 3DS Max). Since the five focus and context awareness technique were implemented as extensions to the Blender modeling software, it was important to analyze the effect of experience with Blender on the results of the study. The results of the general linear model analysis are given in Table 7.19. There are four groups showing the Blender participants in SLD, the Blender participants in MLD, the non-Blender participants in SLD, and the non-Blender participants in MLD.

As shown in Table 7.19, p -values are all greater than 0.05, which indicate that there are no significant differences in term of time taken to complete the task between the Blender and non-Blender participants.

Table 7.19: Mean task completion time based on the participants experience with Blender, grouped by the experiment conditions

Tasks No	BLENDER (SLD)	BLENDER (MLD)	NON BLENDER (SLD)	NON BLENDER (MLD)	p-value
1	323.0	445.2	276.1	382.8	0.904
2	507.9	352.1	615.1	375.6	0.482
3	363.9	207.5	295.3	206.6	0.340
4	520.5	314.6	685.6	454.0	0.834
5	803.4	759.0	875.8	724.9	0.556

7.8.2 Results of the Analysis of the Quality of the Completed Models

As mentioned earlier the quality of the models produced by the participants for each task was analyzed and a score of 1 to 3 was given to them. Since there was no time limit for any of the tasks, the scores assigned to the finished models were not weighted by the completion time. The average scores of the completed models are shown in Figure 7.23. Wilcoxon matched-pairs signed-rank test (Howell, 1992) was used for analyzing the scores. The results showed that for none of the five tasks, there was any significant difference between the quality of the models produced.

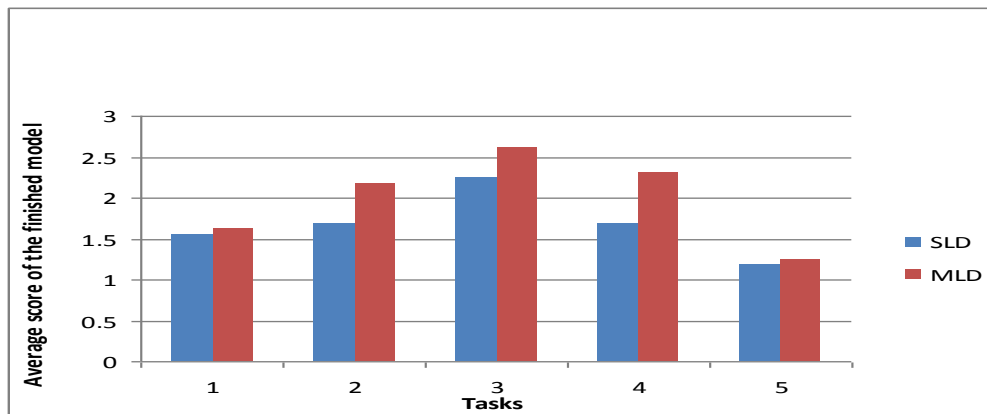


Figure 7.23: Quality of the completed model

Despite this lack of difference between SLD and MLD in terms of the mean score for completed models, it is interesting to note that as shown in Table 7.20, a larger number of perfect models were produced in MLD.

Task	SLD	MLD
1	1	4
2	4	9
3	7	10
4	1	8
5	0	1

It is interesting to note for tasks 1 and 5 the number of perfect models produced in MLD were rather low, and there was no significant difference between MLD and SLD as discussed and summarized in Section 7.9. These findings indicate that the object isolation technique and peeling focus and context technique used in Task 1 and Task 5 in MLD did not improve the participants' ability toward producing a perfect model. On the other hand, the component segregation, peeling focus, and slicing

techniques have improved the participants' ability resulting a larger number of perfect model being produced in MLD.

7.8.3 Results of the Participant Opinions

7.8.3.1 Task Questionnaires

Table 7.21 shows the results of the Wilcoxon matched-pairs signed-rank analysis of the questionnaire completed by the participants after each task in SLD and MLD. The questionnaires asked the participants to choose on a Likert's scale of 1 to 7 their response to a number of questions. The results show that there were no significant differences between the participants' ratings for these questions in SLD and MLD.

This means that the participants rated MLD the same as SLD in terms of the individual tasks they performed, even though they had not used the focus and context awareness techniques of MLD previously. Therefore, perhaps with more time and exposure to MLD the participants' opinion of the focus and context awareness techniques may improve further.

Table 7.21: Values from the Wilcoxon matched-pairs signed rank test on the questionnaire

Task No.	Question #	SLD	MLD	Critical value	Significant Difference
1	1	45.5	45.5	17	No
	2	24	29	8	No
	3	40.5	50.5	17	No
2	1	7	38	5	No
	2	21.5	69.5	17	No
	3	27.5	38.5	10	No
	4	14	64	13	No
3	1	28	50	13	No
	2	19	72	17	No
	3	24	42	10	No
4	1	43.5	47.5	13	No
	2	15.5	29.5	3	No
	3	56	64	25	No
5	1	52.5	25.5	10	No
	2	14.5	21.5	3	No

7.8.3.2 Final questionnaire

As mentioned in Section 7.7, the participants were also asked to answer another set of questions to obtain their overview of the two experimental conditions. Questions 1 to 3 (see Table 7.10), were used to determine the difficulty level of aligning objects, to understand the usefulness of depth perception, and to identify the effectiveness of the techniques used for separation of objects in SLD and MLD. Questions 4 to 7 were used to identify the effectiveness of the techniques used to improve users' work performance while conducting modeling tasks, and Question 8 obtained the participants' preference for MLD over SLD.

Table 7.22: Values from the Wilcoxon matched-pairs signed rank test on the final questionnaire (questions 1 to 3)

Question #	SLD	MLD	Critical value	Significant Difference
1	16.0	103.5	25	Yes
2	7.5	70.5	10	Yes
3	13.5	77.5	17	Yes

Table 7.22 shows the results of the Wilcoxon matched-pairs signed-rank analysis of questions 1 to 3. These questions asked the participants to choose on a Likert's scale of 1 to 7 their response. The results show that there are significant differences between the participants' responses in SLD and MLD. From these three questions, it is clear that the participants noted that the separation of objects from other objects, depth perception, and aligning objects are more effective in MLD than SLD.

Findings for the second group of questions is presented in Table 7.23. For these average ratings, numbers from 1 to 7 are assigned to the Likert scale level. One is for strongly disagree up to seven for a strongly agree. These findings show that in general, the subjects participants agree with the four statements.

Table 7.23: The number of participants that strongly disagree, strongly agree, and in between with the statements of the questionnaires

Questions	Statements	Average Rating
1	Depth perception increase work performance	4.5
2	Object isolation increase work performance	6.1
3	Focus and context visibilities increase work performance	5.5
4	The ability to maintain focus and context awareness improved my work performance	4.5

For Question 5 the findings as presented in Table 7.24 shows that in general, the subject participants agree that modeling in MLD is more effective than SLD. Perhaps with more time and exposure to MLD the participants' rating may improve further.

Table 7.24: The participants' preferences toward the MLD

Questions	Statements	Average Rating
5	In general, modeling in MLD is more effective than in SLD	4.5

7.8.3.3 Interviews

The purpose of the interviews was to get the participants' feedbacks on using the five focus and context awareness techniques developed for MLD. The participants were asked to describe what they liked about MLD. Most of the participants responded that they like the physical separation between the two layers. They claimed that this feature gave them a better sense of viewing 3D models compared to conventional 2D displays. They mentioned that this feature combined with object isolation and component segregation techniques reduce their common problems of selecting the wrong side of the objects or components. They also noted that the ability to view both solid and wireframe objects simultaneously in peeling focus, slicing, and peeling focus and context eliminates the difficulty of locating hidden objects.

The participants also highlighted several problems that they noticed during the experiment. These are:

1. In the object isolation technique, having the entire context in wireframe mode caused some difficulties in aligning objects and recognizing distance.
2. The choice of color combinations for the components of the selected and non-selected objects was not optimal.
3. The disappearance of selected objects from the front layer in the peeling focus, slicing, and peeling focus and context techniques caused them some difficulty in completing their tasks.
4. The fixed thickness of the peeler in the slicing technique caused them difficulty in seeing objects on the front layer.
5. The peeling focus and context technique often removed the context of the model which was relevant to the task.

A detailed discussion of these problems will be covered in Chapter 8, where further improvement to the focus and context awareness techniques are proposed and developed.

7.9 Discussion

The results of the study showed that only three of the five new techniques developed for MLD worked effectively in improving the participants' modeling performances, by reducing the task completion time in MLD.

The object isolation technique used in Task 1 did not improve the participants' performance in term of task completion time significantly in MLD. As mentioned earlier, the participants claimed that the use of the wireframe mode on both the front and back layers of MLD made it difficult for them to recognize the relative position of the objects. As such, they may have taken longer to realize the relationship between the object of interest and the context.

The component segregation technique used in Task 2 was found to be effective. This technique which separated the components of the selected object onto the front and back layers enabled the participants to recognize the relative position of the components involved. The way the object of interest and context were presented on the front and back layer of the MLD may have contributed toward faster task completion time in MLD. It can therefore be claimed that the ability to make a direct comparison in MLD by looking at the object of interest on the front layer while

realizing its relationship with the context on the back layer reduces the task completion time.

The peeling focus technique used in Task 3 was also found to be effective. This technique enables obscured objects to be seen without visually affecting or distorting the object (i.e. through zooming). Thus, the participants could locate the object of interest and realize their relationships with the relevant context more effectively. At the same time, this technique also allowed the participants to work in a less cluttered environment. Results from the analysis, as discussed earlier, suggest that this technique helps the participants to complete their tasks faster in MLD than when using conventional modeling techniques provided in SLD.

The slicing technique used in Task 4, however, was slower when used for locating objects of interest in MLD compared to using the hiding technique in SLD. As mentioned above, the participants have highlighted that the fixed slicer size used in this technique caused some problem to the participants. The fixed slicer limits the size of the object to be displayed on the front layer.

The peeling focus and context technique used in Task 5 was not as effective as peeling focus used in Task 3. In general, the difficulty faced by the participants when using this technique was caused by the slower processing speed, and the fact that the relevant context was sometime removed from both layers due to the clipping process. Consequently, maintaining the relationship between the object of interest and the context was difficult.

7.10 Summary

This chapter has presented a user study of the focus and context awareness techniques described in Chapter 6. Although three of the five techniques have shown some improvements over conventional modeling tools available with existing software, further improvements can be made to all the techniques developed in this thesis. The next chapter discusses some of these improvements.

CHAPTER 8

Improving the Focus and Context Awareness Techniques

Findings from the previous study, as discussed in Chapter 7, showed that the participants' task completion times were significantly better when using some of the new focus and context awareness techniques than when using conventional 3D modeling techniques. Further findings suggested that the component segregation, peeling focus, and slicing techniques had contributed to improving the completion times for different tasks. However, the completion times for tasks using the other two techniques of object isolation and peeling focus and context in MLD were not significantly different to when using conventional techniques provided by existing 3D modeling software.

This chapter discusses several modifications made to the five techniques evaluated in the previous user study. These modifications aim to improve the focus and context awareness techniques based on the suggestions made by the study participants. Throughout the discussion in this chapter, the term MLD1 will be used to refer to the original focus and context awareness techniques, while MLD2 will be used to refer to the new modified techniques.

This chapter begins with a summary of the difficulties identified by the participants of the previous study (Section 8.1). This is followed by a discussion of the modifications made to the original focus and context awareness technique of MLD1 to develop MLD (sections 8.2. to 8.6). Section 8.7 then summarizes the modified techniques presented in this chapter.

8.1 Summary of the Problems with MLD1

As mentioned in Chapter 7, a short interview was conducted during the previous study, to identify the strengths and weaknesses of the five focus and context awareness techniques of MLD1. The interviews identified the following problems with MLD1.

1. In the object isolation technique, having the entire context in wireframe mode caused some difficulties in aligning objects and recognizing distance.
2. The choice of color combinations for the components of the selected and non-selected objects was not optimal.
3. The disappearance of selected objects from the front layer in the peeling focus, slicing, and peeling focus and context techniques causes them some difficulty in completing their tasks.
4. The fixed thickness of the peeler in the slicing technique caused them difficulty in seeing objects on the front layer.
5. The peeling focus and context technique often removed the context of the model which was relevant to the task.

These problems and the proposed solutions to address them will be discussed in the following sections. As with Chapter 6, screen shots will be presented to illustrate how a model is displayed in MLD. In most cases, the screen shots will consist of a set of three images. The two images on the left will show how the model appears on the back and front layers of MLD, while the image on the far right will show an actual photograph of MLD screen.

8.2 Object Isolation

The object isolation used in MLD1 is used to split the objects of the model between the front and back layers of MLD. In this technique, the object of interest (i.e. focus) is placed on the front layer in solid mode, while the rest of the model (i.e. context) appears on the back layer in wireframe mode. As discussed in Chapter 6, the aim of this technique is to provide modelers with an overview of the model on the back layer while working on the object of interest on the front layer. Based on the feedback received from the participants, it was found that they were not able to recognize the position and the orientation of objects shown in a wireframe mode easily due to the overlapping edges of the model. This issue was highlighted by 6 of the participants.

One of the participants said that “...*comparing the object with another object in wireframe mode is not an easy task and can be time consuming. Also, the result may not be accurate*”.

Therefore, different display modes are applied in MLD2 where the model shown on the back layer is no longer in wireframe mode but in solid mode. Figures 8.1 and 8.2 demonstrate the processes that take place when using this techniques in MLD1 while figures 8.3 to 8.4 demonstrate the processes in MLD2. Figure 8.1 shows that on the front layer the main body of the car is displayed in solid mode while the rest of the context, including the main body of the car is shown in wireframe mode on the back layer. In this example, the car chassis floor is selected and colored in yellow.

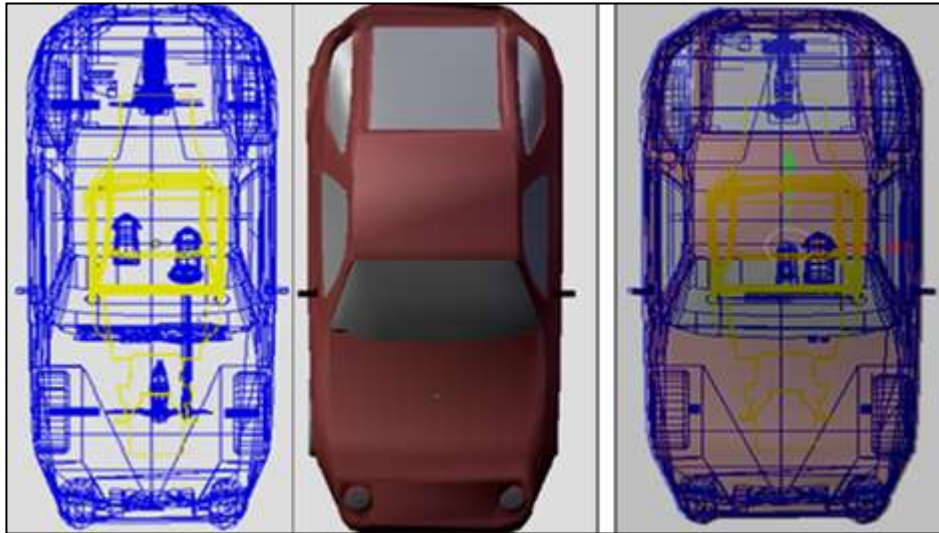


Figure 8.1: MLD1: View of the model before the object isolation technique is applied

When the object isolation technique is applied, the chassis floor is changed to solid mode and moved to the front layer as shown in Figure 8.2, while the context shown on the back layer remains in wireframe mode. In this example, tasks where the size of the chassis floor needs to be maximized, the actual size of the car (i.e. context) which is relevant to the task has to be visible to the viewer. However, due to the overlapping edges in wireframe mode, recognizing the floor size of the car can be difficult.

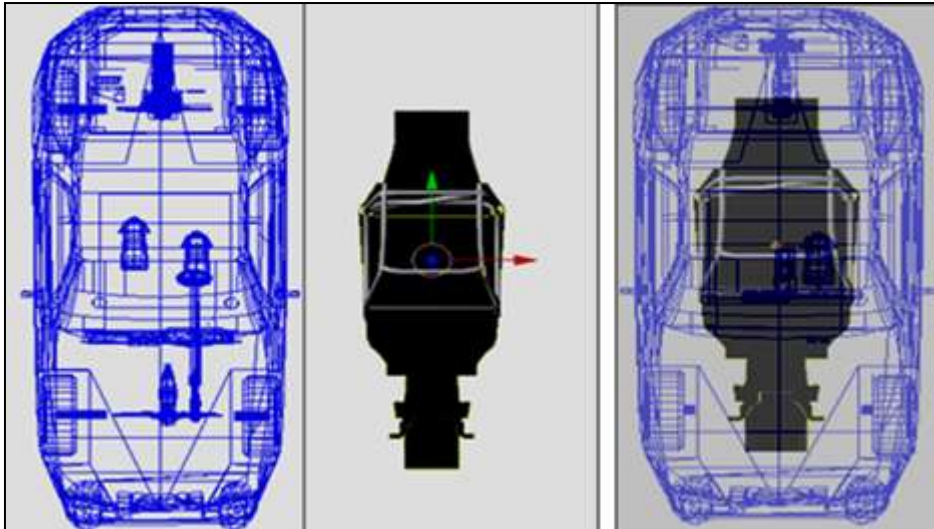


Figure 8.2: MLD1: View of the model after the object isolation technique is applied

As mentioned above, in MLD2 a different approach is taken. When the object isolation technique is applied, the chassis floor is moved to the front layer and shown in solid mode (Figure 8.3) similar to MLD1. However in MLD2, on the back layer, the context (i.e. the external part of the model) is now displayed in solid. At this stage, realizing the relationship between the object of interest with the internal parts of the model is still rather difficult, and therefore, further improvement needs to be made to this technique.

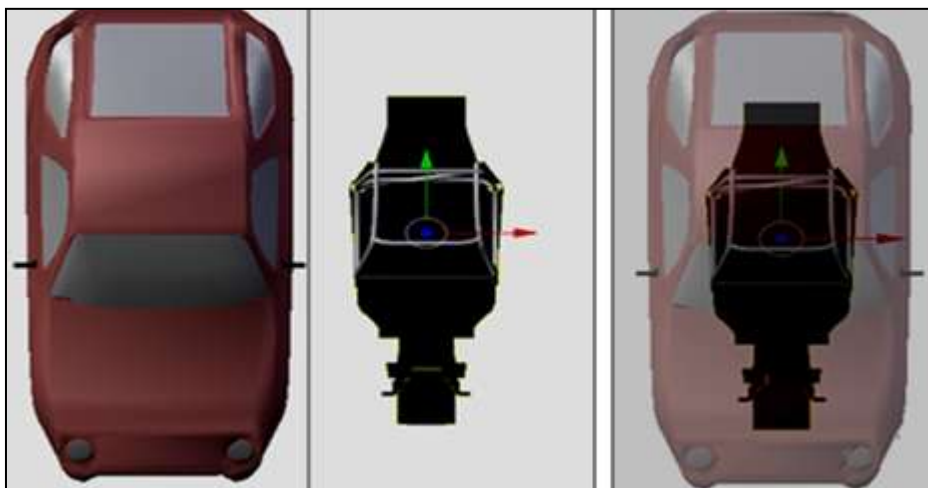


Figure 8.3: MLD2: View of the model after the object isolation technique is applied

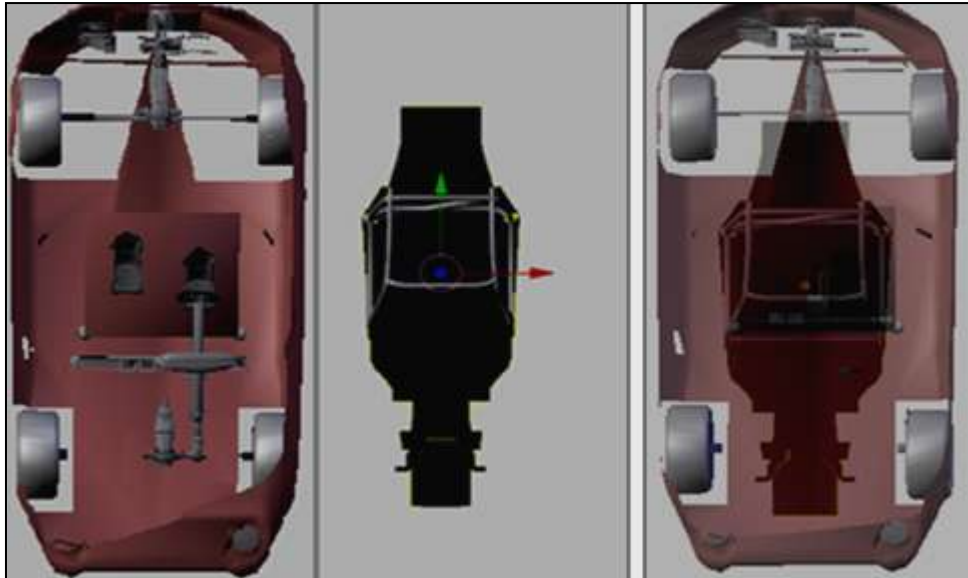


Figure 8.4: MLD2: View of the model after the object isolation and peeling focus techniques are applied

In MLD2, the peeling focus technique is integrated with the object isolation technique. Using this new peeling focus technique, portions of the object on the back layer can be removed steadily. By doing so, the hidden objects which are relevant to the task being performed can be made visible. As shown in Figure 8.4, the roof of the car can be peeled to allow the user to view what is inside the car in solid mode. This modification aim to allow users to interactively realize the effects of the changes they make in relation to the specified constraint inside a 3D model.

8.3 Color Combinations

Most of the participants of previous study suggested that MLD1 could be made more effective if different combinations of colors between components of selected and non selected objects are used. As stated by one of the participants “...*recognizing the distance between the components is a lot easier in MLD, however using different color combination may improve its usability*”.

The participants pointed out that color of the edge of the non-selected objects needs to be different to the edges of the selected objects. The combination of colors shown in Table 8.1 were used in MLD1 (for details see Chapter 6). Blue color was used for the edges of the objects on the back layer. The participants however had difficulty in distinguishing between the edges of the selected (i.e. focus) and non-selected objects (i.e. context). Changing the color combinations was therefore necessary in order to improve the effectiveness of the component segregation technique.

Table 8.1: Color combinations used in MLD1

Set	Action	Back layer		Front layer	
		Components or Objects	Color	Components or Objects	Color
1	Object is selected	Selected object	Yellow	Selected object	Yellow
		Non selected objects	Blue	Non selected objects	
2	Component is selected	Selected components of the selected object	Yellow edges and red vertices	Selected components of the selected object	Yellow edges and red Vertices
		Non selected component of the selected object	Blue edges and red Vertices	Non Selected component of the selected object	Yellow edges and red vertices

In MLD2, the components of the selected object shown on the back layer are no longer in blue but instead they are shown in black. Furthermore the intensity and brightness of the vertices of both layers have also been changed to make the brightness of the vertices on the back layer less than the vertices on the front layer.

Figures 8.5 and 8.6 illustrate the differences between MLD1 and MLD2. Figure 8.5 shows the combination of colors used in MLD1. In this example there is no component selected. As shown on the right most images, the blue edges of the back layer are visible from the front. However, because the edges of both selected and non selected objects are shown in blue, identifying the difference between them can be difficult.

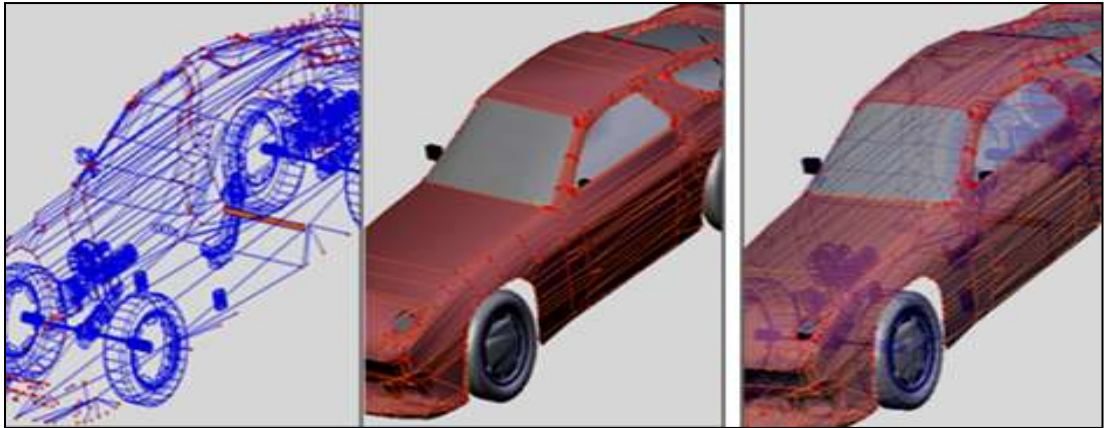


Figure 8.5: MLD1: The color of the edges of the selected object (i.e. body of the 3D car model) is blue

Figure 8.6 shows the new color combinations used in MLD2. As can be seen, black color is applied to the edges of the selected object shown on both the front and back layers while blue is applied to the non-selected objects shown the back layer.



Figure 8.6: MLD2: The color of the edges of the selected object (i.e. body of the 3D car model) is black

The aim of this modification is to improve viewers' ability to distinguish the components of the selected object (i.e. focus) shown on the front layer from the components of the non-selected objects (i.e. context) shown on the back layer of MLD.

8.4 Showing focus

In MLD1, all the objects, selected or not, are removed from the front layer when the slicing, peeling focus, or peeling focus and context techniques are applied. Findings from the interviews indicated that this method was not favored by most of the participants (13 of 16 participants). They claimed that the selected object (i.e. the object of interest) should remain visible at all times. They further highlighted that when the object of interest was no longer visible, recognizing the relationship between it and the context shown on the back layer became difficult. Two examples

in which the disappearance of the object of interest from the front layer became problematic are highlighted by the participants. One of the participants points out that “[I] spend a lot of time trying to locate the object when it became invisible, and often needed to undo or reset the orientation of the model in order to locate the missing object”. Similarly another participant mentioned that “working with an invisible object is almost an impossible task”.

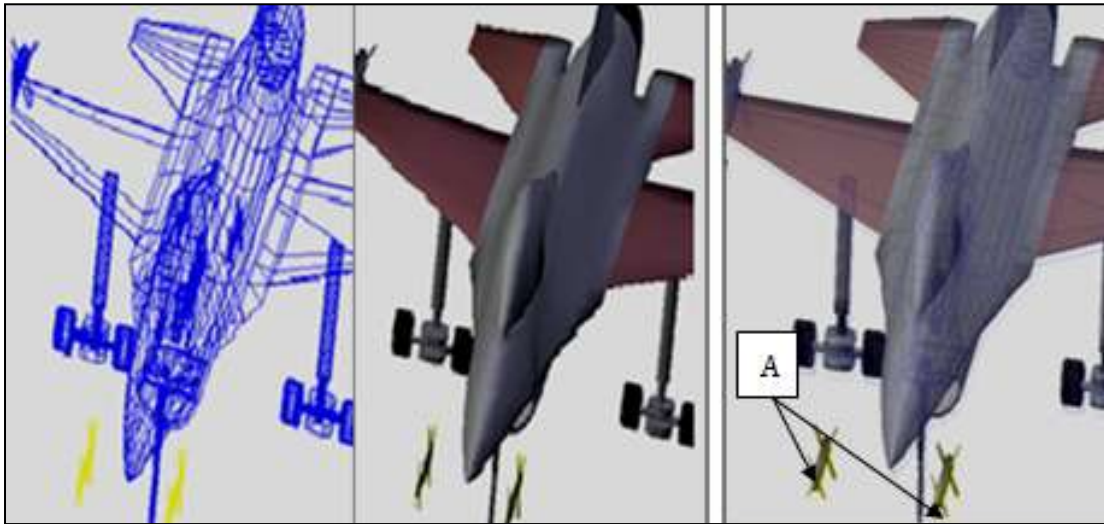


Figure 8.7: MLD1 and MLD2: Selected objects of interest (i.e. torpedoes A) and the context are visible

Figures 8.7 to 8.9 illustrate the differences between MLD1 and MLD2 in terms of visibility of the objects of interest in both cases. In Figure 8.7 which applies to both MLD1 and MLD2, the objects of interest (i.e. the torpedoes shown in grey and yellow) and the context are visible on both layers of MLD prior to applying any of the three techniques mentioned above.

As further slicing or peeling is performed in MLD1, the torpedoes are gradually removed from both layers because they move out of the area of focus shown on the front layer (see Figure 8.8). Consequently, performing any tasks involving these torpedoes becomes impossible.

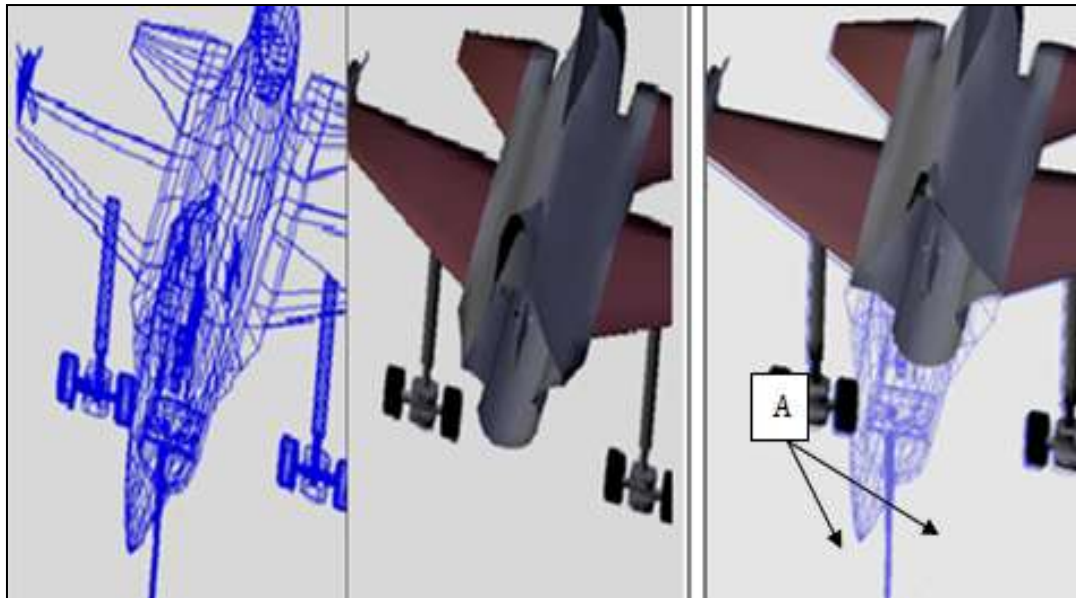


Figure 8.8: MLD1: Selected objects of interest (i.e. torpedoes A) are no longer visible on the front layer as they moved beyond clipping plane

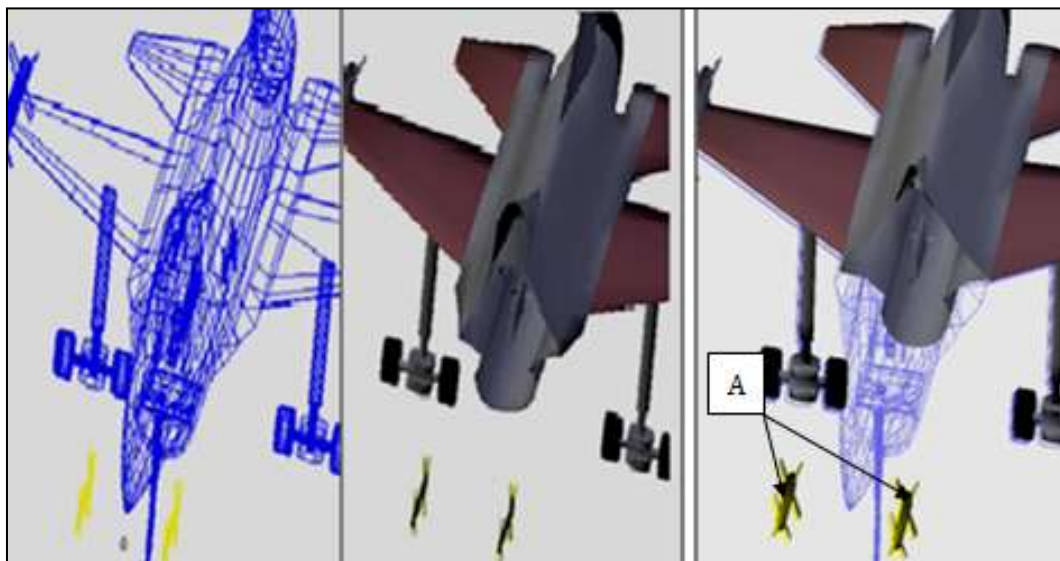


Figure 8.9: Selected objects of interest (i.e. torpedoes A) remain visible even after the clipping plan is moved beyond them on the front layer

In MLD2, however the selected objects of interest remain visible at all times. This means that the position of clipping plane as described in Chapter 6 has no effect on the visibility of the selected object of interest. Figure 8.9 illustrates this example where the objects of interest (i.e. torpedoes) remain visible even after other portions of the model are removed from the front layer.

8.5 Slicing

Nearly half of the participants (7 out of 16) of the previous study claimed that the fixed depth set in the slicing technique of MLD1 sometime caused them to lose

portions of the objects of interest when they applied the slicing method. Consequently, they had difficulty in recognizing the relationships between the objects of interest and the context.

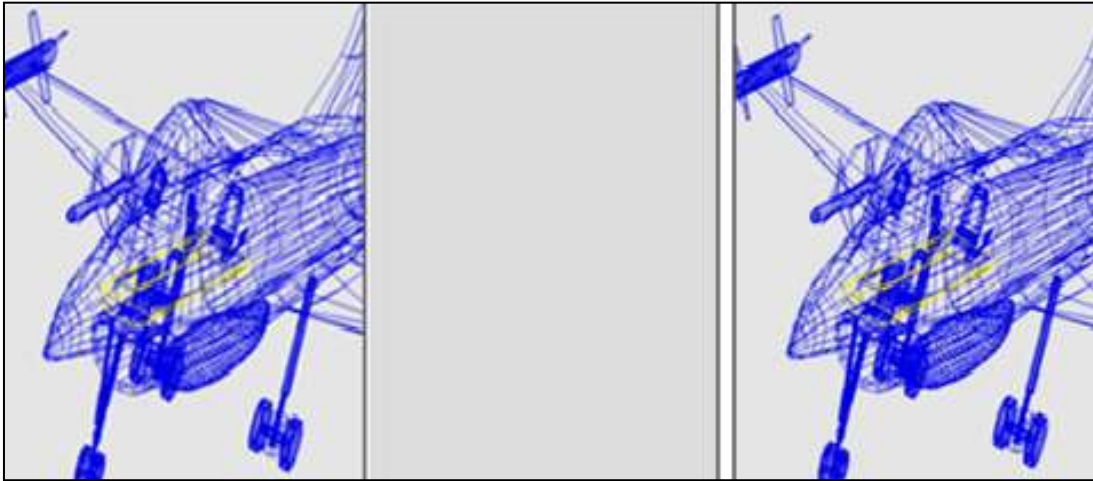


Figure 8.10: MLD1: Initial view of the model before the slicing technique is applied

Figures 8.10 to 8.14 demonstrate the slicing technique used in MLD1. As explained in Chapter 6, the slicing technique works by progressively moving portions of the model from the back layer to the front layer. Figure 8.10 shows the view of the model before the slicing technique is applied. In this example, there is no image displayed on the front layer, and on the back layer the context of the model is shown in wireframe mode.

As slicing is performed, portions of the model are removed from the back layer and appear on the front layer, as shown in Figure 8.11. However, as the slicing process is continued, portions of the model that are currently shown on the front layer are eventually removed and replaced with new portions of the model (see Figure 8.12). This technique therefore makes it impossible to see completely any portions of the model on the front layer that are bigger than the width (thickness) of the slicer.

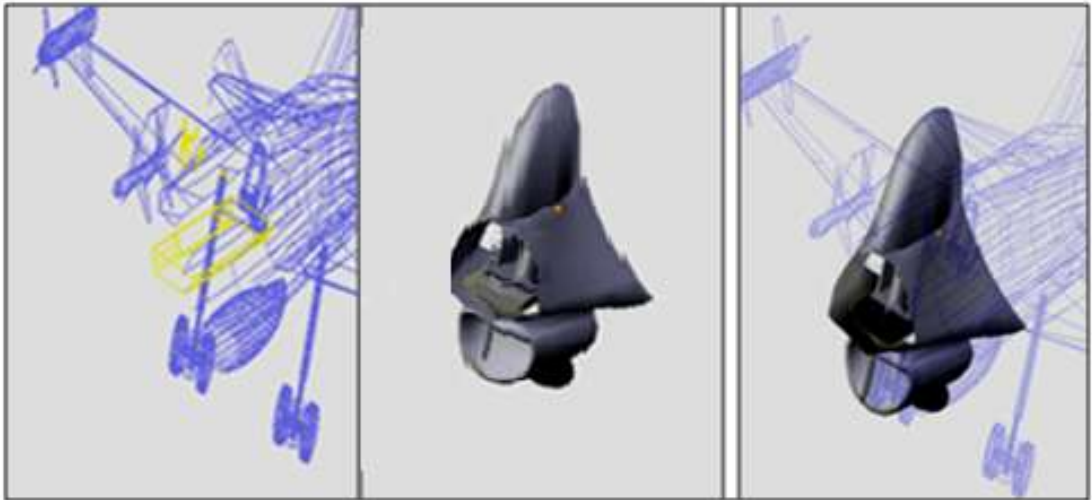


Figure 8.11: MLD1: Portions of the model are moved from the back layer to the front layer as slicing is applied

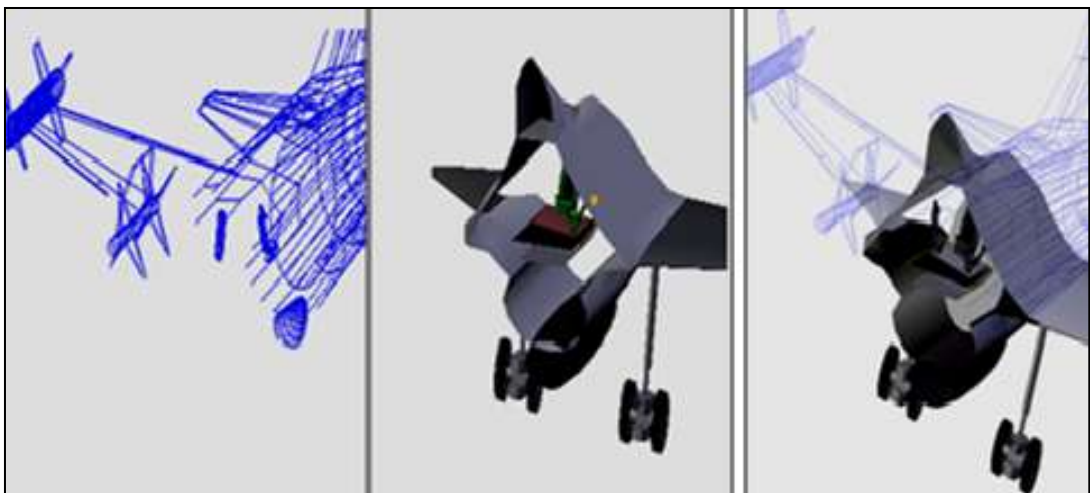


Figure 8.12: MLD.: Different portions of the model appear on the front layer as further slicing is performed

In MLD2, this problem is addressed by enabling the user to increase or decrease the thickness of the slicer. Figures 8.13 and 8.14 illustrate the slicing technique applied in MLD2. Figure 8.13 is similar to Figure 8.11, where portions of the model have been removed from the back layer and are shown on the front layer.

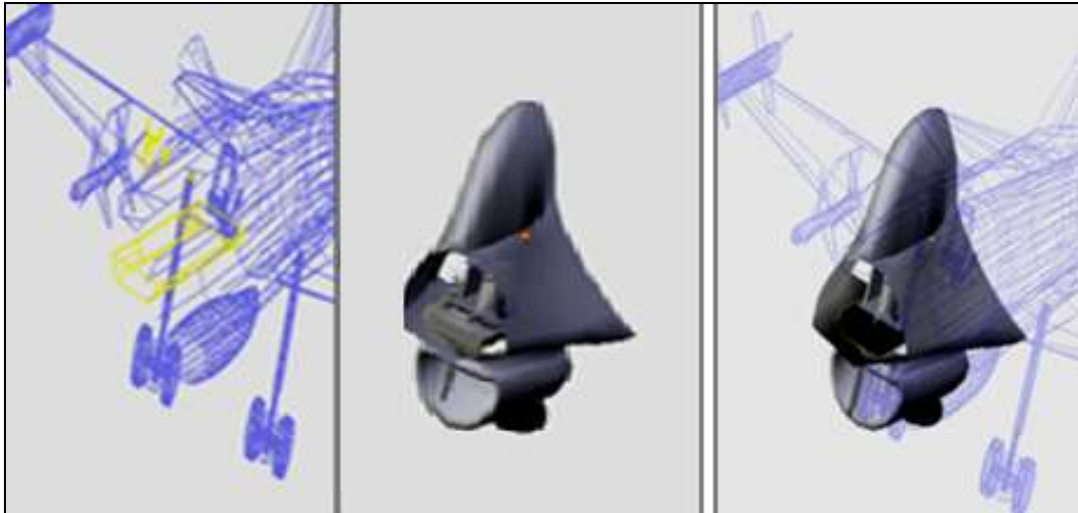


Figure 8.13: MLD2: Portions of the model are moved from the back layer to the front as slicing method is applied

As slicing is applied in MLD2, however, the user can change the thickness of the slicer. This means that the portions of the object currently displayed on the front layer can remain visible if the user increased the size of the slicer. Figure 8.14, shows how the thickness of the slicer is increased to make a larger portion of the model visible on the front layer. In this example, the wheel and portions of the wing which were not visible in Figure 8.13 have now appeared on the front layer.

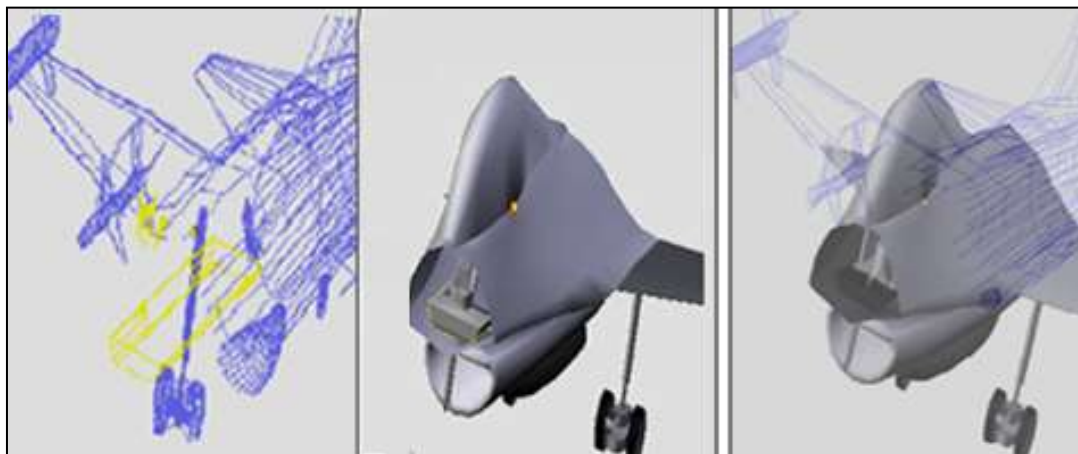


Figure 8.14: MLD2: A larger portion of the model is shown on the front layer as the size of the slicer is increase

The aim of this modification is to give the users the option of changing the size of the area shown on the front layer so that they can manually manage the relationship between the view of focus and context.

8.6 Peeled Focus and Context

When the peeling focus and context technique is applied in MLD1, portions of the

model are removed from both the front and back layers of MLD. Consequently, the overview of the entire model is no longer available on the back layer. Figures 8.15 to 8.19 illustrate the difference between this technique used in MLD1 and MLD2. Figure 8.15 shows the initial view of the model in both MLD1 and MLD2 before the peeling focus and context technique is applied.

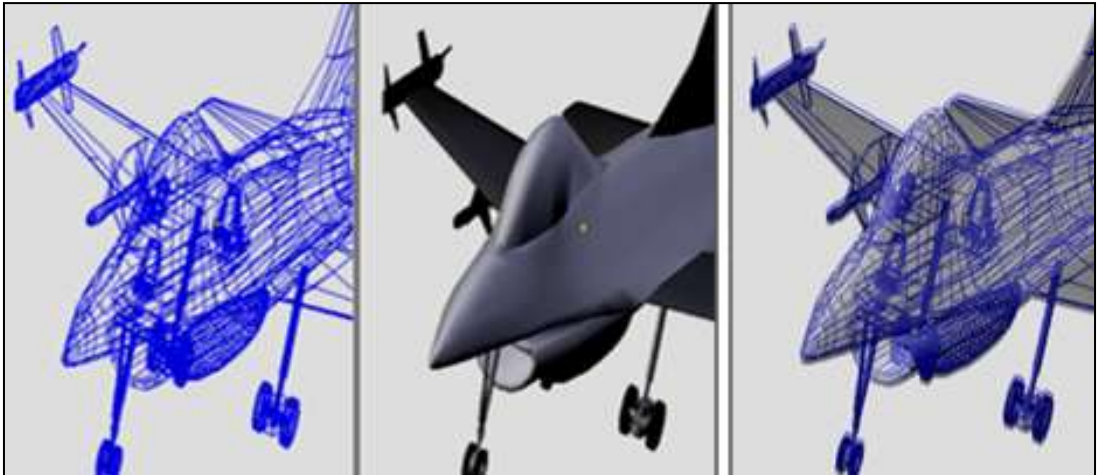


Figure 8.15: MLD1 and MLD2: The initial view of the model before the peeling focus and context technique is applied

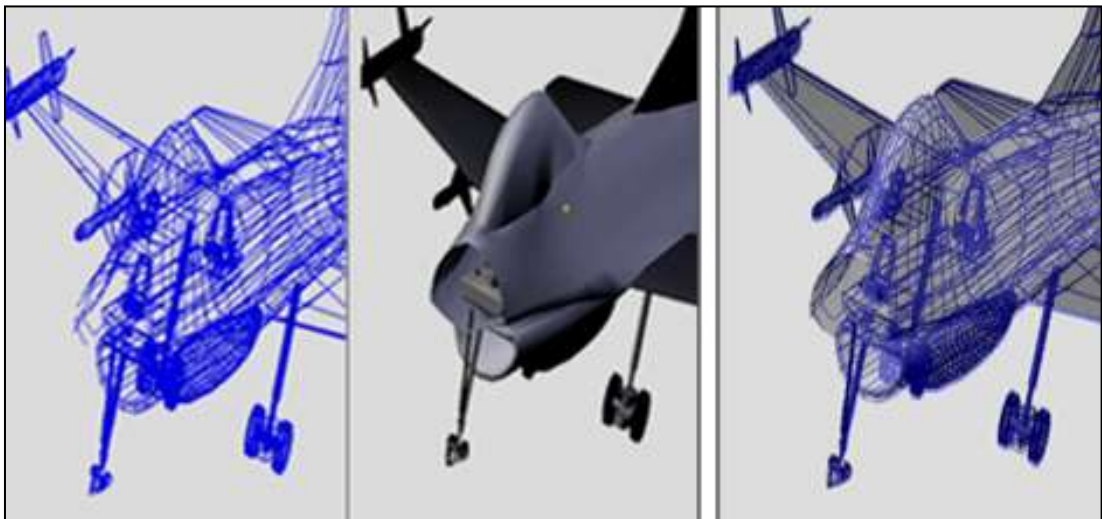


Figure 8.16: MLD1: Portions of the model are removed from both layers as the peeling focus and context technique is applied

As peeling focus and context is performed in MLD1, portions of the model are removed from both layers, as shown in Figure 8.16. Thus, the overview of the entire model is no longer available. As further peeling focus and context is carried out (see Figure 8.17), larger portions of the model are removed, and less context becomes visible to the user.

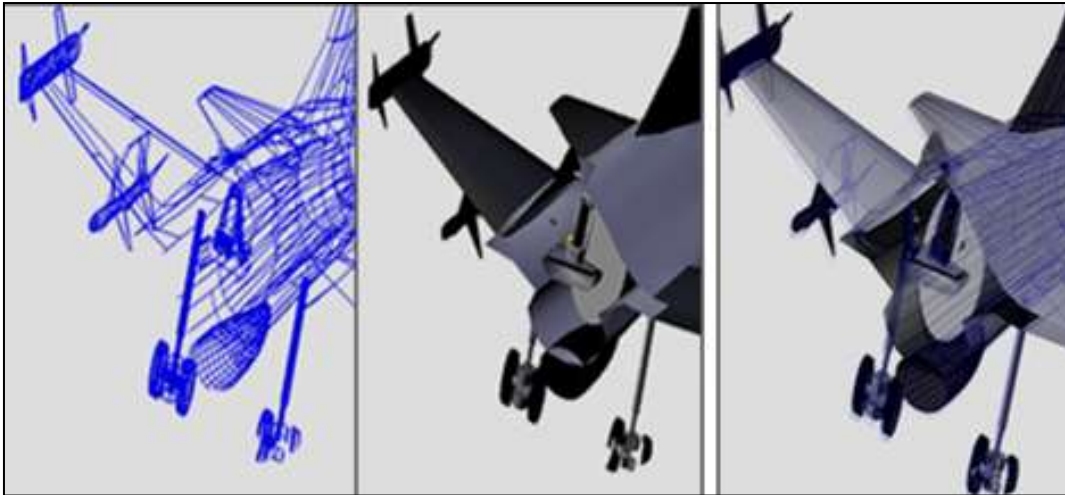


Figure 8.17: MLD2: As further peeling of focus and context is applied, larger portions of the model are removed from both layers

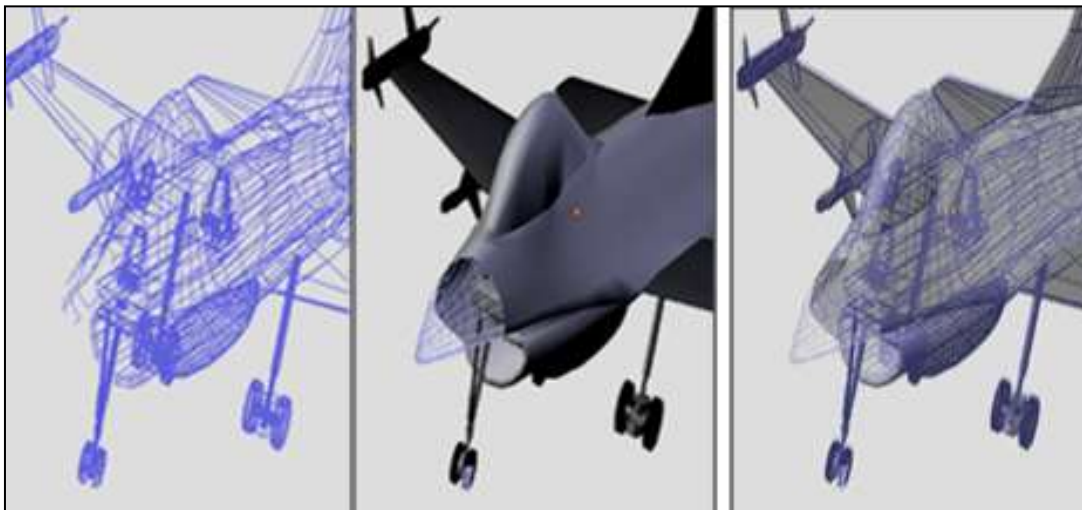


Figure 8.18: MLD2: Portions of the model that are removed from the back are shown on the front layer in wireframe mode

To address this issue in MLD2, as shown in figures 8.18 and 8.19, when portions of the model are removed from the back layer, they are moved to the front. In addition, the portions that are moved to the front layer are changed and shown in wireframe mode. With this modified technique, the overview of the model remains available to allow users to maintain their focus and context awareness at all times.

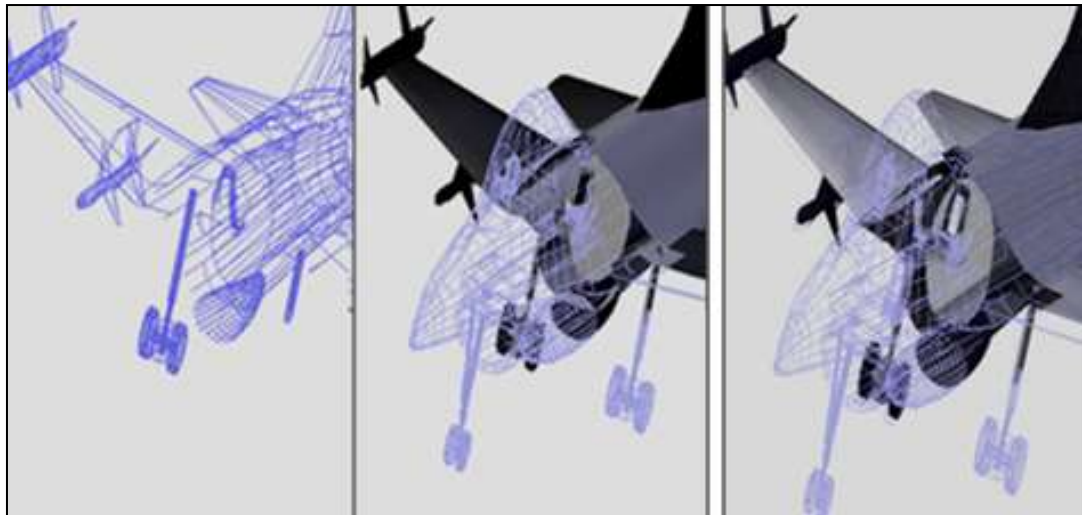


Figure 8.19: MLD2: A larger portion of the model is shown on the front layer in wireframe mode after being removed from the back layer

8.7 Summary

This chapter has discussed several modifications made to the techniques developed previously (see Chapter 6) based on the feedback from the participants who took part in the study presented in Chapter 7. Table 8.2 shows a summary of the modifications that were made to MLD1.

Table 8.2: Summary of the modifications made to MLD1 to develop MLD2

Modifications	Description
1	In object isolation technique, the context shown on the back layer is in solid mode instead of wireframe mode used in MLD1.
2	Combinations of colors used for the components of the selected and non-selected objects were different to MLD1.
3	Selected objects of interest appear at all times even after other portions of the model are removed from the front layer.
4	Thickness of the peeler in slicing technique is flexible, and users are able to increase or decrease it.
5	Peeled object are visible on the front layer of MLD2.

In order to evaluate the effectiveness of these modifications, it was necessary to carry out a user study of MLD2. The next chapter describes a user evaluation comparing the five techniques modified in MLD2 with the original techniques of MLD1.

CHAPTER 9

Evaluation of the Modified Focus and Context Awareness Techniques

As discussed in Chapter 8, several modifications were made to the focus and context awareness techniques developed previously (see Chapter 6) based on the findings from the study presented in Chapter 7. The summary of the modifications that were made are listed below. Note that in this chapter, the term MLD1 is used to refer to the original focus and context awareness techniques, while MLD2 is used to refer to the modified focus and context awareness techniques.

- In the object isolation technique, the context shown on the back layer in MLD2 is in solid mode instead of the wireframe mode used in MLD1.
- The combination of colors used to display the components of selected and non-selected objects in MLD2 is different to the combination used in MLD1.
- In the peeling focus technique, the selected objects of interest appear at all times even after the other parts of the model are removed from the front layer of MLD2.
- Thickness of the peeler used in slicing technique in MLD2 is adjustable, allowing the user to increase or decrease its depth.
- Peeled objects are visible on the front layer of MLD2 in the peeling focus and context technique.

This chapter presents a study conducted to evaluate the effectiveness of these modified focus and context awareness techniques. The study discussed in this chapter was conducted with the approval of the Ethics Committee of the Faculty of Computing and Mathematical Sciences, University of Waikato. A copy of the approval letter is attached in Appendix G.

The chapter begins with a discussion of the evaluation research questions (Section 9.1). This is followed by a description of the two controlled experimental conditions

(Section 9.2), an overview of the study participants (Section 9.3), and the setup and study methodology (sections 9.4 and 9.5 respectively). A detailed discussion on the tasks assigned to the study participants and the three types of data gathered during the study are covered in sections 9.6 and 9.7. The results of the study are presented in Sections 9.8. The chapter concludes with a discussion (Section 9.9) and summary (Section 9.10).

9.1 Evaluation research questions

The goal of this study was to identify whether the modification made to the focus and context awareness techniques had an impact on their effectiveness. The study therefore aimed to answer the following questions:

1. Does showing the context in solid mode in MLD2 in the object isolation technique improve focus and context awareness in comparison to showing the context in wireframe mode in MLD1?
2. Does the combination of colors used to display the components of selected and non-selected objects in MLD2 improve focus and context awareness in comparison to using the previous colors combination in MLD1?
3. Does showing the selected objects of interest in the peeling focus at all times in MLD2 improve focus and context awareness in comparison to peeling it after other parts of the model are removed in MLD1?
4. Does providing an adjustable peeler thickness in the slicing technique in MLD2 improve focus and context awareness in comparison to a fix peeler thickness provided in MLD1?
5. Does showing the peeled object on the front layer of MLD2 in the peeling focus and context technique improve focus and context awareness in comparison to removing the peeled object in MLD1?

9.2 Experimental conditions

In this study two experimental conditions were used where participants were asked to perform a number of tasks using specific modeling techniques in each of the experiment environments. The two experimental conditions are presented in Table 9.1.

Table 9.1: Overview of the two experimental conditions

MLD1	MLD2
The context of the model is shown in wireframe mode on the back layer	The context of the model is shown in solid mode on the back layer
Components of the selected object shown on the back layer are in blue color	Components of the selected object shown on the back layer are in black color
The selected objects of interest are removed from the front layer after other parts of the model are peeled off in the peeling focus, slicing, and peeling focus and context techniques.	Selected object of interest appear on the front layer at all time in the peeling focus, slicing, and peeling focus and context techniques.
The thickness of the peeler s fixed in the slicing technique	The thickness of the peeler is adjustable in the slicing technique
The peeled object is removed from the front layer in peeling focus and context technique	The peeled object is displayed in wireframe mode on the front layer in peeling focus and context technique

Note that in this study, the participants were not informed that MLD1 and MLD2 correspond to the original and modified versions of the focus and context awareness techniques. The two versions of the techniques were made known to the participants as the X and Y systems.

9.3 Participants

An open invitation was sent to undergraduate computer science students taking a course in graphics and multimedia⁶ at the University of Waikato. The minimum requirement for taking part in this experiment was that the participants should have some experience in 3D modeling tasks and they had not participated in the previous study. The reason for not allowing the participants from the previous study was to avoid any learning effect.

Twenty participants took part in this study. Eighteen of the participants were male and 2 were female. None of the participants had any previous experience using MLD.

9.4 Setup

A Deep Video™ (Puredepth 2012) 17 inch flat monitor with dual front and back

⁶ This was the same course used for finding participants as the pilot study presented in Chapter 4, but a few months later and with new students.

layers was used in this study. A Pentium 4 CPU, running Microsoft Windows XP, with a speed of 3GHz and the RAM size of 1GB was used to run the MLD1 or MLD2 versions of the software. The hardware used in the experiment came with two graphic cards that were required for MLD.

The experiment was conducted in the Usability Laboratory of the Department of Computer Science at the University of Waikato. The participants were observed from a control room through a one-way mirror.

9.5 Methodology

The study required the participants to perform 10 tasks, which were the same as those used in the previous study. A set of five tasks were performed in MLD1, and another set of five tasks were performed in MLD2. The tasks and their difficulty levels were comparable.

The order of the use of MLD1 and MLD2 was counterbalanced to reduce any possible learning effects across the two conditions. The experiment was a within-subjects design, where each participant was required to experience both conditions. Half of the participants completed the first set of tasks in MLD1 followed by the second set of tasks in MLD2, while the other half of the participants worked in MLD2 first, followed by MLD1. The complete ordering of the task and experiment conditions is given in Appendix H.

At the beginning of each session the participants were required to complete a tutorial. The purpose of this tutorial was to familiarize them with the focus and context awareness techniques of MLD1 and MLD2. There was no time limit for the tutorial session, and the participants were allowed to ask for further explanations from an observer if need. The participants were also given a sheet of paper containing a summary of various commands, such as short-cut keys and command buttons.

During the actual study tasks the participants were given several printed images of models relevant to the tasks they were performing. These images included:

- The initial condition of the model
- A zoomed in view of the object of interest (i.e. focus) that needed to be manipulated
- A zoomed in view of other objects (i.e. context) relevant to the tasks

- The expected outcome (finished model) that needed to be produced.

In addition to these, the participants were also given detailed instructions on the requirements of each task. These instructions described the conditions that needed to be observed when manipulating the objects of interest (i.e. focus) and the rest of the model (i.e. context).

9.6 Tasks

As mentioned above, the participants were asked to complete 10 tasks in this study (five in each environment). These tasks were the same as those used in the previous study and have been discussed in detail in Section 7.6. A summary of the tasks is given below in Table 9.2. For each task, types a and b were randomly assigned to the MLD1 and MLD2 environments. A complete tasks sheet used in the study is included in Appendix I.

Table 9.2: Summary of the tasks used in the study

Task No.	a	b
1	<i>Increasing the size of a particular object under the constraint of other objects.</i>	
	To maximize the size of the middle part of the floor tray of the main chassis frame to cover a bigger area of the car as shown.	To maximize the size of the back part of the floor tray of the main chassis frame to cover a bigger area of the car as shown.
2	<i>Matching the shape of object on the opposite sides.</i>	
	To replicate (without copying or duplicating) the design of the right side windscreen to the left side windscreen of the car, that is to edit the left side windscreen to be the same as the right side windscreen.	To replicate (without copying or duplicating) the design of the left side door to the right side door of the car, that is to edit the right side door to be the same as the left side door.
3	<i>Relocating an object inside an obscured area.</i>	
	To place the main chassis frame in the designated area.	To install steering wheel gears in the designated area.
4	<i>Positioning two objects inside obscured area.</i>	
	To place the front engine and the speedometer in its new location.	To place the steering wheel and driver's seat in their designated area.
5	<i>Aligning two objects or components.</i>	
	To complete making the square frame under the main chassis.	To create a link or a bar between the front and back track rods under the main chassis.

Once again, it is important to note that each task was divided into two subtasks. The first subtask was to locate the object of interest (i.e. focus) and the second subtask was to perform the actual modeling activity. The participants were instructed to use a specific modeling techniques for each of the tasks.

9.7 Data Collection

Three sets of data were collected in this study. The first two were based on the questionnaires that the participants answered, one at the end of each task in each of the environments, and one at the end of both tasks type for each task. At the end of each task type the participants were asked to rate the ease with which they performed

that task in the environment they had used (see Table 9.3).

Table 9.3: Questionnaire for the ease of completing the task using focus and context awareness technique

Questions	Response on a scale of 1-7	
How easy was it to perform this task using this system?	Very Difficult 1	Very Easy 7

Once the participant had used both environment for each task, they were asked to rate the system environment they preferred (see Table 9.4).

Table 9.4: Question for the preferred system

Questions	Answer
Which system would you prefer to use? []: X []: Y []: Both system are equally the same	

The third type of data collected was based on the quality of the completed models, measured to evaluate the output for each task by the participants. As with the previous study, a score of one to three was given to each finished model.

9.8 Results

The results of this study are divided into three groups, and are discussed in detail in sections 9.8.1. to 9.8.3. These three groups are:

- Ease of completing the tasks
- Preferred system
- Quality of the completed model.

9.8.1 Ease of Completing the Tasks

Table 9.5: Values from the Wilcoxon matched-pairs signed rank test on the questionnaire of ease of task

Task No.	Sum MLD1	Sum MLD2	Critical value	Significant Difference?
1	145.4	25.5	40	Yes
2	86	19	21	Yes
3	155.5	15.5	40	Yes
4	105	0	21	Yes
5	159	31	46	Yes

Table 9.5 presents the results of the Wilcoxon matched-pairs signed-rank analysis for the ratings the participants gave to the ease with which they completed their tasks in each of the two environments. The results show that there were significant differences between the participants' ratings for MLD1 and MLD2. The participants rated MLD2 higher than MLD1 in terms of the ease of completing individual tasks. The analysis of the participants' ratings for each of the study tasks are presented below.

9.8.1.1 Task 1

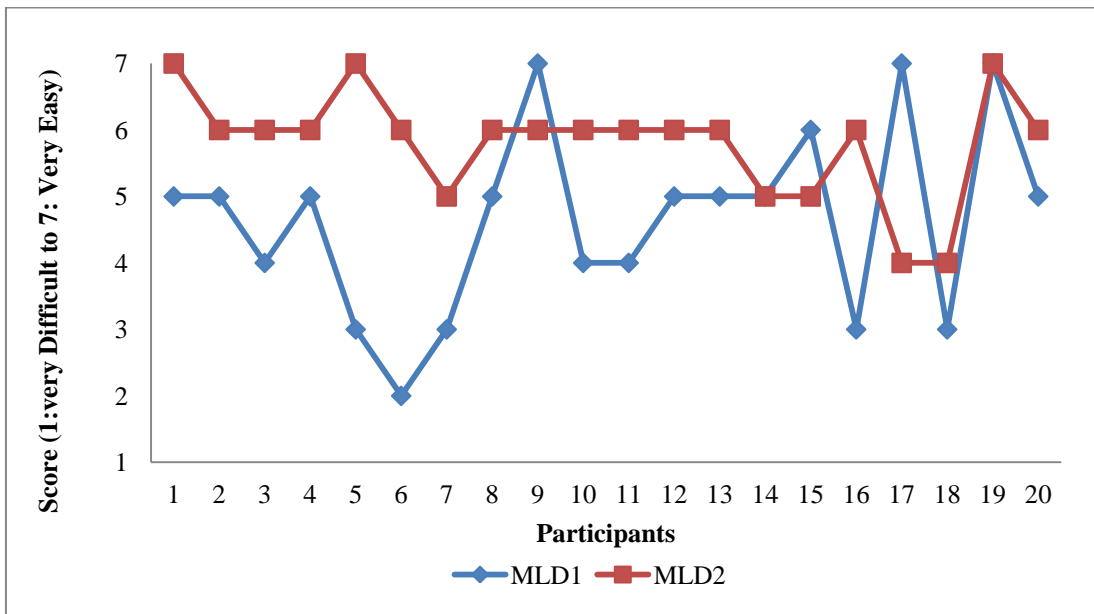


Figure 9.1: Ease of completing Task 1 in MLD1 and MLD2

Results from the Wilcoxon test indicate that the differences between the participants' ratings for Task 1 in MLD1 and MLD2 were significant (see Table 9.6). As Figure 9.1 shows, sixteen of the participants rated MLD2 more favorably. This suggests that showing the context in solid mode in MLD2 in the object isolation technique improved focus and context awareness in comparison to showing the context in wireframe mode in MLD1.

9.8.1.2 Task 2

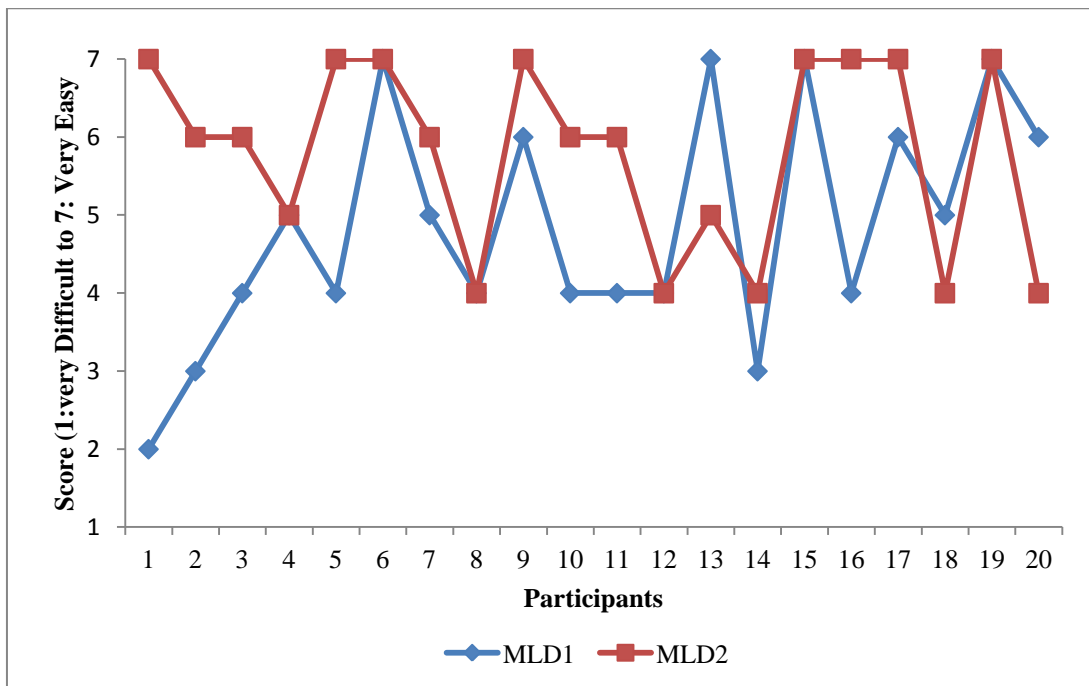


Figure 9.2: Ease of completing Task 2 in MLD1 and MLD2

Results from the Wilcoxon test indicate that the differences between the participants' ratings for Task 2 in MLD1 and MLD2 were also significant (see Table 9.6). As Figure 9.2 shows, eleven of the participants rated MLD2 more favorably. This suggests that the combination of colors used to display the components of selected and non-selected objects in MLD2 improved focus and context awareness in comparison to using the previous colors combination in MLD1.

9.8.1.3 Task 3

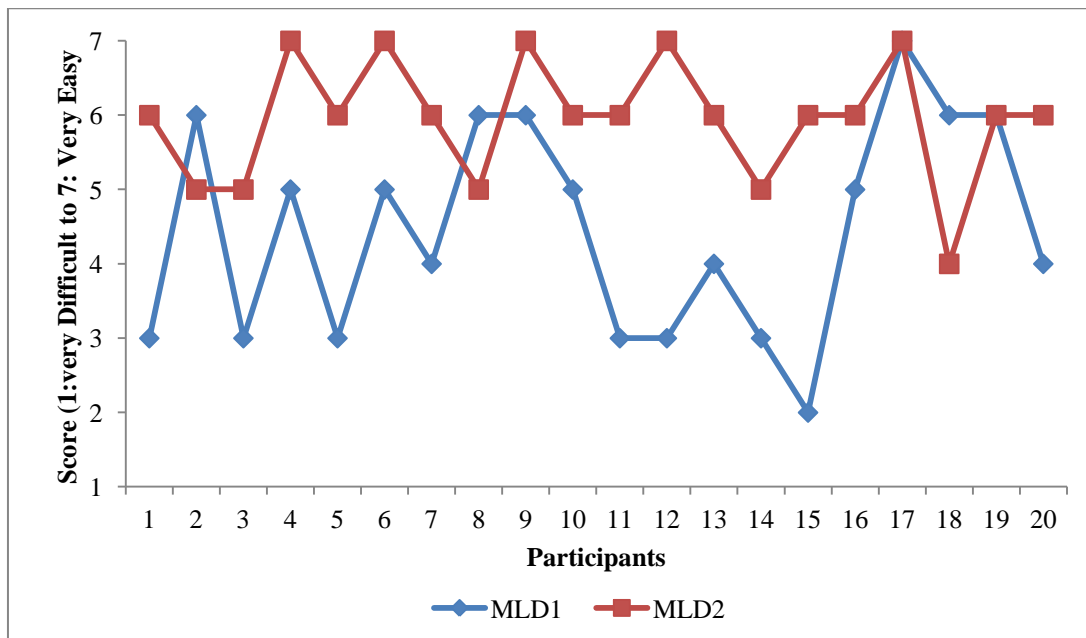


Figure 9.3: Ease of completing Task 3 in MLD1 and MLD2

Results from the Wilcoxon test indicate that the differences between the participants' ratings for Task 3 in MLD1 and MLD2 were significant (see Table 9.6). As shown in Figure 9.3, sixteen of the participants rated MLD2 more favorably. This suggests that showing the selected objects of interest in the peeling focus technique at all times in MLD2 improved focus and context awareness in comparison to peeling it after other of the other parts are removed in MLD1.

9.8.1.4 Task 4

Results from the Wilcoxon test indicate that the differences between the participants' ratings for Task 4 in MLD1 and MLD2 were significant (see Table 9.6). As shown in Figure 9.4, eighteen of the participants rated MLD2 more favorably. This suggests that providing an adjustable peeler thickness in the slicing technique in MLD2 improved focus and context awareness in comparison to a fix peeler thickness provided in MLD1.

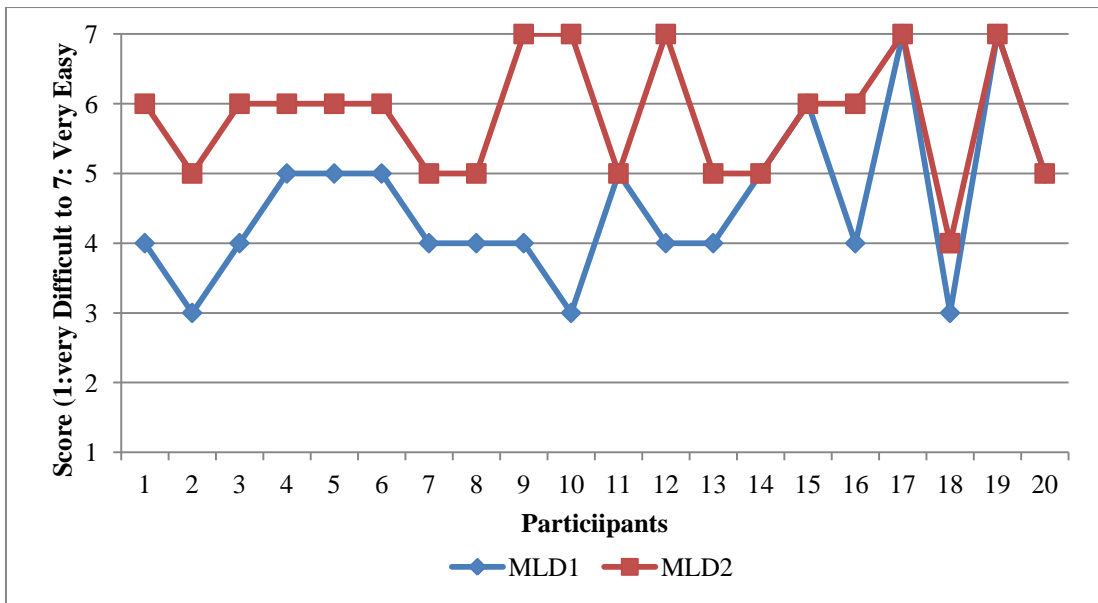


Figure 9.4: Ease of completing Task 4 in MLD1 and MLD2

9.8.1.5 Task 5

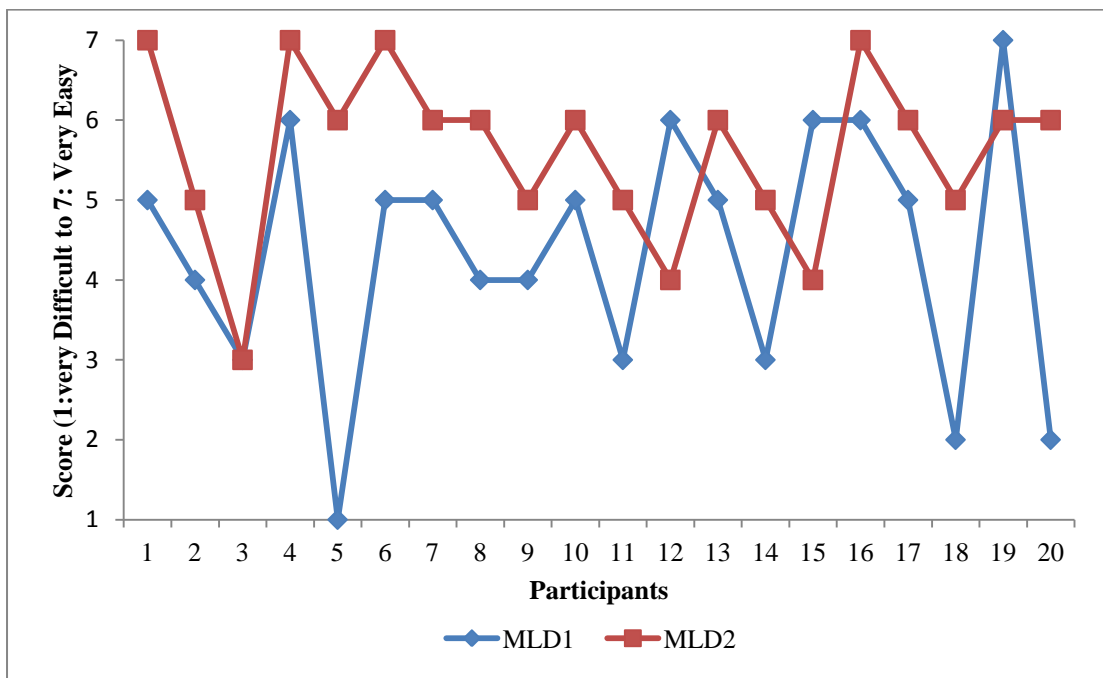


Figure 9.5: Ease of completing Task 5 in MLD1 and MLD2

Results from the Wilcoxon test indicate that the differences between the participants' ratings for Task 5 in MLD1 and MLD2 were significant (see Table 9.6). As Figure 9.5 shows, sixteen of the participants rated MLD2 more favorably. This suggests that showing the peeled object on the front layer of MLD2 in the peeling focus and context technique improved focus and context awareness in comparison to hiding the peeled object in MLD1.

9.8.2 Preferred System

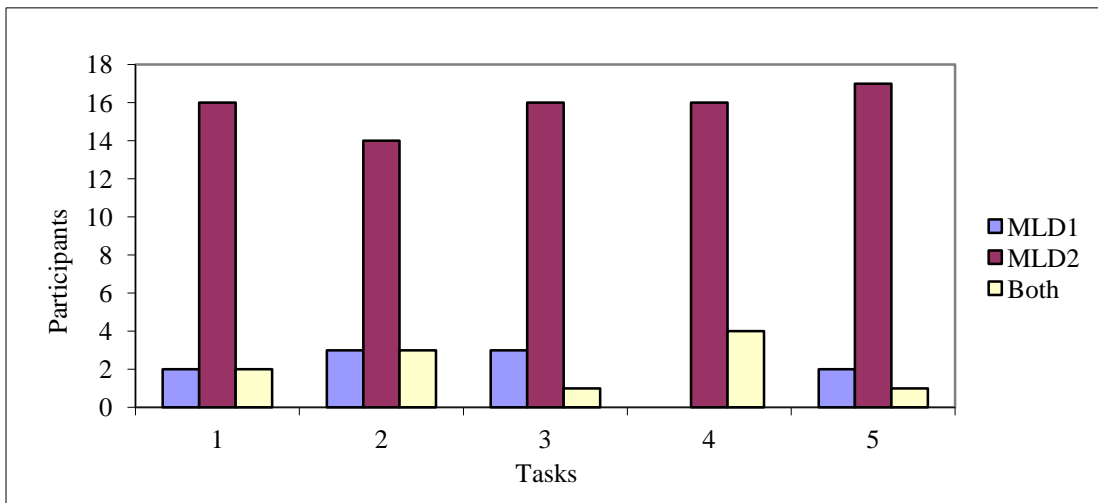


Figure 9.6: Participants preferred system

Figure 9.6 shows the results of the participants' preference for each of the two systems. It is clear that most of the participants preferred MLD2 over MLD1 in all the study tasks. This suggests that the modifications made to the focus and context awareness techniques in MLD2 were favored by the participants in comparison to MLD1.

9.8.3 Quality of the Completed Models

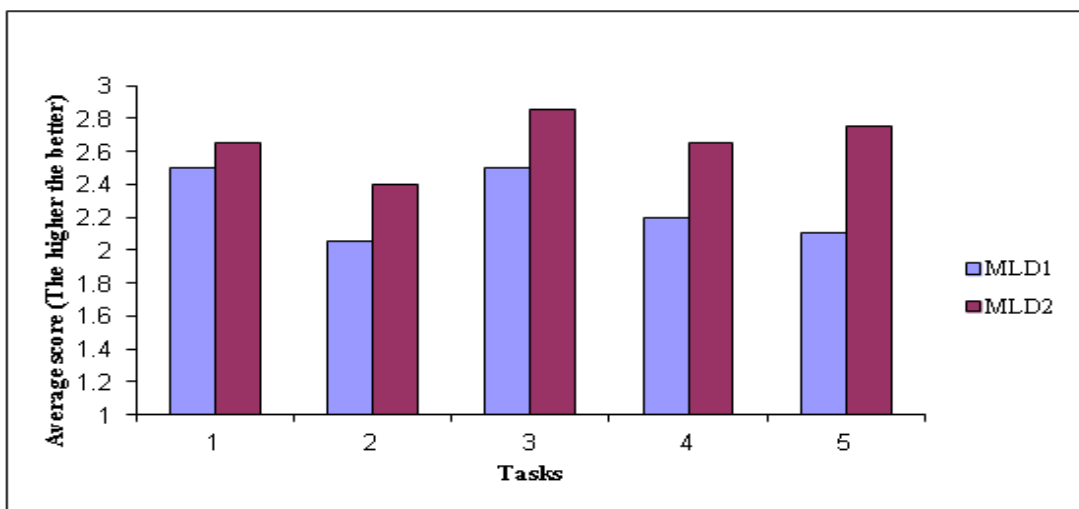


Figure 9.7: Quality of the completed models

As with the analysis of the completed models in the previous study, Wilcoxon matched-pairs signed-rank test was used for analyzing the scores given to the completed models in this study. The findings show that for none of the five tasks, there was any significant difference between the average score given to the finished

model produced by the participants in MLD1 and MLD2.

9.9 Discussion

Findings from the statistical analysis indicate that the differences between MLD1 and MLD2 in terms of the ease of completing the tasks were significant. In all five tasks, the participants rated MLD2 more favorably than MLD1 in terms of the ease of use. Most of the participants also preferred MLD2 over MLD1 overall. However, the quality of completed models was not significantly different between the two systems. This suggests that the modification to MLD1 made all of the techniques easier to use in MLD2 but did not improve the quality of the completed models.

Findings from this study also answered the five questions posed earlier in this chapter, that was whether the modified techniques in MLD2 improve focus and context awareness in comparison to MLD1 or not. Answers in relation to each of the question are listed below:

1. Showing the context in solid mode in MLD2 in the object isolation technique improves focus and context awareness in comparison to showing the context in wireframe mode in MLD1.
2. The combination of colors used to display the components of selected and non-selected objects in MLD2 improves focus and context awareness in comparison to using the previous colors combinations in MLD1.
3. Showing the selected objects of interest in the peeling focus at all times in MLD2 improves focus and context awareness in comparison to peeling it after other parts of the model are removed in MLD1.
4. Providing an adjustable peeler thickness in the slicing technique in MLD2 improves focus and context awareness in comparison to a fix peeler thickness provided in MLD1.
5. Showing the peeled object on the front layer of MLD2 in the peeling focus and context technique improves focus and context awareness in comparison to removing the peeled object in MLD1.

9.10 Summary

This chapter presented a study that was conducted to compare the effectiveness of

focus and context awareness techniques between MLD1 and MLD2. Based on the findings of this study it was concluded that the modification made to the focus and context awareness techniques in MLD2 improved them.

The next chapter presents a number of alternative hardware and software setups to provide focus and context awareness in different environments.

CHAPTER 10

Multiple Viewports and Displays

The focus and context awareness techniques developed so far as part of this thesis have all relied on the use of two overlaid viewports, one for focus and one for context, which are displayed on two physical layers of an MLD computer screen. This chapter presents alternatives in terms of the hardware display set up used, as well as the number of viewports overlaid for focus and context awareness.

This chapter is divided into two parts. The first part focuses on the extensions to the focus and context awareness techniques using multiple viewports (Section 10.1) and the second part presents an alternative to the display hardware setup used (Section 10.2). The chapter ends with a brief summary in Section 10.3.

10.1 Supporting Focus and Context Awareness with Multiple Viewports

The user studies presented in chapters 4 and 5 showed that 3D modelers often rely on the use of multiple viewports to perform their tasks. The results of these studies also showed that the use of multiple viewports can cause some difficulties in terms of maintaining focus and context awareness. Based on these findings a set of five techniques were developed for MLD which relied on the use of only two viewports. Although these techniques have been shown to be effective, there are cases where having multiple viewports can add further support for focus and context awareness in more complex tasks than those studied so far in this thesis. For instance using multiple windows viewports can be beneficial to modelers when comparing two or more objects of a model especially when the objects involved are obstructed or hidden, or when they are in different parts of the 3D modeling space.

This section presents the idea of using multiple viewports to display focus and context on the two physical layers of MLD. One possibility is to have two viewports on the front layer to show areas of focus, and two viewports on the back layer to show areas of context. Figure 10.1 shows an example of two side-by-side viewports of focus on the front layer of MLD overlaid on two side-by-side viewports of context on the back layer. This would enable the model shown on each pair of viewports to be

viewed from different orientation or at different zoom levels as shown in Figure 10.2.

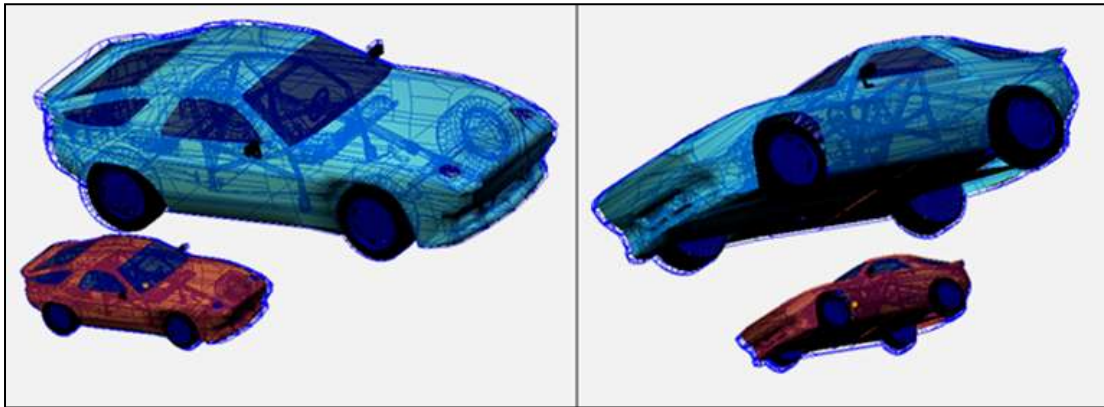


Figure 10.1: Two side-by-side viewports on the front and back layers of MLD

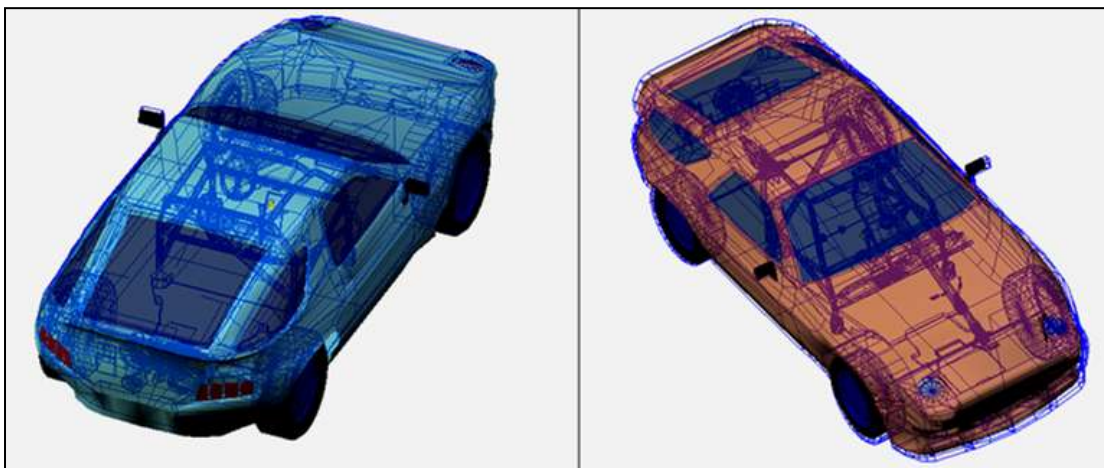


Figure 10.2: Different parts of the model shown on the left and right pair of viewports

This would also allow different focus and context awareness techniques to be applied to each pair of the viewports independently. For example, the peeling focus technique could be used on the right viewports, while slicing is applied on the left viewports depending on the task being performed.

10.1.1 Example Scenario

This section presents an example tasks scenario that could be better performed using multiple viewports. This task is carried out using a multiple viewport system developed for MLD.

In this example scenario the user needs to make the internal steering objects of two car models to look the same. To do this the user needs to locate several hidden objects in order to determine the differences between them. At the same time, the user also needs to be aware of the relationships between the objects of interest (i.e. steering gears) and their relative positions inside each of the cars.

In order to realize the relationships between the objects of interest and context in each car, portions of the model (e.g. the outmost part of the car) need to be removed to make the hidden objects visible. Figure 10.1 shows the initial view of the models. At this stage the differences between the steering gears of the two cars can not be identified, since they are shown in wireframe mode. Also in this figure, the size of the red car shown on the left viewports is smaller than the blue car shown on the right viewports. In the next step, the red car on the left is zoomed in so that its size becomes comparable to the blue car shown on the right window as shown in Figure 10.3. As shown in Figure 10.4, the peeling technique can then be applied to the right car.

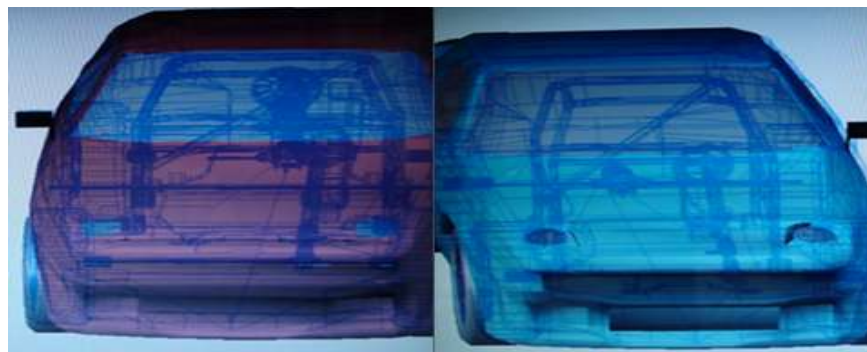


Figure 10.3: Both the blue and red cars are zoomed-in

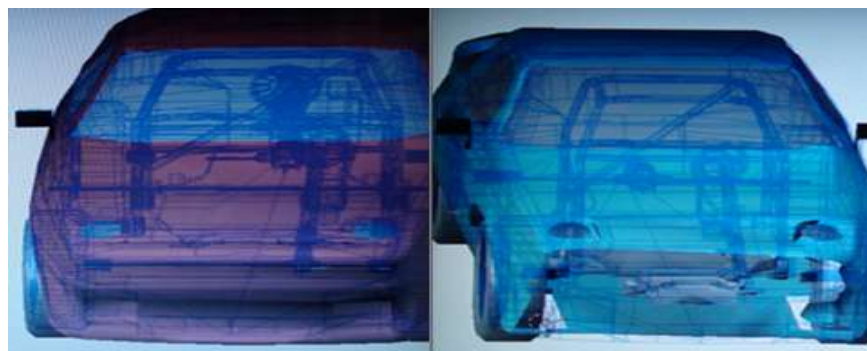


Figure 10.4: The blue car is peeled, removing some of its parts

This enables portions of the model to be removed, gradually making the objects which were initially obscured become visible. Note that the internal objects which are now visible are shown in solid mode. As this technique is further applied, the object of interest (i.e. steering gears) becomes visible, as shown in Figure 10.5.

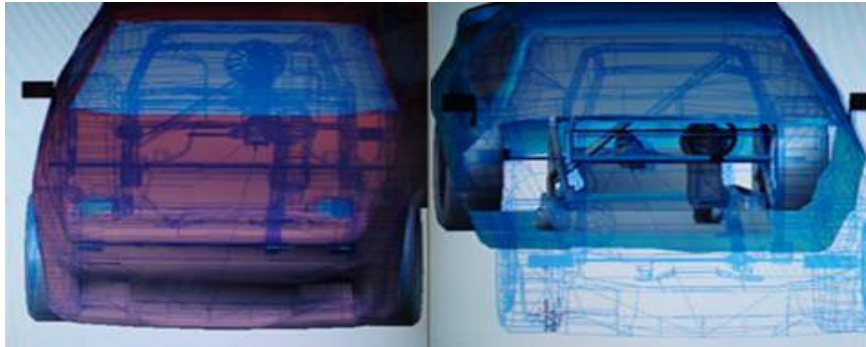


Figure 10.5: New portions of the blue car are shown in solid as the technique is further applied

As mentioned earlier, different focus and context awareness technique can be applied to each pair of the viewports. For example, Figures 10.6 shows the start of the slicing technique being applied to the car on the right viewports. The slicing technique starts by removing all the objects shown on the front layer so that the overview of the model is displayed in wireframe mode on the rear layer.

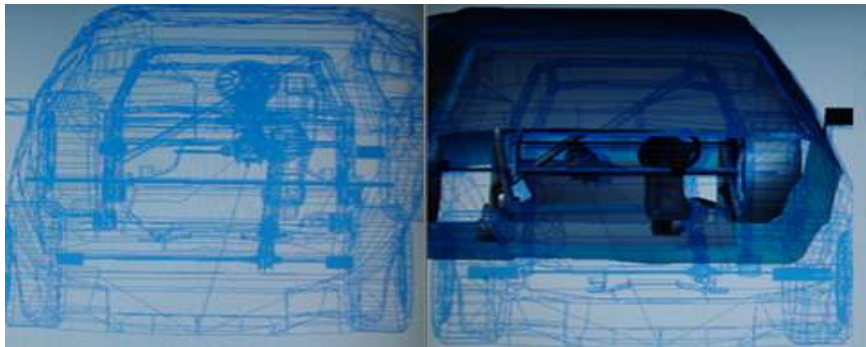


Figure 10.6: Initial view of the model when the slicing technique is applied to the viewport on the left

Figures 10.7 to 10.9 show three stages of the slicing technique in progress. As with the blue car on the right, the object of interest on the left viewports on the front layer of the MLD in solid mode, as shown in Figure 10.9.



Figure 10.7: Portions of the model appear to the front layer as slicing is applied to the car on the left

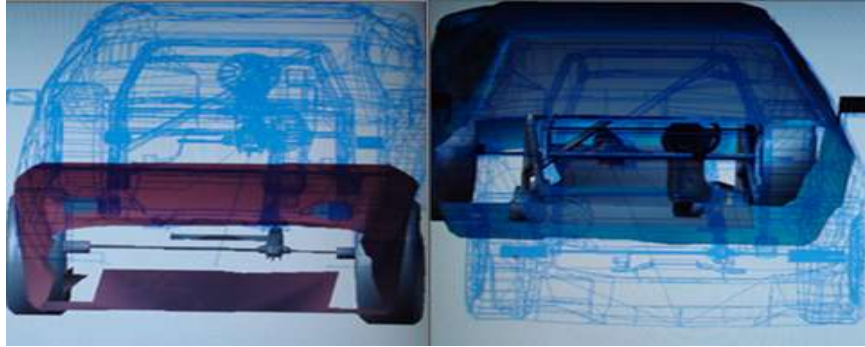


Figure 10.8: New portions of the model are displayed on the front layer as further slicing is applied to the car on the left

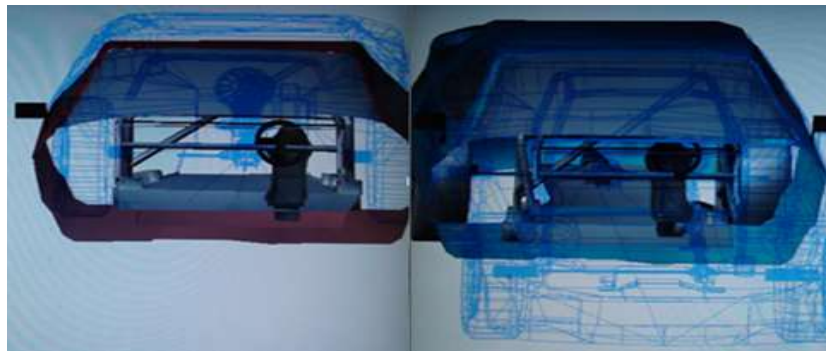


Figure 10.9: Same objects of interest have become visible on both cars using different technique on the left and right viewports

Finally, as shown in Figure 10.10, the orientations of the objects of interest of the left and right viewports are rotated to make comparing the two sets of objects easier. Further zooming is also applied to the left and right viewports to increase the visibility of the objects of interest. This would enable users to identify the differences between the objects of interest more effectively while maintaining their relationships with the context displayed on the rear layer of MLD. In this example scenario, the position of the steering wheel and the rod of the red car on the left viewports is not the same as the blue car on the right. In the red car, the steering rod is passing through the bar A while the steering rod of the blue car is located between the bars A and B. As shown in this example scenario, the contexts relevant to the tasks being performed are continuously visible at all time on both pairs of viewports. This enables the relationships between focus and context to be maintained more effectively.

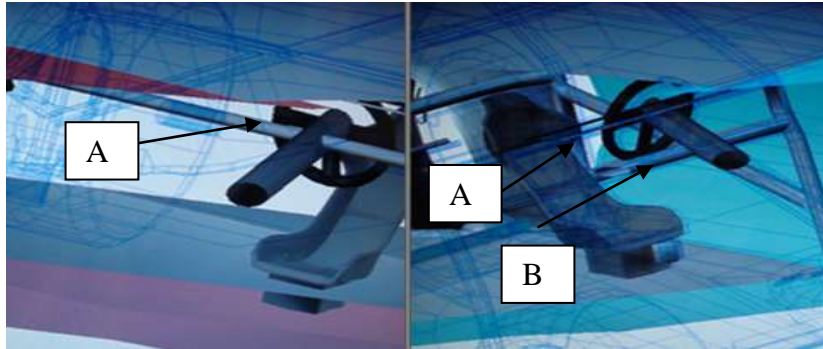


Figure 10.10: Objects of the interest of the two models are clearly visible

10.2 Supporting Focus and Context Awareness with Alternatives Display Hardware Setup

Since MLD may not always be available, an alternative set up was tested to see if the focus and context awareness techniques could be used with multiple monitors. For the purpose of this test, however, using multiple monitors (e.g. side-by-side) was considered be like having a large monitor, where separation of viewports as discussed previously would still cause problems.

Instead, in the alternative display setup a 15" conventional flat 2D monitor, and a projector were used to display the front and back images of MLD respectively. images. The distance between the monitor and the projector screen was about 4.5 meter.

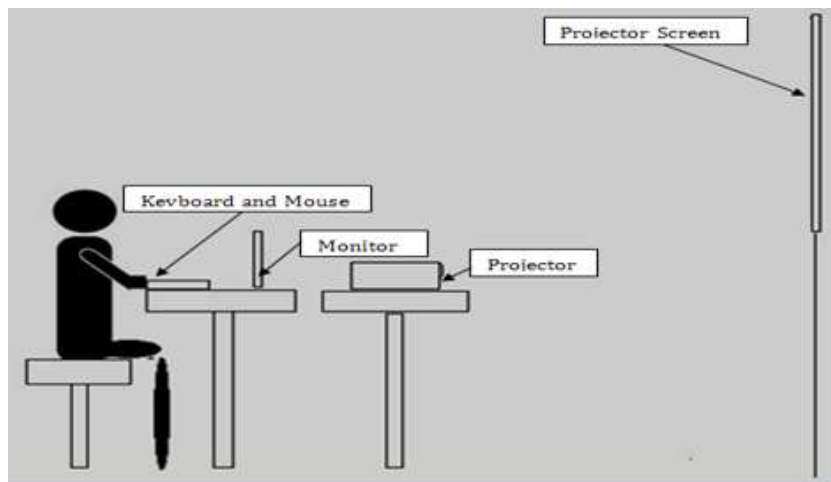


Figure 10.11: Setup for the multiple hardware display

Figure 10.11 shows the setup of the two display devices, where the level of projector screen and monitor are set to require very little or no head movements when changing the viewing focus between the monitor and the projector. This enable the 3D model shown on the monitor and the projector to be seen simultaneously.

Figure 10.12 illustrates an example of what the viewer would see when using this setup. As shown in this figure, the model of the car is shown in wireframe mode on the projector screen (top) while it is displayed in solid mode on the desktop monitor (bottom).

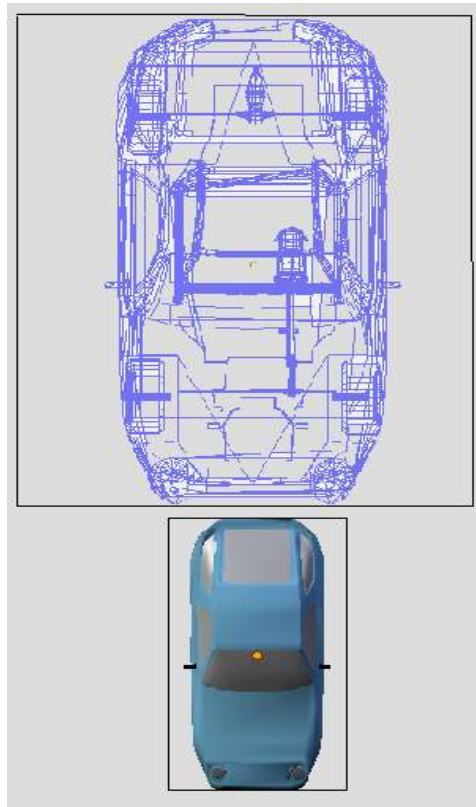


Figure 10.12: View of the model on (top) the projector screen and (bottom) the desktop monitor

Using this setup, the five focus and context awareness techniques discussed in the previous chapters were tested in order to gauge their effectiveness. The object isolation technique was, however, modified to suit this new setup, as will be discussed in the following section.

10.2.1 Object Isolation

The object isolation technique used in this setup was modified to allow the objects of interest to appear on both displays. In MLD the front and back layers are similar in size and are parallel to each other, therefore the relationship between the focus and context can be maintained through the transparency of the front layer. In this setup, however, the two displays are separate from one another, and so it was necessary to show the objects of interest on both displays. In addition, this technique was also integrated with the peeling focus technique.

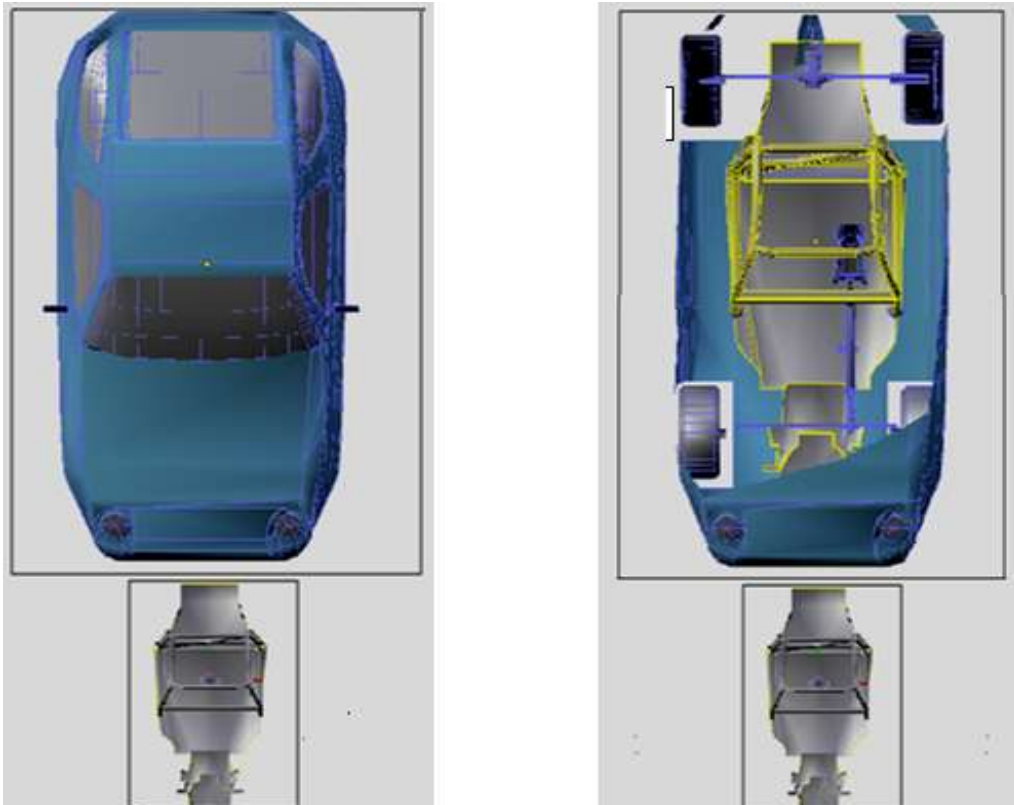


Figure 10.13: View of the model (left) after the object isolation technique is applied, and (right) after the peeling focus technique is applied

Figure 10.13 illustrates an example of using the object isolation technique in this setup. The left figure shows the images after this technique is applied where the object of interest (i.e. chassis) is shown on the front display while the rest of the model is displayed on the back. At this stage, the chassis is not visible on the back display because it is located under the main body of the car.

Using the peeling focus technique together with the object isolation allows portions of the model on the back display (i.e. projector screen) to be removed as shown in the Figure 10.13 (left). As the peeling focus technique is further applied, the chassis which was previously hidden behind the main body becomes visible.

The modification made to the object isolation technique aimed to enable users to maintain their focus and context awareness while performing their modeling tasks in a less crowded environment on the front display.

10.2.2 Component Segregation

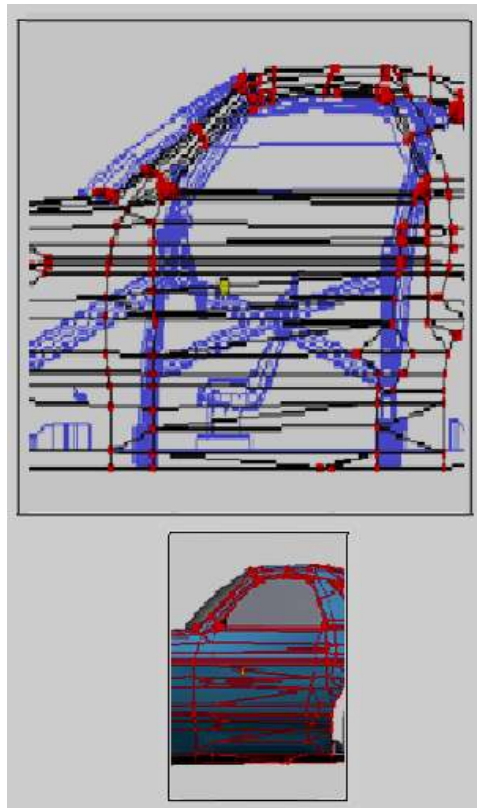


Figure 10.14: Components of the left side of the model are on the front display while those of the right side of the model are on the back display

In the component segregation technique, the two sides of the selected object (near and far components) are split between the two displays. As shown in Figure 10.14, the edges and vertices of the left side of the car are shown on the front display (i.e. monitor) while the components of the right side of the car appear on the back display (i.e. projector screen). As expected, due to the differences between the physical sizes of the displays, the sizes of the model shown on the two displays are different.

While the viewer can change their eye focus from the front to the back display and vice versa, the task of maintaining focus and context awareness is unlikely to be as effectiveness as doing so in MLD.

10.2.3 Peeling Focus

The peeling focus technique is designed to display the model in solid mode on the front display, and wireframe mode on the back display. The combination of these two modes aims to enable modelers to see the context of the model while focusing on the objects of interest. Even though in this setup the two layers are not directly behind each other as in MLD, maintaining focus and context awareness is still possible to

some extent as the context is visible on the back display.

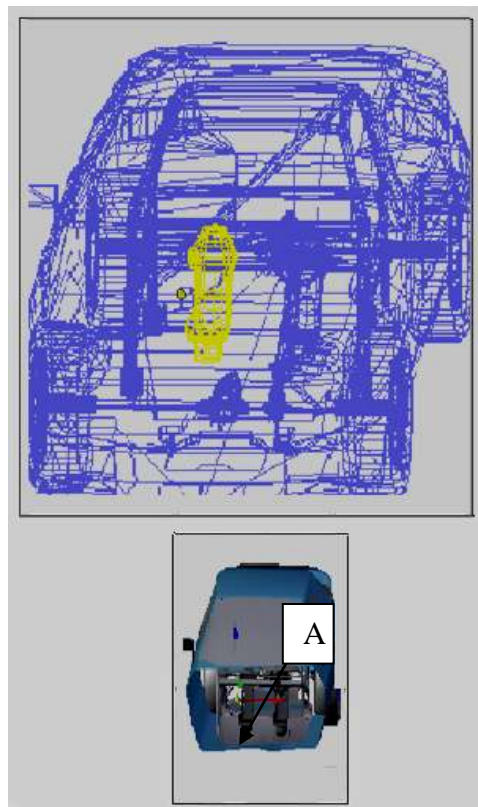


Figure 10.15: Peeling focus technique is being used

For example, as shown in Figure 10.15, the car seat A is selected and shown with yellow edges on front and back displays. While manipulating the object of interest (i.e. the seat) on the front display, its relationship with other objects can be seen on the back display. Therefore the modeler should be able to see the effects of the actions being carried out on the object of interest in relation to the context.

10.2.4 Slicing

Figure 10.17 demonstrates an example of the slicing technique being used. In this example, the front engine parts A need to be aligned with the rear engine B parts. Due to the differences between the size of the two displays and the fact that they are not displayed directly behind each other, verifying the alignment of the objects involved is likely to be difficult.

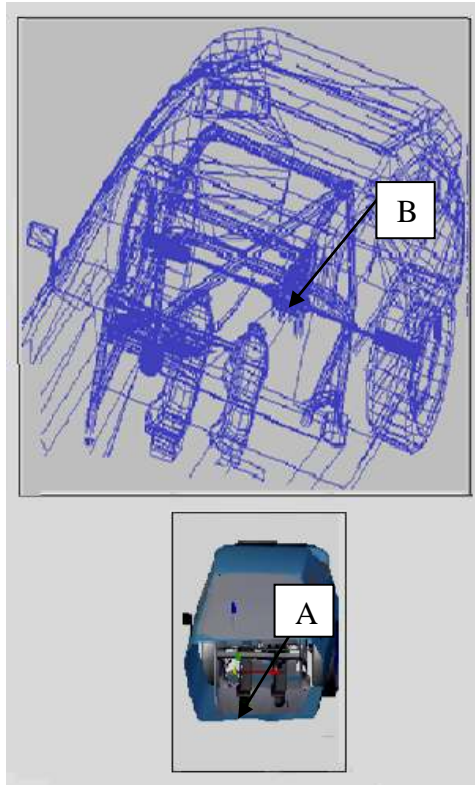


Figure 10.16: Slicing technique is being used

10.2.5 Peeling Focus and Context

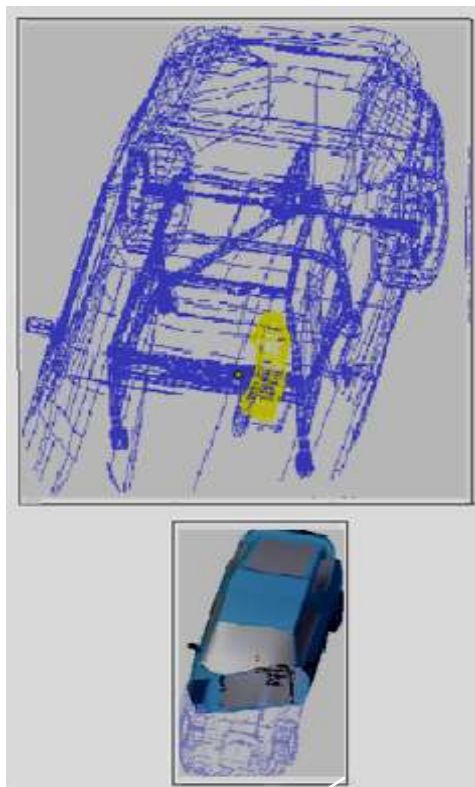


Figure 10.17: The peeling focus and context technique is being used

The peeling focus and context can also be effective in this monitor and projector

setup. In this setup the context of the model also appears on the front display, as shown in Figure 10.17. Thus, the mismatch between the sizes of the objects of interest and context caused by the two displays is minimized. In addition to this, the object of interest shown on the back display makes it possible to see the relationship between the object of interest and the entire model in the larger display.

10.2.6 Effectiveness of the Five Techniques

The examples given in the previous sections have demonstrated that not all of the focus and context awareness techniques are effective in multiple display setups, and therefore require the use of MLD. Table 10.1 provides a summary of the effectiveness of the five techniques.

Table 10.1: The effectiveness of the five techniques

Technique No	Description	Effectiveness
1	Object Isolation	Effective
2	Component Segregation	Not effective
3	Peeling Focus	Effective
4	Slicing	Not effective
5	Peeling Focus and Context	Effective

10.3 Summary

This chapter has presented extensions to the support for focus and context awareness using multiple viewports to assist with tasks that require multiple views of the 3D modeling environment. The chapter has also described an alternative display setup using a conventional computer screen and a projector to support focus and context awareness for multiple displays when an MLD is not readily available. As demonstrated, only three of the five techniques are effective in multiple display setup.

CHAPTER 11

Conclusions and Future Work

This final chapter begins with a summary of the thesis (Section 11.1). This is followed by a discussion of the future work (Section 11.2), and a brief summary (Section 11.3).

11.1 Thesis Summary

This thesis has discussed the key challenges faced by modelers in terms of maintaining focus and context awareness while performing 3D modeling tasks. It has also described the potential solutions to these problems which have been developed and evaluated.

The aim of this research has been to investigate the types of problems faced by 3D modelers in relation to focus and context awareness, to develop techniques to address these problems, and finally to evaluate the effectiveness of these techniques. This investigation, development and evaluation has aimed to provide the answer to the key question of this thesis, that is:

To what extent is it possible to better support focus and context awareness in 3D modeling environments?

As discussed in Chapter 1, there are also four other secondary questions that this thesis has attempted to address. The questions are:

1. *What are the main problems faced by modelers while performing 3D modeling tasks?*
2. *How do modelers attempt to overcome these problems using conventional modeling software tools?*
3. *What are the techniques that can be developed to address these problems by better supporting focus and context awareness in 3D modeling?*
4. *How effective are these focus and context awareness techniques in assisting 3D modelers in performing their modeling tasks?*

Questions 1 and 2 have been addressed through the initial pilot study and the study of professional 3D modelers, discussed in chapters 4 and 5 respectively. Based on the

results of these studies a set of five focus and context awareness techniques have been developed and discussed in Chapter 6 to address Question 3. Question 4 has required an evaluation of these techniques, as discussed in Chapter 7, and their further refinement and evaluation, as discussed in chapters 8 and 9.

The following sections provide a summary of the contributions of this thesis in response to its four secondary research questions. Based on these, in response to the main research question of this thesis, it can be clearly concluded that it is indeed possible to better support focus and context awareness in 3D modeling environments, and this thesis provides several techniques for this purpose.

11.1.1 Focus and Context Awareness Problems

The results of the studies conducted with novice and professional 3D modelers (see chapters 4 and 5) showed that the problems faced by these modelers while performing their modeling tasks can be divide into four categories:

- **Maintaining position awareness:** This category refers to the difficulty of maintaining awareness of the position and orientation of objects of a model in 3D space while performing manipulation and navigation type tasks.
- **Identifying and selecting objects or components of interest:** This category refers to situations where modelers face difficulties in selecting objects or components of interest. As discussed earlier, overlapping of objects and components is the main factor contributing to this type of problem.
- **Recognizing the distance between objects or components:** This category relates to problems faced by modelers in recognizing the location of objects or components in the virtual 3D modeling space. This includes the difficulty of recognizing near and far objects or components. This type of problem often manifests itself when models are displayed in the wireframe mode.
- **Realizing the relative position of objects or components:** This category is related to the difficulty of placing or aligning objects in the virtual 3D space. The studies showed that modelers often need to view a model being manipulated from various angles in multiple viewports. This in turn leads to the problems associated with relying on multiple viewports.

11.1.2 Design and Implementation of Potential Solutions

A detailed discussion of the design and implementation of the potential solutions to the problems associated with focus and context awareness has been presented in the second part of this thesis (see Chapter 6). Five focus and context awareness techniques were developed for MLD. These techniques are:

- **Object Isolation:** This technique is used for separating the objects of interest from the rest of the model. It is intended to be used when modelers need to shape an object that overlaps with other objects within a model. The object isolation technique works by presenting the selected objects of interest and the non-selected objects on different layers of MLD. The object of interest is shown on the front layer while the context of the non-selected objects is shown on the back layer.
- **Component Segregation:** This technique is aimed at addressing the problem of manipulating individual components of the model. It allows the components of interest to remain visible on the front layer, while the context is shown on the back layer in wireframe mode. This technique is different from the component segregation technique because it is intended to be used for manipulating the vertices, edges, and faces of a model, whereas the object isolation technique is used when manipulating individual objects of the model.
- **Peeling Focus:** This technique is implemented mainly because in object editing mode, the objects on the front layer of MLD are shown in solid mode, and therefore, only the outer skin of the model is displayed to the viewer and the internal objects are hidden from the view. Using this technique, the skin of the model can be removed to make the hidden objects visible. In addition to this, using this technique, the overall context of the model, including the removed skin remains visible on the back layer of the MLD. This technique enables modelers to remove what is not relevant to their modeling tasks, while allowing them to focus on the objects of interest.
- **Slicing:** This technique allows removing portions of an object from the back layer of MLD and displaying them on the front layer. Parts of the model that appear on the front layer are displayed in solid mode while the remainder of

the model on the back layer are displayed in wireframe. As with the peeling focus technique, the slicing technique enables modelers to remove what is not relevant to their modeling tasks, while allowing them to focus on parts of the object of interest.

- **Peeling Focus and Context:** As with the slicing technique, the peeling focus and context technique removes parts of the model from both layers of MLD. The difference between these two techniques however is that when using this method, the same portions of the model (i.e. objects of interest and contexts) are shown on both the front and back layers of MLD. In contrast, when using the slicing technique, different portions of the model are displayed on the two layers.

11.1.3 Evaluations and Modifications

These focus and context awareness techniques were then evaluated to compare their effectiveness with existing tools provided by conventional 3D modeling software. The findings of this study suggested that three of the five techniques (i.e. the component segregation, peeling focus, and slicing) improved the completion times of the study tasks. The study also showed that further improvements could be made to these techniques.

Several modifications were then made to improve the effectiveness of the focus and context awareness techniques. The modified techniques were subsequently compared with their original versions. The results of this evaluation showed that the participants preferred the improved techniques over their original versions.

11.2 Future work

This research has investigated the need to address the issues related to focus and context awareness in 3D modeling tasks. As such, the focus of this work has been on the difficulties faced by modelers while performing 3D modeling tasks. The five focus and context awareness techniques developed in this research have therefore targeted 3D modeling tasks only. Thus, it would be interesting to study whether issues related to focus and context awareness exist in other 3D application areas, for examples in computer animation and medical field, and how they can be supported.

In computer animation, focus and context awareness developed for MLD can perhaps

be used to allow the user to edit the skeleton keyframe animation on the front layer, while seeing the skinned animation on the back layer.

In the medical field, the techniques could be used for studying 3D human anatomy. Using these techniques the organs of interest can be shown on the front layer while others are shown on the back layer. As with performing 3D modeling tasks, these two applications require the objects of interest and the context to be viewed simultaneously. Therefore, the focus and context awareness techniques developed for MLD could allow viewers to achieve this goal.

It should also be noted that the techniques developed as part of this thesis for MLD which has only two layers and the distance between them is fixed. It would be possible to develop more advanced focus and context awareness techniques for display hardware that has more than two layers, with adjustable distance between them. This type of hardware and software development has been beyond the scope of this thesis.

11.3 Summary

The conclusion of this research is that the four problems related to maintaining focus and context awareness (i.e. maintaining position awareness, selecting objects or components of interest, recognizing distance between objects or components, and realizing relative position of objects or components) can be overcome if a more effective combination of hardware and software is used. This would allow 3D modelers to maintain their focus and context awareness more effectively while performing their modeling task, which would lead to their improved performance.

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Appendix A

Ethics Approval for the Pilot Study

This appendix includes the letter of approval from the ethics committee of the Faculty of Computing and Mathematical Science, University of Waikato for the study described in Chapter 4.

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THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

12th May 2008

Azmi Bin Yusof
C/- Department of Computer Science
University of Waikato

Dear Azmi Bin

Request for experimental approval

I have considered your request for approval to run a user questionnaire involving human participants during May this year, which will be distributed to students taking COMP304A after one of their lectures.

The procedure described in your request, is acceptable.

I note your statements that completing the questionnaire at the end of a class is voluntary and that the questionnaires are anonymous, therefore there is no need for the participant to sign a Research Consent Form.

I therefore approve your application to undertake the experiment.

Yours faithfully

A handwritten signature in cursive script, appearing to read 'Dave Nichols'.

Dave Nichols
Department of Computer Science
Human Research Ethics Committee
School of Computing and Mathematical Sciences

Appendix B

The Assignment Sheet

This appendix includes the handout specifying the 3D modeling requirement described in Chapter 4.

Graphics Project One: Modelling a character. Due at end of week 3.

Check the class Moodle site for more information. In particular there are detailed instructions and required software for obtaining the UT skeleton and import/export of models.

Your task is to make a 3D model of a character, suitable for use in Unreal Tournament. The character will be attached to the Unreal Tournament skeleton and will therefore be capable of all the normal game animations – ie: walking, running ...

The purpose of the exercise is to gain experience in 3D modelling using Blender. For this reason you are asked to hand in a description of the modelling, texturing and skinning processes – think of it as notes that could be followed by another person (who was reasonably familiar with operation of Blender, but might want to know how you used Blender's capabilities to make your character).

Your character will have the following characteristics:

- It will be modelled as a mesh – with no more than 3000 triangles, or 1500 quads. In other words it will not be very detailed. The ideal number of triangles for a UT1999 character is in the vicinity of 600 – 1200.
- It will be humanoid – and will fit the UT Male skeleton – this means that it will have a head, two arms and two legs, with normal human proportions.
- It will have some additional feature – (for example wings, horns or two faces)

To Do:

- Model your character as a 3D mesh.
- Make a texture for your character and apply it as a UV map.
- Import the UT skeleton and 'skin' your character to the skeleton.
- Export the character from Blender and import it into UT. Check that the animations look acceptable.

Optional Extra:

- Try making an animation in Blender for your character. A good example to try is a bow action, but you could try a wave or even have your character take a step. We won't be able to use these animations in the UT game, but they can be watched in Blender.

Hand In:

- Your written description of the modelling task.
- A screen shot of your character.

Be prepared to demonstrate your character to me and the class.

Appendix C

Ethics Approval for the Study of Professional 3D Modelers

This appendix includes the letter of approval from the ethics committee of the Faculty of Computing and Mathematical Science, University of Waikato for the study described in Chapter 5.

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27th August 2008

Azmin Bin Mohd Yusof
Department of Computer Science
University of Waikato

Dear Azmin

Request to perform an interview

I have considered your request for approval to perform an interview between September and October this year, targeting groups of 3D modelling experts and professionals in New Zealand, with the individual interviews taking place at the interviewee's work place.

The purpose of the interview is to understand user experiences and challenges when working on 3D modelling tasks.

The procedure described in your request is acceptable. I note your statements that confidentiality and participant anonymity will be strictly maintained, all information gathered will be used for statistical analysis only and no names or other identifying characteristics will be stated in the final or any other reports.

The research participants' Bill of Rights and the Research Consent form comply with the requirements of the University's human research ethics policies and procedures.

I therefore approve your application to undertake the experiment.

Yours faithfully



Mike Mayo
Department of Computer Science
Human Research Ethics Committee
School of Computing and Mathematical Sciences

Appendix D

Codes Used for Determining the Visibility of the Components to be Displayed

This appendix includes the codes used for calculating the dot products (i.e. normal values) of the polygons and those for determining the visibility of the components to be displayed (i.e. either on the front or back layers) described in Chapter 6.

```
for (i=0,efa=G.editMesh->faces.first; efa; i++,efa=efa->next)
{ g_em_face_array[i] = efa;
  if (G.vd->drawtype > OB_WIRE)
  { norm = efa->n[0]* G.vd->viewinv[2][0] + efa->n[1]*G.vd->viewinv[2][1] + efa->n[2]*G.vd-
>viewinv[2][2] ;
    if ((norm < 0) && (win_id == G.top_layerwin_id)) continue;
    if ((norm > 0) && (win_id == G.bottom_layerwin_id)) continue;
    if (win_id == G.top_layerwin_id)
    { G.top_layer_arr[top_layer_ctr][0] = efa->v1->co[0];
      G.top_layer_arr[top_layer_ctr][1] = efa->v1->co[1];
      G.top_layer_arr[top_layer_ctr][2] = efa->v1->co[2];
      G.top_layer_arr[top_layer_ctr][3] = efa->v2->co[0];
      G.top_layer_arr[top_layer_ctr][4] = efa->v2->co[1];
      G.top_layer_arr[top_layer_ctr][5] = efa->v2->co[2];
      top_layer_ctr++;

      G.top_layer_arr[top_layer_ctr][0] = efa->v2->co[0];
      G.top_layer_arr[top_layer_ctr][1] = efa->v2->co[1];
      G.top_layer_arr[top_layer_ctr][2] = efa->v2->co[2];
      G.top_layer_arr[top_layer_ctr][3] = efa->v3->co[0];
      G.top_layer_arr[top_layer_ctr][4] = efa->v3->co[1];
      G.top_layer_arr[top_layer_ctr][5] = efa->v3->co[2];
      top_layer_ctr++;

      if(efa->v4)
      { G.top_layer_arr[top_layer_ctr][0] = efa->v3->co[0];
        G.top_layer_arr[top_layer_ctr][1] = efa->v3->co[1];
        G.top_layer_arr[top_layer_ctr][2] = efa->v3->co[2];
        G.top_layer_arr[top_layer_ctr][3] = efa->v4->co[0];
        G.top_layer_arr[top_layer_ctr][4] = efa->v4->co[1];
        G.top_layer_arr[top_layer_ctr][5] = efa->v4->co[2];
        top_layer_ctr++;

        G.top_layer_arr[top_layer_ctr][0] = efa->v4->co[0];
        G.top_layer_arr[top_layer_ctr][1] = efa->v4->co[1];
        G.top_layer_arr[top_layer_ctr][2] = efa->v4->co[2];
        G.top_layer_arr[top_layer_ctr][3] = efa->v1->co[0];
        G.top_layer_arr[top_layer_ctr][4] = efa->v1->co[1];
        G.top_layer_arr[top_layer_ctr][5] = efa->v1->co[2];
        top_layer_ctr++;
      }
    }
  else
  { G.top_layer_arr[top_layer_ctr][0] = efa->v3->co[0];
```

```

        G.top_layer_arr[top_layer_ctr][1] = efa->v3->co[1];
        G.top_layer_arr[top_layer_ctr][2] = efa->v3->co[2];
        G.top_layer_arr[top_layer_ctr][3] = efa->v1->co[0];
        G.top_layer_arr[top_layer_ctr][4] = efa->v1->co[1];
        G.top_layer_arr[top_layer_ctr][5] = efa->v1->co[2];
        top_layer_ctr++;
    }
}
if (win_id == G.bottom_layerwin_id)
{
    G.bottom_layer_arr[bottom_layer_ctr][0] = efa->v1->co[0];
    G.bottom_layer_arr[bottom_layer_ctr][1] = efa->v1->co[1];
    G.bottom_layer_arr[bottom_layer_ctr][2] = efa->v1->co[2];
    G.bottom_layer_arr[bottom_layer_ctr][3] = efa->v2->co[0];
    G.bottom_layer_arr[bottom_layer_ctr][4] = efa->v2->co[1];
    G.bottom_layer_arr[bottom_layer_ctr][5] = efa->v2->co[2];
    bottom_layer_ctr++;

    G.bottom_layer_arr[bottom_layer_ctr][0] = efa->v2->co[0];
    G.bottom_layer_arr[bottom_layer_ctr][1] = efa->v2->co[1];
    G.bottom_layer_arr[bottom_layer_ctr][2] = efa->v2->co[2];
    G.bottom_layer_arr[bottom_layer_ctr][3] = efa->v3->co[0];
    G.bottom_layer_arr[bottom_layer_ctr][4] = efa->v3->co[1];
    G.bottom_layer_arr[bottom_layer_ctr][5] = efa->v3->co[2];
    bottom_layer_ctr++;
    if(efa->v4)
    {
        G.bottom_layer_arr[bottom_layer_ctr][0] = efa->v3->co[0];
        G.bottom_layer_arr[bottom_layer_ctr][1] = efa->v3->co[1];
        G.bottom_layer_arr[bottom_layer_ctr][2] = efa->v3->co[2];
        G.bottom_layer_arr[bottom_layer_ctr][3] = efa->v4->co[0];
        G.bottom_layer_arr[bottom_layer_ctr][4] = efa->v4->co[1];
        G.bottom_layer_arr[bottom_layer_ctr][5] = efa->v4->co[2];
        bottom_layer_ctr++;

        G.bottom_layer_arr[bottom_layer_ctr][0] = efa->v4->co[0];
        G.bottom_layer_arr[bottom_layer_ctr][1] = efa->v4->co[1];
        G.bottom_layer_arr[bottom_layer_ctr][2] = efa->v4->co[2];
        G.bottom_layer_arr[bottom_layer_ctr][3] = efa->v1->co[0];
        G.bottom_layer_arr[bottom_layer_ctr][4] = efa->v1->co[1];
        G.bottom_layer_arr[bottom_layer_ctr][5] = efa->v1->co[2];
        bottom_layer_ctr++;
    }
    else
    {
        G.bottom_layer_arr[bottom_layer_ctr][0] = efa->v3->co[0];
        G.bottom_layer_arr[bottom_layer_ctr][1] = efa->v3->co[1];
        G.bottom_layer_arr[bottom_layer_ctr][2] = efa->v3->co[2];
        G.bottom_layer_arr[bottom_layer_ctr][3] = efa->v1->co[0];
        G.bottom_layer_arr[bottom_layer_ctr][4] = efa->v1->co[1];
        G.bottom_layer_arr[bottom_layer_ctr][5] = efa->v1->co[2];
        bottom_layer_ctr++;
    }
}
}
}
if (G.vd->drawtype > OB_WIRE)
{
    if (win_id == G.top_layerwin_id)
    {
        G._totaltop_layer_ctr = top_layer_ctr;
        G.top_layer_arr[top_layer_ctr][0] = 999;
    }
    if (win_id == G.bottom_layerwin_id)
    {
        G._totalbottom_layer_ctr = bottom_layer_ctr;
        G.bottom_layer_arr[bottom_layer_ctr][0] = 999;
    }
}
}
}

```

Appendix E

Ethics Approval for the Study of Focus and Context Awareness Techniques

This appendix includes the letter of approval from the ethics committee of the Faculty of Computing and Mathematical Science, University of Waikato for the study described in Chapter 7.

Computing and Mathematical Sciences
Rorohiko me ngā Pūtaiao Pūngarau
The University of Waikato
Private Bag 3105
Hamilton
New Zealand

Phone +64 7 838 4322
www.scms.waikato.ac.nz



21st October 2009

Azmi Bin Mohn Yusof
C/- Department of Computer Science
THE UNIVERSITY OF WAIKATO

Dear Azmi

Request for approval to perform user studies involving human participants

I have considered your request for approval to carry out a series of user tests commencing in October 2009 as a partial requirement for your PhD study.

The goal of this project is to address some of the major issues related to focus and context awareness in 3D modelling tasks.

The procedure described in your request is acceptable. I note your statements that only the researcher and supervisor will be privy to the notes, documents recordings and the paper written and that all data collected will be destroyed and recordings erased five years after your PhD has been completed. The transcriptions of the recordings and a copy of the paper will be treated with strict confidentiality. No participants will be named in the publications and every effort will be made to disguise their identity.

The Participant Information Sheet and Consent forms comply with the requirements of the University's human research ethics policies and procedures.

I therefore approve your application to perform the user study.

Yours sincerely



Dave Nichols
Human Research Ethics Committee
School of Computing and Mathematical Sciences

Appendix F

Instruction Manual and Handout Used in the Study of the Focus and Context

Awareness Techniques

This appendix includes the instruction manual and handout used in the study of the focus and context awareness techniques described in Chapter 7. It is divided into two categories:

- The instruction manual and handout used while performing modeling tasks using focus and context awareness techniques.
- The instruction manual and handout used while performing modeling tasks using conventional modeling techniques.

The instruction manual and handout used while performing modeling tasks using focus and context awareness techniques

Task 1.

From the menu, click on File, Open Recent and finally on \USABILITY_MLD\TASK1.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To increase the size of the floor tray (A) of main chassis frame, and to create a separator (back engine compartment) (D) between passenger area and back engine area.

- i. The position of the four legs of the main chassis frame and the four holders should remain the same at B.
- ii. The increased floor tray area (C) should not extent beyond the body of the car.
- iii. The divider is to be placed right behind the rear tyres (E).

Subtask A Separate between internal floor and other objects into front and back viewport.

Method to use Object Isolation

Press Save (CTRL W) to save the file.

Subtask B Maximize the area of the floor covered from A and C.

Suggested method: Scaling.

Press Save (CTRL W) to save the file.

Task 2.

From the menu, click on File, Open Recent and finally on \USABILITY_MLD\TASK2.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose: To imitate (without copying or duplicating) the design of the left side door to the right side door of the car (Figure 1b).

Subtask A Determine the differences between the left and the right side of the car's door.

Method to use Component Segregation

Press Save (CTRL W) to save the file.

Subtask B Move the vertices and create new edges as necessary.

Suggested method: Use function key "W" to subdivide the edge, function key "F" to create new edges and function key "G" to grab and move.

Press Save (CTRL W) to save the file.

Task 3.

From the menu, click on File, Open Recent and finally on \USABILITY_MLD\TASK3..blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To install steering wheel, steering shaft and track rod at the proper place which are initially outside the car (A).

- i. The end of the track rod must be placed in the stub axle of both front tyres (B).
- ii. Steering shaft (D) must be positioned between the two safety bars.

Subtask A Locate the two safety bars (C) where steering shaft will pass through.

Method to use Peeling Focus.

Press Save (CTRL W) to save the file.

Subtask B Adjust an angle of the steering shaft.

Suggested method: Rotation in side view

Press Save (CTRL W) to save the file.

Subtask C. Place the track rod that will connect the two front tyres.

Suggested method: Translation.

Press Save (CTRL W) to save the file.

Task 4.

From the menu, click on File, Open Recent and finally on \USABILITY_MLD\TASK4.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To relocate the steering wheel (A) and driver's seat (B) to the designated area

- i. The seat must be placed in the designated seat area (C).
- ii. The seat's head rest must touch the divider (F).

Subtask A Locate the driver seat's raised floor (C) and the steering shaft (D).

Method to use Slicing.

Press Save (CTRL W) to save the file.

Subtask B Place and align the seat at the designated area (C).

Suggested method: Translation and rotation.

Press Save (CTRL W) to save the file.

Subtask C Connect the steering wheel with the steering shaft (E).

Suggested method: Translation.

Press Save (CTRL W) to save the file.

Task 5.

From the menu, click on File, Open Recent and finally on \USABILITY_MLD\TASK5.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To create a link or a bar between the front and back track rods.

- i. Linkage or a bar is to be done between point (A) to point (B).
- ii. The new linkage or the bar (C) is located between the floor tray of the main chassis frame (D and the floor of the car.
- iii. The new linkage or the bar must be parallel to the body of the car.

Subtask A Determine point A and point B.

Method to use Peeling Focus and Context.

Press Save (CTRL W) to save the file.

Subtask B Create the linkage or the bar from point A to point B.

Suggested method: Extruding while in wireframe draw type.

Press Save (CTRL W) to save the file.

Subtask C Relocate starting point A, so that the linkage from point A to point B will be parallel to the body of the car.

Suggested method: Grab and move with function key “G”.

Press Save (CTRL W) to save the file.

Task 1

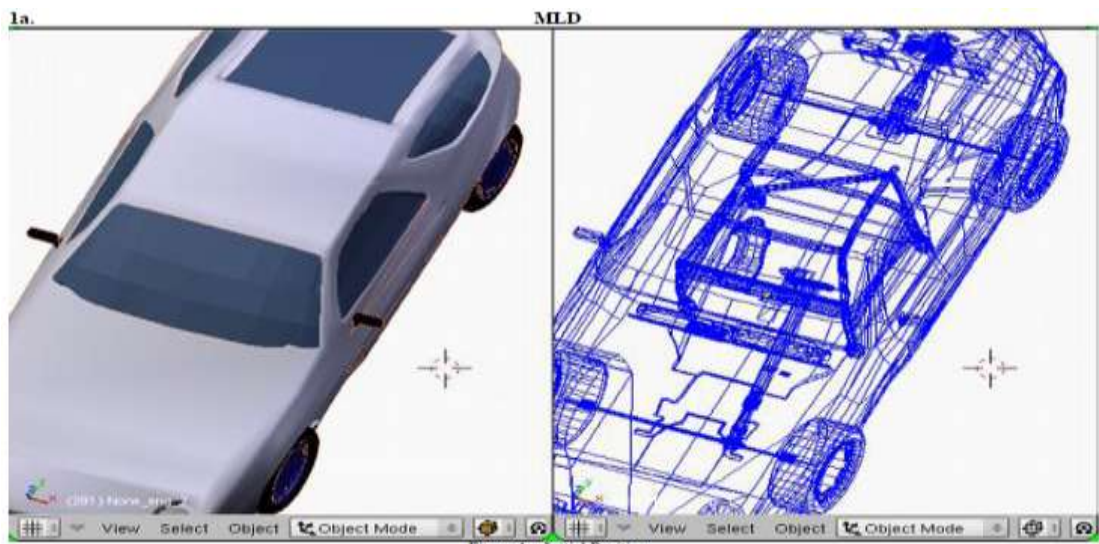


Figure 1a: Initial Position.

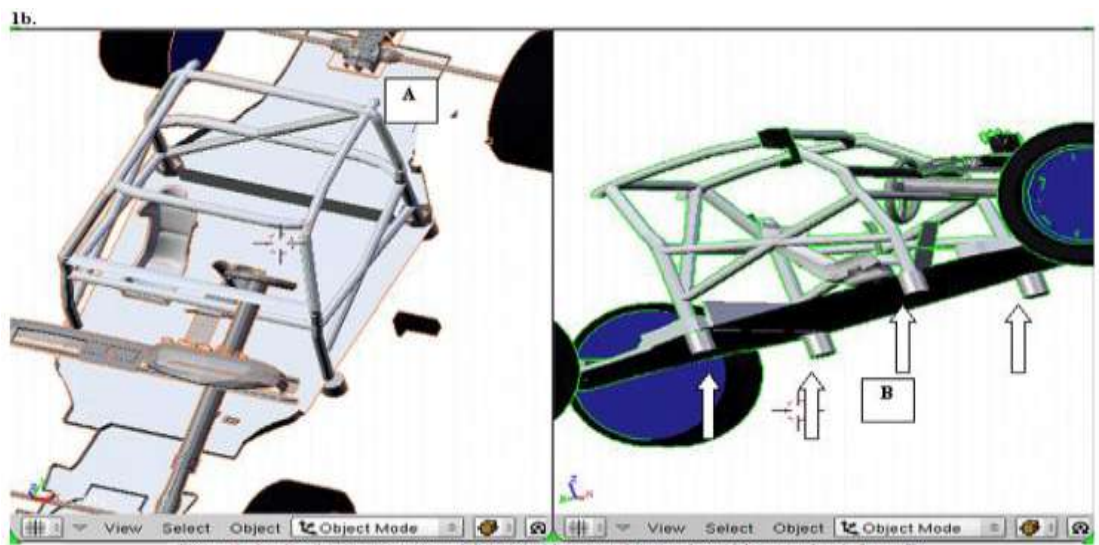


Figure 1b: Smaller floor tray size (A) and the original location of the four legs of the main chassis frame (B).

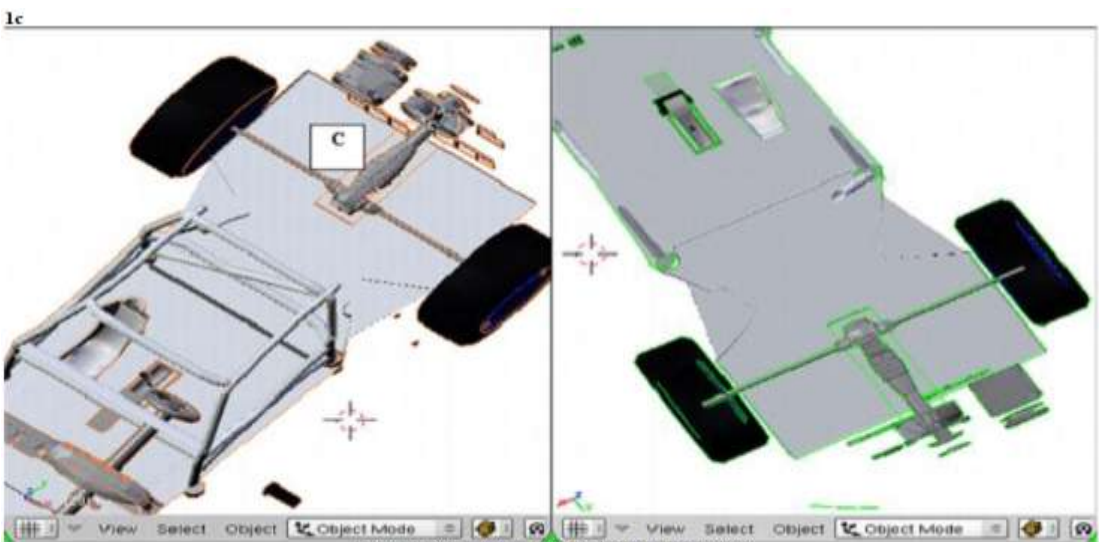


Figure 1c: Expected output with bigger floor tray size (C).

Task 2

2a.

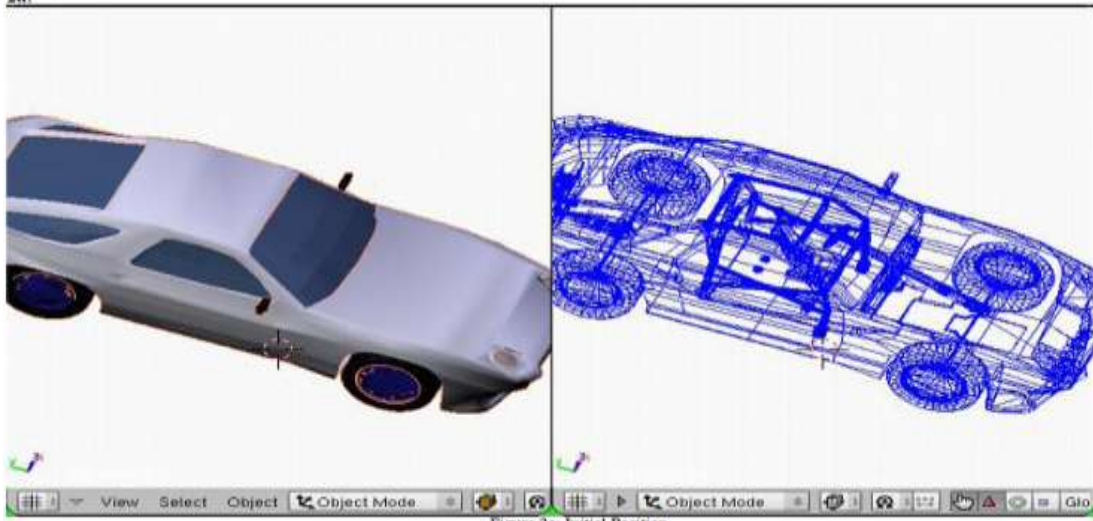


Figure 2a: Initial Position

2b.

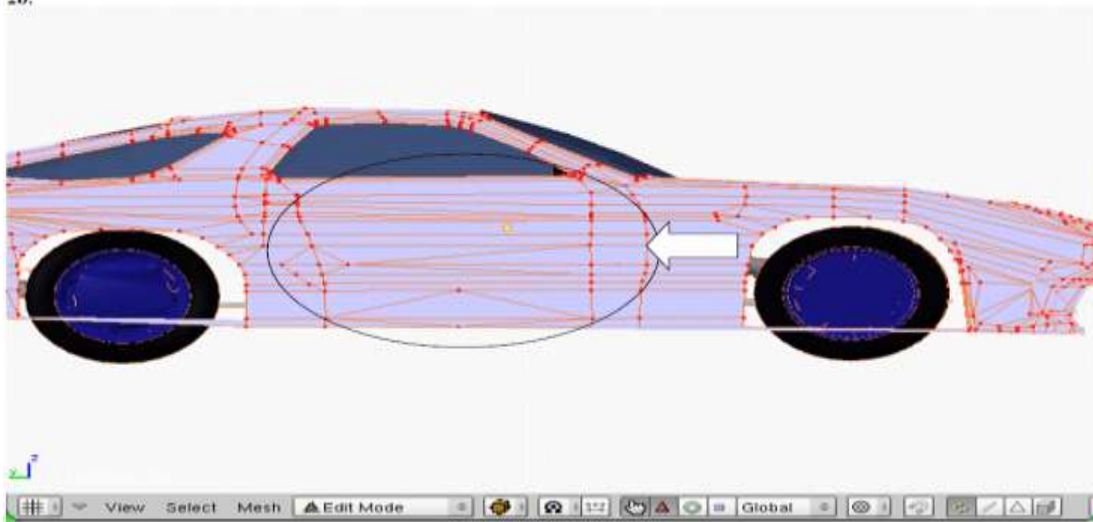
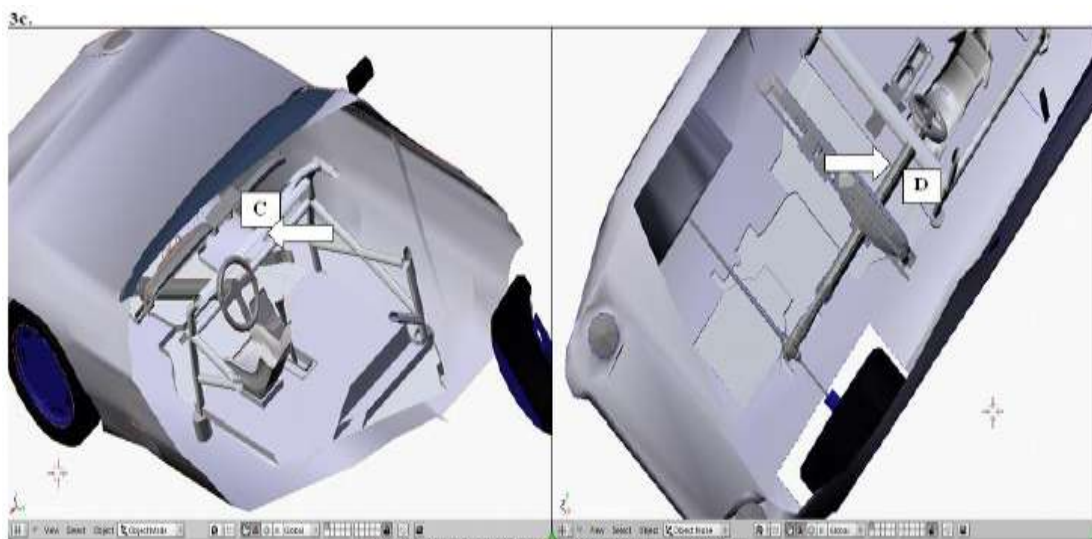
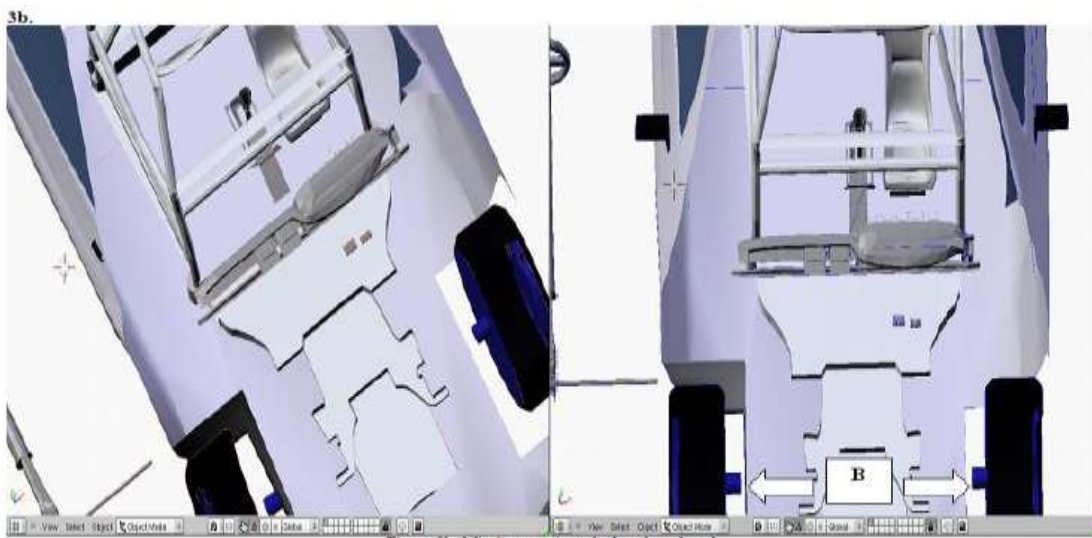
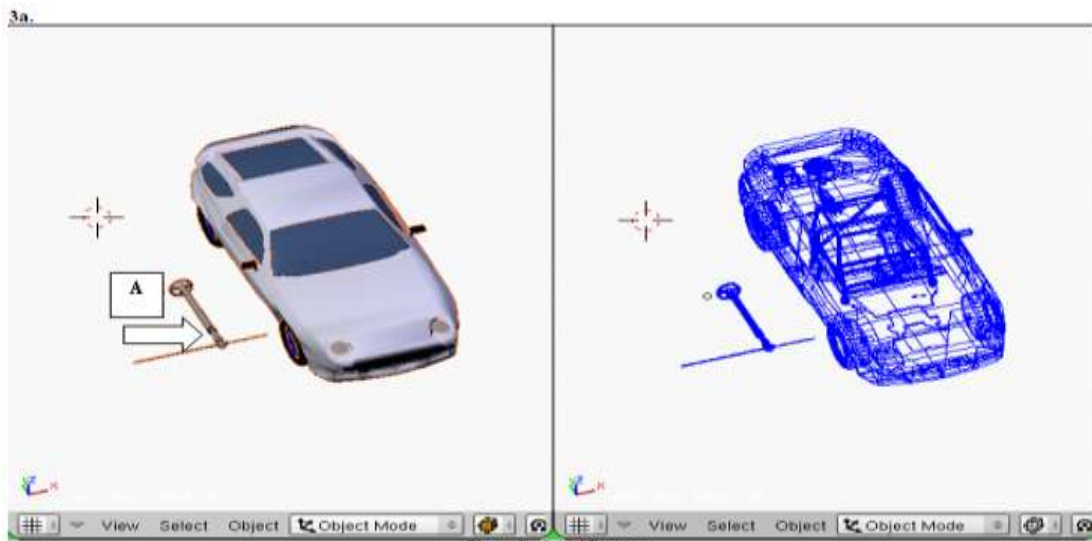


Figure 2b: Right side of the car

Task 3



Task 4

4a.

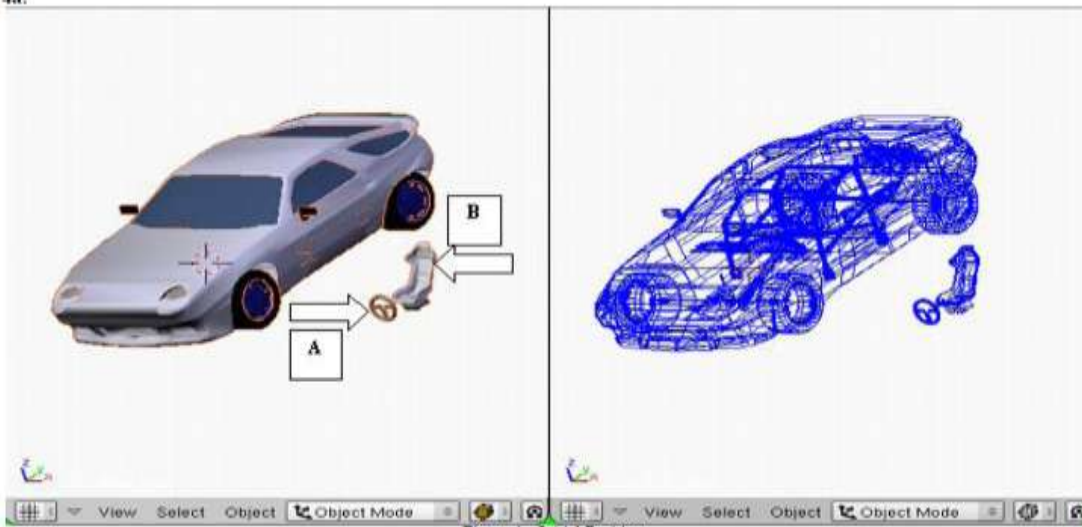


Figure 4a: Initial Position.

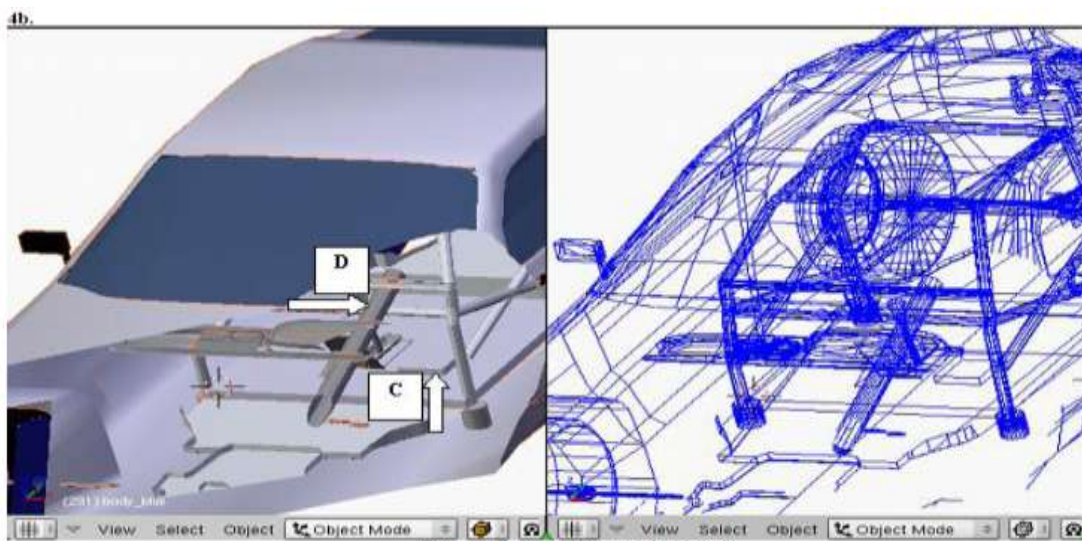


Figure 4b: Designated location of the seat (C)

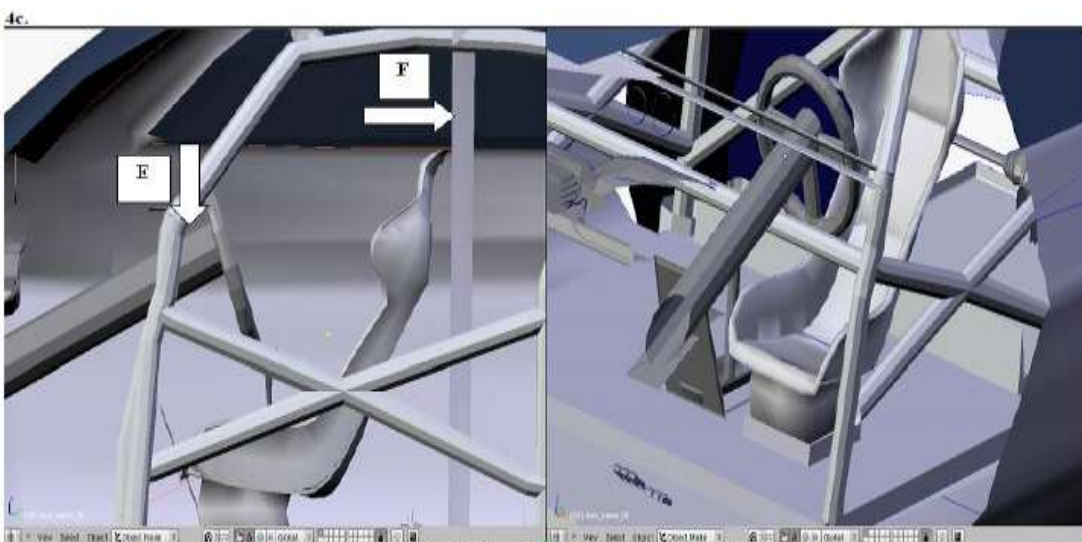
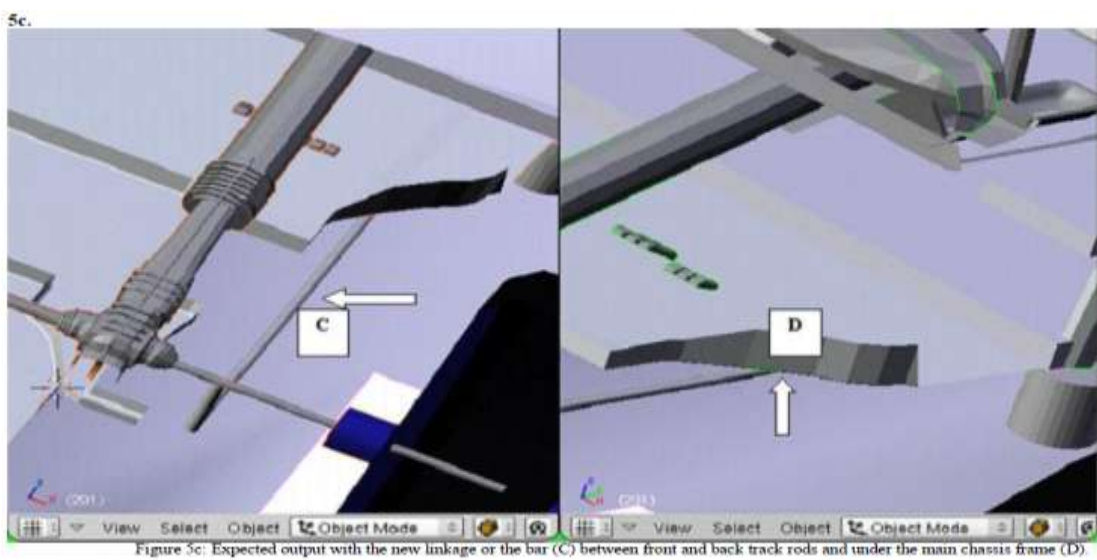
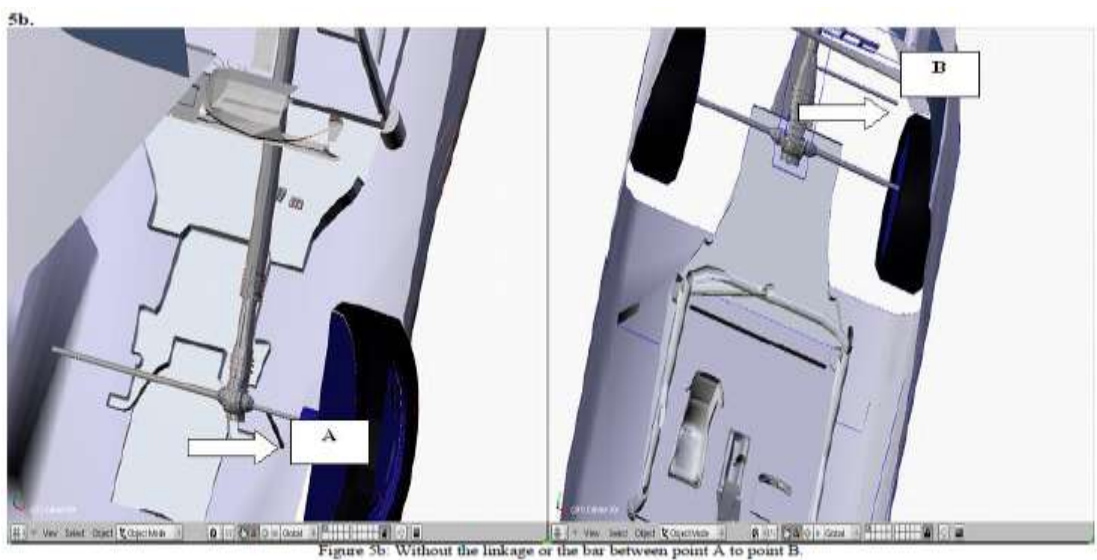
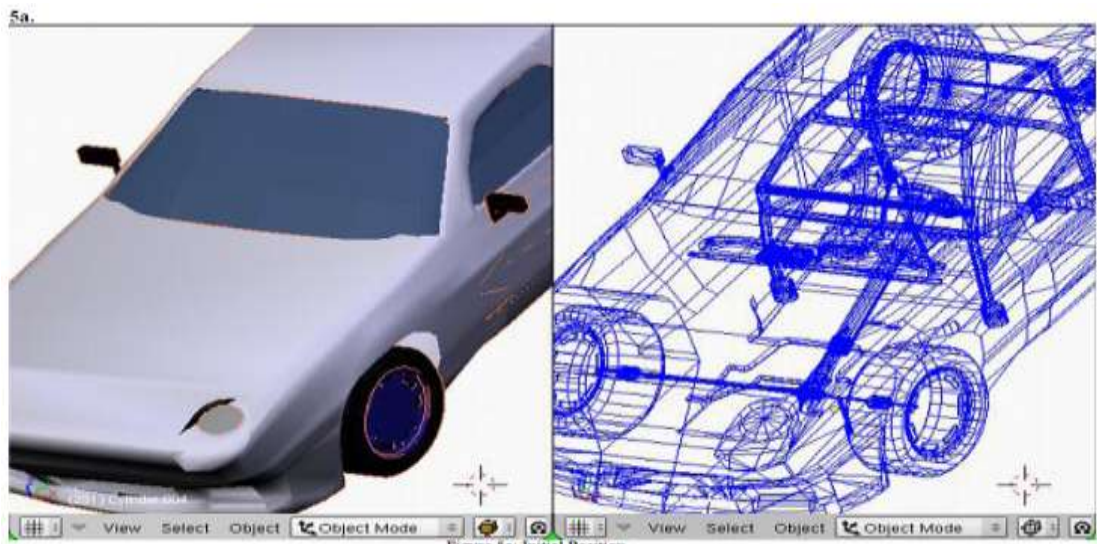


Figure 4c: Expected output with seat at the designated location.

Task 5



The instruction manual and handout used while performing modeling tasks using conventional modeling techniques

Task 1.

From the menu, click on File, Open Recent and finally on \USABILITY STD\TASK1.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To increase the floor tray size of the main chassis frame (A) to cover a bigger area of the car as shown at C, and to add a separator (front engine compartment) (D) between driver area and front engine area.

- i. The floor area should not extend beyond the body of the car.
- ii. The position of the four legs of the main chassis frame and the four holders should remain the same (B).
- iii. The separator is in between speedometer (E) and front tyres.

Subtask A Isolate the object, so that no other objects appear on the left viewport except main chassis frame.

Method to use Hides other objects with Numpad “/” key on the left viewport.

Press Save (CTRL W) to save the file.

Subtask Maximise the area of the floor tray from A to B.

Suggested method: Scaling.

Press Save (CTRL W) to save the file.

Task 2.

From the menu, click on File, Open Recent and finally on \USABILITY STD\TASK1.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To imitate (without copying or duplicating) the design of the right side windscreen to the left side windscreen of the car (Figure 1b).

Subtask A Determine the differences between the left and the right windscreen.

Method to use In edit mode, set to side view in order to see both left and right side of the windscreen.

Press Save (CTRL W) to save the file.

Subtask B Move the vertices and create new edges as necessary.

Suggested method: Use function key “W” to subdivide the edge, function key “F” to create new edges and function key “G” to grab and move.

Press Save (CTRL W) to save the file.

Task 3.

From the menu, click on File, Open Recent and finally on \USABILITY STD\TASK2.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To place the main chassis frame (A) to the designated area.

- i. The four legs of the main chassis frame (B) must be placed into the four holders (C).
- i. Steering shaft is resting on safety bar (D).
- ii. The height of the safety bar is as shown in (E).

Subtask A Locate the designated area of the main chassis frame and the four holders.

Method to use Zooming in perspective view.

Press Save (CTRL W) to save the file.

Subtask B Adjust an angle of the main chassis frame to be flat on the floor.

Suggested method: Rotation in side view.

Press Save (CTRL W) to save the file.

Subtask C Place the main chassis frame to its designated area and position the four legs into the holders.

Suggested method: Translation.

Press Save (CTRL W) to save the file.

Task 4.

From the menu, click on File, Open Recent and finally on \USABILITY STD\TASK3.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To place the front's engine (A) to its new location (C) and to relocate the speedometer (B) to a new location (G)

- i. Track rod will connect the two front tyres at D & E.
- ii. The shaft and steering wheel are connected on the safety bar (F).

Subtask A Locate the front engine designated area and the speedometer's area.

Method to use Hiding ("H" key).

Press Save (CTRL W) to save the file.

Subtask B Place the engine at the designated area and align the steering shaft with the steering wheel.

Suggested method: Translation and rotation.

Press Save (CTRL W) to save the file.

Subtask C Place the speedometer at the designated area.

Suggested method: Translation.

Press Save (CTRL W) to save the file.

Task 5.

From the menu, click on File, Open Recent and finally on \USABILITY STD\TASK4.blend.

Press Save (CTRL W) to save the file.

Note In each of the following tasks, Press Save (CTRL W) after each subtask has been completed.

Purpose To complete making the square frame under the main chassis and join with the safety bar.

- i. The extension of the square frame needs to be done from point A.
- ii. Safety bar and the newly completed square frame need to be joined at point B and C.
- iii. The entire square frame (D) is to be placed between the main chassis and car's bottom floor.

Subtask A Locate the bar.

Method to use Change draw type to wireframe draw type.

Press Save (CTRL W) to save the file.

Subtask B Complete the square of the bar.

Suggested method: Region based extrusion.

Press Save (CTRL W) to save the file.

Subtask C Connect both sides of the safety bar (B) (left and right) with the newly completed square frame at point C (left and right).

Suggested method: Extruding.

Press Save (CTRL W) to save the file.

Task 1

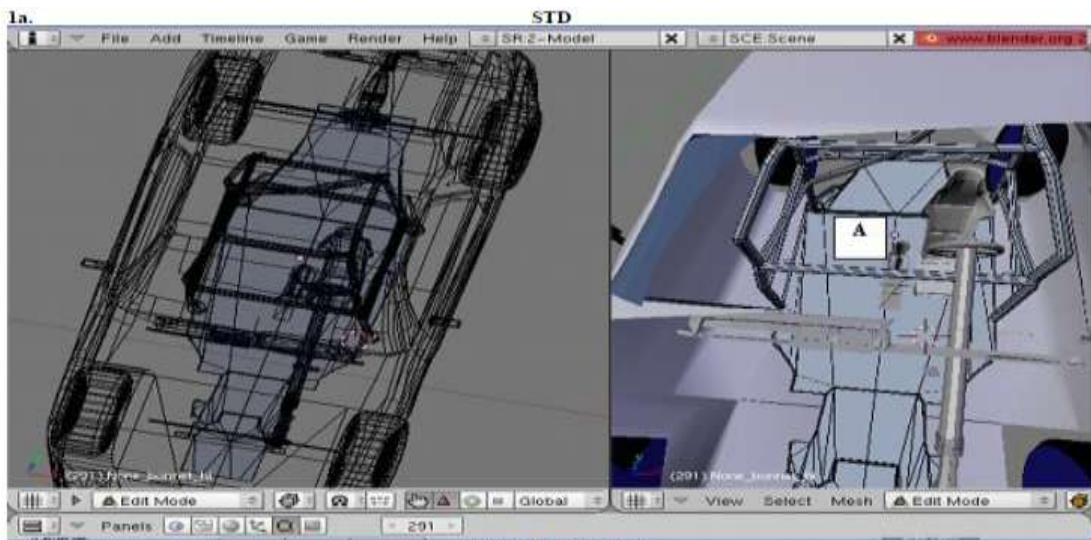


Figure 1a: Initial Position.

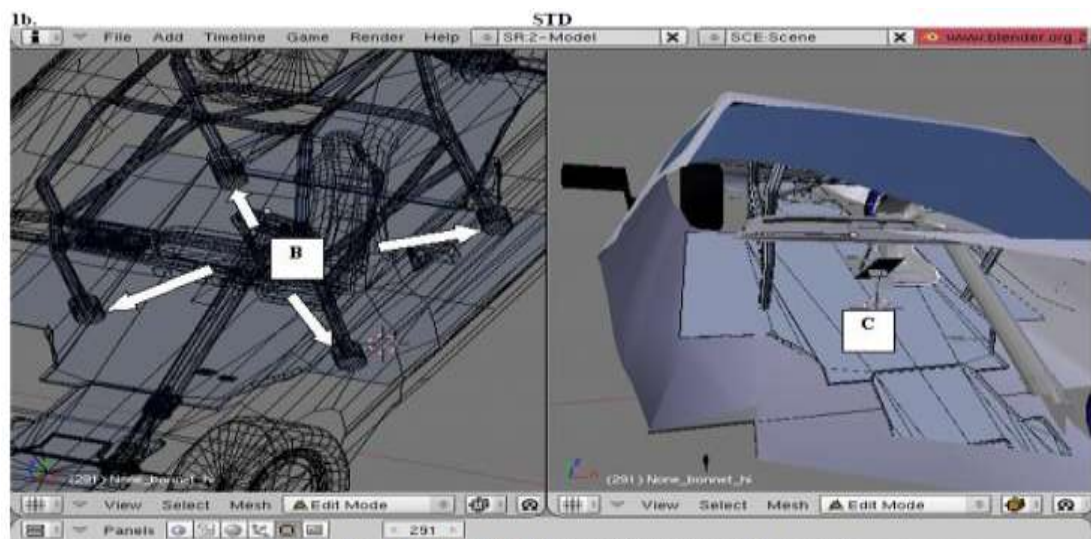
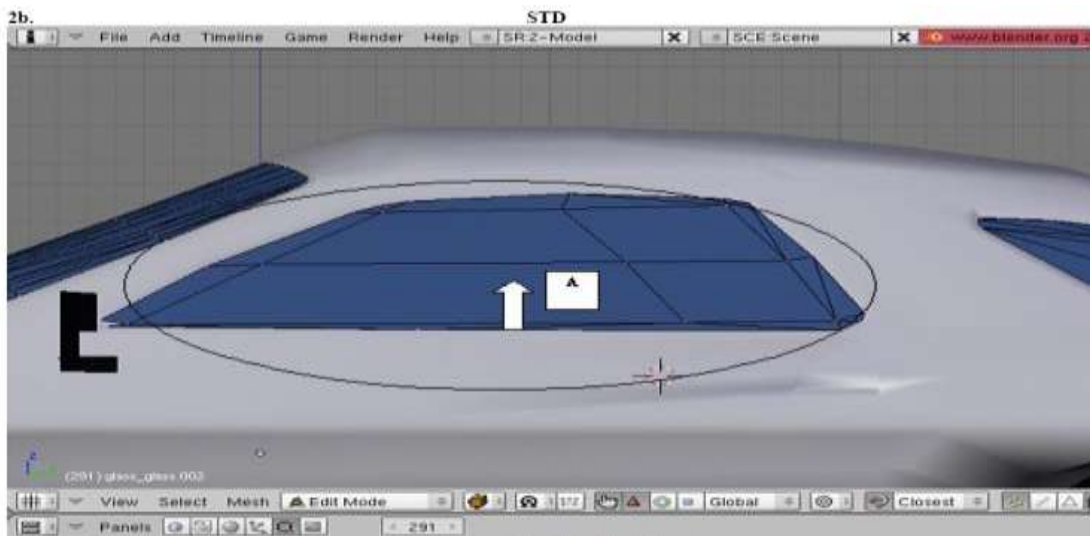
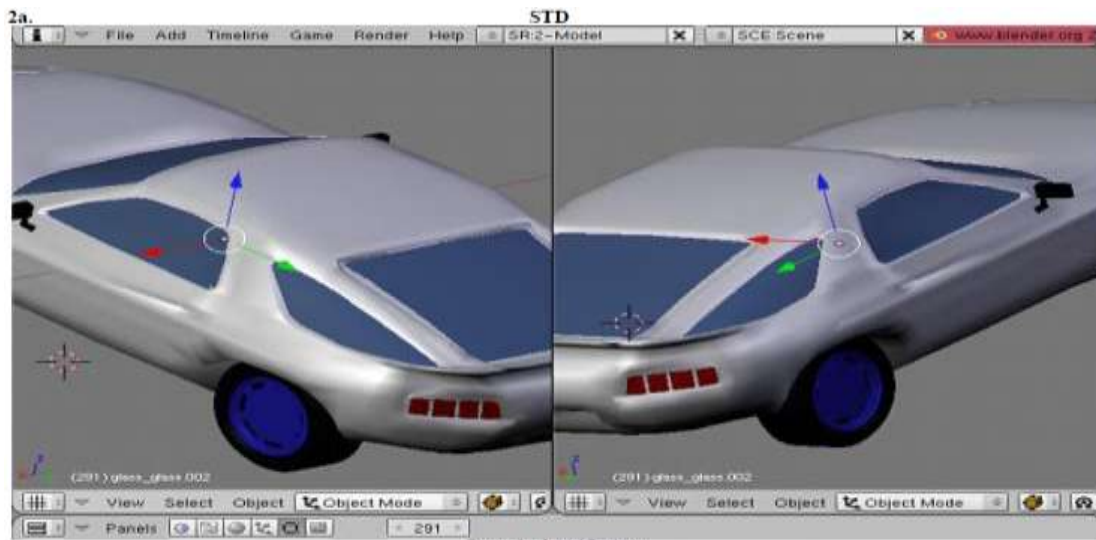
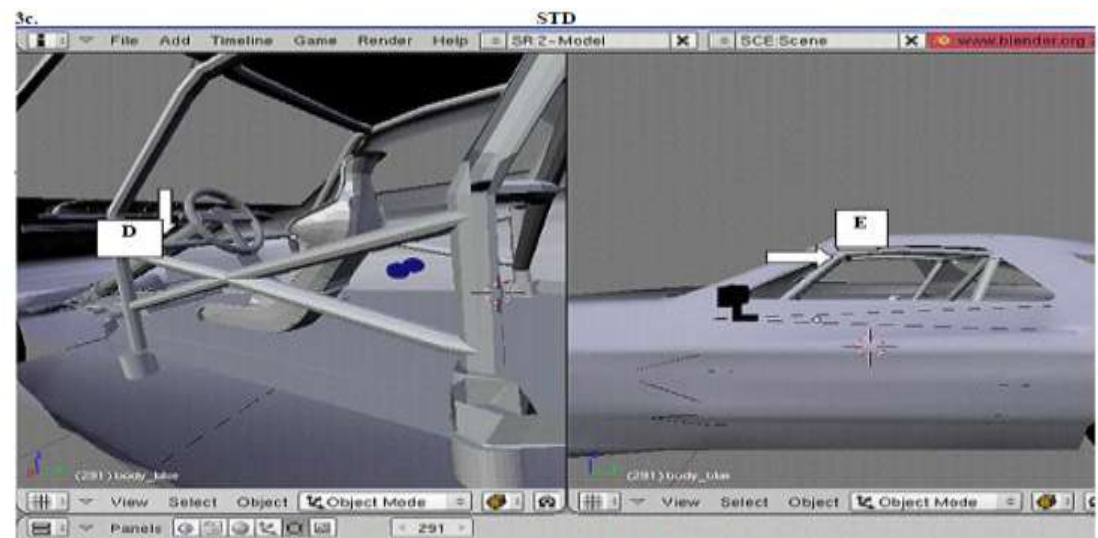
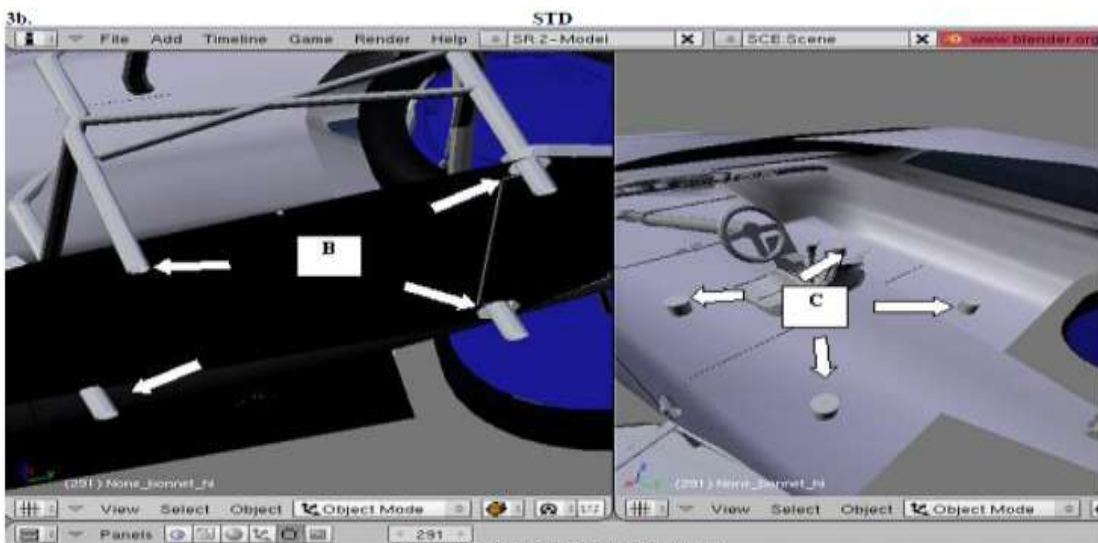
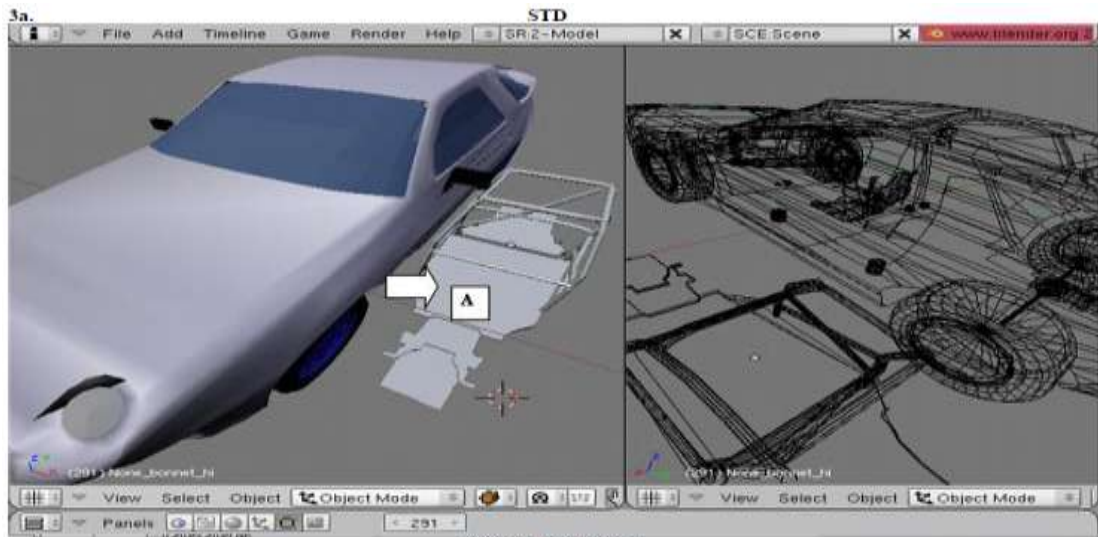


Figure 1b: Expected output with bigger floor tray area (C) of the main chassis frame.

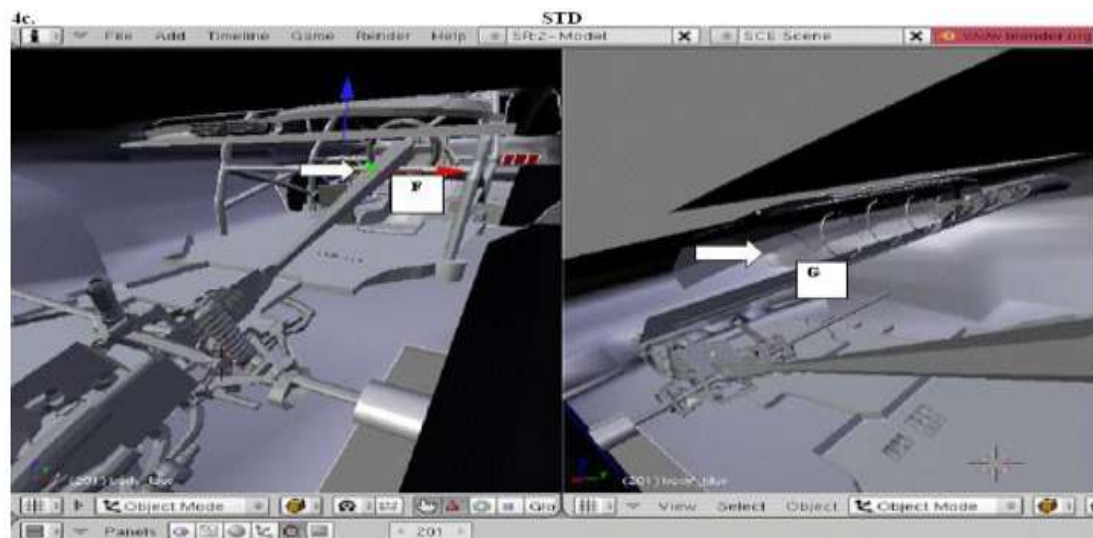
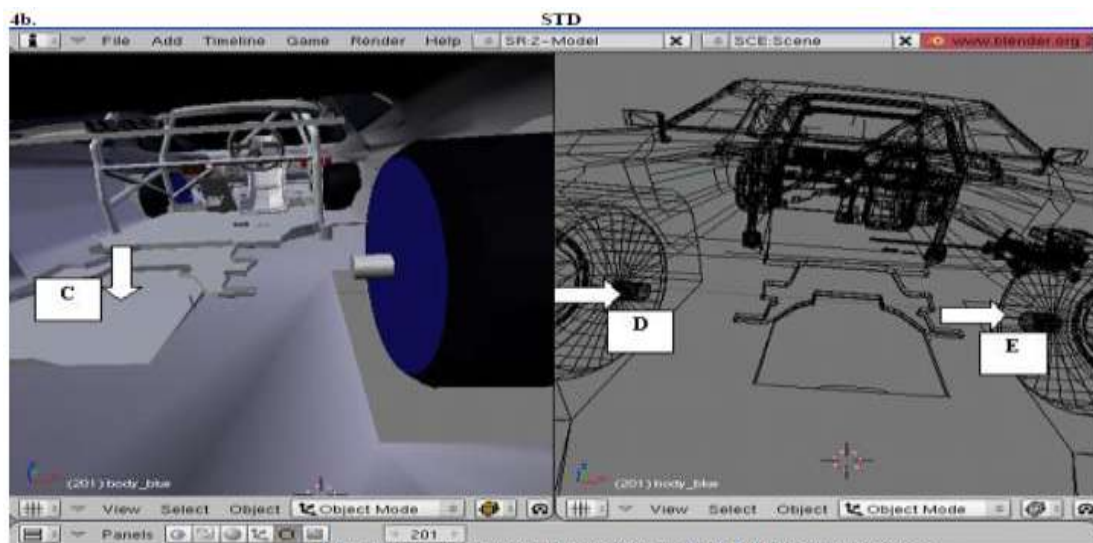
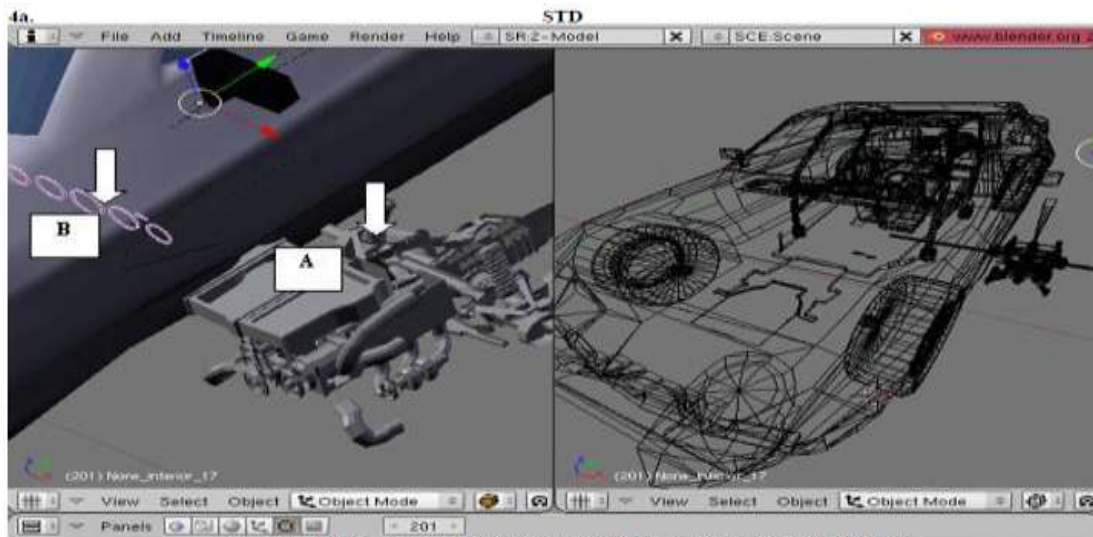
Task 2



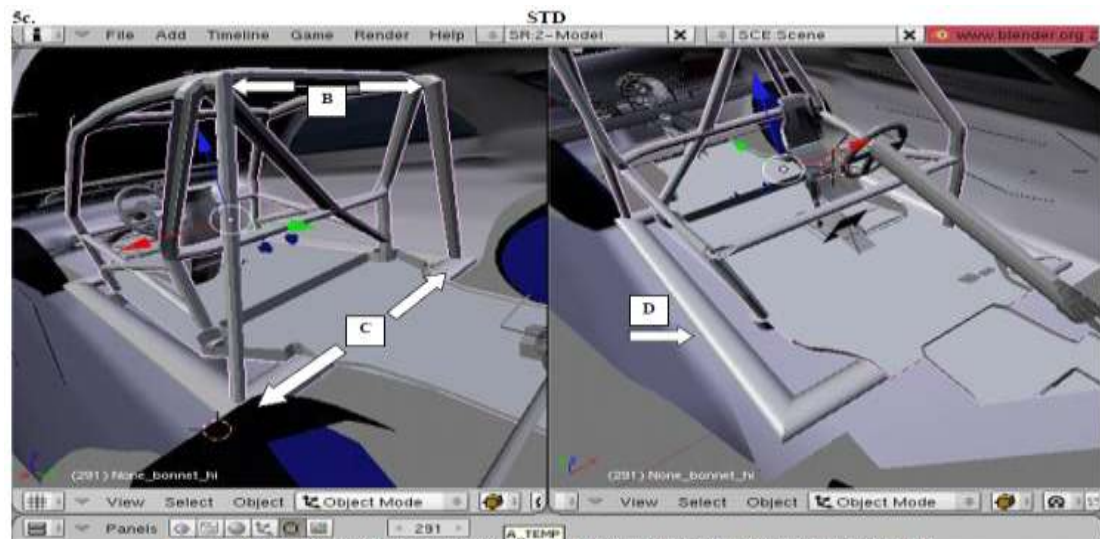
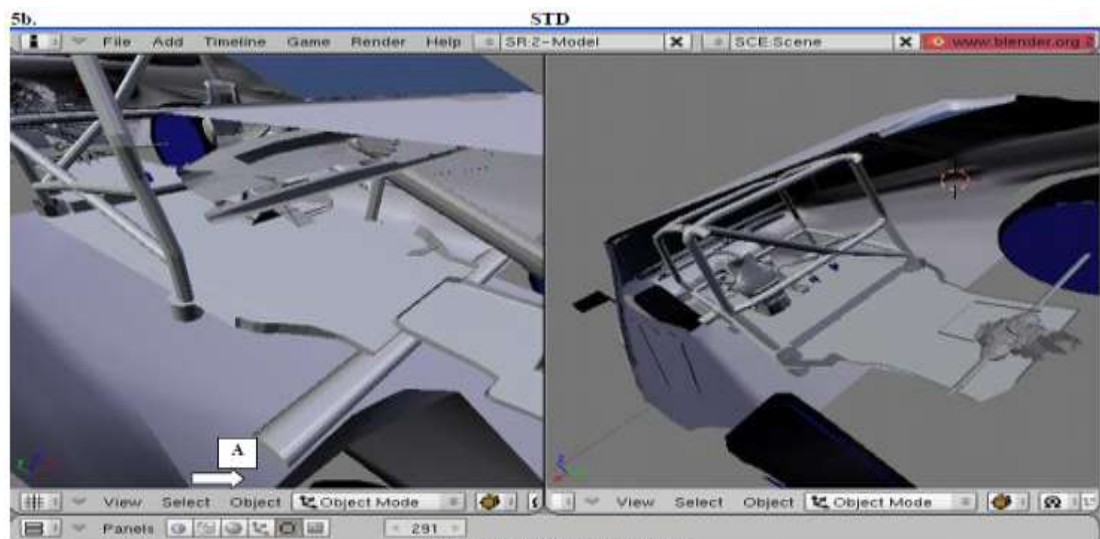
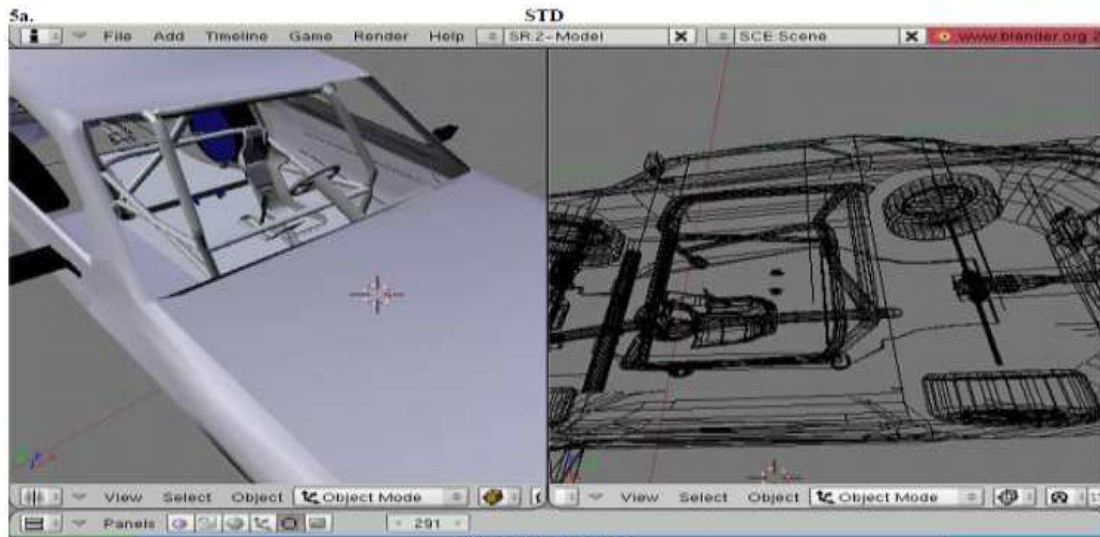
Task 3



Task 4



Task 5



Appendix G

Ethics Approval for the Study of Modified Focus and Context Awareness Techniques

This appendix includes the letter of approval from the ethics committee of the Faculty of Computing and Mathematical Science, University of Waikato for the study described in Chapter 9.

Faculty of Computing and
Mathematical Sciences
Rorohiko me ngā Pūtakeo Pūngarau
The University of Waikato
Private Bag 3115
Hamilton 3240
New Zealand

Phone +64 7 838 4322
www.scms.waikato.ac.nz



13 September 2010

Azmi Bin Mohd Yusof
C/- Department of Computer Science
THE UNIVERSITY OF WAIKATO

Dear Azmi

Request for approval to perform user studies involving human participants.

I have considered your request for approval to carry out a series of user tests commencing in September 2010 as a partial requirement for your PhD study.

The goal of this project is to address some of the major issues related to focus and context awareness in 3D modelling tasks for single and multi-user asynchronous collaborative environments.

The procedure described in your request is acceptable. I note your statements that there may be a conference or journal paper published from this research, that only the researcher and supervisor will be privy to the notes, documents recordings and the paper written. All data collected will be destroyed and recordings erased five years after your PhD has been completed. The transcriptions of the recordings and a copy of the paper will be treated with strict confidentiality. No participants will be named in the publications and every effort will be made to disguise their identity.

The Participant Information Sheet and Consent forms comply with the requirements of the University's human research ethics policies and procedures.

I therefore approve your application to perform the user study.

Yours sincerely

Mike Mayo
Human Research Ethics Committee
Faculty of Computing and Mathematical Sciences

Appendix H

The Ordering of the Task and Experiment

Condition

This appendix includes the complete ordering of the task and experiment conditions described in Chapter 9.

Subject No	Orders	Task 1	Orders	Task 2	Orders	Task 3	Orders	Task 4	Orders	Task 5
1	MLD1	a	MLD2	b	MLD1	a	MLD2	b	MLD1	a
	MLD2	b	MLD1	a	MLD2	b	MLD1	a	MLD2	b
2	MLD1	a	MLD2	b	MLD2	a	MLD1	b	MLD2	a
	MLD2	b	MLD1	a	MLD1	b	MLD2	a	MLD1	b
3	MLD2	a	MLD2	a	MLD2	b	MLD2	a	MLD1	b
	MLD1	b	MLD1	b	MLD1	a	MLD1	b	MLD2	a
4	MLD2	a	MLD2	a	MLD1	b	MLD2	a	MLD2	b
	MLD1	b	MLD1	b	MLD2	a	MLD1	b	MLD1	a
5	MLD2	b	MLD1	a	MLD2	a	MLD1	b	MLD1	a
	MLD1	a	MLD2	b	MLD1	b	MLD2	a	MLD2	b
6	MLD2	b	MLD2	a	MLD1	a	MLD2	b	MLD2	a
	MLD1	a	MLD1	b	MLD2	b	MLD1	a	MLD1	b
7	MLD1	a	MLD1	b	MLD2	a	MLD1	a	MLD1	b
	MLD2	b	MLD2	a	MLD1	b	MLD2	b	MLD2	a
8	MLD2	a	MLD2	b	MLD2	a	MLD1	a	MLD2	b
	MLD1	b	MLD1	a	MLD1	b	MLD2	b	MLD1	a
9	MLD1	b	MLD1	a	MLD1	b	MLD2	a	MLD1	a
	MLD2	a	MLD2	b	MLD2	a	MLD1	b	MLD2	b
10	MLD1	b	MLD1	a	MLD2	b	MLD1	a	MLD2	a
	MLD2	a	MLD2	b	MLD1	a	MLD2	b	MLD1	b
11	MLD1	b	MLD1	a	MLD1	b	MLD2	a	MLD2	b
	MLD2	a	MLD2	b	MLD2	a	MLD1	b	MLD1	a
12	MLD2	b	MLD2	a	MLD2	b	MLD1	a	MLD1	b
	MLD1	a	MLD1	b	MLD1	a	MLD2	b	MLD2	a
13	MLD2	b	MLD1	b	MLD1	a	MLD2	b	MLD2	a
	MLD1	a	MLD2	a	MLD2	b	MLD1	a	MLD1	b
14	MLD1	b	MLD2	b	MLD1	a	MLD1	b	MLD1	a
	MLD2	a	MLD1	a	MLD2	b	MLD2	a	MLD2	b
15	MLD1	a	MLD1	b	MLD2	b	MLD2	a	MLD1	b
	MLD2	b	MLD2	a	MLD1	a	MLD1	b	MLD2	a
16	MLD2	a	MLD2	b	MLD1	b	MLD2	a	MLD2	b
	MLD1	b	MLD1	a	MLD2	a	MLD1	b	MLD1	a
17	MLD2	b	MLD1	a	MLD2	b	MLD1	b	MLD1	a
	MLD1	a	MLD2	b	MLD1	a	MLD2	a	MLD2	b
18	MLD1	b	MLD1	a	MLD1	b	MLD1	b	MLD2	a
	MLD2	a	MLD2	b	MLD2	a	MLD2	a	MLD1	b
19	MLD2	a	MLD1	b	MLD2	a	MLD1	b	MLD1	b
	MLD1	b	MLD2	a	MLD1	b	MLD2	a	MLD2	a
20	MLD1	a	MLD2	b	MLD1	a	MLD2	b	MLD2	b
	MLD2	b	MLD1	a	MLD2	b	MLD1	a	MLD1	a

Appendix I

Instruction Manual Used in the Study of the Modified Focus and Context Awareness Techniques

This appendix includes the instruction manual and handout used in the study of the modified focus and context awareness techniques described in Chapter 9.

Task 1

Task 1a. Correcting a shape difference between left and right doors.

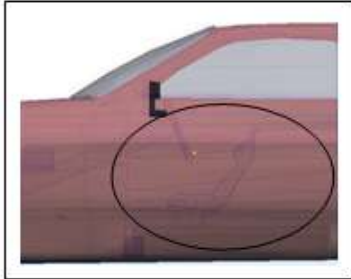


Figure 1: Initial view of the model.

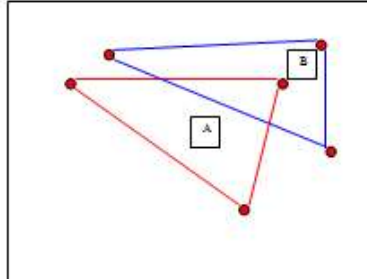


Figure 2: Example before the edges of the right door "B" (blue) are aligned with the edges of the left door "A" (red).

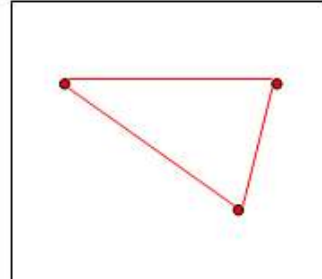


Figure 3: Example after vertices of the right door are aligned with the vertices of left door.

- Step i. Start System X.
- Step ii. Open a file called `ModelA_Segregation.blead` from the list in Open Recent.
- Step iii. Select the main body of the car.
- Step iv. Change system mode from object to edit mode.
- Step v. Align the vertices of both left (top layer) and right (bottom layer) doors by selecting and moving the vertices on the left door horizontally or vertically.
- Step vi. Press Save (CTRL W) to save the file when you have finished your tasks.
- Step vii. Please answer the question.

Task 1b. Correcting a shape difference between left and right windows.

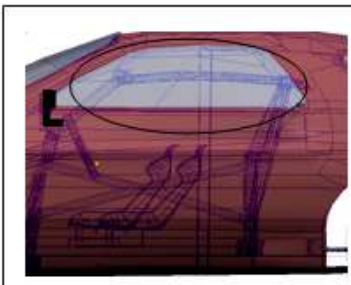


Figure 1: Initial view of the model

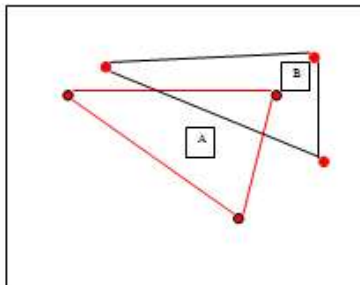


Figure 2: Example before the vertices of the right window "B" (black) are aligned with the vertices of left window "A" (red).

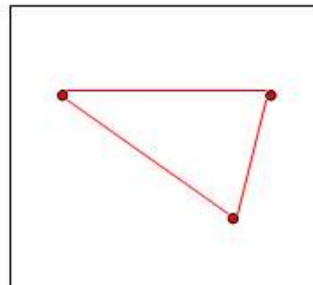


Figure 3: Example after vertices of the right window are aligned with the vertices of the left window.

- Step i. Start System Y.
- Step ii. Open a file called `ModelB_Segregation.blead` from the list in Open Recent.
- Step iii. Select the window of the car.
- Step iv. Change system mode from object to edit mode.
- Step v. Align the vertices of both left (top layer) and right (bottom layer) windows by selecting and moving the vertices on the left window horizontally or vertically.
- Step vi. Press Save (CTRL W) to save the file when you have finished your tasks.
- Step vii. Please answer the question.

Task 2

Task 2a. Extending the front axle.



Figure 1. Initial view of the model



Figure 2. Short axle "A" of front tires

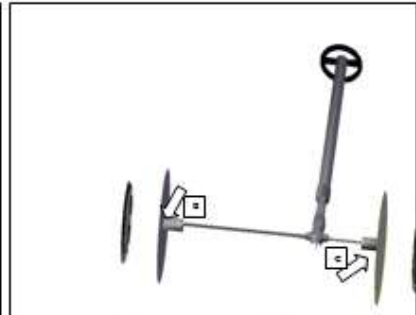


Figure 3. Maximized length of the axle till reaches the rim "B"

- Step i. Start System X.
- Step ii. Open a file called ModelA_Separation.blend from the list in Open Recent.
- Step iii. Select the axle "A" of the front tires (as shown in figure 1 and 2).
- Step iv. Change from object mode to edit mode.
- Step v. Use "Selected object on the front layer only" function to isolate the selected object from others.
- Step vi. Drag the ends of the axle "A" (as shown in figure 2), so that it connects to points B and C (as shown in figure 3).
- Step vii. Press Save (CTRL W) to save the file when you have finished your tasks.
- Step viii. Please answer the question.

Task 2b. Extending the back axle.



Figure 1. Initial view of the model

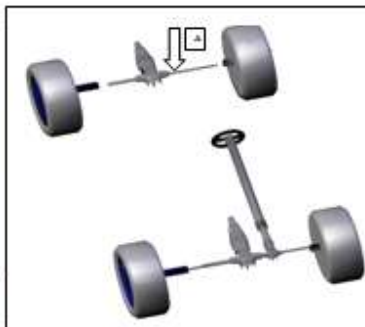


Figure 2. Short axle "A" of back tires

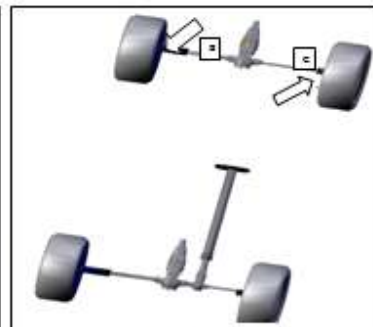


Figure 3. Maximized length of the axle till reaches the rim "B"

- Step i. Start System Y.
- Step ii. Open a file called ModelB_Separation.blend from the list in Open Recent.
- Step iii. Select the axle "A" of the back tires (as shown in figure 1 and 2).
- Step iv. Change from object mode to edit mode.
- Step v. Use "Selected object on the front layer only" function to isolate the selected object from others.
- Step vi. Use up arrow key to peel off the model in the bottom layer until back tires are visible.
- Step vii. Drag the ends of the axle "A" (as shown in figure 2), so that it connects to points B and C (as shown in figure 3).
- Step viii. Press Save (CTRL W) to save the file when you have finished your tasks.
- Step ix. Please answer the question.

Task 3

Task 3a. Inscribe the front differential.



Figure 1. Initial view of the model

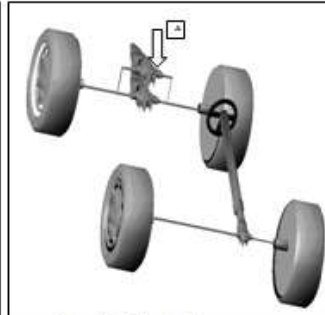


Figure 2. Back engine "A"

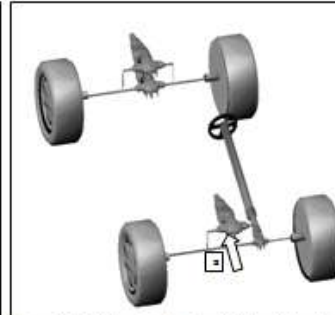


Figure 3. After back engine is duplicated and placed at the front "B"

- Step i. Start System X.
- Step ii. Open a file called ModelA_Focus_and_Context.blead from the list in Open Recent.
- Step iii. Use "Peeling Focus and Context" function to find the back differential "A" (as shown in figure 2).
- Step iv. Select the engine and duplicate the object with shortcut key Alt D.
- Step v. Move the duplicated differential to the front axle (as shown in figure 3), so that it is aligned with the differential at the rear axle. You may need to change your view.
- Step vi. Press Save (CTRL W) to save the file when you have finished your tasks.
- Step vii. Please answer the question.

Task 3b. Inscribe the front axle.



Figure 1. Initial view of the model

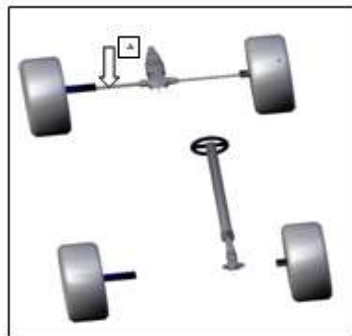


Figure 2. Back axle "A"

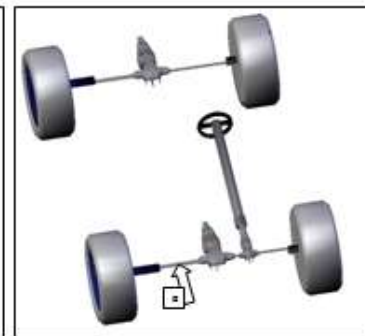


Figure 3. After back axle is duplicated and placed at the front "B"

- Step i. Start System Y.
- Step ii. Open a file called ModelB_Focus_and_Context.blead from the list in Open Recent.
- Step iii. Use "Peeling Focus and Context" function to find the back axle "A".
- Step iv. Select the axle and duplicate the object with shortcut key Alt D.
- Step v. Move the duplicated axle to the front (as shown in figure 3), so that it is aligned with the rear axle. You may need to change your view.
- Step vi. Press Save (CTRL W) to save the file when you have finished your tasks.
- Step vii. Please answer the question.

Task 4

Task 4a. Aligning front and back fans.



Figure 1. Initial view of the model

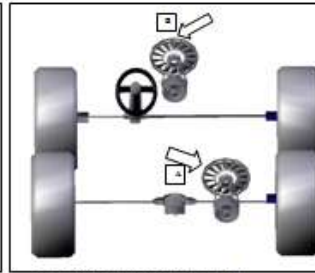


Figure 2. Rear fan "A" and front fan "B"



Figure 3. After both fans are aligned horizontally and vertically. View of rear fan from behind. Showing front fan almost completely obscured

- Step i. Start System X.
- Step ii. Open a file called ModelA_Slicing blend from the list in Open Recent.
- Step iii. Use "Slicing" function to find the rear fan "A" (as shown in figure 1).
- Step iv. Continue pressing up-arrow key until the front fan "B" is visible (as shown in figure 2).
- Step v. Move the rear fan "A", so that both fans ("A" and "B") are parallel both horizontally and vertically (as shown in figure 3).
- Step vi. Press Save (CTRL W) to save the file when you have finished your tasks.
- Step vii. Please answer the question.

Task 4b. Aligning rear and front differentials.



Figure 1. Initial view of the model

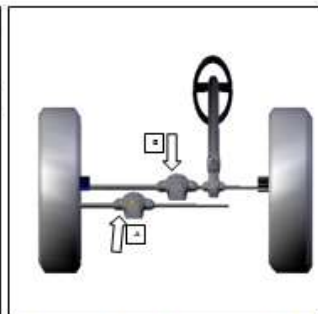


Figure 2. Front's differential "A" and back's differential "B"

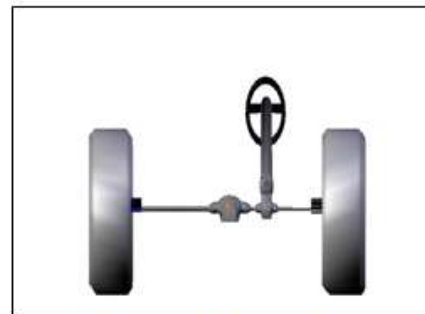


Figure 3. After both differentials are aligned horizontally and vertically. View of differential from front. Showing back differential almost completely obscured

- Step i. Start System Y.
- Step ii. Open a file called ModelB_Slicing blend from the list in Open Recent.
- Step iii. Use "Slicing" function to find the front differential "A" (as shown in figure 2).
- Step iv. Increase the thickness of the slicer by using right-arrow key until the back differential "B" is visible (as shown in figure 2).
- Step v. Move the front differential "A", so that both differentials ("A" and "B") are parallel both horizontally and vertically (as shown in figure 3).
- Step vi. Press Save (CTRL W) to save the file when you have finished your tasks.
- Step vii. Please answer the question.

Task 5

Task 5a. Placing the car's dashboard surface in dashboard surround.



Figure 1. Initial view of the model.

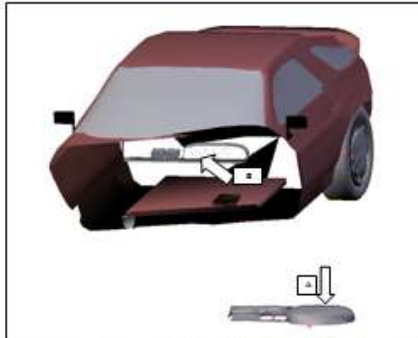


Figure 2. View of the separated dashboard surface "A" from dashboard surround "B".



Figure 3. After dashboard surface is placed on the dashboard surface.

- Step i. Start System X.
- Step ii. Open a file called ModelA_Peeling.blend from the list in Open Recent.
- Step iii. Select the car's dashboard surface "A" (as shown in figure 1).
- Step iv. Use "Peeling focus" function to find and to determine the dashboard surround "B" as shown in figure 2.
- Step v. Place the car's dashboard surface "A" to dashboard surround "B" (as shown figure 3). You may need to change your view.
- Step vi. Press Save (CTRL W) to save the file when you have finished.
- Step vii. Please answer the question.

Task 5b. Placing the car's seat on the seat mount.

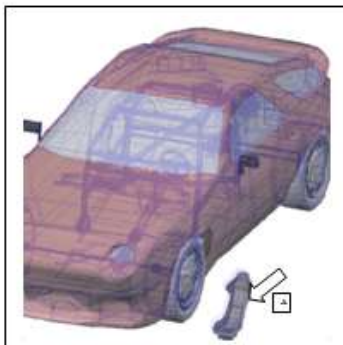


Figure 1. Initial view of the model.

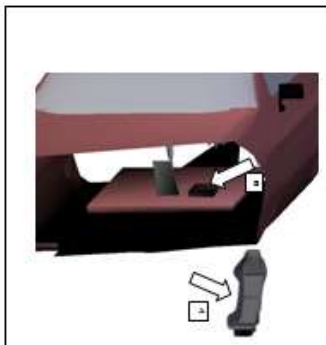


Figure 2. View of the car's seat "A" and the seat mount "B".



Figure 3. After seat is placed on the seat mount.

- Step i. Start System Y.
- Step ii. Open a file called ModelB_Peeling.blend from the list in Open Recent.
- Step iii. Select the car's seat "A" (as shown in figure 1).
- Step iv. Use "Peeling focus" function to find and to determine the seat mount "B" (as shown in figure 2).
- Step v. Place the car's seat "A" on the seat mount "B" (as shown in figure 3). You may need to change your view.
- Step vi. Press Save (CTRL W) to save the file when you have finished.
- Step vii. Please answer the question.

Appendix J

Video Demonstration

A video demonstration of the two Focus and Context Awareness Techniques Prototypes described in chapters 6 and 8 has been include in this thesis.