Designing Virtual Worlds - The Cognitive Map Probe

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ABSTRACT

What does an Industrial Designer do? Design is all around us, yet very few people truly understand the role of an industrial designer. Yet, their work is evident everywhere we look. Architectural, furniture, automotive, textile, graphic and product are all examples of different types of design. The designer is one who gives form to function, one who balances art and technology. Design is expanding in exciting directions as designers address design issues in other disciplines. This paper will focus on one such collaborative project that branches design, rehabilitative medicine and computer science. The Cognitive Map Probe project is the culmination of efforts from many researchers from diverse fields of study. This paper will document its development from a designer's point of view and will show the techniques and methods used by the researchers to solve the design problems. It will also show the inter-disciplinary nature of design and how it crosses over to the field of computer sciences. The paper will provide a guided tour from the early thought processes through to the implementation of solutions. It will hopefully demonstrate some of the abilities of designers and show the positive effects of working collaboratively.

1. Introduction

This paper will focus on the topic of collaborative design. It will look into the process of interdisciplinary co-operation between computer sciences and industrial design and will document the journey that was taken to bring virtual reality to a (miniaturized) physical reality.   The development of the Cognitive Map Probe (CMP) will be used as the backdrop to demonstrate the process of collaborative design. The Cognitive Map Probe was a project that was originated by Dr. Ben Watson and Ehud Sharlin from Computer Sciences and eventually expanded to include Industrial Design as well as Rehabilitation Medicine departments at the University of Alberta. This paper will document some of the problems encountered from an industrial designer's perspective during the different phases of development. The objective of this discussion will be to show the importance of interdisciplinary work and benefits achieved by working outside of one's field of research.

2. Background

The CMP is a project that deals with several computer sciences/graphics issues such as Human-Computer Interfaces (HCIs), Tangible User Interfaces (TUIs), 3D Cad design, Intelligent Modeling Systems, 3D Model Polygon optimization, texture mapping and Virtual Reality (VR) simulation.

2.1   Cognitive Mapping and the CMP

Cognitive Maps can be defined as *an overall mental image or representation of the space and layout of a setting*. Cognitive mapping can be defined as the *mental structuring process leading to the creation of a cognitive map* [1]. The Cognitive Map Probe (CMP) is therefore a tool that assesses the user's cognitive mapping abilities. One focus of the CMP will be to examine the feasibility of using it to test individuals in the early phases of Alzheimer Disease (AD). A decline in cognitive mapping ability has been associated with early phases of AD. The CMP uses a Tangible User Interface (TUI) as a natural and automatic way to assess the user's cognitive mapping skills. The CMP has a Virtual Reality (VR) component to further engross the participant in the cognitive mapping testing and a physical model to interact with as an input device.

2.2 The Segal Model and TUIs

The CMP's architecture is based upon the Segal model (see Figure 1) developed by John Frazer as a Machine Readable Model that allowed the user to interact with a floor plan both tangibly and virtually [2,3]. Frazer's early work with Machine Readable Models can now be viewed as an example of a Tangible User Interface [4]. Tangible User Interfaces can be defined as: interface devices that use physical objects as means of inputting shape, space and structure into the virtual domain [6,7]. TUIs offer an alternative to the standard Human-Computer Interfaces such as the Keyboard-Mouse-Monitor interface and the Window-Icon-Menu-Pointer method. TUIs can offer a more relevant and intuitive interaction with the computer for specific tasks.
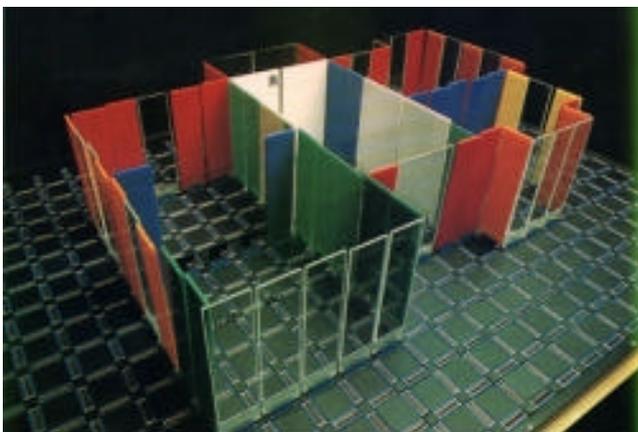

Figure 1. The Segal Model [3].

Frazer's work on Machine Readable Models lead to the development of the Segal model and the design of intelligent 3D input devices. The early intention of the Segal model was to be used as an architectural 3d-modeling tool. The user, by placing 3D input devices into slotted connectors that form the base of the Segal Model could design a floor plan with the assistance of design feedback provided by the program. The input devices (see Figure 2) each with a unique diode based code, would be placed on the Segal model board which consisted of arrays of edge connector slots that would connect with any number of the 3D input devices. The Segal model would scan in real time the board and detect the identity, geometry and position of the 3D input devices. On the modified CMP board, the Segal model is connected to a PC through a standard parallel port and a Linux driver to scan the board at approximately 500 times a second [8].
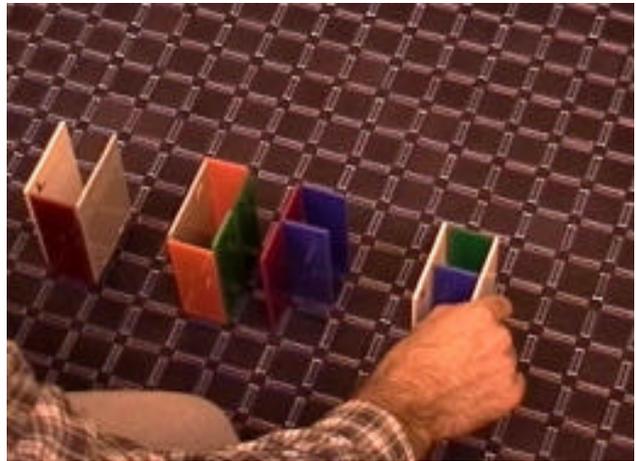

Figure 2. Placing TUIs onto the Segal board [3].

3. Designing the CMP

Early in the development of the CMP, the researchers sought advice from different departments to address issues that they were not familiar with. In collaboration with Rehabilitation Medicine, a need for applying computers to evaluation of cognitive function was identified. Industrial Design (ID) was one of the departments approached because of their knowledge about 3D modeling and rapid prototyping technologies. The early rapport between the departments lead to a strong and prosperous relationship and changed the shape of the project in exciting ways. The CMP proved to be an excellent vehicle for cross-disciplinary work as it offered the chance for researchers from both fields to contribute uniquely to the project as well as giving the researchers a chance to learn from their collaborators about different aspects of the project. One of the strengths was a shared common ground in terms of some of the tools used and it became a working vocabulary that all researchers could communicate through, albeit from slightly different perspectives. There was an understanding to reach a shared goal and that promoted a healthy and uniting working environment for all involved. The motivation was to create a unique solution that was the result of contributions made by two different fields of study.

3.1 Designing the TUIs

Originally, ID was consulted for their advice on how to produce the physical TUI components. Designers are familiar with creating objects with human factors in mind and therefore, the ID department was sought out for consultation on the CMP project. Product design often deals with not only functionality, but also how the artifact relates to the end user. Addressing the needs of the human user often differentiates what industrial designers do and what engineers do. It was decided to give the TUIs a more meaningful and appropriate form to their function. As the CMP was to be a testing tool for cognitive mapping, a decision was made to have the testing area take form as a generic neighborhood. The input devices would take the form of realistic small-scaled models of unique architectural landmarks such as residential houses, a supermarket, a gas station, a church and a fire department. The landmarks were chosen for their distinctive characteristics and also how they collectively created the sense of a local neighborhood that the end user could relate to. For every physical, small-scale 3D house, there would be a virtual counterpart that was full sized in the VR simulation. The user would be able to partake in a VR simulation of the neighborhood and then go back to the Segal board and recreate the scene using the model houses (3D input devices). The CMP would therefore use not only one cognitive mapping technique but several to test the level of immersion required for effective cognitive mapping. The main emphasis when designing the TUIs was to make it as easy as possible for the end user to understand, use and interact with the CMP.

3.2 3D Modeling

The advantage of using a CAD tool to do 3D modeling is that once the object is created, the data can be exported to many formats for different purposes. Blueprints, renderings and prototypes can be all constructed relatively easily from the initial 3D model. 3D modeling has become a well versed part of an Industrial Designer's vocabulary because of its many uses to communicate the designer's ideas. Designers will always use sketches, renderings, draftings, mock-ups and models to realize and express their designs but using the computer simplifies many of those tasks. Computer modeling is an efficient tool that allows for faster turn around and design time with the ability to produce several different formats from one model. The computer model can also be exported to analysis software where tolerances, structural integrity and flow control can be optimized for the later phases of manufacturing. The decision to use 3D modeling allows for great versatility in the design phase and allows for many contributors to work on the project concurrently with the same data.

Once it was decided to create a model neighborhood, designers went about and researched landmarks and recreated them using 3D CAD tools. The available software the researchers had access to at that time was 3D Studio MAX and a relatively new program called Rhinoceros. Rhino (for short) was an inexpensive NURBS based modeling tool that the industrial designers used to create the first versions of the model houses.

The models constructed at this phase would act as blueprints for all versions (virtual and physical) utilized for the CMP. When constructing the landmarks, the designers were careful not to create too highly detailed models (to keep geometry relatively simple for future applications). However, the models retained certain aesthetic qualities to act as signifiers to keep a sense of realism. For example, the church model was simplified in terms of structural detail such as windows and doorways but retained the spire and cross as signifiers pertinent to the visual understanding of the model's semblance to a real church (see Figure 3). All the models were edited this way to keep a sense of realism and simplicity for construction.
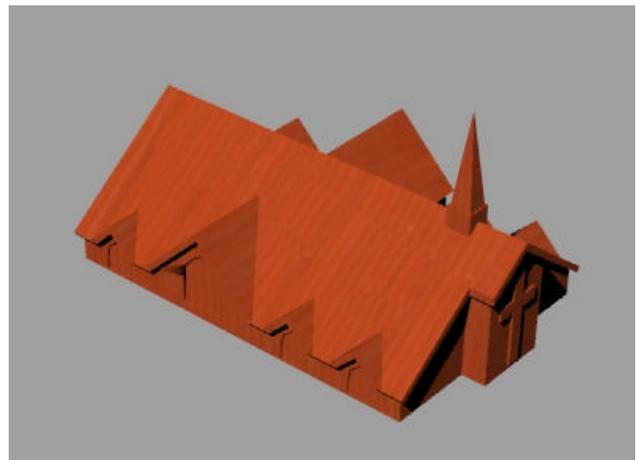

Figure 3. 3D model of Church built in Rhino.

A supporting environment was also designed to provide context to the models. It was decided that a simple map consisting of landscape landmarks would be used so that the participants could use them to help construct their cognitive map. At first, common outdoor objects were considered for the landmarks such as: mailboxes, traffic signs, trees, ponds and hills. However, these objects would not only have to be built virtually but physically and due to the small scale of the objects they were ultimately deemed too fragile for a testing environment. A simple map with a four-way intersection and a T-intersection was ultimately chosen to be the supporting environment. The road structures were deemed the 'Static Map', as it would be a standard structure that would not move in both the virtual and physical representations.

Once the models were completed in Rhino, they were exported as polymeshes to 3DS format. This was done early on as the graphical engine powering the CMP was a modified video game engine called Half-Life. At that time of development, the Half-Life engine was an easy tool to demonstrate the CMP's potential functionality on a standard PC and it was able to import geometry in 3DS format.

3.3 Printing Virtual Reality

The finished solid models from Rhino were also exported in stereo-lithography (STL) format to be rapid prototyped. The University of Alberta's Industrial Design Department used a Fused Deposition Modeler (FDM) to create working prototypes

from the STL files. A StrataSys Genisys was used to create the 10 handheld-scaled model houses. The Genisys printer uses polyester wafers as its building material and creates the prototypes by slowly building up layers of hot, extruded polyester webbing. This process was chosen because of the accuracy and speed of construction over traditional methods of model building. The time it took to build the 10 models ranged from 8 to 16 hrs of printing time each on the Genisys. The advantage of rapid prototyping is that the polyester model is a very durable, accurate depiction of the computer model that took only a few hours to create. The automated process saved time and energy and having a hard copy model that could withstand heavy usage during testing was essential.

Each model had a built-in slot so that a unique diode identifier (edge connector) could be fitted into each model. The unique diode identifier would distinguish each model from the rest when the Segal board scanned it. The edge connectors were fastened in place with a resin epoxy with the edge connectors protruding out the bottom side of the model by a given depth. (See Figure 4) It was found that a minimum connection depth was required for a good response to the Segal board. If the edge connector was too shallow, errors would be read when the CMP scanned the board.
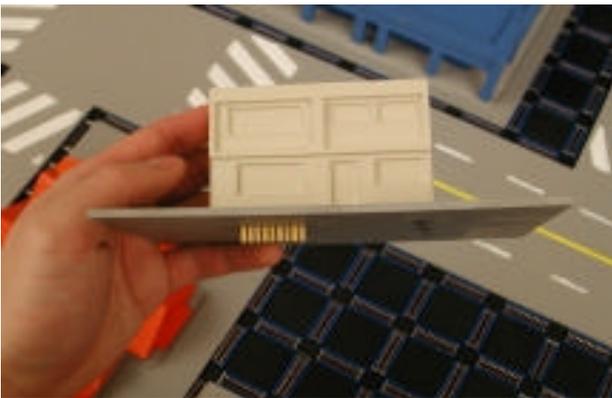

Figure 4. Edge connector protruding from bottom of the model.

3.4 Adding Some Color

In keeping with a simplified aesthetic, a simple color plan was chosen for the models. It was argued that photo-realism of the models was not an important criteria for the type of cognitive testing the researchers had proposed for the CMP. Bright, high-contrasting colors were chosen for the models to make them easier to be perceived by the elderly. Most of the palette consisted of primary and complimentary colors. This simple color scheme was implemented in the 3D models as well as the physical scaled models.

The models were painted with a very simple, singular color scheme. If there were particular highlights in the model, those would be painted with a contrasting color. The objective was to keep each model distinctly individual with a simple and bright color scheme. Once the models were printed from the Genisys, they were primed and then spray painted. Small details like the letters on the supermarket were done by hand.

Texture maps were created by exporting the Rhino models to 3D Studio Max (3DS) format, because Rhino was incapable of mapping UVW points onto a polymesh model, while 3D Studio Max could. A simple low resolution color patch was created in Corel Photo Paint and then used as the texture bitmap.

3.5 Making Better Connections

The slots that the edge connectors were fixed in were originally placed in the most structurally sound part of the scaled model. However, after some initial testing it was found that there was difficulty encountered when attempting to place the scaled houses onto the Segal board. It appeared that connecting the models to the board was not an easy or intuitive task. It was difficult to discern the location of the edge connector in relation to the connecting slot. A solution was proposed that would rectify the connection problem by adding a base to the bottom of the models that would align to the array of slot connectors on the Segal board.

First, the original Segal model was measured with digital calipers and recreated full scale as a blueprint drawing in Rhino. Next, the outlines of the 10 scale model houses were superimposed onto the Rhino Segal board drawing. The houses were aligned using their existing edge connector positions with the Segal board's slot connectors. (See Figure 5) It was decided to use the edge of the slot connectors on the Segal board as a reference line to align the bases for the houses. Next, an optimal sized rectangle was created that fitted the reference line created on the four sides by the array of slot connectors and was big enough to contain the outline of the house. This method of connecting the TUIs to the Segal board was chosen because of its versatility in allowing the user to align the house bases along any of its four sides with the edges of the slot connectors on the Segal board. (See Figure 6).
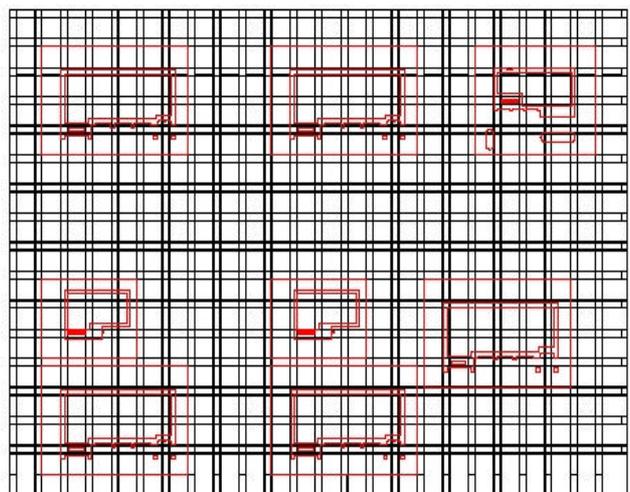

Figure 5. Building outlines aligned using edge connector positions.
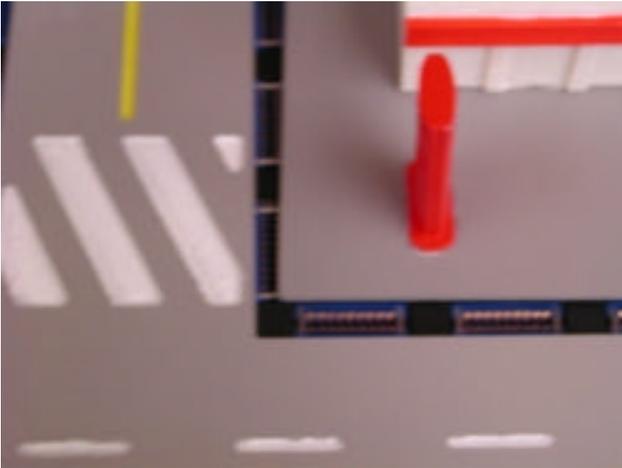
Figure 6. Finished model aligned using the edge of the slot connectors.

Once the bases for all the house were sized, they were superimposed along with the house outlines against the Segal board drawing. The static map (roadways) was then designed using the bases and Segal board as boundary conditions. The design allowed for the largest house bases to be placed in any orientation in most of the open areas. The design of the roadways also permitted all of the ten models to be placed onto the board at the same time in many different configurations. The designers wanted as much freedom of choice for the user to place the models on the Segal board as possible so as to not hinder or disrupt the cognitive mapping process. The completed static map consisted of a main street with two intersections: a four-way and a T-intersection. There were five open areas that allowed for a variety of possible configuration options for the user to place the models in. The placement of the roads corresponded with the original alignment of the arrays on the Segal board (similar to how the house bases were aligned) (see Figure 7). This design was made possible by the help of superimposing the building, map and base outlines and using the boards natural grid nature as a boundary. The resulting map and bases are intuitive in design and act as natural extensions of the Segal board.
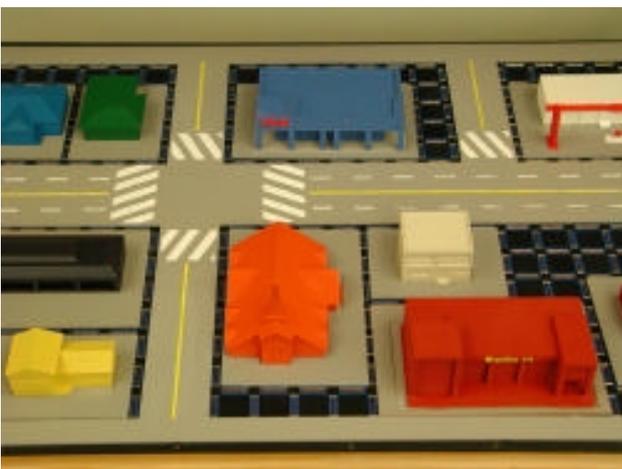

Figure 7. Finished map aligned with models on Segal board.

To create the physical components of the map and bases, their outlines were laid out in Rhino and arranged to be cut from a 2' x 4' stock of 1/8" material. The material chosen was a polyvinyl chloride (PVC) sheet plastic called Sintra that is durable, easy to router cut and inexpensive. The outlines were then exported in IGES format and taken to a program called a MaseterCAM to generate G-code. Once the code was written it was uploaded to a Computer Numerical Controlled (CNC) machine and it cut the forms out of the Sintra sheet. Once the bases were removed from the CNC cutting bed, they were hot-glued onto the bottom of the model houses. Care was taken to ensure proper alignment of the models with the bases to the Segal board.

4. Trouble Shooting

Once the CMP was operating as a prototype, the researchers evaluated the project's stasis and made recommendations for improvement. The first change involved switching from the Half-Life video game graphics engine to a virtual environment software tool called Simple Virtual Environment (SVE) [5,9]. Due to limited functionality of the Half-Life engine, SVE was chosen because of its expanded applications for VR uses. This shift required very little adjustments from the designers, and only required that the 3D models be exported as OBJ and MTL files to be imported into SVE.

The next issue to be addressed was a low frame rate. Although the shift in graphical engines might have solved this issue, it was decided to reduce the polygon count in the 3D models as much as possible to provide a smooth frame rate for SVE. Limited by time and available resources, it was decided to modify each model's poly count by hand. The reasoning was that the geometry was relatively simple (no compound curves), there were a limited number of models to be reduced and higher-end mesh editing tools were not available to the department at that time.

The original problem was that when Rhino exported the solid models as meshes, the polygon reduction algorithm was not that good. Even with the settings at the lowest polygon count, the model houses often had poly counts over 1600. The goal was to aim for reduced models with poly counts as low as 200 and not higher than 700. Fortunately most of the geometry was simple and consisted of rectangular shaped surfaces that could easily reduce to two polygons. The result of the manual method was an identical model (in terms of geometry) to the original model but with fewer polygons. However, the reduced models had irregular shaped polygons instead of uniform sized/shaped polys. (See Figure 8) This was not a problem for the application since the texture maps applied were of a single and flat color scheme where orientation and edge artifacts were not a concern. A comparison between the original polygon count and the reduced polygon count is shown in Table 1.
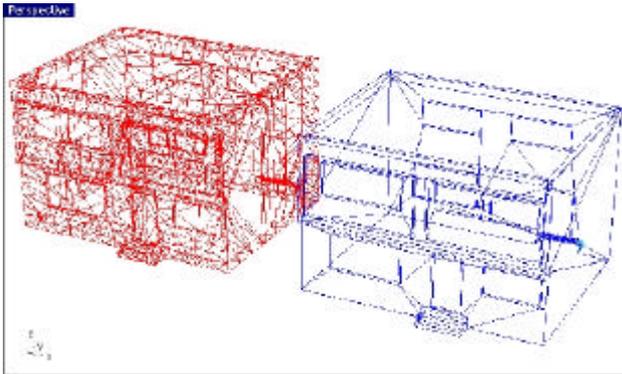
Figure 8. Comparison of Original (L) and Reduced (R) polymesh models in Rhino.

Table 1. Comparison of Original and Reduced Polygon Count in Models

Model	Original Polygon Count	Reduced Polygon Count	Difference
Church	8076	610	7466
Gas Station	2693	314	2379
Fire Station	9072	229	8843
House 1	848	153	695
House 2	2160	253	1907
House 3	1768	310	1458
House 4	4411	446	3965
IGA	1462	734	728
Strip Mall	3594	532	3062
Walk Up	1638	263	1375

It was discovered during the manual editing of the polymeshes that the models that had the highest poly counts were the ones that had letters that acted as signage in the model. After analyzing the problem of the letters, it was deemed that the curved structures were extraneous and did not need a 3D representation. Instead, it was decided to create a bitmap image with the letters and map it to the original position of the 3D letters. The decision was made after manually reducing the 3D letters with minimal effectiveness to the poly count. Outlines of the letters were made from the original 3D structures. The outlines were then exported to a bitmap editor and a texture map was created. A rectangular polymesh face was created in Rhino with the exact dimensions of the bitmap of the letters and then the texture was mapped onto the mesh. The mesh was positioned one-thousandth of an inch in front of the original position of the letters so that the user could not see the 'floating'

bitmap. This created the illusion that the letters were actually on the model.

5. Future Work

The next stage will involve preliminary testing of subjects on the CMP. The researchers will wait to receive feedback on how effective the CMP is and where adjustments should be made. At this stage, the researchers are confident that they have addressed the issues of CMP's tangible user interfaces and resolved most of the hardware/software issues. From a designer's point of view, there are a few items that would be done differently if it were done again.

It would have been helpful to use a tool like Polyworks to reduce the polygon count. If there were more difficult geometry, or more models, then an automatic poly reducer would probably be best. As is, it would have also been interesting to compare the results of our manually edited models with the poly count of an automatic method.

The issue of alignment should also be addressed early on in the design phase next time. There may be other solutions and options if the issue was recognized at an earlier phase. As now, the base and static map solution proves well, but a better solution may be to integrate the alignment of the models with the design of the models.

As technology moves forward, the method of 3D printing can also be improved. More ecologically friendlier biodegradable starch models can be built on newer 3D printers that also have an additional head that will color the model as it is 3D printed. This would eliminate the need to spray paint the models. The costs of producing 3D printed objects have also declined over the years.

In the next version, it may be decided to go with a photorealistic look and that would be interesting to see. Also, different platforms may be explored. For example, using the CMP in a VR Cave environment or a head mounted display unit may be an interesting option for some users. By using SVE, it should be relatively simple to translate the CMP to different VR environments (Figure 9).
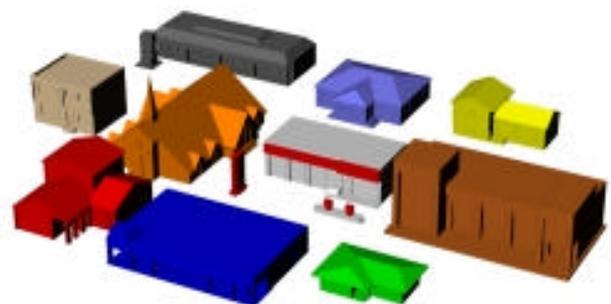

Figure 9. The existing look of the CMP may change to a more photo-realistic look and placed in a VR cave in future versions.

6. Conclusion

The CMP was a unique and rewarding project to be involved in from a designer's point of view. There were some very technical as well as human issues that were addressed during the project's development. It brought together people from many different fields and their insight and experience contributed enormously. All of the problem solving addressed in this paper was done with the collaboration of many researchers with diverse backgrounds that produced solutions that had to meet just as many requirements. Each solution posed had to take into account criteria from an industrial designer's point of view, the requirements from rehabilitation medicine perspective, as well as meet the needs of the computer scientist. However, it is this collaboration of many minds to solve a problem that proved to be the strongest point in the project. An industrial designer cannot design in isolation. Advancements cannot be made without venturing outside one's sphere of comfort. Collaborative projects opens eyes to understanding and being receptive to the needs of others. Design as a practice must always accommodate for the end user, and in many scenarios, the designer must consult and work with other experts. The vice versa is true also in that designers can be a benefit to a project because of their skills and problem solving abilities. One can hope there will be more collaborative projects in the future as designers and researchers realize the positives of working together.

7. Acknowledgments

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