Using 4 D CAD and Immersive Projection Display Technology to Improve Nuclear Power Plant Construction Planning

Master of Science Thesis Proposal in

Architectural Engineering

By

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Abstract

The need to reduce the overall development costs of new nuclear plants resulted in the development of new plant designs (e.g., Generation IV nuclear power plant design) and adoption of modular method of construction. However, to reduce the capital costs considerably, a reliable construction time has to be achieved. This requires a thorough review of the construction schedule prior to actual construction. An optimum construction schedule that eliminates potential schedule problems (e.g., space conflicts, safety hazards) should be developed. Previous research performed in developing such optimum construction schedules used computer generated 3D and 4D models (3D models linked to construction schedules) to check the construction sequence and these models were viewed on computer monitors. But for complex facilities like nuclear power plants, visualization of minute details such as interaction of welding machines and temporary support structures with the rest of construction becomes very important. This calls for visualization of a construction schedule in a 1 to 1 scale. Immersive projection display (IPD) technology with its walkthrough capabilities gives a project team an opportunity to analyze construction sequences in 1 to 1 scale.

This research explores the possibility of using 4D modeling and IPD technology to improve the construction sequence which otherwise would be left undetected prior to the actual construction. For this purpose, a 4D model of the installation sequence of the modules and spool pieces in a particular section of a nuclear power plant will be generated. This 4D model will then be imported into the IPD (CAVE) available at Penn State University. A review of the installation sequence will be made and an optimum construction sequence will be recommended. This research is expected to give improved schedule reliability to nuclear power plant construction.

1. Introduction

1.1. Introduction to the Research Problem

For nuclear energy to be cost competitive with non-nuclear technologies, the capital costs of new nuclear plants should be reduced so that they are comparable to non-nuclear power plants. To achieve this, EPC contractors should be able to reduce the overall development costs of these new plants. New plant designs (Generation III+ and Generation IV) that employ a modular system of construction and use 3D CAD technologies in design have been developed. These designs reduce the time of construction by allowing extensive pre-construction planning via modular construction.

During the construction of previous nuclear power plants, full-scale mockups were used to perform constructability reviews for congested areas. The cost and time invested in the construction of these full-scale mockups form a substantial percentage of the total development cost of a nuclear power plant (Baratta et al. 2002). In addition, a construction cost allowance was commonly included in the estimates to account for re-work and field generated change orders. The new plant designs use 3D CAD models, which have improved the design process as virtual models can be developed to review field conflicts and decrease changes during construction. But these models do not allow a thorough review of the construction sequence of the modules and the spool pieces connecting these modules.

It is now possible to review these constructability issues by reviewing the construction sequences via 4D models (3D CAD models linked to the construction schedule) in virtual environments using an immersive projection display. This can be performed in less time and cost than full-scale mockups. In addition, the entire plant can be modeled instead of limited portions of the plant. This research will focus on the value of expanding the use of 4D models by importing them into a full scale virtual environment.

1.2. Goal

The goal of this research is to improve schedule reliability of nuclear power plant construction with the help of 4D CAD implemented in a virtual environment. The researcher intends to develop a process model for improving the construction planning for nuclear plant construction. This process will identify the steps to be followed, in a chronological order, to develop a 4D model in IPD. The key lessons learned during the development of this process model will be documented. An optimum construction schedule will be developed and reviewed using this technology. A benefit analysis will be performed to determine the value of using this technology. The researcher also intends to demonstrate its use as a communication tool between the designers and construction engineers.

1.3. Objectives

The objective of this research is to generate a 4D model of the installation sequence of the modules and spool pieces in room 12306 in the auxiliary building of the AP 1000 nuclear power plant. By implementing this 4D model in CAVE-like IPD, the construction sequence will be reviewed and an optimum construction schedule will be recommended.

2. Research Methodology

Exploratory research methods will be extensively used throughout this research. The research techniques will concentrate on identifying variables to validate the use of this 4D implemented in virtual environment. An explanation of the selected research techniques is provided below.

2.1. Research Techniques

Several research techniques will be used in this research. These techniques include a case study research method, survey techniques, and content analysis. These techniques are described in detail in the following sections.

2.1.1. Case Study Research Method

A case study research method is used to examine contemporary real-life situations. By applying the research ideas or techniques to these case studies one can examine their validity in real-life. The case study research method is defined as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (Yin 1984, pp. 23). The case study research method is a very useful tool for exploratory research. The case study used for this research addresses 'how' 4D models immersed in virtual environments can be used to reduce the construction cost and time of new nuclear power plants. According to Yin (1999, pp. 33), the four tests commonly used to establish the quality of a case study are:

1.) Construct Validity: establishing correct operational measures for the concepts being studied.

2.) Internal Validity (for explanatory or casual studies only, not for descriptive or exploratory studies): establishing a casual relationship, whereby certain conditions shown to lead to other conditions, as distinguished from spurious relationships.

3.) External Validity: establishing the domain to which the study's finding can be generalized.

4.) Reliability: demonstrating that the operations of the study - such as the data collection procedures can be repeated, with the same results

The case study used for this research is the installation sequence study of the modules and spool pieces that connect the modules in room 12306 in the auxiliary building of the AP1000 nuclear power plant.

2.1.2. In-depth interview

Kahn and Cannell (1957) describe the interview research method as "a conversation with a purpose". Interviews are categorized into three general types: the informal conversational interview, the general interview guide approach, and the standardized open-ended interview (Catherine and Gretchen 1999). In addition to these categories, there are several more specialized in-depth interviews, including ethnographic interviewing, phenomenological interviewing, elite interviewing, focus group interviewing, and interviewing children (Catherine and Gretchen., 1999). The elite interviewing technique will be discussed in detail, because of its appropriateness to the research context. According to Catherine and Gretchen (1999), an elite interview is a specialized case of interviewing that focuses on a particular type of interviewee. "Elite" individuals are those considered to be influential, prominent, and/or well-informed people in an organization or community; that are selected for interviews on the basis of their expertise in areas relevant to the research.

Two interviewing styles will be used for data collection through out the research: unstructured interviews and structured in-depth interviews. According to Dexter (1970, p.3) an unstructured interview involves: stressing the respondent's definition of the situation; encouraging the respondent to structure the account of the situation; and letting the respondent introduce, to a considerable extent, his notions of what he regards as relevant. Unstructured interviews will be conducted to formulate metrics for the evaluation of the model, which will assist in developing detailed questions for future structured interview. A structured interview is an interview where the "questions have been formulated ahead of time, and the respondent is expected to answer in terms of the interviewer's framework and definition of the problem" (Guba and Lincoln, 1981, p.156). Structured interviews will also be performed to evaluate the models. The following sections describe the selection of the interview team and the methods used for reducing bias.

2.1.2.1. Interview Team

The interviewee candidates selected for this research will be individuals responsible for designing, and overseeing the construction of nuclear power plants. The designers and project managers from Westinghouse Electric Co., Burns & Roe., and Panlyon

Technologies (hereon referred to as the “review team”) have been selected as the interview candidates. These people were selected on the basis of their expertise and experience in nuclear power plant design and construction.

2.1.2.2. Interview Bias

Bias is “a tendency to observe the phenomenon in a manner that differs from the ‘true’ observation in some consistent fashion” (Simon and Burstein 1985, p.242). Two methods may be used to reduce the bias imposed by the interviewer. One method is to develop questions that do not necessitate the interview candidate to answer within the interviewer’s framework. The other method is to avoid bias during the interpretation of the interviews. A content analysis will be performed for each interview to systematically analyze the interview data. The content analysis method is described in the next section.

2.1.2.3. Content Analysis

Content analysis is a widely accepted technique to systematically analyze data obtained through qualitative research (Holsti 1969). Content analysis is defined as a phase of information processing in which communication content is transformed, through objective and systematic application of categorization rules, into data that can be summarized and compared (Holsti 1969).

A content analysis will be developed for each interview conducted. The specific method that will be used to develop the content analysis will be to listen to the recording of the interview, and document the concepts discussed by the expert in a structured format.

2.2. Research Steps

The research steps that will be performed to achieve the objectives of this research are explained in a sequential order in this section.

2.2.1. Literature Review

A literature review for information on the use of 3D/4D modeling, virtual environments, and visualization in the construction industry will be performed. A preliminary literature review is included in Chapter 3.

2.2.2. Preliminary Unstructured Interviews

The researcher intends to conduct preliminary unstructured interviews with individuals of the “review team”. The interviews will focus on understanding the use of 4D models immersed in virtual reality in their potential for construction cost and time reduction of a nuclear power plant. A few general questions concerning the feasibility of the technology and the interviewee’s understanding of the installation sequence will be asked in the interview. The researcher intends to gather rough cost estimates of each design error and/or schedule error detected through these interviews. A preliminary list of questions that will be asked in the interview are included in Appendix B.

2.2.3. Develop of a 4D Model

A 4D model of the installation sequence of a room in the auxiliary building of the AP1000 nuclear power plant will be developed. The development of the 4D model will be achieved by linking the 3D models of the module construction and the connecting spool pieces to the installation schedule. The 4D model will then be imported into an IPD by converting it into an appropriate file format. The model will be studied for schedule errors, spatial aspects of the temporary support structures and temporary equipment by immersing the “review team” into the IPD. Alternate schedules will be generated and the most cost effective and time effective schedules will be suggested.

Throughout the generation of the model a time log will be maintained and a cost factor will be included to estimate the cost of generation of the model. The cost factor essentially includes the hourly wage of a design professional times the number of hours taken to generate this model plus the hourly rental rate of the IPD times the number of IPD-hours used.

2.2.4. Develop metrics for evaluating Application of 4D Models in IPD

A content analysis will be performed on each interview and metrics that can be used to evaluate the 4D model projected in the IPD will be developed from the analyses. The content analysis developed will also evaluate the potential use of the model and qualitative feedback obtained from the interviewers.

2.2.5. In-depth Structured Interviews

After incorporating all the suggestions and improvements made by the "review team" and identifying the variables for evaluation, in-depth structured interviews that focus on additional information related to the variables will be conducted. The interviewees will be asked to give any additional information or missing variables they feel will be important to evaluate the model. The interviewees will be asked to give a rough estimate of each of the design/ schedule errors detected.

2.2.6. Results

The model will be evaluated for the variables identified and the results will be tabulated. Also, a detailed cost of the entire process will be tabulated and compared to the cost and time savings in terms generated through the use of the technology.

3. Literature Review

This chapter presents the previous research related to the topics that influence the application of 4D CAD and immersive projection displays in the construction cost reduction of Nuclear power plants. This chapter will discuss the previous research performed in visualization in construction, 4D CAD/ Graphical construction simulation, and use of virtual reality in construction.

3.1. Visualization in construction

The Center for the Management of Information (CMI), University of Arizona defines Visualization as "transformation and analysis to aid in the formation of a mental picture of symbolic data. Such a picture is simple, persistent, and complete". Visualization techniques are being used in a variety of industries like automobiles, appliances, and aerospace (Kasik et al., 2002).

Visualization presents the project team with an opportunity to design and evaluate construction projects and visually communicate the project information. By visualizing a project electronically, potential problems in the design and schedule can be identified prior to the actual construction (McKinney et al., 1998). A project can be visualized in 2D, 3D, or 4D. Research in the areas of 3D and 4D CAD visualization is explained in detailed in section 3.2.

A wide variety of visualization tools and techniques are used to graphically illustrate construction processes. An example of visualization techniques include the use of highlight and overlay techniques (Liston et al., 2000). The highlighting approach is based on emphasizing information by selection of objects (e.g., building components or construction activity), spatial regions (e.g., components that occupy a space), and temporal regions (e.g., activities that occur during a particular time frame). The overlaying technique may be used to visually compare and relate project information from document to document of the same type (e.g., placing a Gantt chart onto: object to document of the same type (e.g., placing activities onto a Gantt chart), document to document of different type (e.g., placing a 3D model onto a Gantt chart) and object to document of different type (e.g., placing a building component onto a Gantt chart) (Retik, 1993). Other techniques include interactive visualization where a person can "walk through" the models in a projection display. The display can be a simple computer monitor, 50-inch plasma panels, Vision stations (Kasik et al., 2002), or CAVE (Cruz-Neira et al., 1993) that use virtual reality display technology.

3.2. 4D CAD/Graphical Construction Simulation

4D CAD may be defined as 3D CAD linked to the construction schedule (Koo and Fischer, 2000). 4D CAD has been and is being used on different types of construction projects. This section presents the previous research done in this area to demonstrate the capabilities of 4D CAD. One should note that there are different terms to express linking 3D models to construction schedules; the term 4D is only one among them. The research done in the area of "linking 3D models to the construction schedule" is studied in this review.

The Center for Integrated Facility Engineering (CIFE) of Stanford University has done extensive research in the area of 4D modeling. Studies have been done on the use of 4D CAD on different building types. The benefits and challenges of 4D modeling on a complex project is demonstrated by the Walt Disney Concert Hall Project (Haymaker and Fischer, 2001). Koo and Fischer (2000) studied the use of 4D CAD on commercial office buildings. Collier, E., and Fischer (1996) demonstrated the use of 4D CAD on the demolition, renovation, remodeling, and new construction on an existing hospital with the hospital functional at all times. 4D CAD in the form of 4D Workplanner (Akinci and Fischer, 2000) gives construction planners the ability to manage activity space requirements and identify time-space conflicts. This approach is based on the automation of project-specific activity space requirements and time-space conflict analyses. The use of 4D models as a tool to identify possible temporary support problems during the construction is demonstrated by McKinney and Fischer (1997). The temporary support analysis requires every component to satisfy at least one of the five support conditions for the roof construction identified by the researchers. The reasoning mechanism is invoked at the start of the 4D simulation and analysis for each component then begins with the completed component to check its support conditions.

The generation of a 4D model may be done with the use of variety of software. For example, the 4D modeling on the Walt Disney Concert Hall Project used the 4D modeling software developed by Walt Disney Imagineering (WDI) and CIFE with the help of 3D models developed in CATIA and the construction schedule developed in Primavera P3. Four 4D models were generated for this project for steel, concrete and exterior enclosure; interior work; interior hall and detailed hall ceiling. Developing these models posed challenges related to geometry, schedule, and the linking of the geometry to the schedule. However, the researcher notes that such issues are quite common during the development of 4D models, especially when 3D models are created without knowledge of the needs for 4D modeling and construction planning. Akinci, and Fischer (2000) developed 4D workplanner, a prototype system for automated generation of construction spaces and time-space conflict analysis. Koo and Fischer (2000) used AutoCAD r14 to convert 2D CAD drawing obtained from the general contractor and Primavera™ P3 scheduling software. Collier and Fischer (1996) used AutoCAD for 3D models, Primavera™ for scheduling and Jacobus Technology's Construction Simulation Toolkit software to generate the 4D model. For the purpose of this research, Microstation V8 for 3D modeling, Primavera™ P3 and Bentley's Schedule Simulator are being used.

3D animation can visually reflect the impact of changes when a computerized schedule is used for sequencing (Collier and Fischer, 1996). Previous research on 4D CAD identified the advantages of using 4D CAD as a visualization tool: visualizing and interpreting construction sequence; conveying spatial constraints of a project; integration tool: formalizing design and construction information; promoting interaction among project participants; and analysis tool: anticipating safety hazard situations; allocating resources and equipment relative to site workspace; running constructability reviews; 4D models also assist constructions planners in planning the lay down areas, visualizing the overall project access at critical junctures in the project, for schedule analysis, and as a communication and team building tool.

3.3. Use of virtual reality in construction

Virtual reality may be defined as an experience in which a person is "surrounded by a three dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach it grab it, and reshape it." (Rheingold, H. 1991). The terms Virtual Reality (VR) and Virtual Environments (VE) may be used interchangeably, but virtual environment differs from virtual reality in the sense that it has a somewhat grander definition that encompasses virtual reality (Cruz-Neira et al., 1993). Virtual reality technology has been used in a variety of areas including 3-D movies, video games, 3-D scientific visualizations, architectural plans, automobile design, space walking experiences, etc. Virtual reality in construction is being used to visualize construction operations, design and analysis of construction equipment (Op den Bosch and Hastak, 1995), and to communicate and train the project team (Haymaker and Fischer, 2001).

Virtual environments may be navigated in two ways: using a simple computer monitor or complex rooms that use immersive projection technology (e.g., CAVE). The research done by Nelson, Cook and Cruz-Neira (1999), to compare the visualization in 3-D immersive VR and 2-D workstation display conclude, "When viewing high-dimensional data, the added dimension appears to allow a user to better make decisions regarding the structure of the data."

4. Schedule

This section describes the key milestones in the research effort and the relevant dates that the researcher aims to achieve them in.

Thesis Proposal: The researcher intends to submit the research proposal by August 2002 and get the approval of all the committee members.

Preliminary Unstructured Interviews: Unstructured interviews will be conducted on the 12th of September to help develop metrics for the evaluation of the model.

Model Development: The researcher intends to develop the 4D model of the modules and connecting spool pieces and import the model into CAVE. A review of the model will then be made by the "review team". The researcher intends to complete these tasks by October 2002.

Model Testing: The model developed will be tested for the improvements suggested by the interview candidates. The researcher intends to perform this task during the months of September and October 2002.

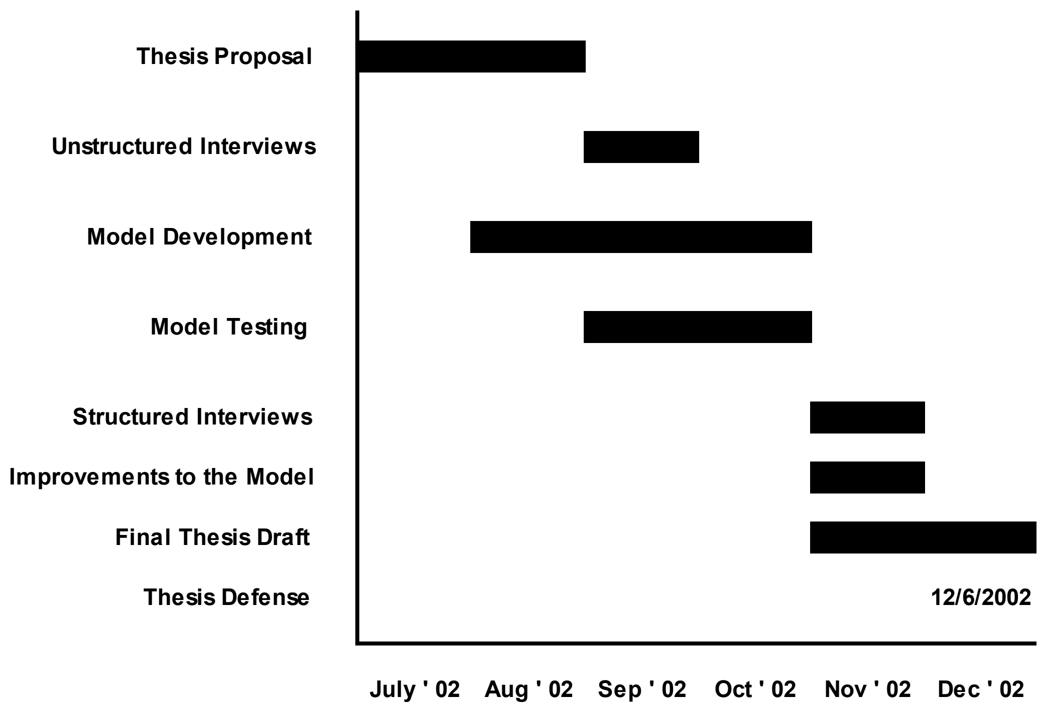
Structured Interviews: The variables for evaluation will be developed and in-depth structured interviews will be performed. The model will be evaluated for the variables identified. The information will be used to find the cost and time savings generated by the use of this technology. The researcher intends to complete this task by November 2002.

Improvements to the Model: Improvements will be made to the model developed to incorporate the suggestions of the interview candidates. The researcher intends to perform this task during the month November 2002 simultaneous with the structured interviews.

Final Thesis report: A final thesis draft will be made during the months of November and December 2002.

Thesis Defense: The researcher intends to wrap up the research by defending the thesis on the 6th of December 2002.

A bar chart of the key milestones and the schedule is shown in the next page.


Thesis Proposal
Unstructured Interviews
Model Development
Model Testing
Structured Interviews
Improvements to the Model
Final Thesis Draft
Thesis Defense
12/6/2002
July ' 02
Aug ' 02
Sep ' 02
Oct ' 02
Nov ' 02
Dec ' 02

5. Scope and Limitations

The scope of this research will be limited to the use of 4D CAD and virtual environment for AP 1000 nuclear power plant project. The installation sequence of the modules and spool pieces in a room of the auxiliary building would be used to generate the 4D CAD model and then immersed in IPD virtual environment. A recommendation of the type of projects that can use this technology will be made.

6. Challenges

This research encountered a number of challenges during the generation of the 4D model. The experiences of other researchers who dealt with 4D models show that these issues are quite common.

6.1. Technology issues

6.1.1. 3D Models

The 3D models currently available to the researcher are in Microstation dgn file format. These files have been converted to Schedule Simulator's jsm file format to enable linking the 3D components to their schedule activities. After the conversion from one format to the other it was noticed that some of the components were missing. The researcher is currently communicating with the technical support personnel of the software company to resolve this issue.

6.1.2. 4D Modeling

Developing a 4D model requires the components in the 3D model to be grouped according to their schedule activities. Grouping these components in the 3D model is a time-consuming task, as each component was designed as combination of numerous 3D elements (lines, splines, and other 3D shapes) and there are a large number of components to group.

6.1.3. Implementation in IPD

The projection of the 4D model in an immersive projection display requires the transformation of object-oriented files (4D model) to VRML files to enable stereographic display. This might require an interface program that does the transformation. The researcher is currently seeking the help of the personnel at Applied Research Laboratories and the Computer Science Department at Penn State University to develop the interface program.

6.2. Scheduling team review

The review team consists of professionals from Westinghouse, Burns & Roe and Panlyon technologies. Scheduling a review of the model with all the team members present at the same time is an issue as the professionals are not always available.

7. Expected Results

The results of this research are expected to identify metrics to evaluate the use of 4D models immersed in virtual reality in the construction cost reduction of new nuclear power plants. These metrics will be developed in a way that would take into account the technological issues; issues related to the installation sequence of the modules; and the time and cost invested into developing this model. The metrics will help identify the extent to which 4D models immersed in virtual reality can reduce construction costs of nuclear power plants and aid as a tool for planning and communication to the project team.

APPENDIX A

REFERENCES

Akinci, B., and Fischer, M. (2000). "4D WorkPlanner - A prototype system for automated generation of construction spaces and analysis of time-space conflicts." *Eighth International Conference on Computing in Civil and Building Engineering (ICCCBE-VIII), Renate Fruchter, Feniosky Pena-Mora and W.M. Kim Roddis (Eds.)*, August 14-17, 2000, Stanford University, 740-747.

Baratta, A. J., Whisker, V. E., Mouli, S. C., Shaulis, S. A., Shaw, T. S., Warren, M. E., Winters, J.W., and Clelland, J. A. (Westinghouse) (2002). "Generation IV Construction Cost Reductions Using Virtual Environments." *TANSAO 86 40.* Vol. 86. June

Cherneff, J., Logcher, R., and Sriram, D. (1991). "Integrating CAD with construction-schedule generation." *J.Comp. in Civ. Engrrg.,* ASCE, 5(1), 64-84.

Christodoulou, S., (2002). "Discussion of "Feasibility study of 4D CAD in commercial construction" by Koo, B., and Fischer, M." *J. Constr. Engrg. And Mgmt.,* ASCE, May/June, 274-275.

Collier, E., and Fischer, M. (1996). "Visual-based scheduling: 4D modeling on the San Mateo County Health Center." *Proc., 3rd Congr. On Comp. In Civ. Engrg.,* ASCE, New York, 800-805.

Cruz-Neira, C., Sandin, D.J., DeFanti, T.A. (1993) "Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE," *Computer Graphics Proceedings of SIGGRAPH '93*, ACM SIGGRAPH, August, 135-142.

Czaja, R., and Blair, J. (1996). *Designing Surveys: A Guide to decisions and procedures.* Pine Forge Press. CA.

Dexter, L.A (1970). *Elite and specialized interviewing.* Northwestern University Press, Evanston, IL.

Fischer, M., and Aalami, F. (1996). "Scheduling with computer-interpretable construction method models." *J. Constr. Engrg. And Mgmt.,* ASCE, 122(4), 337-347.

Guba, E.G., and Lincoln, Y.S. (1981). *Effective evaluation.* Jossey-Bass, San Francisco, CA

Haymaker, J. and Fischer, M., (2001). “Challenges and benefits of 4D modeling on the Walt Disney Concert Hall Project”. *CIFE Working Paper #064, Stanford University*, Sanford, CA, January 18.

Holsti, O. (1969). *Content analysis for the social science and humanities.* Addison-Wesley publishing company, Reading, MA.

Jägbeck, A. (1994). “MDA planner: interactive planning tool using product models and construction methods.” *J. Comp. in. Civ. Engrg.,* ASCE, 8(4), 536-554.

Jolliffe, R.F. (1986). *Survey design and analysis*. Ellis Horwood Limited, West Sussex, England.

Kahn, R., & Cannell, C. (1957). *The dynamics of interviewing*. John Wiley, New York, NY.

Kamat, V., and Martinez, J. (2001). “Visualizing Simulated Construction Operations In 3D.” *Journal of Computing in Civil Engineering*, ASCE, 15 (4), October.

Kasik, D., Troy, J., Amorosi, S., Murray, M. and Swamy, S. (2002). “Evaluating graphics displays for complex 3D models.” *Graphics in Advanced Computer-Aided Design,* IEEE, May/June, 56-64.

Koo, B. and Fischer, M. (2000). “Feasibility study of 4D CAD in commercial construction”. *J. of Constr. Engr. and Man.,* ASCE, 126(4), 251-260.

Lincoln. Y.S., and Guba. E.G. (1985). *Naturalistic inquiry.* Sage Publications, Newbury Park, CA.

Lipman, R., and Reed, K. (2000). “Using VRML in construction industry applications.” *Web3D-VRML 2000 symp.,* available: http://cic.nist.gov/vrml , accessed on July 12.

Liston, K., Fischer, M., and Kunz, J. (2000). "Designing and evaluating visualization techniques for construction planning." *Eighth International Conference on Computing in Civil and Building Engineering (ICCCBE-VIII), Renate Fruchter, Feniosky Pena-Mora and W.M. Kim Roddis (Eds.)*, Stanford University, August 14-17, 2000, 1293-1300.

Marshall, C., and Gretchen, R. (1999). *Designing Qualitative Research*. Sage publications, Inc., Newbury Park, CA.

McKinney, K., and Fischer, M. (1997). "4D Analysis of Temporary Support." *Proceedings of the Fourth Congress on Computing in Civil Engineering,* ASCE, Philadelphia, PA, June 16-18, 470-476.

McKinney, K., Fischer, M., and Kunz, J. (1998). "Visualization of Construction Planning Information." *IUI98: 1998 SIGCHI, SIGART International Conference on Intelligent User Interfaces*, San Francisco, ACM, January 6-9, 135-138.

Mauch, J., and Birch, J. (1998). *Guide to the successful thesis and dissertation.* Marcel Dekker, Inc., New York, NY.

Nelson, L., Cook, D., Cruz-Neira, C. (1999). "XGobi vs. the C2: Results of an experiment comparing data visualization in a 3-D immersive virtual environment with a 2-D workstation display". *Computational Statistics (14)*. 39-51

O'Connell, M., Fischer, M., and Gupta, A. (2001). "Development of methods to reduce costs for major containment structures in future nuclear plants." *Transactions, SMiRT 16,* Washington DC, Paper # 1507, August.

O'Connell, M., Turk, R., Matteson, D. (2000). "Report on NERI research project to reduce capital costs and plant construction time for future nuclear power plants." *Proceedings of ICONE 8 Eighth International Conference on Nuclear Engineering.* ASME, Baltimore, April 2-6, 497-501.

Opdenbosch, A., and Baker, N. (1994). "Simulation of construction operations in virtual interactive environments." *2nd Congress for Computing in Civil Engineering*, ASCE, Atlanta, June, 1435-1442.

Opdenbosch, A., Hastak, M., (1995) "Virtual Reality Environment for Design and Analysis of Automated Construction Equipment" *2nd Congress for Computing in Civil Engineering*, ASCE, Atlanta, June, 566-573.

Retik, A. (1993). “Visualization for decision making in construction planning.” *Visualization and intelligent design in engineering and architecture,* J.J. Connor et al., eds., Elsevier Science, New York, 587-599.

Simon, J.L., and Burstein, P. (1985). *Basic research methods in social science.* Random House, New York, NY

Tatum, S., Byrum, J., and Rourke, P. (1994). “Design validation using computer models in lieu of full-scale mockups”. *Marine Technology*, 31(3), July, 225-230.

Van Wagenen, R.K. (1991). *Writing a thesis: Substance and style.* Prentice-Hall, Inc., Englewood Cliffs, NJ.

Voronin, V. and Prokhorov, Y. (1993). “Role of prototype ground-test stands in developing transportable nuclear power installations”. *Scientific-Research Institute NITI.* FEI. Translated from Atomnaya Energiya, 74(4), April, 339-344.

Yin, R. (1984). *Case study research: Design and Methods.* SAGE publications, Newbury Park, CA.

Yin, R. (1999). *Case study research: Design and Methods.* SAGE publications, Newbury Park, CA.

APPENDIX B

INITIAL INTERVIEW QUESTIONS

INITIAL UNSTRUCTURED INTERVIEW QUESTIONS

This section contains questions that will be asked during the initial unstructured interviews. Each interview starts with the candidate's general information, followed by questions regarding the technology, and questions related to the development of the 4D model.

General Information:

1. What is your position in your company?

2. How long have you been in this position?

3. What nuclear power plant design/construction experience do you have?

4. What is your current/past role in the design/construction of nuclear power plants?

Room Construction:

1. What sequencing rules do you use when you construct a room like room 12306?

2. Where do you generally encounter field conflicts?

3. Do you schedule projects by days or hours? How do you decide?

4. What activities in the schedule would be critical to the successful installation of the modules and why?

5. What would be an appropriate clearance for the various equipments used (e.g. Welding machines etc.)?

Technology Questions:

1. What do you think are the benefits/disadvantages of 4D models immersed in virtual reality?

2. What methods can be used to evaluate cost to benefits of 4D models immersed in virtual reality?

3. Can you think of any additional features that might help improve the use of 4D models immersed in virtual reality?

4. Is there anything you would like to add?