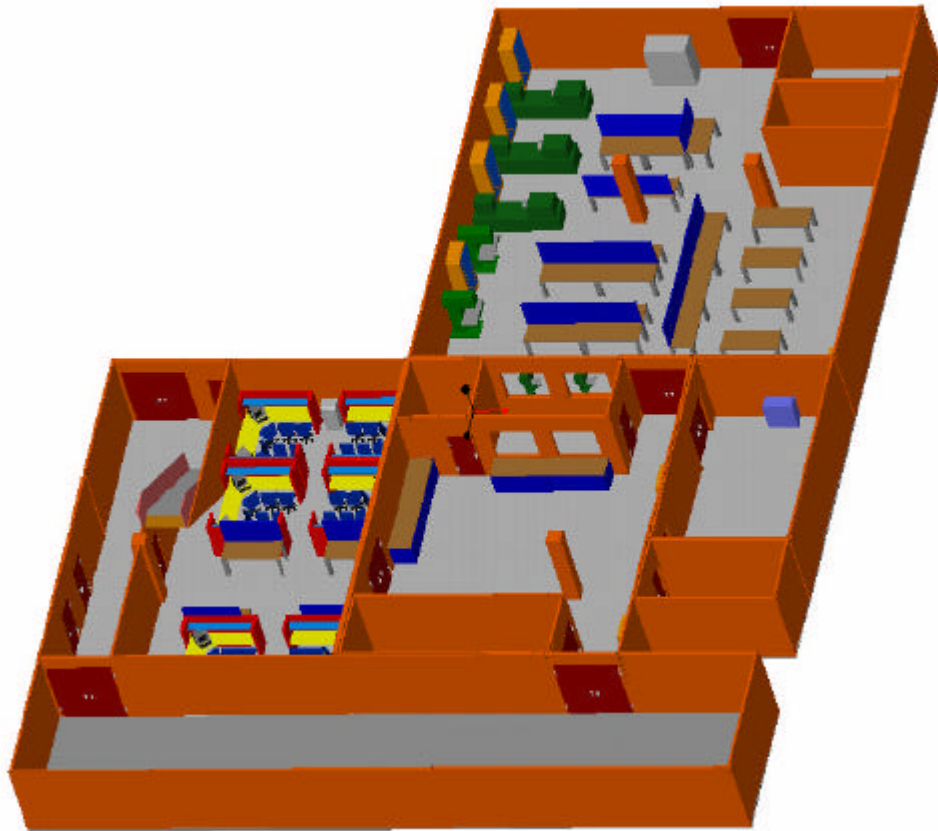


# The Use of Virtual Reality in the Development Process of a Physical Prototyping Laboratory



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June 18, 2001

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## **Preface**

The following report is done as a project during a three-month study stay from April to June 2001 at Chalmers University of Technology in Göteborg, Sweden.

This study stay takes place within the ERASMUS project.

The report is written under the supervision of Assoc. Prof. Johan Malmqvist at the department of Machine and Vehicle Design (MVD) at the School of Mechanical and Vehicular Engineering.

## **Abstract**

Virtual Reality is a good concept to visualize objects that are not existing yet. Therefore its meaning in the development processes especially in mechanical engineering grows. As most of the development is done already with 3D CAD systems it is quite easy to create virtual reality models out of this CAD data. This model can be used for further considerations or evaluations.

A very common use of virtual reality is in the car manufacturing industry in the development of new cars.

It is especially a concept of showing the results of the work to those people who are not directly involved in the development.

The use of virtual reality in such a development process is shown in this report at the example of the development of a physical prototyping laboratory at Chalmers University of Technology in Göteborg, Sweden.

Therefore a 3D model of the laboratory is created, which is converted into a virtual reality model.

The presentation of this model will take place in a Virtual Reality CAVE.

## **Table of Contents**

<b>1</b>	<b>INTRODUCTION</b>	<b>2</b>
1.1	DEVELOPMENT PROCESS OF THE LABORATORY	2
1.2	GOALS	2
1.3	OUTLINE OF THIS REPORT	3
<b>2</b>	<b>VISUALIZATION CONCEPTS</b>	<b>4</b>
<b>3</b>	<b>INTRODUCTION TO 3D CAD</b>	<b>6</b>
<b>4</b>	<b>INTRODUCTION TO VIRTUAL REALITY</b>	<b>7</b>
<b>5</b>	<b>CAD MODEL OF THE PHYSICAL PROTOTYPING LABORATORY</b>	<b>11</b>
5.1	MODEL CONTENTS	11
5.2	ROOMS	11
5.3	EQUIPMENT	12
<b>6</b>	<b>CREATION OF THE VR MODEL</b>	<b>14</b>
6.1	VISUAL BEHAVIOUR	15
6.1.1	<i>Colour</i>	15
6.1.2	<i>Texture</i>	15
6.2	INTERACTION	16
6.3	PEOPLE INSIDE THE LABORATORY	18
<b>7</b>	<b>INSTRUCTION FOR THE USE OF THE MODEL</b>	<b>19</b>
7.1	STARTING OF THE MODEL	19
7.2	INTERACTIONS	19
7.3	MOVING OF PARTS	19
7.4	ADDING OF NEW PARTS	19
<b>8</b>	<b>WALK THROUGH THE LABORATORY</b>	<b>20</b>
<b>9</b>	<b>CONCLUSIONS</b>	<b>32</b>
<b>10</b>	<b>REFERENCES</b>	<b>33</b>
<b>11</b>	<b>APPENDIX</b>	<b>I</b>
11.1	MAP OF THE LABORATORY (CONCEPT 4)	I
11.2	PARTS FOR THE DRILL	II
11.3	FILE DRILL.VDI	III
11.4	LISTING OF THE FILES	IV
11.5	CONTENTS OF THE CD-ROM	XII

# **1 Introduction**

## **1.1 Development Process of the Laboratory**

At the School of Mechanical and Vehicular Engineering at Chalmers University of Technology a new physical prototyping laboratory is planned.

This laboratory is part of the CDIO project.

In the CDIO project, Conception – Design – Implementation – Operation, the following universities are involved: CTH in Göteborg, KTH in Stockholm, Linköping University and the MIT.

One important element within this project is the extensive use of hands-on education. Although some of this hands-on education can take place in the classroom it is a great support to have facilities in which the students can design, build and test new systems in teams.

This is the reason for developing the Chalmers Product Realization Lab as a part of the CDIO project. The development process of the laboratory is described in [1].

The laboratory will consist of two basic facilities.

First the IDE [Industrial Design Engineering] studio in which the student teams are able to work with virtual prototypes. Therefore this part of the lab includes computers, mathematical and engineering software, and advanced visualization systems like a powerwall and a virtual reality cave.

The second basic facility is the prototyping lab itself. This part enables the students the possibility of implementation and operation of their designs. The lab resources will enable the creation of physical prototypes ranging from very simple and cheap models made out of Styrofoam to more detailed near-manufacturing quality prototypes. The technologies will include mechanics, electronics and software.

The lab will be used in ME [Mechanical Engineering] education, in IDE education and in the Automation Engineering program.

During the academic year 00-01 the concept of the lab should be developed, the implementation of the lab is planned to take place in the academic years 01-02 and 02-03.

The lab design process is divided into three phases: Requirements and resource analysis, Concept Design and Embodiment Design.

## **1.2 Goals**

During the design process there are several different concepts in use. In order to facilitate the vision of these concepts the design process is supported by a visualization of the labs.

The task of this project is the development of a visualization for concept number 4, which is presented in [1]. In April 2001, the beginning of this project, this concept was the one with the best chances of becoming realized.

The goal is to implement the geometry of the rooms for the laboratory as well as the equipment of that concept in a virtual reality system. The geometry is to be taken from the drawings in [1] and by a measurement of the existing rooms.

In order to increase the effect of the visualization in virtual reality some interactions are to be implemented. These interactions are planned for the doors – open and close the doors by touching and pulling the handle – and for the drill machines – pulling the handle of that machines will “operate” them.

Finally some people shall be integrated in the laboratory to get a feeling for the dimensions in it.

The use of animations within the virtual reality model is not a high priority task and is not directly needed for the visualization. If there is time left, some of the people will be animated, e.g. one person operating a drill machine, one person working at a bench.

### **1.3 Outline of this report**

The outline of this report is divided in three major parts.

The first part, which contains the following chapters: Visualization Concepts, Introduction to 3D CAD and Introduction to Virtual Reality, will give a theoretical background of the topic.

The chapter “Visualization Concepts” will present different possibilities for the visualization of models. The next two chapters will give introductions to 3D CAD and virtual reality in order to clear the terms and the function.

In the second part the construction of the CAD model and the implementation in the virtual reality is described.

The third part describes a virtual walk through the laboratory.

## **2 Visualization Concepts**

As mentioned the design process is supported by the visualization of the different concepts. This visualization is needed for an evaluation and decision for each concept.

These visualizations can be done in various ways, from a very simple sketch via two-dimensional and three-dimensional CAD systems to the use of virtual reality.

The conventional way is to create 2D drawings with two or more views. Some details can be zoomed in and displayed in another drawing. Cuts are also a possibility to show some details, e.g. hidden parts. An easier, not so detailed, way, which is used for a very fast and general overview is the sketch. Here is only the general geometry of interest and not the exact measurements.

The advantage of the 2D drawing is that the creation is relative easy to do. It can be done by the use of computer or in the traditional way by using a pen and paper.

The major disadvantage is that the views are fixed and therefore it is not possible to explore the model. The imagination of the drawings as a three-dimensional environment depends mostly on the viewer's skills. This imagination will not be a problem for engineers, but probably for managers, customers, etc. to whom the drawing is presented.

For a complex design there are several different drawings needed in order to get all information of the model. This takes a long time because it is not possible to generate one drawing out of the other one.

Because of these disadvantages it is better to create the model directly in a 3D CAD program. There are different possibilities for the creation of such a model in 3D. A very common and easy way nowadays is to build the model up from solid parts. These parts are arranged in assemblies. Today's 3D CAD systems are very comfortable to use and gives the user many possibilities for the creation, such as features, parametrical design and patterns.

There are many different CAD systems in use, so it is possible to take that system, which offers the best possibilities for each situation. For some situations it will be sufficient to use a very easy program with only few geometry primitives. While for complex models a more complex program is needed, which offers more possibilities in the creation of the 3D models.

The major advantage of these 3D models is, that the viewer gets an impression of the model itself. He can move and rotate the model in order to explore it from different points. If needed the generation of 2D drawings, including cuts, is very easy to realise.

The limitation of these 3D models is that the viewer cannot explore it and that it is only displayed on the flat computer screen. So it is not really three-dimensional.

Only the transformation into virtual reality gives the possibility of getting immersed in the created world and to explore it like reality. The adding of interactions with the model increases the feeling of the immersion.

But to reach this immersion great demands are made on the used hardware. Special outputting devices are needed, such as a CAVE or at least, for a low cost solution, shutterglasses. These hardware requirements are explained in chapter 4.

If the hardware requirements are complied, the immersion into the virtual reality gets really impressive.

The use of virtual reality during the design process of the lab gives the opportunity to evaluate and check the design concepts in a better way than it is possible with, for example, 2D CAD drawings. Especially for those people who are not so involved in the design process and because of this not so familiar with all details which will be necessary to understand for example the 2D drawings.

It is not so difficult to do the step from the 3D CAD model into virtual reality. The 3D model, which is already created, is the base for the transformation into the virtual reality system. In this system the interactions can be designed and the colours of the parts are defined by colours itself or by the use of textures.

The transformation of the 3D model into Virtual Reality software gives the chance to clear the limitation of the 3D model.



### **3 Introduction to 3D CAD**

The first step for the creation of a virtual world is the creation of a 3D model of it. This takes place in a 3D CAD system. There are different types of CAD systems in use, the general difference between them is the buildup of the models itself. The possibilities are to build up the model with single lines, the combination of surfaces and the most comfortable possibility is the use of solid bodies.

The system, which is used at Chalmers University of Technology, is Pro/Engineer from PTC [7]. This is a 3-D solid modeling system. The advantage of solid bodies is that every body is defined by volume, mass, centre of gravity, Inertia, etc. It is also possible to check collisions between bodies.

Pro/E is a parametrical and associative system, that means that each model is defined geometrically and non-geometrically by parameters. One parameter can be changed without disturbing other parameters. The model itself is changed when it is regenerated.

The associativity of the program gives the opportunity to make changes in the parameters throughout the development process. The changes can be made in the parts itself as well as in the assemblies, the drawings or in the manufacturing data. The program will update all parameters automatically.

Pro/Engineer offers several types of modes to create a model. The most common modes are the Part mode and the Assembly mode. For the creation of drawings the Drawing mode is used.

In most times the creation of a new component will take place in the part mode. This construction process always starts with the creation of a sketch in a two-dimensional environment. This sketch includes the general geometry of the new component. The size of it can be changed by manipulation of the parameters such as distances and the manipulation or definition of constrains. Afterward the third dimension is created by translation along one axis or rotation around an axis. This is called protrusion. One part can consist of several protrusions. Other possible features for the creation of a part are cuts, holes, sweeps, rounds, chamfers, etc.

A number of parts can be combined to an assembly. This is done in the assembly mode. Within an assembly one part can be used several times without the need of creation new parts with the same properties. It is also possible to manipulate or create new parts in the assembly mode.

Large models can consist of several assemblies. Within the assembly mode parts and assemblies are treated the same way. An assembly can be integrated as a subassembly into any assembly.

For the use of the created 3D model within virtual reality it is necessary that some notes are respected. Everything that shall be animated in VR is to be created as a single part. It is only possible to move whole parts in the virtual environment. The other note is that each part can only be mapped with one texture. So if there is a need of mapping different textures you have to create several parts for it.

## **4 Introduction to Virtual Reality**

As mentioned the visualization of the design concepts is created by the use of Virtual Reality. But what is virtual reality?

In the next chapter a short introduction into this theme follows in order to clear this term.

Virtual Reality is the term for the creation of an artificial world by the use of computer systems. The user is able to navigate in this world and gets the impression of being inside of it.

There are different types of virtual reality (VR) systems in usage. The range is from very easy, desktop based systems up to full immersive systems.

The desktop based systems are running on ordinary PCs and the visual world is displayed on the conventional computer monitor. These systems are used for low cost solutions and for example for computer games. They are also known under the name Window on a World (WoW), because the screen is like a window through which the user is looking into the virtual world.

Another method of showing this world especially to a group of people is the projection of the imagines onto a screen.

These are all non- immersive VR systems. In these systems the user is not fully integrated into the virtual world.

The other group of VR systems are the immersive systems. In a completely immersive system the user has no visual contact with the physical world. The user feels himself as a part of the environment. For the feeling of getting immersed in the virtual world it is necessary that the immersion view angle is larger than 200 degrees.

Immersive systems are for example Head Mounted Displays. These are helmets in which a visual and auditory system is implemented. The user who is wearing such a helmet is free in his movement through the virtual world.

The HMD consists typically of two display screens for the creation of a view into the virtual world and a motion tracker which continuously measures the position and orientation of the user's head so the image can be adjusted to the current view. This is necessary because otherwise it will cause irritations to the user if the movement of his head does not correlate with the creation of the views in virtual reality.

By using Head Mounted Displays the user is completely isolated from the real, physical world.



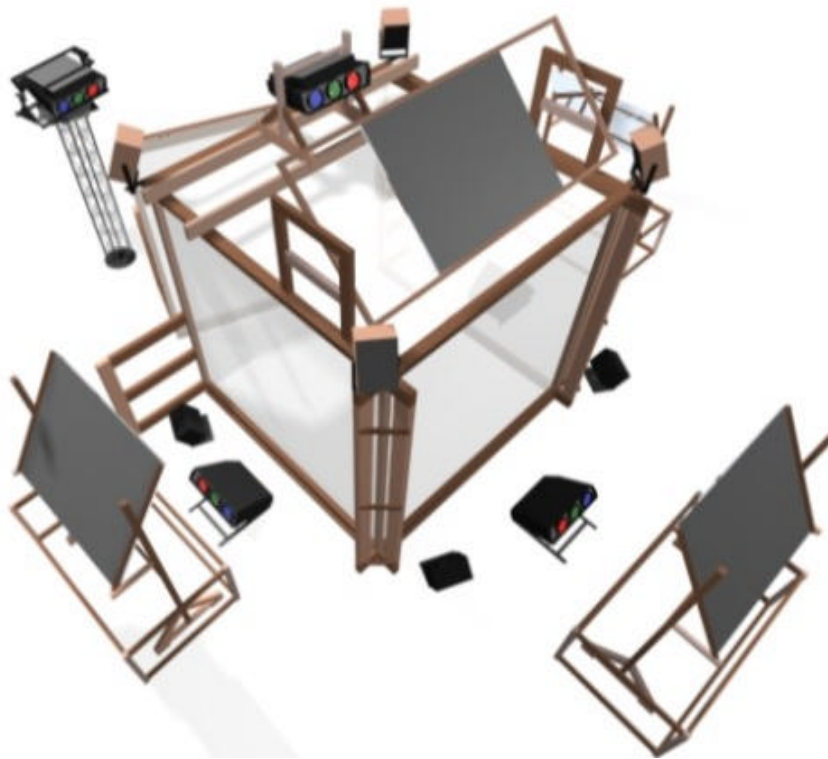
**Figure 1: Head Mounted Display**

Another example for immersive systems is the CAVE. In the Cave the images are projected to screens which surround the user. In this system the number of screens is important for the feeling of immersion.

The CAVE (Cave Automatic Virtual Environment) was developed at the University of Illinois at Chicago and first presented on the SIGGRAPH '92.

It enables one or more persons the possibility of being immersed in a completely surrounded virtual environment formed by 3D-video and 3D-audio.

There are different types of caves possible, depending on the level of immersion. The basic of the cave is an approximately 3-meter wide cube where the walls are formed as screens on which the images are projected by rear projectors. The low-end solution is the use of a four-sided cave. In this cave there are three screens and the bottom on which images are projected either by rear projectors, for the walls, or by a down-projector for the image of the bottom.



**Figure 2: CAVE**

The high-end solution will offer the user a full six-sided projection including the fourth wall and the top. This solution is not often used because the requirements to the room for the cave are very high. A roof height of approximately 10m is needed in order to install the projector for the bottom screen that will consist of glass.

Because of this the most common configuration is the five-sided cave. In this one all four walls and the floor are used for the projection of the images. Because of the lack of the top a down projector can be used for the floor image.

The dimensions of the CAVE make it possible for a group of people to move around the virtual environment in a realistic way. One person of the group is the leading viewer, he has the abilities for the navigation through the virtual world. For the best impression the images are related to the position and direction of the leading viewer's view.

In combination with 3D-sound the feeling of being immersed in the virtual environment becomes impressive.

It is possible to combine parts of the real, physical world together with the virtual environment. This is used for instance in flight simulators.

One thing that is often included in virtual reality systems is stereo vision. The feeling of stereo vision in reality is created in the brain by the different viewpoints of the eyes. So a person gets two different images, which differ in the angle of the view direction. In the brain these two images are combined to one image, so the person is able to check the distances.

In computer generated and on a screen displayed worlds there is only one picture with no information about the depth of the displayed objects. The three-dimensional feeling is created by the use of perspective and perhaps fog in the distance.

In order to get a real three-dimensional view there are some tricks needed. The solution is to create two different images, one for each eye. So the brain is outfoxed and combines the two images to a stereoscopic view. There are two major possibilities for the creation of these two images.

First you can show each image on its own display, so you need two displays, one for each eye. This system is used in the Head Mounted Displays for example.

The second possibility is to display both images sequentially on one screen. The correlation of the images to each eye is done with Liquid Crystal shutter glasses. These shutter glasses are synchronised to the display rate. If the succession is rapid enough, the brain fuses the images into a single scene and perceives depth. The display swapping rate must be pretty high in order to avoid flickering. A value of minimum 85 Hz is needed. This system is used in all systems where the images are displayed on a screen, such as a CAVE.

The generation of the images is very time critically and time consuming. There are high requirements to the hardware in order to calculate and generate an image in the time. At a display-swapping rate of 85 Hz there are only 11ms for the generation of each image. This means that very fast computers are needed to create the images because the size of the database has a major influence on the update rate. It is depending on how much of the database is in the field of view of the user. The most common computers used in VR laboratories are from Silicon Graphics Inc. SGI is specialized in the manufacturing of high end graphic computers.

The computers used for the image generation for the CAVE at Chalmers University of Technology are Silicon Graphics Onyx II systems with three graphic pipes. Each graphic pipe has two graphic channels, each one for one projector. There is a texture memory of 64 MB for each pipe which is similar to 256 MB of texture memory in a PC. This system enables an update rate of up to 96 hz.

One major part of virtual reality is the interaction with the virtual world. Without interaction the feeling of getting immerse in this world is not so great. So you can say that interaction is one of the key elements of virtual reality. In order to interact there are some systems needed.

First is the tracking of a real world object, such as the head or the hand of a user. The technology used for tracking should provide all six degrees of freedom, which means three measures for the position (x,y,z) an three measures for the orientation (roll, pitch, yaw). The orientation is defined as follows: roll is the angle of rotation about the z-axis, pitch is the angle of rotation about the x-axis and yaw is the angle of rotation about the y-axis.

The biggest problem of tracking the position is the time, which is required to make the measures and preprocess them before input in the simulation engine.

One of the simplest input devices are conventional mouse, joystick or trackball. These are only two dimensional devices, but with some tricks they can be used as 6D controls, for example by the combination of buttons and actions to control the z-dimension and the rotations and not only the xy-translations. For professional use there are real 6D devices available. These devices offers the direct access to the three translations and orientations.

A very common system for interacting with the virtual world is the data glove which is outfitted with sensors on the fingers and an overall position and orientation tracker. With this glove it is possible to control a virtual hand that is displayed in the virtual reality. It is also possible to get a tactile feedback from the virtual world.

As mentioned there are tracking systems needed in order to get information about the position and the orientation of the user. These information caught either by the use of ultrasonic sensors, electromagnetic fields, or optical sensors.

The ultrasonic sensors consist of a system of emitters and receivers. The position is got by measuring the time lags between an impulse sent by the emitter and its receive at the receiver. There are some problems with the use of ultrasonic sensors, which such as are the interference from echoes and other noises and the long time lags.

For the use of magnetic sensors there is an electromagnetic field to be produced. The sensors determine the strength and angles of the magnetic field in order to get the current position. This system is the most common for tracking the position of the user, although there are some problems left. There is interference possible from other ferrous materials within the field, the range is limited and there is a high latency for the measurement and preprocessing.

The last mentioned tracking system is the optical system. This system requires a ceiling grid of LEDs and head mounted cameras. The LEDs are pulsed in sequence and the camera detects the flashes. The major problem of this system is the lack of information about the rotation. So it cannot be used for full motion activities.

## 5 CAD model of the Physical Prototyping Laboratory

### 5.1 Model Contents

The laboratory consists of the rooms 202, 212, 214, 215, and 216 in the basement of the M building at Chalmers. These rooms are modelled in the CAD system. The equipment of each room is shown in the map in the appendix (11.1). For a better understanding it is listed here in a table.

Room	Equipment
202	labplaces, computers, benches
212	benches on wheels, toolboxes
214	circular saw, power hack saw
215	-
216	band saw, benches, drills, Lathes, mills, power plane, power sander, sheet metal, toolboxes, model lathe, NC in room for precision mechanics

### 5.2 Rooms

The basic feature of the geometry of the model is the combination of parts and assemblies. The geometry itself is built up with the basic parts of the model, the walls. There are seven different parts for the walls in use. These parts are available in lengths from 100mm up to 10000mm. These modules give an easy possibility of building the rooms of the laboratory.

The different types of the doors are integrated into the grid of the different parts of the walls. Overall there are four different types of doors used in the model. Two types of double doors, where the difference is in the size of the doors and two types of single doors, where the difference is the position of the hinges.

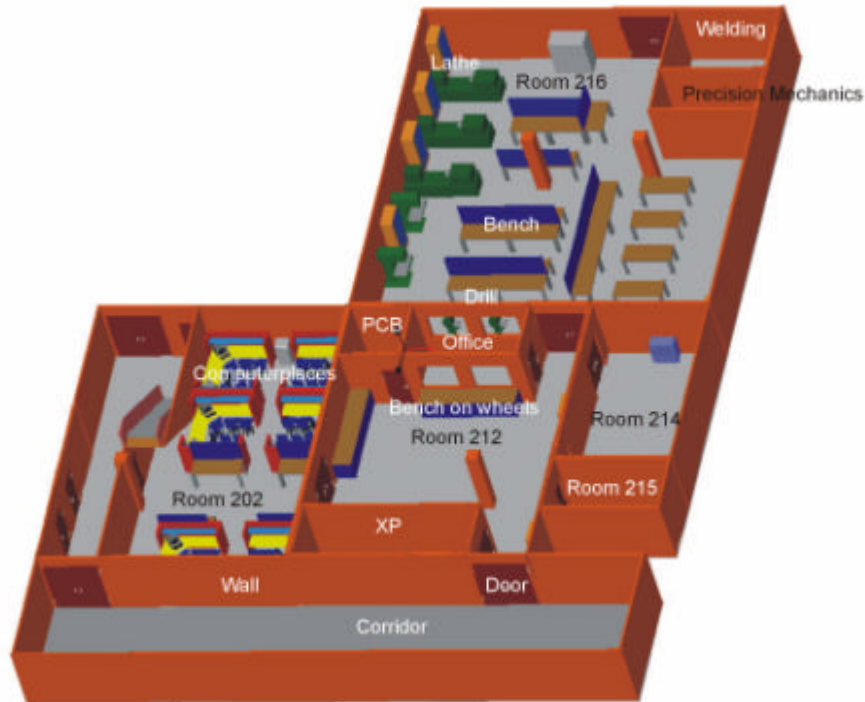
Because of the integration of the doors into the size of the wallparts, it is very easy to create the basic geometry of the laboratory.

Each room of the laboratory is created as a single assembly which can consist of several other assemblies. The walls of the rooms are for example created as assemblies with the wallparts and the doors. The floor for each room is created as a part itself as the ceiling.

The addition of the stairs in room 202 and the columns in the rooms 202, 212 and 216 completes the basic geometry. The staircase is composed of three parts because of the texture mapping in the virtual reality system.

All rooms are combined in the final assembly for the lab. This assembly is called: 1concept4.asm, which means that this is the assembly of concept no. 4. The number "1" in the file name is only for its position in the filetree. In order to get an easier access to the file it is better if it is in the first position in the folder.

A map of the geometry of concept 4 for the laboratory is pasted in the appendix.



**Figure 3: CAD model of the laboratory**

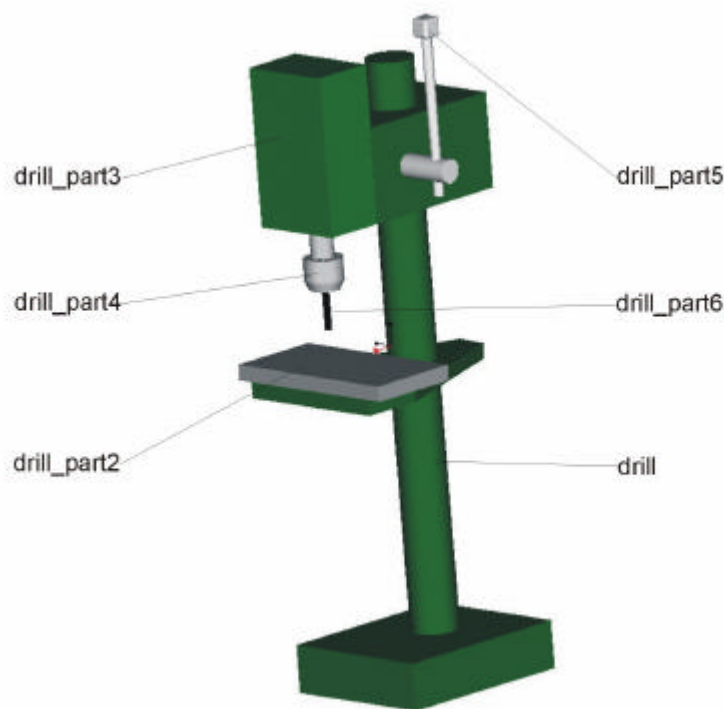
### **5.3 Equipment**

The equipment of the laboratory consists of several types of machines and furniture. The machines, which are integrated in the laboratory, are drills, mills, lathes, saws, and some other smaller machines. The used furniture are benches to work on as well in the metal shop as in the wood shop, and the furniture needed for the computer space, like desks, chairs, and computer equipment.

The data for this equipment – size, shape, and colour appearance – were taken from real objects in the workshop of the department and from catalogues.

The equipment is created in the same way as the rooms. Every object is created as an assembly consisting of one or more parts. Also the objects which would be able to be created out of one part have been made as an assembly. This offers the possibility of easy changes. Especially those parts, which get different textures or become animated, are to be created as single parts within an assembly.

The creation of such an object is now shown by example of the drill. This machine is to be animated in VR, so there are some things of interest during the construction of this machine.



**Figure 4: Drill**

The drill consists of six parts. The largest part, `drill.prt`, is the basic part of the assembly. It consists of a number of protrusions, these are the stand, the base of the work piece table and one protrusion for the drive of the drill. All these protrusion are combined with one protrusion.

The next part, `drill_part2.prt`, represents the table on which the work piece is located. It is created as an part for its own, because it is mapped with another texture in virtual reality.

The drive of the drill is represented also by part `drill_part3.prt`. This part is not directly built up in `drill.prt` because it is easier to move parts instead of protrusions in order to get the final design.

The drill chuck, `drill_part4.prt`, is located directly at the drive, part 3. This part gets an animation in the virtual reality system, therefore it has to be an own part.

Just below the chuck the drill bit, `drill_part6.prt`, is located. This part is moved together with the chuck in VR.

The handle to operate the drill is represented by `drill_part5.prt`. This part is fixed on the drive and by pulling it the user is able to “operate” the drill in the virtual reality.

The parts that are used for the drill are pasted in the appendix.

The other objects are created in the same way. One object can consist out of parts or assemblies, e.g. the computer places. The object `labplatser.asm` is a combination of parts such as the computer, the desks, and assemblies, such as the chairs.

The following image shows the model of the laboratory after its creation in Pro/E. The corridor in front of the laboratory rooms 202 and 212 is added to the model in order to give a starting point for the exploration of the laboratory in virtual reality. The rooms beneath to the lab hinted by the doors are not part of it and are not modelled for the visualization.

The CAD model is exported to dVISE where the implementation in virtual reality takes place.



## **6 Creation of the VR model**

The implementation of the CAD-model in virtual reality is done with the program dVISE from PTC [8]. This program allows it to create a virtual presentation of the model. The basics of this virtual model are the engineering data from the CAD program. The fundamental features of virtual reality, audio, visual and behavioural characteristics (such as animation, movement constraints and collision properties) are created in this program.

The beginning of the creation of the VR model is the export of the CAD model out of the CAD program into the VR program. During the export process all data which are relevant for the representation of the VR model are extracted from the CAD model.

Along with this export there are four new directories created. These directories are `geometry`, `texture`, `vdifiles` and `material`. These four directories are needed in order to describe the virtual model.

The directories `texture` and `material` includes the information of the visual characteristics of the model. The data for the material are taken out of the CAD model and includes the information of the colour of each part. Directly after the conversion the `texture` directory is still empty. In this directory all information of the textures, which improve the visual impression, are saved. These information are combined within the program with the material.

Every part of the CAD model is defined in dVise as a geometry file. This file contains the information needed for rendering the part in virtual reality.

The VDI files are used for the top level representation of the assembly. These files use an ASCII-based scripting language, so they are readable for the user. One example for such an VDI file is shown in the appendix (11.3).

Within the `vdi` file the assembly, the hierarchy, the interdependences and the properties are defined. Each assembly in the CAD model creates its own `vdi` file. But, because of its hierarchical character only the `vdi` file of the top level assembly is needed to work with. In it all the other `vdi` files are included.

In the `vdi` files is described, which parts and/or assemblies are used and which geometry file is needed for the construction. Additionally the position and orientation of each part is saved within the `vdi` file.

After the conversion the `vdi` file of the model is opened in dVISE. As mentioned above it includes the whole geometry of the model.

Within dVISE all parts that are not to be animated or moved in any way have to be fixed. Otherwise it is possible to change the total geometry by moving the parts.

There are different types of fixing possible. The option “fixed” kills all six degrees of freedom, while the three “hinge” options allow a rotation round the defined axis.

The last option is a free combination of all six degrees of freedom.

The setting of the constraint properties of the parts is necessary because otherwise it is not possible to create animations in a special direction.

## **6.1 Visual Behaviour**

After setting the constraints the visual behaviour of the parts is set. Therefore it is necessary to define a material, which is assigned to the part. This material is saved in the directory material.

The materials are managed in the MaterialLibrary. The material describes the surface properties by the use of colour and texture.

### **6.1.1 Colour**

The colour of the material is set by a combination of the light properties for the part or the assembly and the reflection of that light.

The lightning of the assembly is defined in general as an ambient and a number of directed light. The ambient light is a light with no source or direction but it provides background illumination. Directed light is shining in the direction of the orientation of the assembly. This lights can have a colour that is set in the light properties dialog. As mentioned the colour appearance of one part is the combination of the colour of the light that illuminates it and the reflection properties of the part. These properties set how much of the light is reflected.

The light properties can be set for every part itself. They are combined with the general settings of the light.

### **6.1.2 Texture**

In order to increase the realism of the model it is possible to rise the complexity of the geometry. Another, faster and easier, method is the texture mapping. With this method the details for the surface are taken from a 2D image. This image can be taken from real objects with a digital camera for example. Other possibilities are scanning a photograph or painting the texture. This image is mapped onto the surface of the assembly.

In most times the level of realism is better by using textures instead of a more complex geometry.

The images that are needed for the creation of the textures are taken with a digital camera from real objects, like drill machines, the brick wall, the floor, steel, and wood.

The use of the digital camera instead of a conventional one makes it easier to use the photos within the computer. By using the conventional camera the photos have to be developed first and then scanned for the use in the computer.

These images are taken in the JPEG-format, which is not usable for textures. The images have to be converted in the Division multi-format .vtx. This is handled with the program "img2vtx". The use of this program is not discussed in this report.

For the best result of visual realism the textures have to be square. The most common sizes that are used in the model of the lab are 512x512 and 128x128. The size of the texture shows how the level of details is, especially when the viewer is very near to it in the model.

For that reason the high resolution is used especially for the walls and doors.

As a result of the basic geometry used for the creation of the model of the laboratory, cubes, the textures are mapped on the surfaces by using the axial mapping. In this method the texture is mapped on every surface. In the other method, plane mapping the texture is mapped on one surface and than sliced along the third axis. This method is especially used for mapping flat surfaces such as terrain.

The type of mapping can be changed with the program ‘`bgftmap`’.  
This program adds the information about the mapping to the geometry files.

The textures are also saved in the MaterialLibrary. In this library the name and the texture-file are set. The wrapping behaviour is also set in this library. This is how the texture is wrapped along the axis u and v that are plane on the surface.  
The defined textures are assigned to the material. Because of the design of the model, there are no transparencies, only the front material is needed.

## **6.2 Interaction**

In order to interact with the virtual laboratory there are some interactions implemented. By touching the handle of a door and pushing or pulling it, depending on the side on which the user is located, it can be opened and closed.  
This interactivity is not implemented in the doors that are going to rooms that are not part of the laboratory. These rooms were not built in the CAD-system and are therefore not available in the virtual reality.

The other interactivity is the handling of the drill machines. At these three machines the user is able to “work” with the machine by pulling the handle.

The following shows the branch of the drill in order to demonstrate the hierarchy.

drill	(Assembly)
drill	(drill_part1)
drill_part2	
drill_part3	
drill_part4	(cuck)
drill_part6	(drill bit)
Hinge	
drill_part5	(handle)

Event	Actions
Create	dVAssign("@drill", "0")
Pick	dVAssign("@drill", "1") dVAssign("@oldrotation", "45")
Tick	dVCall("equ(@drill,1)", . , drill)
Drop	dVAssemblyOrientation(/.../Hinge, 0, 0, 45) dVAssemblyPosition(/.../drill_part4, 0.6, 1.75, 0.25) dVAssign("@drill", "0")
drill	dVAssign("@rotation", "ooZ(/.../Hinge)") dVAssign("%divrotation", "fsu(@rotation, @oldrotation)") dVAssign("@translation", "fmu/%divrotation, 0.0025)") dVAssemblyTranslate(/.../drill_part4, 0, @translation, 0) dVAssign("@oldrotation", "@rotation")

**Table 1: Interaction of the drill**

The interaction with the drill is done with the events and actions listed above. The events "Create", "Pick", "Tick", and "Drop" are events provided by dVISE, while drill is an user defined event.

The events and the actions are now explained in order to demonstrate how the interaction is working.

The event "Create" takes place at every time when the program is starting with the vdi-file of the model of the laboratory. The action belonging to this event sets the value of the global variable "@drill" to the value "0". The task of this variable is only to indicate the picking status of the handle of the drill.

When the handle (drill\_part5) is picked with the pointing device (event "Pick") the value of "@drill" is set to "1" and the value for "@oldrotation" is set on the value "45" which is the angle of the hinge at the beginning of the interaction. The variable "@oldrotation" is used for the indication of the movement of the handle.

If the handle is picked, the event "drill" is called, which forms the correlation between the rotation of the handle and the translation of the chuck. The first thing that happens in this event is the setting of the variable "@rotation" to the value of the orientation of the hinge around the Z-axis. This angle is subtracted from the oldrotation and set to "%divrotation" in order to get information about the moving of the handle. When the handle is kept in one position the chuck shall not move. The value for the translation of the chuck along the Y-axis is got by a multiplication of the "%divrotation" with 0.0025. This value is saved under "@translation". For the next use of the event the current value of the rotation is now saved under "@oldrotation".

These actions are done 25 times per second until the handle is dropped.

When the handle is dropped (event "Drop") the orientation of the hinge and therefore the orientation of the handle and the position of the chuck are set to the values at the beginning.

Finally the indicator for the picking of the handle (@drill) is set to “0”.

In order to work with these interactions the collision properties of the door handles and the drill handles are to be set.

Collision state

### **6.3 People inside the Laboratory**

Finally, in order to get a better feeling of the dimensions of the laboratory, some people are integrated in the rooms. These humans are imported from a program that is included in dVise, dVmanikin. The humans consist of several different parts, so they can be arranged in different positions.

Some of the persons inside the laboratory are animated. This increases the feeling of being inside a “real” laboratory.

It gives the user the feeling that the laboratory, which is only planned at this time, already exists. This is the sense of virtual reality.

## **7 Instruction for the use of the model**

This chapter will give a short instruction for the use of the model, including changes of it like adding or moving parts.

### **7.1 Starting of the model**

To start the presentation of the model of the laboratory it is necessary to open the file `dVise\vdifiles\concept4.vdi` on the CD-ROM in dVISE. As mentioned in the beginning of this chapter all information about the model are included in the top level vdi-file. After opening of this file the branch of the model has to be loaded in the Assembly Manager. Now the model is ready for the presentation.

### **7.2 Interactions**

The user is able to interact with the model via the following parts. The three drill machines are to be used and the doors to the other rooms of the laboratory can be opened.

In order to interact with the model the user has to touch the parts, handle of the drill or the door, then press the button and move his hand in the right direction.

### **7.3 Moving of parts**

The movement of parts is done directly in dVISE either by the drag and drop function, where you pick the part you want to move and move it around with the mouse or by using the geometrical properties.

In order to use the drag and drop function for the most parts the constraints have to be controlled, because almost all parts inside the model are fixed in order to avoid unintentional movement.

By using the function of the geometrical properties it is possible to set the position and orientation by the input of values for the three axes.

In both cases all parts that are linked to the moving part are also moved.

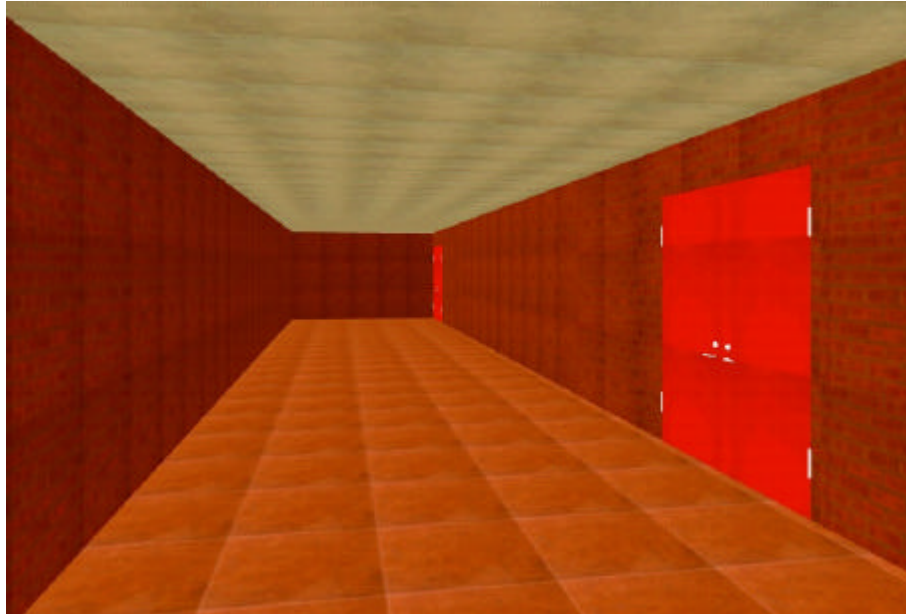
### **7.4 Adding of new parts**

The adding of new parts for the model takes place by creating this part in a 3D CAD program, e.g. Pro/E, and exporting it to dVISE. This creates a new geometry file. In order to add this file into the model, a new assembly inside the Assembly Manager has to be created. This assembly can be linked to another one or can be the start of a new one.

By editing the visual properties of this assembly the geometry file can be assigned and the materials for it can be set.

## 8 Walk through the Laboratory

This chapter will show a virtual walk through the laboratory.



**Figure 5**

The walk begins in the corridor outside of the laboratory. This is the basement of the M building at Chalmers.



**Figure 6**

After walking through the main entrance we are entering room 212, which is the **Design and Build Area**.



**Figure 7**

On the way to room 202, the **Electronics Manufacturing**, we are passing through room 212.



**Figure 8**

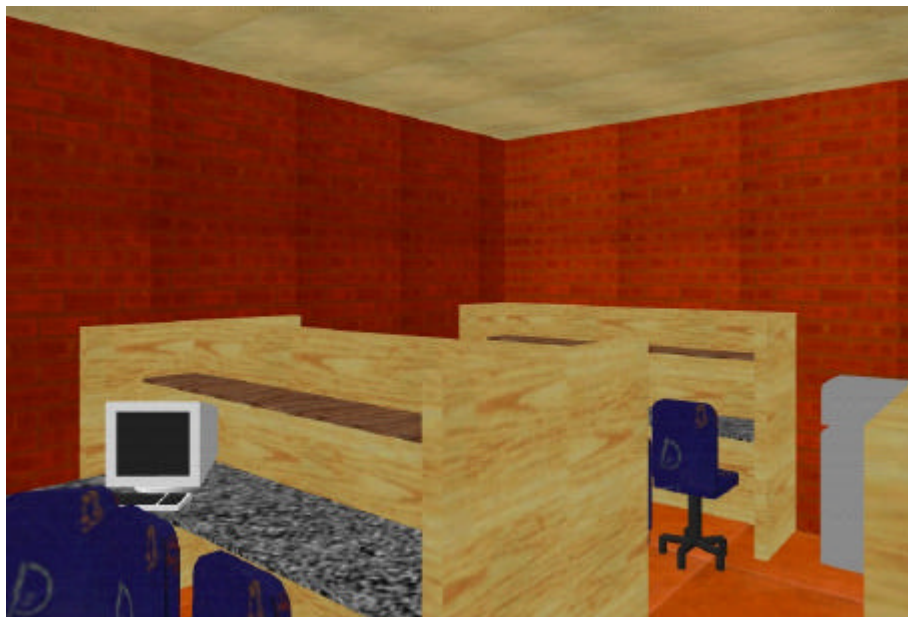
We are now in the **Electronics Manufacturing** where the systems are designed on computers and electronic systems can be manufactured.





**Figure 9**

One student is working with a computer. Six of these workplaces are available in the Laboratory.



**Figure 10**

A view on another workplace in that room. At the end of the floor the printer is located.



**Figure 11**

One student is working on an electronic system.



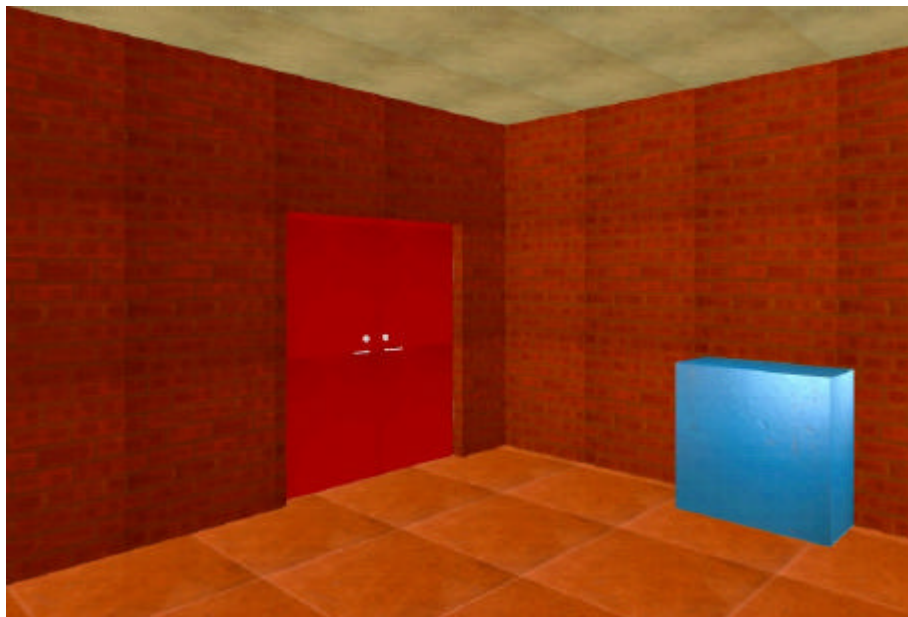
**Figure 12**

On the way back through room 212 we meet a group of students discussing a problem.



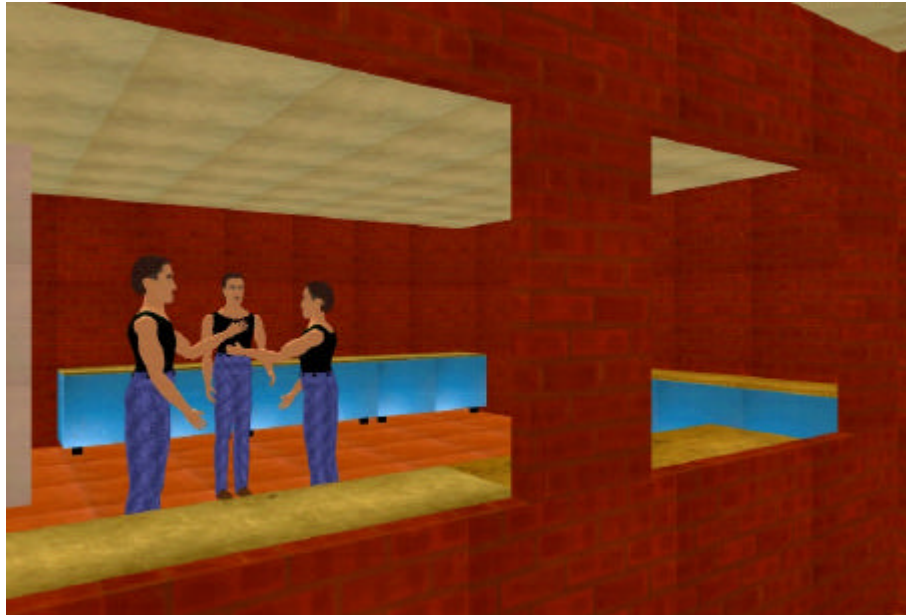
**Figure 13**

After passing through room 212 we reach the **Material Storage** (room 214). On the left a circular saw is positioned.



**Figure 14**

A view in the other direction of room 214. On the right a power hack saw is located.



**Figure 15**

We are now in the office of the laboratory and look into room 212.



**Figure 16**

We turn and look into room 216.





**Figure 17**

After leaving the office we are entering room 216



**Figure 18**

This is the **Wood and Foam Shop** of the laboratory.



**Figure 19**

We are passing through the wood and foam shop.



**Figure 20**

Now we are in the room for **Precision Mechanics**.



**Figure 21**

After leaving the precision mechanics we are walking into the **Metal Shop**.



**Figure 22**

A view into the metal shop in the direction of the office.



**Figure 23**

After passing the lathes we look back.



**Figure 24**

One student is manufacturing some parts for a mechanical system





**Figure 25**

We are now in the part of the metal shop where the drills are.



**Figure 26**

One student is operating the drill.



**Figure 27**

Now we are back in room 212, the **Design and Build Area**, and our walk through the laboratory ends.

## **9 Conclusions**

The advantage of a virtual reality model is that you are able to explore this model. Especially in the development process of the Physical Prototyping Laboratory the creation of such a model is very useful in order to get a feeling for the dimensions of the rooms.

Another advantage is that it is easier to see the positions of the used machines and perhaps change these positions in order to get a more ergonomical workspace.

The level of details that had been chosen for the visualization is good enough for the presentation of the concept to people who are not directly involved in the development process but have to make decisions about it.

Any higher level of details will not be in relation to the profit of the presentation.

Some limitations of the created model are that it is not possible to move the equipment from one place to another during the presentation. In order to do this, the geometrical behaviour of the parts has to be changed in dVISE. This is possible, but not as comfortable to do this during the presentation in the CAVE.

Overall the goals that were set for this project had been reached.

## 10 References

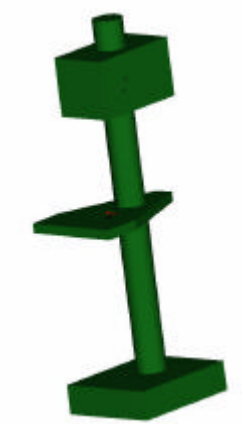
- [1] M. Distner, J. Malmqvist, *Development of a Physical Prototyping Lab at Chalmers University of Technology – Status Report* April 2001, Göteborg
- [2] J. Vince, *Virtual Reality Systems* 1995
- [3] *What Is Virtual Reality*  
[www.isdale.com/jerry/VR/WhatisVR.html](http://www.isdale.com/jerry/VR/WhatisVR.html)
- [4] K.P. Beier, *Virtual Reality: A Short Introduction*  
[www-vrl.umich.edu/intro](http://www-vrl.umich.edu/intro)
- [5] M. Louka, *An Introduction to Virtual Reality*  
[w1.2691.telia.com/~u269100246/vr/vrhiof98/](http://w1.2691.telia.com/~u269100246/vr/vrhiof98/)
- [6] *Chalmers Medialab*  
[www.medialab.chalmers.se](http://www.medialab.chalmers.se)
- [7] PTC Homepage  
[www.ptc.com](http://www.ptc.com)
- [8] *dVise Homepage*  
[www.ptc.com/products/division/index.htm](http://www.ptc.com/products/division/index.htm)

# 11 Appendix

## 11.1 Map of the Laboratory (Concept 4)



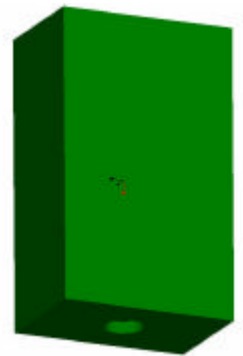
## 11.2 Parts for the drill



**drill.prt**



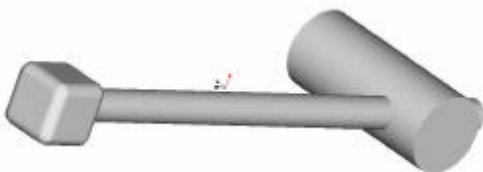
**drill\_part2.prt**



**drill\_part3.prt**



**drill\_part4.prt**



**drill\_part5.prt**



**drill\_part6.prt**

### 11.3 File drill.vdi

```
DIV-VDI3
header (version=4:0; date=1:6:101; time=14:21; unit=m ){}

definelibrary (name="libdrill"){
  assembly (name="drill") {
    assembly (name="drill") {
      orientation {-90, 0, -90}
      visual {
        geometry {"drill"}
      }
    }
  }
  assembly (name="drill_part2") {
    position {0.4, 1.05, -0.05}
    orientation {90, 0, 0}
    visual {
      geometry {"drill_part2"}
    }
  }
  assembly (name="drill_part3") {
    position {0.7, 2, 0.1}
    orientation {0, -90, -90}
    visual {
      geometry {"drill_part3"}
    }
  }
  assembly (name="drill_part4") {
    position {0.6, 1.7, 0.25}
    orientation {90, 0, 0}
    visual {
      geometry {"drill_part4"}
    }
  }
  assembly (name="drill_part5") {
    position {0.353, 1.57, -0.025}
    orientation {-90, 0, 180}
    visual {
      geometry {"drill_part5"}
    }
  }
  assembly (name="drill_part6") {
    position {0.6, 1.32, 0.25}
    orientation {90, 0, 0}
    visual {
      geometry {"drill_part6"}
    }
  }
}
}
```

## 11.4 Listing of the Files

Model Name

-----  
-----

```

1CONCEPT4.ASM
  ROOM_212_41.ASM
    WALL_2000.PRT
    WALL_500.PRT
    WALL_5000_WINDOW.PRT
    DOOR_DOUBLE_LARGE.PRT
    ROOM_212_WALL2_C41.ASM
      WALL_5000.PRT
      WALL_2000.PRT
      DOOR_DOUBLE_SMALL.ASM
        DOOR_DOUBLE_SMALL.PRT
        DOOR_HUNGE_WALL.PRT
        DOOR_HUNGE_WALL.PRT
        DOOR_HUNGE_WALL.PRT
        DOOR_HUNGE_WALL.PRT
        DOOR_SMALL_LEFT.ASM
          DOOR_DOOR_SMALL.PRT
          DOOR_HANDLE.PRT
          DOOR_HANDLE.PRT
          DOOR_HUNGE_DOOR.PRT
          DOOR_HUNGE_DOOR.PRT
          DOOR_DOOR_LOCKER.PRT
        DOOR_SMALL_RIGHT.ASM
          DOOR_DOOR_SMALL.PRT
          DOOR_HANDLE.PRT
          DOOR_HANDLE.PRT
          DOOR_HUNGE_DOOR.PRT
          DOOR_HUNGE_DOOR.PRT
          DOOR_DOOR_LOCKER.PRT
      WALL_4000.PRT
      WALL_100.PRT
      WALL_100.PRT
    WALL_5000.PRT
    WALL_2000.PRT
    WALL_500.PRT
    DOOR_DOUBLE_LARGE.ASM
      DOOR_DOUBLE_LARGE.PRT
      DOOR_HUNGE_WALL.PRT
      DOOR_HUNGE_WALL.PRT
      DOOR_HUNGE_WALL.PRT
      DOOR_HUNGE_WALL.PRT
      DOOR_LARGE_LEFT.ASM
        DOOR_DOOR_LARGE.PRT
        DOOR_HANDLE.PRT
        DOOR_HANDLE.PRT
        DOOR_HUNGE_DOOR.PRT
        DOOR_HUNGE_DOOR.PRT
        DOOR_DOOR_LOCKER.PRT
      DOOR_LARGE_RIGHT.ASM
        DOOR_DOOR_LARGE.PRT
        DOOR_HUNGE_DOOR.PRT
        DOOR_HUNGE_DOOR.PRT
        DOOR_HANDLE.PRT

```

```

    DOOR_HANDLE.PRT
    DOOR_DOOR_LOCKER.PRT
  WALL_100.PRT
  WALL_4000.PRT
  DOOR_SINGLE_RIGHT.ASM
    DOOR_SINGLE.PRT
    DOOR_HUNGE_WALL.PRT
    DOOR_HUNGE_WALL.PRT
    DOOR_SMALL_RIGHT.ASM
      DOOR_DOOR_SMALL.PRT
      DOOR_HANDLE.PRT
      DOOR_HANDLE.PRT
      DOOR_HUNGE_DOOR.PRT
      DOOR_HUNGE_DOOR.PRT
      DOOR_DOOR_LOCKER.PRT
  WALL_100.PRT
  WALL_100.PRT
  WALL_500.PRT
  DOOR_SINGLE_RIGHT.ASM
    DOOR_SINGLE.PRT
    DOOR_HUNGE_WALL.PRT
    DOOR_HUNGE_WALL.PRT
    DOOR_SMALL_RIGHT.ASM
      DOOR_DOOR_SMALL.PRT
      DOOR_HANDLE.PRT
      DOOR_HANDLE.PRT
      DOOR_HUNGE_DOOR.PRT
      DOOR_HUNGE_DOOR.PRT
      DOOR_DOOR_LOCKER.PRT
  WALL_4000.PRT
  DOOR_DOUBLE_SMALL.ASM
    DOOR_DOUBLE_SMALL.PRT
    DOOR_HUNGE_WALL.PRT
    DOOR_HUNGE_WALL.PRT
    DOOR_HUNGE_WALL.PRT
    DOOR_SMALL_LEFT.ASM
      DOOR_DOOR_SMALL.PRT
      DOOR_HANDLE.PRT
      DOOR_HANDLE.PRT
      DOOR_HUNGE_DOOR.PRT
      DOOR_HUNGE_DOOR.PRT
      DOOR_DOOR_LOCKER.PRT
    DOOR_SMALL_RIGHT.ASM
      DOOR_DOOR_SMALL.PRT
      DOOR_HANDLE.PRT
      DOOR_HANDLE.PRT
      DOOR_HUNGE_DOOR.PRT
      DOOR_HUNGE_DOOR.PRT
      DOOR_DOOR_LOCKER.PRT
  WALL_500.PRT
  WALL_100.PRT
  COULUMN.PRT
  BOTTOM_212.PRT
  TOOLS.ASM
    TOOLS.PRT
    TOOLS_DOOR.PRT
  TOOLS.ASM

```



TOOLS .PRT	DOOR_HUNGE_DOOR .PRT
TOOLS_DOOR .PRT	DOOR_HUNGE_DOOR .PRT
XP .ASM	DOOR_DOOR_LOCKER .PRT
WALL_5000 .PRT	WALL_500 .PRT
WALL_2000 .PRT	WALL_5000_WINDOW .PRT
WALL_500 .PRT	WALL_2000 .PRT
WALL_2000 .PRT	WALL_500 .PRT
WALL_500 .PRT	BENCH_WHEEL .ASM
WALL_5000 .PRT	BENCH_WHEEL_PART1 .PRT
WALL_2000 .PRT	BENCH_LARGE_PLATE .PRT
WALL_500 .PRT	Pattern
WALL_100 .PRT	(BENCH_WHEEL_PART2 .PRT)
WALL_100 .PRT	BENCH_WHEEL_PART2 .PRT
WALL_100 .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_DOUBLE_SMALL .ASM	BENCH_WHEEL_PART2 .PRT
DOOR_DOUBLE_SMALL .PRT	BENCH_WHEEL .ASM
DOOR_HUNGE_WALL .PRT	BENCH_WHEEL_PART1 .PRT
DOOR_HUNGE_WALL .PRT	BENCH_LARGE_PLATE .PRT
DOOR_HUNGE_WALL .PRT	Pattern
DOOR_HUNGE_WALL .PRT	(BENCH_WHEEL_PART2 .PRT)
DOOR_SMALL_LEFT .ASM	BENCH_WHEEL_PART2 .PRT
DOOR_DOOR_SMALL .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HANDLE .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HANDLE .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HUNGE_DOOR .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HUNGE_DOOR .PRT	BENCH_WHEEL .ASM
DOOR_DOOR_LOCKER .PRT	BENCH_WHEEL_PART1 .PRT
DOOR_SMALL_RIGHT .ASM	BENCH_LARGE_PLATE .PRT
DOOR_DOOR_SMALL .PRT	Pattern
DOOR_HANDLE .PRT	(BENCH_WHEEL_PART2 .PRT)
DOOR_HANDLE .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HUNGE_DOOR .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HUNGE_DOOR .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_DOOR_LOCKER .PRT	BENCH_WHEEL_PART2 .PRT
WALL_100 .PRT	BENCH_WHEEL .ASM
WALL_100 .PRT	BENCH_WHEEL_PART1 .PRT
PCB .ASM	BENCH_LARGE_PLATE .PRT
WALL_500 .PRT	Pattern
WALL_1000 .PRT	(BENCH_WHEEL_PART2 .PRT)
DOOR_SINGLE_RIGHT .ASM	BENCH_WHEEL_PART2 .PRT
DOOR_SINGLE .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HUNGE_WALL .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HUNGE_WALL .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_SMALL_RIGHT .ASM	BENCH_WHEEL .ASM
DOOR_DOOR_SMALL .PRT	BENCH_WHEEL_PART1 .PRT
DOOR_HANDLE .PRT	BENCH_LARGE_PLATE .PRT
DOOR_HANDLE .PRT	Pattern
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DOOR_DOOR_LOCKER .PRT	BENCH_WHEEL_PART2 .PRT
OFFICE .ASM	BENCH_WHEEL_PART2 .PRT
WALL_1000 .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_SINGLE_RIGHT .ASM	BENCH_WHEEL_PART2 .PRT
DOOR_SINGLE .PRT	BENCH_WHEEL .ASM
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DOOR_HUNGE_WALL .PRT	BENCH_LARGE_PLATE .PRT
DOOR_SMALL_RIGHT .ASM	Pattern
DOOR_DOOR_SMALL .PRT	(BENCH_WHEEL_PART2 .PRT)
DOOR_HANDLE .PRT	BENCH_WHEEL_PART2 .PRT
DOOR_HANDLE .PRT	BENCH_WHEEL_PART2 .PRT
	BENCH_WHEEL_PART2 .PRT

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 BENCH\_WHEEL\_PART1.PRT  
 BENCH\_LARGE\_PLATE.PRT  
 Pattern  
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 BENCH\_WHEEL\_PART2.PRT  
 ROOM\_214\_C4.ASM  
 WALL\_5000.PRT  
 WALL\_5000.PRT  
 WALL\_3000.PRT  
 WALL\_5000.PRT  
 WALL\_500.PRT  
 DOOR\_SINGLE.PRT  
 WALL\_4000.PRT  
 DOOR\_DOUBLE\_SMALL.PRT  
 WALL\_500.PRT  
 BOTTOM\_214.PRT  
 CIRCULARSAW.ASM  
 CIRCULARSAW\_PART1.PRT  
 CIRCULARSAW\_PART2.PRT  
 CIRCULARSAW\_PART3.PRT  
 HACKSAW.ASM  
 HACKSAW.PRT  
 ROOM\_215\_C4.ASM  
 WALL\_5000.PRT  
 WALL\_2000.PRT  
 WALL\_500.PRT  
 WALL\_5000.PRT  
 WALL\_1000.PRT  
 WALL\_500.PRT  
 DOOR\_SINGLE.PRT  
 BOTTOM\_215.PRT  
 ROOM\_216\_C41.ASM  
 ROOM\_216.ASM  
 WALL\_3000.PRT  
 WALL\_5000.PRT  
 DOOR\_DOUBLE\_LARGE.ASM  
 DOOR\_DOUBLE\_LARGE.PRT  
 DOOR\_HUNGE\_WALL.PRT  
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 DOOR\_DOOR\_LOCKER.PRT  
 DOOR\_LARGE\_RIGHT.ASM  
 DOOR\_DOOR\_LARGE.PRT  
 DOOR\_HUNGE\_DOOR.PRT  
 DOOR\_HUNGE\_DOOR.PRT  
 DOOR\_DOOR\_LOCKER.PRT  
 DOOR\_HANDLE.PRT  
 DOOR\_HANDLE.PRT  
 DOOR\_DOOR\_LOCKER.PRT

WALL\_500.PRT  
 WALL\_4000.PRT  
 WALL\_100.PRT  
 WALL\_500.PRT  
 WALL\_5000.PRT  
 WALL\_5000.PRT  
 WALL\_5000.PRT  
 WALL\_5000.PRT  
 WALL\_100.PRT  
 DOOR\_DOUBLE\_LARGE.ASM  
 DOOR\_DOUBLE\_LARGE.PRT  
 DOOR\_HUNGE\_WALL.PRT  
 DOOR\_HUNGE\_WALL.PRT  
 DOOR\_HUNGE\_WALL.PRT  
 DOOR\_HUNGE\_WALL.PRT  
 DOOR\_LARGE\_LEFT.ASM  
 DOOR\_DOOR\_LARGE.PRT  
 DOOR\_HANDLE.PRT  
 DOOR\_HANDLE.PRT  
 DOOR\_HUNGE\_DOOR.PRT  
 DOOR\_HUNGE\_DOOR.PRT  
 DOOR\_DOOR\_LOCKER.PRT  
 DOOR\_LARGE\_RIGHT.ASM  
 DOOR\_DOOR\_LARGE.PRT  
 DOOR\_HUNGE\_DOOR.PRT  
 DOOR\_HUNGE\_DOOR.PRT  
 DOOR\_HANDLE.PRT  
 DOOR\_HANDLE.PRT  
 DOOR\_DOOR\_LOCKER.PRT  
 WALL\_5000\_WINDOW.PRT  
 WALL\_500.PRT  
 WALL\_2000.PRT  
 WALL\_5000.PRT  
 WALL\_5000.PRT  
 WALL\_5000.PRT  
 WALL\_5000.PRT  
 WALL\_500.PRT  
 COULUMN.PRT  
 COULUMN.PRT  
 BOTTOM\_216.PRT  
 WELDING\_AREA.ASM  
 WALL\_4000.PRT  
 WALL\_500.PRT  
 WALL\_3000.PRT  
 WALL\_500.PRT  
 WALL\_4000.PRT  
 DOOR\_SINGLE\_RIGHT.ASM  
 DOOR\_SINGLE.PRT  
 DOOR\_HUNGE\_WALL.PRT  
 DOOR\_HUNGE\_WALL.PRT  
 DOOR\_SMALL\_RIGHT.ASM  
 DOOR\_DOOR\_SMALL.PRT  
 DOOR\_HANDLE.PRT  
 DOOR\_HANDLE.PRT  
 DOOR\_HUNGE\_DOOR.PRT  
 DOOR\_HUNGE\_DOOR.PRT  
 DOOR\_DOOR\_LOCKER.PRT  
 WALL\_2000.PRT  
 PRECISION\_MEC.ASM  
 WALL\_4000.PRT  
 WALL\_500.PRT

WALL_2000.PRT	BENCH_SMALL.PRT
WALL_500.PRT	BENCH_SMALL_PLATE.PRT
WALL_4000.PRT	BENCH_SMALL_TOOLS.PRT
DOOR_SINGLE_RIGHT.ASM	BENCH_SMALL.ASM
DOOR_SINGLE.PRT	BENCH_SMALL.PRT
DOOR_HUNGE_WALL.PRT	BENCH_SMALL_PLATE.PRT
DOOR_HUNGE_WALL.PRT	BENCH_SMALL_TOOLS.PRT
DOOR_SMALL_RIGHT.ASM	BENCH_SMALL.ASM
DOOR_DOOR_SMALL.PRT	BENCH_SMALL.PRT
DOOR_HANDLE.PRT	BENCH_SMALL_PLATE.PRT
DOOR_HANDLE.PRT	BENCH_SMALL_TOOLS.PRT
DOOR_HUNGE_DOOR.PRT	BENCH_SMALL.ASM
DOOR_HUNGE_DOOR.PRT	BENCH_SMALL.PRT
DOOR_DOOR_LOCKER.PRT	BENCH_SMALL_PLATE.PRT
WALL_1000.PRT	BENCH_SMALL_TOOLS.PRT
BENCH_LARGE.ASM	BENCH_LARGE.ASM
BENCH_LARGE.PRT	BENCH_LARGE.PRT
BENCH_LARGE_PLATE.PRT	BENCH_LARGE_PLATE.PRT
BENCH_LARGE_TOOLS.PRT	BENCH_LARGE_TOOLS.PRT
BENCH_LARGE.ASM	BENCH_LARGE.ASM
BENCH_LARGE.PRT	BENCH_LARGE.PRT
BENCH_LARGE_PLATE.PRT	BENCH_LARGE_PLATE.PRT
BENCH_LARGE_TOOLS.PRT	BENCH_LARGE_TOOLS.PRT
BENCH_LARGE.ASM	BENCH_LARGE.ASM
BENCH_LARGE.PRT	BENCH_LARGE.PRT
BENCH_LARGE_PLATE.PRT	BENCH_LARGE_PLATE.PRT
BENCH_LARGE_TOOLS.PRT	BENCH_LARGE_TOOLS.PRT
BENCH_LARGE.ASM	BENCH_LARGE.WOOD.ASM
BENCH_LARGE.PRT	BENCH_LARGE.PRT
BENCH_LARGE_PLATE.PRT	BENCH_LARGE_PLATE.PRT
BENCH_LARGE_TOOLS.PRT	BENCH_LARGE.WOOD.ASM
BENCH_LARGE.ASM	BENCH_LARGE.PRT
BENCH_LARGE.PRT	BENCH_LARGE_PLATE.PRT
BENCH_LARGE_PLATE.PRT	BENCH_LARGE.WOOD.ASM
BENCH_LARGE_TOOLS.PRT	BENCH_LARGE.PRT
BENCH_LARGE.ASM	BENCH_LARGE_PLATE.PRT
BENCH_LARGE.PRT	BENCH_LARGE.WOOD.ASM
BENCH_LARGE_PLATE.PRT	BENCH_LARGE.PRT
BENCH_LARGE_TOOLS.PRT	BENCH_LARGE_PLATE.PRT
BENCH_LARGE.ASM	TOOLS.ASM
BENCH_LARGE.PRT	TOOLS.PRT
BENCH_LARGE_PLATE.PRT	TOOLS_DOOR.PRT
BENCH_LARGE_TOOLS.PRT	TOOLS.ASM
BENCH_LARGE.ASM	TOOLS.PRT
BENCH_LARGE.PRT	TOOLS_DOOR.PRT
BENCH_LARGE_PLATE.PRT	TOOLS.ASM
BENCH_LARGE_TOOLS.PRT	TOOLS.PRT
BENCH_SMALL.ASM	TOOLS_DOOR.PRT
BENCH_SMALL.PRT	TOOLS.ASM
BENCH_SMALL_PLATE.PRT	TOOLS.PRT
BENCH_SMALL_TOOLS.PRT	TOOLS_DOOR.PRT
BENCH_SMALL.ASM	LATHE.ASM
BENCH_SMALL.PRT	LATHE_PART1.PRT
BENCH_SMALL_PLATE.PRT	LATHE_PART2.PRT
BENCH_SMALL_TOOLS.PRT	LATHE_PART3.PRT
BENCH_SMALL.ASM	LATHE_PART4.PRT
BENCH_SMALL.PRT	LATHE.ASM
BENCH_SMALL_PLATE.PRT	LATHE_PART1.PRT
BENCH_SMALL_TOOLS.PRT	LATHE_PART2.PRT
BENCH_SMALL.ASM	LATHE_PART3.PRT

LATHE_PART4.PRT	POWERSANDER_PART3.PRT
LATHE.ASM	POWERSANDER_PART4.PRT
LATHE_PART1.PRT	POWERSANDER_PART5.PRT
LATHE_PART2.PRT	MODELLATHE.ASM
LATHE_PART3.PRT	MODELLATHE_PART1.PRT
LATHE_PART4.PRT	MODELLATHE_PART2.PRT
MILL.ASM	MODELLATHE_PART3.PRT
MILL.PRT	MODELLATHE_PART4.PRT
MILL_PART2.PRT	MODELLATHE_PART5.PRT
MILL_PART3.PRT	MODELLATHE_PART6.PRT
MILL.ASM	NC.ASM
MILL.PRT	MODELLATHE_PART1.PRT
MILL_PART2.PRT	MODELLATHE_PART2.PRT
MILL_PART3.PRT	MODELLATHE_PART3.PRT
TOOLS.ASM	NC_PART1.PRT
TOOLS.PRT	NC_PART2.PRT
TOOLS_DOOR.PRT	NC_PART3.PRT
BANDSAW.ASM	SHEET_METAL.ASM
BANDSAW.PRT	SHEET_METAL_PART1.PRT
BANDSAW_PART2.PRT	ROOM_202_C41.ASM
BANDSAW.ASM	ROOM_202_WALL1.ASM
BANDSAW.PRT	WALL_5000.PRT
BANDSAW_PART2.PRT	WALL_1000.PRT
TOOLS.ASM	WALL_100.PRT
TOOLS.PRT	WALL_100.PRT
TOOLS_DOOR.PRT	WALL_100.PRT
DRILL.ASM	DOOR_SINGLE_LEFT.ASM
DRILL.PRT	DOOR_SINGLE.PRT
DRILL_PART2.PRT	DOOR_HUNGE_WALL.PRT
DRILL_PART3.PRT	DOOR_HUNGE_WALL.PRT
DRILL_PART4.PRT	DOOR_SMALL_LEFT.ASM
DRILL_PART5.PRT	DOOR_DOOR_SMALL.PRT
DRILL_PART6.PRT	DOOR_HANDLE.PRT
DRILL.ASM	DOOR_HANDLE.PRT
DRILL.PRT	DOOR_HUNGE_DOOR.PRT
DRILL_PART2.PRT	DOOR_HUNGE_DOOR.PRT
DRILL_PART3.PRT	DOOR_DOOR_LOCKER.PRT
DRILL_PART4.PRT	WALL_500.PRT
DRILL_PART5.PRT	DOOR_DOUBLE_LARGE.ASM
DRILL_PART6.PRT	DOOR_DOUBLE_LARGE.PRT
DRILL.ASM	DOOR_HUNGE_WALL.PRT
DRILL.PRT	DOOR_HUNGE_WALL.PRT
DRILL_PART2.PRT	DOOR_HUNGE_WALL.PRT
DRILL_PART3.PRT	DOOR_HUNGE_WALL.PRT
DRILL_PART4.PRT	DOOR_HUNGE_WALL.PRT
DRILL_PART5.PRT	DOOR_LARGE_LEFT.ASM
DRILL_PART6.PRT	DOOR_DOOR_LARGE.PRT
WOODLATHE.ASM	DOOR_HANDLE.PRT
WOODLATHE_PART1.PRT	DOOR_HANDLE.PRT
WOODLATHE_PART2.PRT	DOOR_HUNGE_DOOR.PRT
WOODLATHE_PART3.PRT	DOOR_HUNGE_DOOR.PRT
WOODLATHE_PART4.PRT	DOOR_DOOR_LOCKER.PRT
POWERPLANE.ASM	DOOR_LARGE_RIGHT.ASM
POWERPLANE.PRT	DOOR_DOOR_LARGE.PRT
POWERPLANE_PART2.PRT	DOOR_HUNGE_DOOR.PRT
POWERPLANE_PART3.PRT	DOOR_HUNGE_DOOR.PRT
POWERPLANE_PART4.PRT	DOOR_HANDLE.PRT
POWERSANDER.ASM	DOOR_HANDLE.PRT
POWERSANDER_PART1.PRT	DOOR_DOOR_LOCKER.PRT
POWERSANDER_PART2.PRT	WALL_100.PRT
	WALL_100.PRT

ROOM_202_WALL2.ASM	WALL_100.PRT
WALL_5000.PRT	ROOM_202_WALL4_C41.ASM
WALL_100.PRT	WALL_5000.PRT
WALL_100.PRT	WALL_2000.PRT
WALL_2000.PRT	DOOR_DOUBLE_SMALL.PRT
WALL_500.PRT	WALL_4000.PRT
DOOR_SINGLE_LEFT.ASM	WALL_100.PRT
DOOR_SINGLE.PRT	WALL_100.PRT
DOOR_HUNGE_WALL.PRT	ROOM_202_WALL5_C41.ASM
DOOR_HUNGE_WALL.PRT	WALL_5000.PRT
DOOR_SMALL_LEFT.ASM	DOOR_SINGLE_RIGHT.ASM
DOOR_DOOR_SMALL.PRT	DOOR_SINGLE.PRT
DOOR_HANDLE.PRT	DOOR_HUNGE_WALL.PRT
DOOR_HANDLE.PRT	DOOR_HUNGE_WALL.PRT
DOOR_HUNGE_DOOR.PRT	DOOR_SMALL_RIGHT.ASM
DOOR_HUNGE_DOOR.PRT	DOOR_DOOR_SMALL.PRT
DOOR_DOOR_LOCKER.PRT	DOOR_HANDLE.PRT
WALL_1000.PRT	DOOR_HANDLE.PRT
DOOR_SINGLE_LEFT.ASM	DOOR_HUNGE_DOOR.PRT
DOOR_SINGLE.PRT	DOOR_HUNGE_DOOR.PRT
DOOR_HUNGE_WALL.PRT	DOOR_DOOR_LOCKER.PRT
DOOR_HUNGE_WALL.PRT	WALL_STAIRS.PRT
DOOR_SMALL_LEFT.ASM	WALL_STAIRS2.PRT
DOOR_DOOR_SMALL.PRT	STAIRS.ASM
DOOR_HANDLE.PRT	STAIRS_PART1.PRT
DOOR_HANDLE.PRT	STAIRS_PART2.PRT
DOOR_HUNGE_DOOR.PRT	STAIRS_PART2.PRT
DOOR_HUNGE_DOOR.PRT	COULUMN.PRT
DOOR_DOOR_LOCKER.PRT	BOTTOM_202.PRT
WALL_500.PRT	LABPLATSER.ASM
WALL_1000.PRT	LABPLATSER.PRT
WALL_1000.PRT	DESK.PRT
ROOM_202_WALL3.ASM	PLATE.PRT
WALL_5000.PRT	DESK.PRT
WALL_100.PRT	LABPLATSER.PRT
WALL_100.PRT	PLATE.PRT
WALL_100.PRT	COMPUTER.PRT
WALL_2000.PRT	COMPUTER.PRT
WALL_500.PRT	CHAIR.ASM
DOOR_DOUBLE_LARGE.ASM	CHAIR_BACK.PRT
DOOR_DOUBLE_LARGE.PRT	CHAIR_BACK.PRT
DOOR_HUNGE_WALL.PRT	CHAIR_STANDING.PRT
DOOR_HUNGE_WALL.PRT	CHAIR.ASM
DOOR_HUNGE_WALL.PRT	CHAIR_BACK.PRT
DOOR_HUNGE_WALL.PRT	CHAIR_BACK.PRT
DOOR_LARGE_LEFT.ASM	CHAIR_STANDING.PRT
DOOR_DOOR_LARGE.PRT	CHAIR.ASM
DOOR_HANDLE.PRT	CHAIR_BACK.PRT
DOOR_HANDLE.PRT	CHAIR_BACK.PRT
DOOR_HUNGE_DOOR.PRT	CHAIR_STANDING.PRT
DOOR_HUNGE_DOOR.PRT	CHAIR.ASM
DOOR_DOOR_LOCKER.PRT	CHAIR_BACK.PRT
DOOR_LARGE_RIGHT.ASM	CHAIR_BACK.PRT
DOOR_DOOR_LARGE.PRT	CHAIR_STANDING.PRT
DOOR_HUNGE_DOOR.PRT	CHAIR.ASM
DOOR_HUNGE_DOOR.PRT	CHAIR_BACK.PRT
DOOR_HANDLE.PRT	CHAIR_BACK.PRT
DOOR_HANDLE.PRT	CHAIR_STANDING.PRT
DOOR_DOOR_LOCKER.PRT	CHAIR.ASM
WALL_100.PRT	CHAIR_BACK.PRT

CHAIR\_BACK.PRT  
CHAIR\_STANDING.PRT  
COMPUTER\_KEYBORD.PRT  
COMPUTER\_KEYBORD.PRT  
LABPLATSER.ASM  
LABPLATSER.PRT  
DESK.PRT  
PLATE.PRT  
DESK.PRT  
LABPLATSER.PRT  
PLATE.PRT  
COMPUTER.PRT  
COMPUTER.PRT  
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COMPUTER\_KEYBORD.PRT  
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LABPLATSER.PRT  
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COMPUTER\_KEYBORD.PRT  
LABPLATSER.ASM  
LABPLATSER.PRT  
DESK.PRT  
PLATE.PRT  
DESK.PRT  
LABPLATSER.PRT  
PLATE.PRT  
COMPUTER.PRT  
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CHAIR\_BACK.PRT  
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CHAIR\_BACK.PRT  
CHAIR\_STANDING.PRT  
COMPUTER\_KEYBORD.PRT  
COMPUTER\_KEYBORD.PRT  
LABPLATSER.ASM  
LABPLATSER.PRT  
DESK.PRT  
PLATE.PRT  
DESK.PRT  
LABPLATSER.PRT  
PLATE.PRT  
COMPUTER.PRT  
COMPUTER.PRT  
CHAIR.ASM  
CHAIR\_BACK.PRT

CHAIR_BACK.PRT	BENCH_LARGE.PRT
CHAIR_STANDING.PRT	BENCH_LARGE_PLATE.PRT
CHAIR.ASM	BENCH_LARGE_TOOLS.PRT
CHAIR_BACK.PRT	BENCH_LARGE.ASM
CHAIR_BACK.PRT	BENCH_LARGE.PRT
CHAIR_STANDING.PRT	BENCH_LARGE_PLATE.PRT
CHAIR.ASM	BENCH_LARGE_TOOLS.PRT
CHAIR_BACK.PRT	BENCH_LARGE.ASM
CHAIR_BACK.PRT	BENCH_LARGE.PRT
CHAIR_STANDING.PRT	BENCH_LARGE_PLATE.PRT
CHAIR.ASM	BENCH_LARGE_TOOLS.PRT
CHAIR_BACK.PRT	BENCH_LARGE.ASM
CHAIR_BACK.PRT	BENCH_LARGE.PRT
CHAIR_STANDING.PRT	BENCH_LARGE_PLATE.PRT
CHAIR.ASM	BENCH_LARGE_TOOLS.PRT
CHAIR_BACK.PRT	PRINTER.ASM
CHAIR_BACK.PRT	PRINTER_PART1.PRT
CHAIR_STANDING.PRT	PRINTER_PART2.PRT
CHAIR.ASM	CEILING_202.PRT
CHAIR_BACK.PRT	CEILING_212.PRT
CHAIR_BACK.PRT	CEILING_215.PRT
CHAIR_STANDING.PRT	CEILING_214.PRT
COMPUTER_KEYBORD.PRT	CEILING_216.PRT
COMPUTER_KEYBORD.PRT	CORRIDOR.ASM
LABPLATSER.ASM	WALL_5000.PRT
LABPLATSER.PRT	WALL_5000.PRT
DESK.PRT	WALL_10000.PRT
PLATE.PRT	WALL_10000.PRT
DESK.PRT	WALL_500.PRT
LABPLATSER.PRT	WALL_5000.PRT
PLATE.PRT	WALL_5000.PRT
COMPUTER.PRT	BOTTOM_CORRIDOR.PRT
COMPUTER.PRT	CEILING_CORRIDOR.PRT
CHAIR.ASM	
CHAIR_BACK.PRT	
CHAIR_BACK.PRT	
CHAIR_STANDING.PRT	
CHAIR.ASM	
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CHAIR_STANDING.PRT	
COMPUTER_KEYBORD.PRT	
COMPUTER_KEYBORD.PRT	
BENCH_LARGE.ASM	

## 11.5 Contents of the CD-ROM

The attached CD-ROM includes all files that have been created throughout the creation of the visualization of the physical prototyping laboratory.

The folder `ProE` contains the files created in the creation process in Pro/E. It contains all parts and assemblies used in the model.

The folder `dVise` contains all directories and files for the use of the virtual reality model in dVise.

The folder `Images` implies some images of the model. These pictures were produced by dVise.

The folder `Movie` contains some movies, which show flights through the laboratory.

The folder `Report` contents this report as a PDF-file.