

A Concept For Virtual Reality Tools For Design Reviews

Klaus Kremer*

Heinz Nixdorf Institute, University of Paderborn

Abstract

The following paper discusses a concept for virtual reality tools for use in design reviews of mechanical products. In this discussion, the special requirements of a virtual environment are given consideration. The focus of this paper is on suggestions for the visualization and arrangement of a product, its structure, its components and their alternatives together in one environment. The realization of these concepts results in an 3D-interface that allows users, especially *engineers*, to evaluate different configurations of a product and gives them direct access to the product structure. By applying various visualization techniques, product components and their attributes, e.g., their price, can be brought together into one visualization. Thus, in contrast to state-of-the-art software, *the product structure, three-dimensional, real-sized components, and attribute values* can be combined *together* in 3D-visualizations. This research was done in cooperation with Christoph Brandt¹, member of the Heinz Nixdorf Institute's² virtual reality group.

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Additional Keywords: virtual reality, virtual environments, visualization, design reviews, product configuration, product structures, product attributes, CAD, PDM, EDM

1 INTRODUCTION

This paper describes a virtual environment that combines and enhances the reality and 2D visualization techniques needed to create a 3D-environment to visualize all mechanical components, their common product structure and their attributes. The idea is to provide a user-friendly and productive interface. In this article, the term "product" refers to all types of consumer products which con-

sist mainly of mechanical components. Such products, for example, would be bicycles or industrial machines.

During the development process of any product, prototypes³ are needed to decide if the product fulfills the set requirements. In addition, prototypes are useful to demonstrate and explain a product to potential customers. In reality, one physical prototype has to be built for each possible configuration of a product to get an impression of its shape and functions. It is obvious that this is not possible for complex or expensive products. As computer technology becomes more sophisticated, virtual reality systems allow users to perceive products in very realistic terms. Today, new products are often designed with 3D-CAD systems, so volume models are available throughout the complete development cycle. If such models can be used in this way, they can also be used to assemble and visualize the configurations of products for distinguishing differences between models, to find weak points or to compare and rate different designs in order to serve the market with a better product. As a consequence, virtual prototypes can often replace physical prototypes. An important aspect is that all users -- dependent upon the output devices -- can have the same view of a product. This gives virtual reality an advantage over physical reality as the following example shows: if someone and his/her friend are standing in front of a car in a physical environment, both of them will have almost the same view, but it is not the same because it is impossible for both of them to be standing exactly in the same position to the car. It is only in VR that

"... what-you-see-is-what-I-see (WYSIWIS)..." [6, p. 41]

can come true. Instead of a physical prototype, a virtual one could be used only if its appearance is very realistic. But, this is not enough -- *every* product has its own environment. Virtual reality tools available for design reviews known by the author; for example, the in 1997 released dV/Reality [3] from Division Inc. [4], do not provide a suitable environment -- *the product is placed in space* ("no" environment). In addition, they do not provide access to real-sized product components *in* the environment. Therefore, the users have to *leave* the virtual environment to configure a product -- losing the 3D impression and interrupting the work process - - or they have to choose *components represented by icons* in the environment *without having access to the product structure*. It seems also to be inconvenient for the work process that the visualization of the components on one hand and the visualization of the product structure on the other hand are separated *into two media*.

Instead of two media, the developed concepts and realizations in this paper demonstrate how user interface techniques and the visualization of structures in VR can be used to create a more comprehensive virtual work environment. As a case study, the concepts have been implemented⁴ on an Onyx RE2 workstation from Sili-

1. Dipl.-Wirt. Ing. Christoph Brandt,
Heinz Nixdorf Institute, University of Paderborn,
Fuerstenallee 11, D-33102 Paderborn, Germany,
e-mail: brandt@hni.uni-paderborn.de
2. <http://hni.uni-paderborn.de>

* Dipl.-Ing. (FH) Dipl.-Inform. Klaus Kremer,
Ottensweg 3, D-32549 Bad Oeynhausen, Germany;
e-mail: hi.please@write.me.com (kkremer@uni-paderborn.de)

3. A classification of prototypes can be found in [12, p. 35].

4. The application is documented on a live recorded video [8]. Application "screen shots" are in $\leq 1280 \times 1024$ pixels (the resolution that the used stereoscopic projection screen supports), reduced from 24-bit color to 256 colors. The product shown is an information terminal from [14].

con Graphics Inc. in C++ using the VR-software dVS 3.1 from Division Inc. [4]. First, the environment will be presented, followed by suggestions for structure and attribute visualizations in 3D.

2 THE WORK ENVIRONMENT

In the following section, concepts are described using the realized prototype, but it should be noted that it is not perfectly textured and modeled. It is important to remember that the goal consists of building standard-software that imports a product structure in ASCII-format from a PDM¹-system and component-models from a CAD-system. The software should also generate a complete environment for the design review process automatically. This should not be product-specific, but will be unique for each product. Thus, the environment must be a compromise.

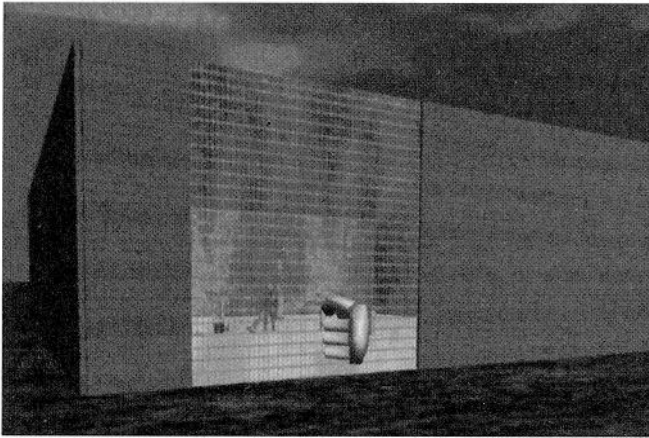


Figure 1: View from the outside of the factory building for design reviews

As mentioned, every product needs an environment. Since the focus is on consumer products and industrial machines, a factory building (Figure 1) was chosen to visualize the work space. During runtime, it will be scaled automatically as needed. In this work environment, a standard of comparison is first provided by the system. For this purpose, a model of a human with the height of 1'80m was chosen -- an exact scale is not necessary: Probably it is sufficient that users have an intuitive impression of the dimensions of the products. Apart from the product itself in its current configuration, alternative components have to 'be available if the user wants to alter the configuration. Users should recognize which components are available for the product. Therefore, they must be able to see the product structure to access them. All these components should be placed around the product to give users direct access.

"Studies show that in cultures which read left-to-right, images are also visually scanned in that order." [17, p. 93]

There is no fixed position for the user in a virtual environment, but a small area is likely to be more important than others. It can be defined as her/his standard position. With these things in mind, the work environment is depicted as Figure 2 shows. In contrast to

traditional interfaces, this virtual environment provides the product itself, its components (both scaled 1:1), the according product structure to the right, and some possible variants for a selected component to the left. A standard of comparison and information for the user on a screen are available, too. This allows the user to change the product configuration through selection of real-sized components *without leaving* the virtual environment.

2.1 Visualization of Product Structures

To test different configurations, users must be able to change the actual configuration quickly. For this task we have to distinguish between two cases:

- A component is already installed and the user wants to replace it with an alternative component. In this article an alternative component is defined as a component that can substitute another component of the same functionality, e.g., a green door can replace a blue one. Which component can substitute another is explicitly defined in the product structure.
- The user wants to add another component to the configuration that is not an alternative component of one that has already been installed.

In both situations, users can only find the best configuration if they can compare the possible alternative components with each other. In the first case, the user must only grasp² the component she or he will change. The system finds the alternatives in the product structure, if there are any, and presents them on the left side of the product. To arrange them, the system puts them in a line. If there are many alternatives, a shelf unit is used to display them. Alternatively, a conveyor belt can be used if there are too many alternatives for a shelf unit, but this has not been implemented yet. In the second case there is nothing to grasp. The user must be able to see the product structure to recognize which components are available for configuration. A product structure is almost hierarchically organized. Here, all components are leaves in the tree and components which have the same parent node are alternatives. Further details can be found in [7] and [2] but they are not relevant for the visualizations which are discussed here. Figure 3 shows a small extract of an input file for the developed application with a product structure -- organized through functional aspects -- where the marked components are alternatives for each other. Later visualizations of this nature in virtual reality are shown.

The main advantage of a virtual environment is that all components look realistic and are in full size. This should be retained in the two different visualizations that should now be distinguished:

- a structure visualization consisting only of the components;
- a complete structure visualization.

The first case is shown in Figure 4. The components are grouped according to two guidelines: components that serve different functions are arranged on the x-axis. At each x-position the components are grouped into the z-axis using one of the Gestalt rules [16]: proximity. *These rules, which have been used by designers for centuries [10], were codified by the Gestalt psychologist Wertheimer [16] in the 1930s.*" [5, p. 418f]. So, components that stand closer together than others appear to be alternatives. Due to a feature of the product structure semantics, not discussed here, the two boxes on the left are alternatives and the other three separated

1. Product Data Management, a system that manages all product data through its complete life time [2].

2. Since the VR-software supports only one grasp mode and no select mode, grasping is used for selecting purposes, too. A component will not move when grasped, if the "moving mode" has not been activated.

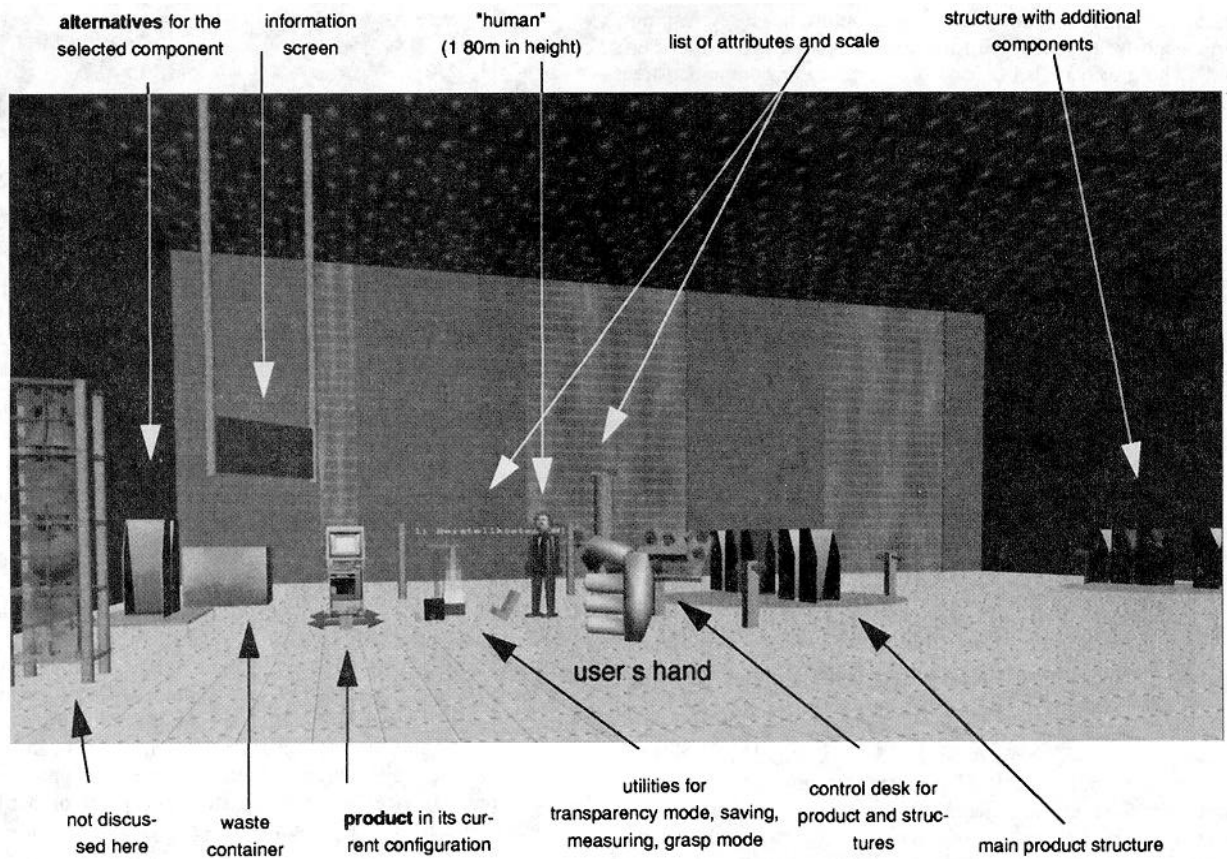


Figure 2: Work environment inside the factory building provides direct access to the product, alternatives of a selected component, the product structure, a standard of size comparison, and allows for comparison of components through visualization of attribute values.

Functional structure

ID	Description	Class	Geometry	Conf.	Manufacturing cost[\$]	Weight[kg]
1	Infoterminal	P	-	f	-	-
1.1	Protecting the device	F	-	f	-	-
1.1.1	Standardbox	LA	-	d	-	-
1.1.1.1	Box for dry rooms	L	-	d	-	-
1.1.1.1.1	Box, painted	LE	geometry/stat3_box__steel	d	150.00	5.00
1.1.1.1.2	Box, weatherproofed	L	-	-	-	-
1.1.1.2.1	Box, steel, galvanized	LE	geometry/stat3_box__galvanized	-	200.00	5.50
1.1.2	Design-box	LA	-	-	-	-
1.1.2.1	Natural box	L	-	-	-	-
1.1.2.1.1	Box, wood	LE	geometry/stat3_box__wood	-	500.00	2.6
1.1.2.2	Box, special, weatherproofed	L	-	-	-	-
1.1.2.2.1	Box, plastic	LE	geometry/stat3_box__plastic	-	300.00	1.48
1.1.2.3	Box, light	L	-	-	-	-
1.1.2.3.1	Box, aluminium	LE	geometry/stat3_box__alu	-	450.00	2.00
1.2	Enter information	F	-	f	-	-
1.2.1	By hand	F	-	f	-	-
1.2.1.1	Keyboard, weatherproofed	LA	-	d	-	-
1.2.1.1.1	Keyboard, film	L	-	d	-	-

Figure 3: Example hierarchical (functional) product structure; alternatives marked.

boxes are alternatives, too. Even if someone does not know the guidelines for the arrangement of components, she or he will instinctively know, which components are corresponding alternatives. For hierarchical structures, proximity indicates which nodes are dependent from others. The greater the distance between nodes at the same level, the greater the distance is to the root of the structure. The advantage of this structure visualization is that all components can be compared without other disturbing objects. Instead of the components' descriptions, which is characteristic of tradi-

tional software, real-sized components are displayed in 3D. Due to the demand for maintaining the visualization of the components, in this context no additional information, e.g., the description of them, can be displayed. Therefore, the components can be placed into selectable containers which allow additional interaction elements as shown in Figure 5. The component description can be displayed on them. This is important if similar-looking components are to be distinguished. The interaction elements are placed at the border. E.g., the handles are intended for grasping a compo-

ment and to change its position in the structure because grasping a component itself is reserved for viewing by rotating in the user's hand. The user can also fade in or out nodes or component-trees using interaction elements that are provided on each node.¹

In the product (on the left, not visible in this Fig.) currently installed components are marked in yellow. Selected component marked in red.

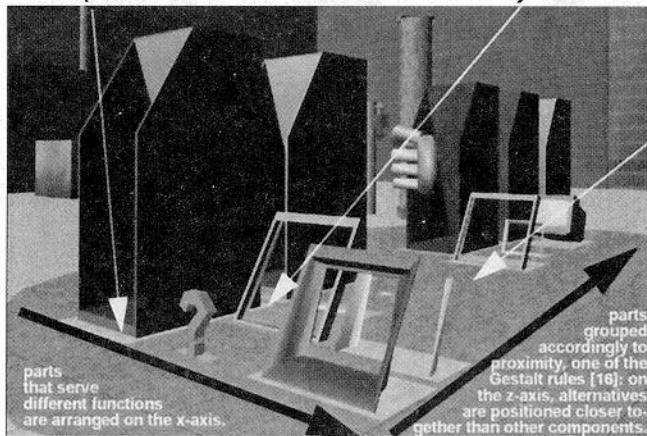


Figure 4: Visualization of the product structure using the real-sized components only.

This is not the completed product structure. To inform the application about the arrangement of components, a control desk is used (Figure 6). Complexity of a product is defined as the number of possible configurations of them. Using four arrow keys, the user can navigate through the tree. The description and ID of the actual node are displayed on the large button in the middle. Pressing this button will display the node and all substructures underneath it and fades them out as well. Every time the configuration changes, the dimensions of the room required by the product and the product structure change, too. The system maintains the posi-

1. Changing the product structure is a component of the concept but has not been implemented yet.

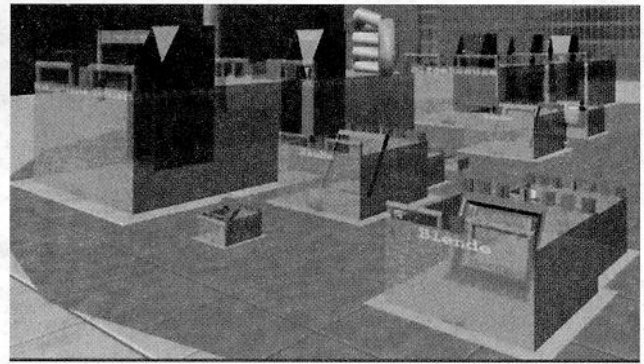


Figure 5: Components placed in containers allows the displaying of additional information on the walls -- as the component description -- and gives possibilities for placing interaction elements e.g., handles. Transparency mode maintains the complete shapes of components and optional coloring allows marking.

tion of the user relative to the current object and rearranges and scales the environment so all elements fit exactly. Tests² with some users show that they do not notice these changes, so ill effects as mentioned in [17, p. 101] are avoided. In addition to grasping components, the control desk can be used to change the configuration of the product. An alternative for it can be found in [18]. No new interaction metaphors were developed. To enable someone to select and manipulate objects out of her/his arm's reach, suggestions are described in [1], [11], and, [15].

In the next step, one of several developed ideas for the second case should be discussed. Since the product structure is hierarchical, it is visualized as a tree. In contrast to cone trees [9], the parts are placed in the nodes, not just the element description. Two and three dimensional trees have been implemented, a two-dimen-

2. Due to time restrictions for the thesis this paper is based on and access restrictions to the hardware no systematic user testing was performed.

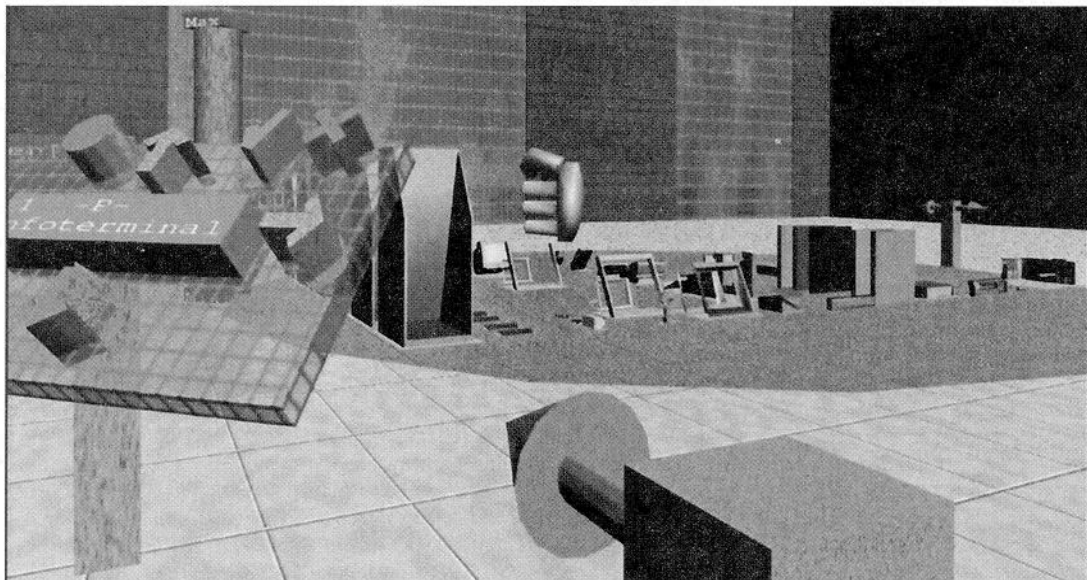


Figure 6: Control desk for determining the complexity of the product structure and complete product structure (only components) for the infoterminal.

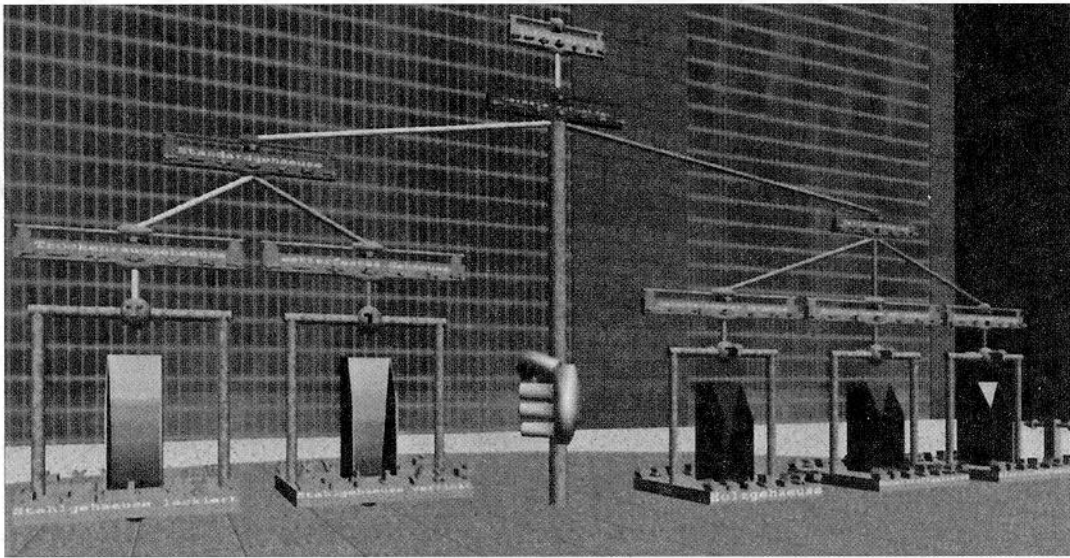


Figure 7: Two-dimensional product structure tree, standing, allowing intuitive and direct visualization of and access to the structure and its components.

sional tree that shows the product structure from Figure 3 is shown in Figure 7. This particular one is standing; a lying tree has the same characteristics, but uses the containers from Figure 5. One advantage of the trees is that users have access to the whole structure. This is important because engineers are always thinking in hierarchies and structures (because assemblies of nearly all mechanical products are defined in hierarchical structures) and so this is second nature to them. This is also a unique opportunity to combine both the structure and the 3D-visualization of the components. Users can walk around or through the structure, fly to the nodes to see components in detail, grasp components and so on. That is not possible on a screen. Here the containers are used for displaying information and placing additional interaction elements, too. The connections between nodes are used to mark the path of selected and installed components from the root to them through the structure. In addition, the complexity is controlled by the control desk because this structure is a replacement of the one in Figure 6. It can also be changed with interaction elements at each node. A disadvantage of this visualization are the dimensions as seen when Figure 6 and Figure 7 are compared. In this case, *fish-eye views* [6] may be added to enhance the usability but this has not been implemented yet. Other traditional visualization techniques, such as perspective walls [9], are designed for screen-based interaction: There, it is necessary that users have a fixed position to the wall, which is not guaranteed in virtual environments. In Figure 8 only person A in front of the wall has an excellent view.

Common knowledge about how to organize a virtual environment is not presented here. All objects -- especially the trees -- are realized so that they can be built in reality, too. This is important because

"... the ill effects are generally more strongly felt in the more immersive media than in traditional artistic media... Indiscriminately breaking rules is seldom wise in artificial world creation or interaction." [17, p. 101]

2.2 Visualization of Assembly Structures

The structure shown here is organized through functional aspects. If an assembly structure is used, the trees can be used to show how a product is built up from individual components. At the leaves

you will find all single components. All nodes up to the root will show the assemblies built from the child components or assemblies. This tree can be generated automatically from the ASCII-structure without additional information by the application'. For a car for example, the components of the motor, chassis, bodywork, and interior will be at the leaves. The parent nodes will show the whole engine, chassis, bodywork, and interior. At the root of the tree the complete car is assembled. This is probably a unique visualization possibility because the user can see the components and all assemblies leading to the final product in 3D. Simultaneously, they can see how the components fit together and how they are assembled to build a complete product.

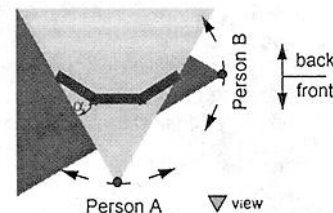


Figure 8: Perspective Wall (upper view) [9]

2.3 Finding The Best Components

Due to the low resolution of Head-Mounted-Displays and other currently available output devices, it is difficult to display fact sheets in the environment. In most cases, simultaneous users want to compare only one attribute of components, e.g. the price. If the components must be selected outside the environment, the user will lose the impression of the shape of the components. A way to keep this impression and allow the user to find the component they are searching for is the following suggestion: the user can select one attribute on the attribute list (see Figure 2, the blue menu in the background) and all components will be colored correspondingly

Unfortunately, the implementation of this feature is not fully completed due to time restrictions for the thesis this paper is based on.

to their values. Therefore, a scale is used with one primary color at each end. The minimum value is equal to the color at the bottom (green); the maximum is equal to the color at the top (red). The colors for all other values are established through interpolation. Because two primary colors are used, a secondary color (yellow) is exactly equal to the average value. The components in the visualization of the product and all components in the product structure are colored. So, at first sight, the user can identify the cheapest component, for example. If some components have nearly the same value, the user can -- dependent upon the visualization -- see the exact value of each of the components displayed on their containers or on the screen. Figure 9 shows the attribute list and the scale in the back, and the colored product in front. Because it is nearly red, it can immediately be seen that the PC has the highest value of all components there. Since the components still maintain their shape, the users *know* that this is a PC. The advantage up against the traditional selection of components is here that the impression of the components is retained and the components themselves are used to communicate extra information. Unfortunately, the natural color of the components is lost. If the structure is displayed using trees, the containers can be used to be colored as in Figure 9. Here, users can select a component using the information about their attribute values and their appearance simultaneously because the visualization of attribute values are not separated from the 3D-visualization of the component's shape.

2.4 Making The Invisible Visible

Virtual prototypes allow to look inside a product without the loss of the impression of the dimensions of it. As Figure 9 shows, it is easy to "make invisible visible" in this case.

3 CONCLUSION

In comparison to traditional systems for design reviews, the new design discussed here shows that user-interfaces can probably be made more user-friendly with new visualization techniques. As a result we find, too, that virtual environments can be developed in a way that all work can be done there without having to leave the environment. Whether this environment is a more productive one, easier to use, and will increase the acceptance of such systems by users must be shown during systematic user testing in the future.

The virtual environment shown in this paper is an idea for the next generation of interfaces in CAD-related virtual environments, especially for design reviews and product configuration. Different visualizations for product structures have been suggested in addition to visualization of product attributes on the components and in the structures.

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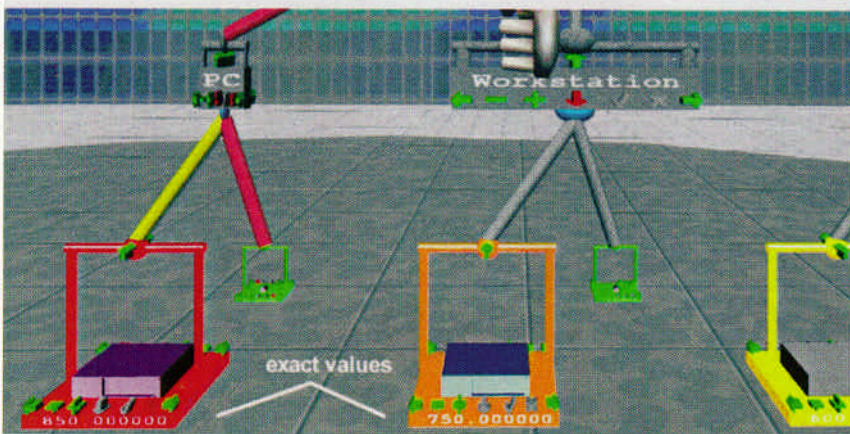
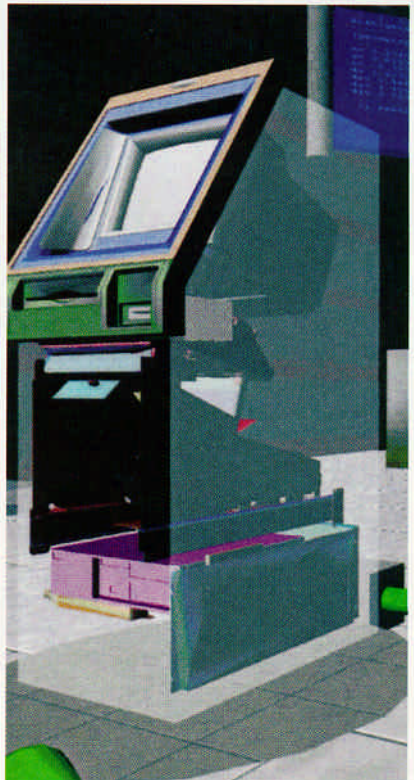
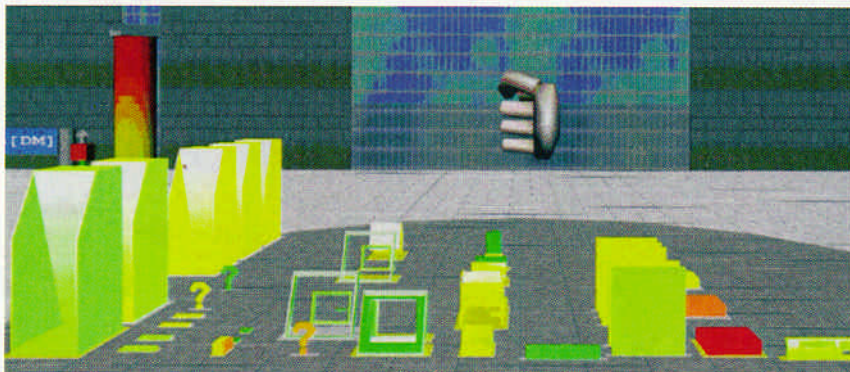
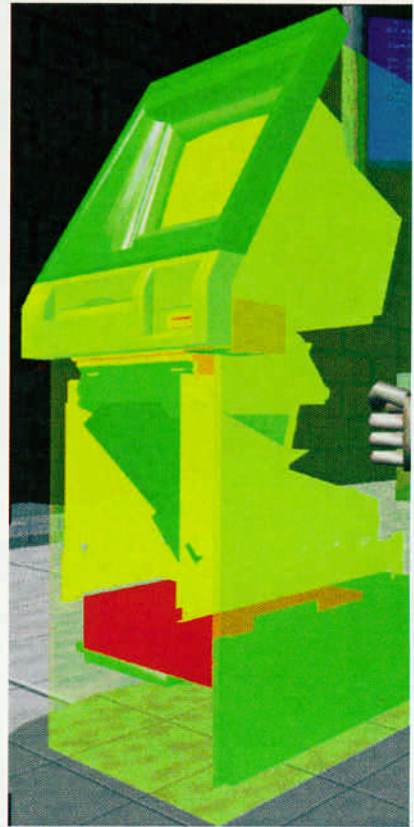


Figure 9: Visualization of attribute values directly on the components (up, middle) and in a tree (down; original: low right); the transparency mode allows to look "in" a product making the invisible visible without losing the impression of the whole dimensions (right) (figures are reduced from 24-bit color to 256 colors).