# CONCEPTUAL DESIGN REVIEW WITH A VIRTUAL REALITY MOCK-UP MODEL

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## ABSTRACT

A number of AEC (Architecture, Engineering and Construction) projects rely on physical mock-up models to be reviewed prior to the final design – a process both costly and time consuming. Additionally, because the review involves the participation of a number of representatives from various organizations, it needs to be structured to make decision-making processes simpler and faster.

We substituted the physical mock-up model of a courtroom with a VMM (Virtual Reality Mock-Up Model) to prove the concept of a VMM and test whether it improves the design review process. The key professionals and decision makers, including the courtroom judges, met in a CAVE (Computer Assisted Virtual Environment) to evaluate the conceptual design and to comment on the usefulness of the VMM as a substitute for the full-scale plywood mock-up model.

The VMM was a computer simulation of a 3D CAD model where the judges, attorneys and other participants were able to virtually "seat" themselves in various positions in the courtroom and could navigate through its spaces. They then evaluated the courtroom design based on various criteria: visual sightlines from the judge's bench to the witness box and other key locations, layout of the courtroom, access to key positions in the room, dimensions and positioning of furniture.

A significant advantage of the VMM over the plywood mock-up model was that it enabled real-time modifications to the design based on the judges' feedback. Additionally, the process used for design verification of the VMM made it easier to focus the collective attention of the participants on one issue at a time. This allowed more rapid consensus building and resolution of issues and cut the decision-making time to less than fifty percent as compared to a plywood mock-up model. This paper diagrams the process used for building the VMM, analyzes whether the model succeeded as a proof-of-concept implementation and recommends improvements for future efforts in this direction.

## KEY WORDS

3D CAD, Computer Assisted Virtual Environment, Simulation, Virtual Reality, Visual Sightlines

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## 1 INTRODUCTION

The General Services Administration (GSA), in collaboration with the Center for Integrated Facility Engineering (CIFE) at Stanford University explored the use of 3D CAD and virtual reality models to support design reviews for new courthouses. Walt Disney Imagineering (WDI) offered use of their CAVE facility in California for viewing the 3D model. The case study presented in this paper is a pilot project which was used by the GSA to determine whether a VMM would succeed as a substitute to the traditional plywood mock-up model by improving the design review process.

## 2 THE USE OF TRADITIONAL PLYWOOD MOCK-UPS FOR DESIGN REVIEW

The traditional method for reviewing the conceptual design of courthouses has been to build full-scale courtroom mock-ups in plywood. Typically, a building close to the actual site of construction is rented for holding design review sessions. Plywood components are fabricated and positioned in this rented space. Judges, attorneys, court reporters and clerks meet in this space to review the plywood mock-up to suggest design modifications.

### 2.1 COMMON DESIGN DEFICIENCIES IN TRADITIONAL PLYWOOD MOCK-UPS

Participants at plywood mock-up review sessions feel that there is considerable variation in the way the A/E (Architect/ Engineer) interprets, designs and fabricates the courtroom mock-up components. Some common design deficiencies are: discrepancies in the dimensions of furniture, missing components from the design and insufficient detailing of components

### 2.2 OTHER DIFFICULTIES IN PLYWOOD DESIGN REVIEW PROCESS

Past experience has shown that some time is lost in these sessions because all the participants don't focus on one issue at the same time. Figure 1 shows participants holding informal discussions in smaller groups. Participants also face other logistical problems like incorrect slope of floor at the mock-up site, unavailability of carpenters to modify the components during the review sessions etc.

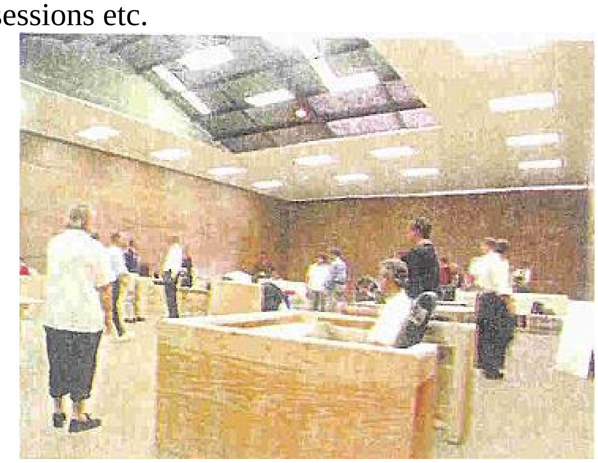

Figure 1. Participants hold informal group discussions during a plywood mock-up session for the design review of a courtroom (Ross Drulis Cusenbery 2002).

### 2.3 RECOMMENDATIONS BY THE GSA FOR AN EFFECTIVE MOCK-UP REVIEW PROCEDURE

The GSA prepared a list of recommendations to ensure that the mock-up fabrication conforms to the architect's design, rework in building the mock-ups is minimized and the judges' time is effectively utilized in reviewing them. These recommendations, listed below, call for input on the design from all concerned parties before the actual fabrication of the mock-up (Ross Drulis Cusenbery 2002).

- Review preliminary courtroom plans, elevations and reflected ceiling plans with the court prior to building the courtroom mock up.
- Incorporate the court's design feedback from the preliminary plans into the courtroom mock up plan.
- Review courtroom mock-up shop drawings prior to construction of the mock-up.
- Provide review comments to the mock-up fabricator prior to the fabrication.
- Schedule a formal mock-up review with the court and judiciary. Prepare and follow an agenda for the mock-up review.
- Review each component on a detailed basis.
- Allow representatives of the court and related agencies to test drive the mock-up components and offer comments. Seat people at all courtroom component locations and assess the quality of sightlines between all locations.
- Develop a format for moderating the mock-up presentation meeting.

## 3 CONTEXT OF VIRTUAL MOCK-UP MODEL

Based on the above recommendations, the GSA wanted to experiment with building a virtual reality mock-up model in lieu of a plywood mock-up to expedite the process of removing design deficiencies and to improve the design review process.

### 3.2 PROCESS FOLLOWED TO BUILD VIRTUAL MOCK-UP MODEL

The GSA provided direction and funding for this research and collected requirements for the courtroom. The project architect prepared 2D drawings documenting the courtroom design based on the requirements. A CIFE researcher (the first author of this paper) built a 3D CAD model from these 2D drawings using the Autodesk Revit software. It held reviews of the 3D model-in-progress with the architect and the GSA, and documented the process followed in this experiment. Once the 3D model was finalized, CIFE converted the format of the model to .vrml using Common Point software because .vrml format best suited WDI's CAVE environment. WDI translated the 3D CAD model into a 3D VR (virtual reality) model for display and interaction in its CAVE. Figure 2 shows the information flow among these project participants.

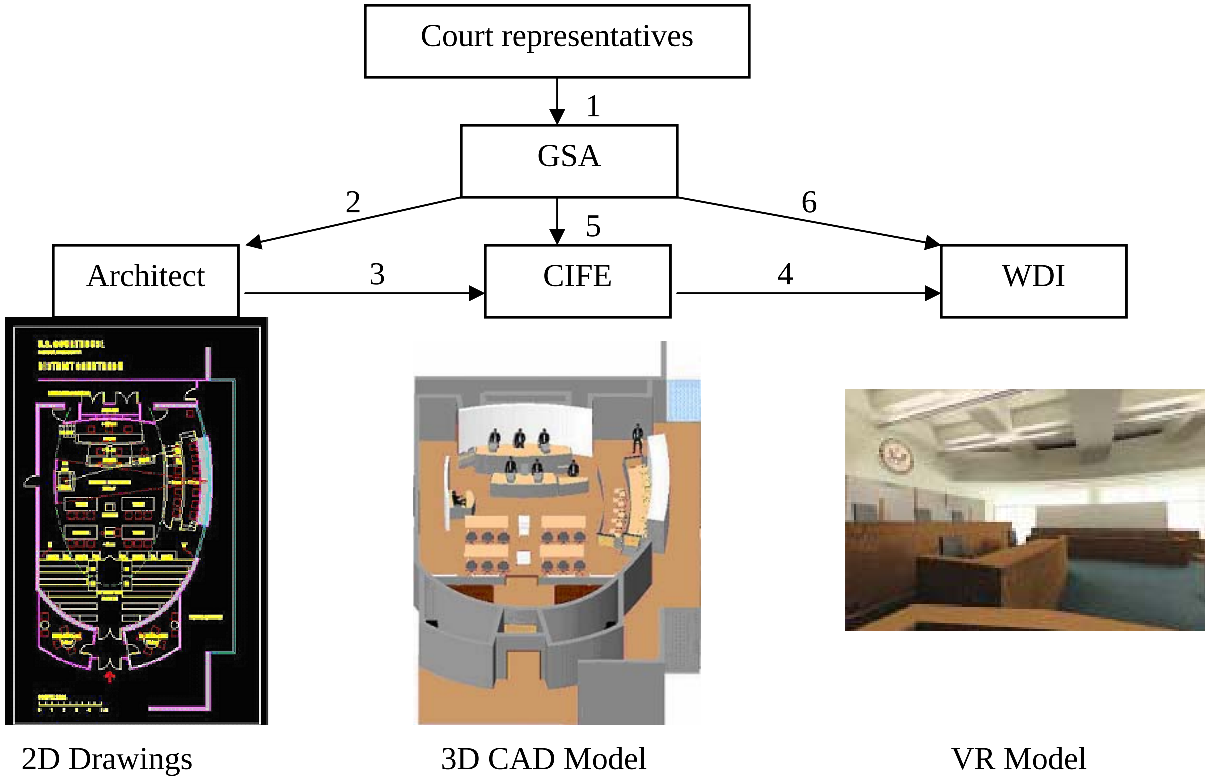


Figure 2. Information flows among project participants: (1) GSA collected requirements from court representatives, (2) GSA conveyed the requirements to the architect, (3) The architect provided 2D CAD drawings to CIFE, (4) CIFE provided 3D CAD model to WDI, (5) GSA reviewed 3D CAD model with CIFE, (6) GSA reviewed VR model with WDI and used the VMM for this pilot project.

## 4 VIRTUAL MOCK-UP REVIEW PROCESS

The review of the virtual mock-up model included reviewing the 3D CAD model to ensure that the model was built right, conforming to the latest design by the architect. It also included reviewing the VR model.

### 4.1 REVIEW OF 3D CAD MODEL

Review of the 3D CAD model involved reviewing each component in detail. A typical courtroom is made up of a courtroom well comprising the judge's bench, deputy clerk's desk, court reporter's desk, jury box etc (Figure 3). The well is the most important part of a courtroom and unobstructed visual sightlines in this area are critical for the success of a courtroom design. Spectator seating, technology carts, bookshelves, monitors etc are some other components that may be evaluated during the design review. This review process ensured the successful implementation of the GSA recommendations mentioned in section 3.3. This was equivalent to reviewing shop drawings before actual fabrication of the plywood mock-up in the traditional mock-up model process.

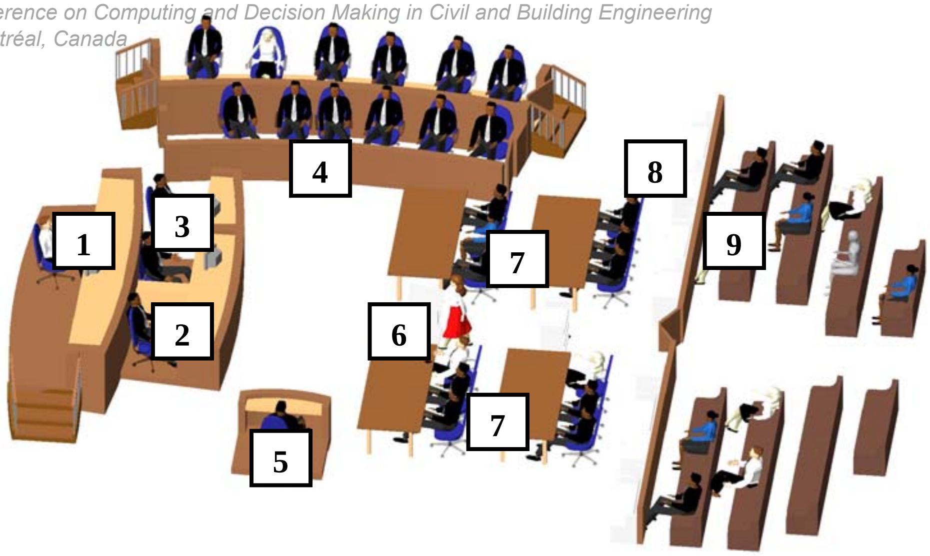


Figure 3. Components of a typical courtroom; items 1 to 7 together form the courtroom well: (1) Judge's Bench, (2) Court Reporter, (3) Deputy Clerk, (4) Jury Box, (5) Witness Box, (6) Attorney Lectern, (7) Counsel Table, (8) Bookshelves, (9) Spectator Seating.

CIFE researchers held weekly or biweekly online meetings with the GSA, court representatives and the architect to review the 3D model. They modified the model according to the feedback received during these meetings (Figure 4). They received updated plans and sections from the architect and incorporated changes from the 2D drawings into the 3D model (Figure 5).

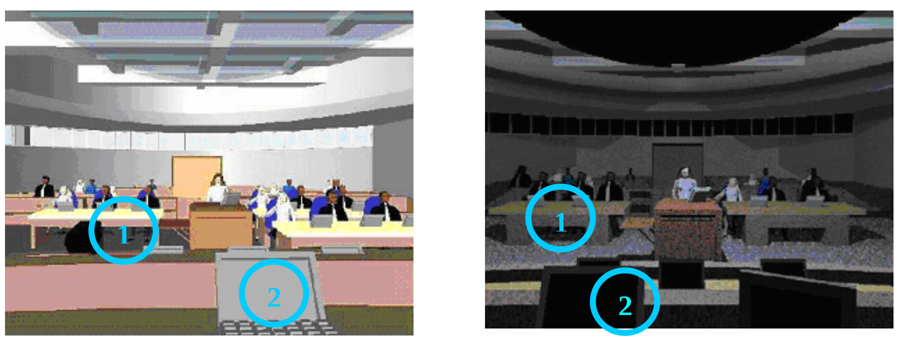


Figure 4. Examples of modifications to the 3D model based on online meetings: (1) Modesty panel added to counsel table, (2) Number of monitors on judge's bench increased from 1 to 3.

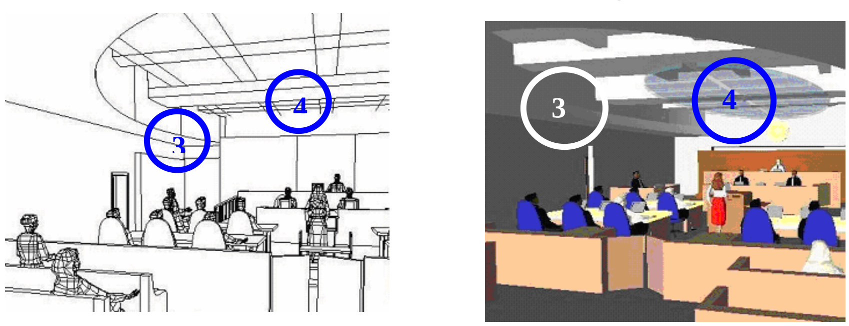


Figure 5. Examples of updates to the 3D model based on design modifications by H3 (the architect): (3) Ceiling soffit made angular, (4) Glass chandelier added as an acoustic baffle.

### 4.2 REVIEW OF VR MODEL

The VR model was reviewed in WDI's CAVE. The CAVE (Computer Assisted Virtual Environment) at WDI has been optimized for viewing 3D environments in real time. Six projectors, each driven by an individual PC are required to achieve the real-time 3D rendering. This optimization was enabled by the creation of a rendering engine and scripting language as well as an image format well suited for real time displays. This "Platform Agnostic Networked Display Architecture" or *Panda3D* is not tied to any particular 3D authoring tool and allows for importing many different 3D formats into the CAVE. Although Panda3D was originally developed for the on-line game community, and the continuing development is supported by researchers in this area, this feature should be particularly useful in the AEC environment where standards and 3D formats are still evolving. The Panda3D code is now open source and can be found at http://www.Panda3D.org/.

The CAVE itself is a curved front projection screen with a polarization-preserving screen material, illuminated with three pairs of projectors. Each pair is plane polarized at 90 degrees and corresponds to left and right eye viewpoints. The use of polarized glasses while viewing the images in the cave results in an immersive stereo 3D point of view. In the case of the configuration used for the courtroom project, the circular section projection surface was evenly illuminated at the image overlaps by hardware warping of the image sets. This feature allowed the display to be mullion free, greatly enhancing the immersive nature of the experience and allowing full stereo vision for the central area in front of the screen, typically about 400 $ft^2$. This large, shared viewing space allows multiple simultaneous users – a critical feature when attempting to communicate difficult design concerns and build consensus around design choices (Figure 6). Navigation of the 3D model in the CAVE environment is accomplished by a hand-held game-type controller which allowed for 6 degrees of freedom control by means of a twin joystick interface. The use of a first person point of view, in essence, a "fly through the model" navigation technique also enables the viewers to more easily understand and trust their perception of the relationships shown on-screen.

Figure 6. Conceptual design review session with judges in the WDI CAVE.

#### 4.2.1 CAVE Session 1

To minimize the judges' time, a trial session was held one day prior to the judges' arrival. Representatives from the GSA, courthouse, the project architect, and CIFE attended this first review session. The purpose of this review session was to predict the concerns of the judges and to rectify errors in the virtual reality model, if any, prior to the review of the courtroom design by the judges the next day. In addition, the participants at this review session developed an agenda for the next day to make the design review by the judges as focused and productive as possible. This was in line with the GSA recommendations mentioned in section 3.3.

All the participants took part in an informal discussion where they suggested modifications to the VR model. Modifications like changing colors and repositioning objects were incorporated in the VR model immediately by WDI staff while others like changing the dimensions of objects in the room were done by the CIFE researcher after the session because they required modifying the 3D CAD model. Table 1 lists the suggestions and modifications by the participants in this session.

Table 1. Modifications suggested to VR model by participants in CAVE session 1.

| **Item discussed** | **Suggestion/ Modification** | **Modification Incorporated** |
|---|---|---|
| Starting point of navigation | To start with view from clerestory & move inside | Yes |
| Color of light fixture | To be made transparent blue to depict glass | Yes |
| Color of wood in the room | To be made lighter | Yes |
| Jury Box | $14^{th}$ Juror (woman) to be added | Yes |
| Court reporter & Deputy Clerk | To be women | Yes |
| Judge | To wear a black robe | Yes |
| Keyboards | To be moved forward and away from monitors | Yes |
| Height of bench rail | To have the options of additional 2" & 4" | Yes |
| Wall behind judge | To be brought down by 2.5m | No |
| Furniture placement | To reposition clerks' monitors | No |
| Color of seal | To be changed to gray | Yes |
| Counsel tables | To have the option of showing a third table | Yes |

#### 4.2.2 CAVE Session 2

The second session in the CAVE focused on obtaining the feedback of the judges about the courtroom design so that the suggestions could be incorporated in the design development of the courthouse. This session was critical because it determined whether the virtual mock-up model succeeded as a proof of concept.

The most senior judge “seated himself” on the judge’s desk in the virtual reality model displayed in the CAVE and gave his feedback on the courtroom design based on the items listed below:

- Bench sightlines: View from the judge’s bench and the court reporter’s seat
- Well sightlines: Views from the counsel tables, lectern, jury box, witness box, and spectator seating.
- Other aspects: Shape of courtroom, ceiling.

## 5 COMPARISON OF VMM WITH PLYWOOD MOCK-UP

As mentioned earlier, the goal of this pilot project was to test whether a VMM could replace a traditional plywood mock-up model for design reviews.

- The second session in the CAVE lasted 3 hours. In comparison, plywood mock-up sessions generally last about 8 hours. Thus, the goal of minimizing judges’ time was met.
- The design verification of the sightlines with the VMM made it easier to focus the collective attention and perspective of the participants on one issue at a time. Once the most senior judge virtually seated himself at one location in the model, the view for all the participants was the same. This allowed more rapid consensus building and resolution of issues. Other researchers have also shown that VR models are an effective means of communication among team members (Yerrapathruni et al. 2003, Gopinath and Messner 2004).
- Some of the modifications suggested by participants were incorporated instantly in the VMM. This would not have been possible in a traditional mock-up.
- As mentioned in section 4.1, the 3D CAD model was reviewed periodically by the GSA and other project participants. This ensured that the model was built right. In the traditional mock-up model, the GSA had observed variations between the architect’s design and the fabricated model. The GSA had recommended that shop drawings should be reviewed before construction of the traditional mock-up began. However, this was not as convenient as reviewing the 3D CAD model online, which allowed representatives from different participant organizations to view the model in progress and comment on it from remote locations.

## 6 MEASURING THE EFFECTIVENESS OF THE CAVE SESSIONS

In prior research, CIFE researchers developed a framework to measure the effectiveness of meetings (Garcia et al. 2003). They identified the following seven types of activities that occur during a meeting: Describe, Explain, Evaluate, Predict, formulate Alternative, Negotiate and Decide (DEEPAND) and developed the DEEPAND framework. The effectiveness of a meeting can be measured by classifying the issues discussed and time spent on tasks according to the seven DEEPAND categories (Figure 7). The goal is to maximize the time spent on the most value-adding tasks.

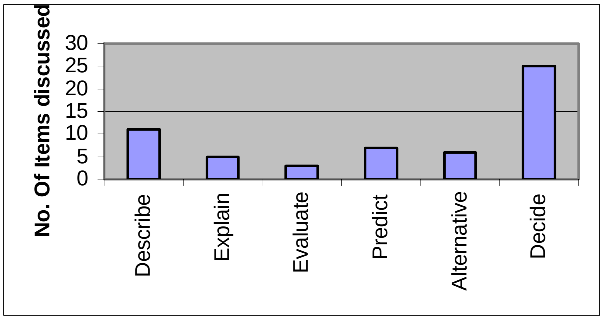


Figure 7. Classification of the issues discussed in the CAVE sessions according to the DEEPAND framework.

Most of the issues addressed fell into the 'Decide' category and most of the time spent was for forward looking activities, such as making predictions, suggesting alternatives. This is in contrast to other meetings we observed that were not supported by VR methods (Liston et al. 2001) and to the experience of the project participants with traditional design review processes where more time was spent on describing and explaining the design.

## 7 RECOMMENDATIONS

The process of building the 3D CAD and VR models can be improved by:

- Modeling the components of all the elements (furniture, walls, etc.) independent of each other: This provides more visualization options. For example, moving a piece of furniture to a different position gave the judges the satisfaction of having viewed several options and selected the best among them.
- Choosing the right software: As experienced in this project, Autodesk Revit was an efficient tool to produce a 3D CAD model in very little time but exporting the resulting 3D model to WDI's format was a multi-step process. The model had to be converted from .rvt to .dwg format and from .dwg to .wrl to be compatible with the software used in WDI's CAVE. In the process, colors and textures from the original Revit 3D model were lost (Figure 8).

Figure 8. Conversion of format led to loss of colors and textures from the 3D CAD model.

## 8 CONCLUSIONS

Observations during the two sessions in the CAVE suggest that the effort of building a 3D virtual reality model was worthwhile and can be put to use more effectively in the future. The project showed that a virtual mock-up model supports quick modifications of the conceptual facility design to explore and decide upon alternatives quickly and with consensus among the decision makers. It offers a better medium of communication for participants from a diverse set of organizations and disciplines. Consensus building on issues is faster. The cost involved in organizing the CAVE session is not yet known. This would have aided in the comparative analysis of the Virtual Reality model versus the Plywood Mock-Up model. The GSA confirmed that the process of a virtual mock-up, though less expensive in terms of building the model, exceeded the budget considering the cost involved in flying the participants to Glendale, CA. It would have been better to carry out the exercise at a CAVE closer to the majority of the participants. However, the focus of this study was not on cost. The judges were satisfied with the result and the VMM succeeded as a proof of concept.

## 9 ACKNOWLEDGMENTS

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