

Using 4D CAD and Immersive Virtual Environments to Improve Construction Planning

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ABSTRACT

The ability to visualize a project via a 4D CAD model (3D CAD model with time as the 4th dimension) allows construction planners to review and generate better construction plans. Over the past ten years, several researchers and industry practitioners have defined many benefits attributed to 4D CAD model development. In all but a few applications, a personal computer based monitor has been used to view and analyse these 4D models.

This study is an investigation of the feasibility of using an immersive, 3D virtual environment to view and generate 4D models to improve the construction project planning process. A group of construction professionals interactively reviewed and generated a construction plan for a portion of a nuclear power plant project in the Immersive Virtual Environment (IVE). By reviewing their schedules in the IVE, the construction professionals were able to readily identify design, constructability, sequencing, and interdisciplinary interfacing issues. By interactively generating the construction schedule in the virtual environment, the professionals developed a plan that resulted in a 28% savings to their original schedule. A model for developing construction plans within the IVE is presented.

KEYWORDS

Virtual Reality, Immersive Virtual Environments, 4D Modelling, CAVETM.

INTRODUCTION

The AEC industry has been witnessing a steady increase in the use of desktop 3D and 4D CAD tools for project planning. A 4D model is developed by linking a CPM schedule to a 3D CAD model. This allows for the visualization of the construction schedule; actually showing which pieces of the project will be constructed in what sequence (Kumi and Retik 1997). 4D models display the progression of construction overtime, sometimes dramatically improving the quality of construction plans and schedules (Rischmoller et al. 2001). Several documented studies have shown 4D CAD as a good visualization and schedule review tool. Project stakeholders can understand a construction schedule more quickly and completely with 4D

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visualization than with the traditional construction management tools (Koo and Fischer 2000; Songer et al. 2001, Messner et al. 2003).

Almost all previous 4D applications used personal computer based monitors to view these models. This is a difficult medium to use to view large, complex facilities. Advancements in computer visualization have led to the development of virtual environments that allow immersive, one to one scale visualization. By using immersive virtual environments, 3D objects may be visualized in 3D environments and at full-scale. This can lead to a more detailed identification of design and schedule related issues, although this has not really been investigated in any detail.

This research analyzes the feasibility of using Immersive Virtual Environments (IVE) to improve the construction planning process. A case study project was selected and a group of construction professionals were allowed to interactively review and generate construction plans while being immersed in a virtual mock-up of the facility.

OBJECTIVES

The objectives of the research were:

1. *To identify the potential benefits of using Immersive Virtual Environments (IVE) for construction project planning, and*
2. *To develop a process model for generating construction plans in an IVE.*

RESEARCH GROUP

The research defined within this paper is one part of a larger study on the value of immersive virtual environments for reducing nuclear plant construction cost (Baratta et al. 2002). This research study is being performed by a research group that includes: Westinghouse Electric Company (a global nuclear engineering and service company); Burns & Roe Enterprises (a comprehensive engineering, construction, operations and maintenance company); Panlyon Technologies LLC (a nuclear safety consultant); and The Pennsylvania State University's Applied Research Laboratory, Department of Mechanical and Nuclear Engineering and Department of Architectural Engineering. The research group held periodic meetings at The Pennsylvania State University to perform design and constructability reviews for the case study project and to test the functionality of the SEA-Lab Immersive Projection Display (Baratta et al. 2002).

CASE STUDY: AP 1000, ROOM 12306

The research case study focused on a portion of the AP1000 nuclear power plant. The AP1000 is a Generation III+ nuclear power plant that is licensed for construction, but no such plants have been built to date. This is a good candidate project for this study because of its complexity. The study specifically focuses on the installation sequence of the modules and spool pieces that connect the modules in Room 12306 in the auxiliary building of the AP1000 nuclear power plant. This room is located on the third level of the auxiliary building, in the northeast corner. The inside dimensions of this room are approximately 46'-0" x 16'-0" x 15'-6". The location of Room 12306 in relation to the containment building is shown in Figure 1.

Room 12306 contains non-radioactive mechanical equipment and piping and also serves as the containment piping penetration area; thus the room houses containment

isolation valves for various fluid systems. This room also contains a number of pre-assembled equipment modules. Figure 2 shows the different modules and assemblies in Room 12306.

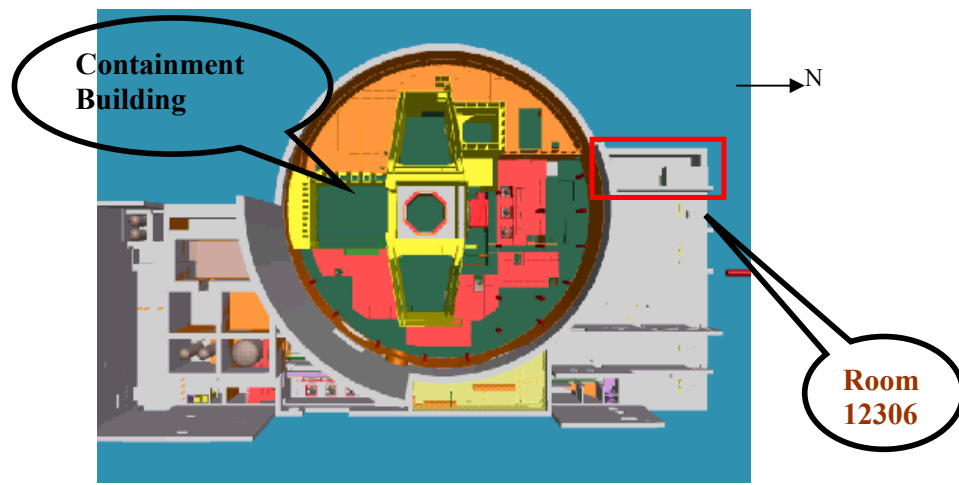


Figure 1: Location of Room 12306 in AP1000 nuclear power plant

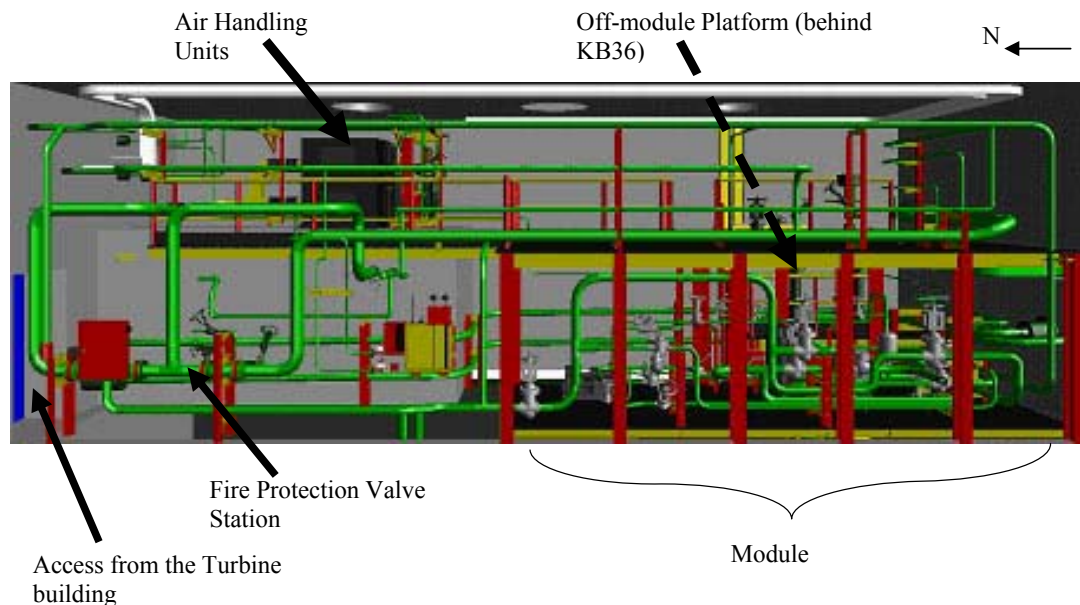


Figure 2: Location of Major Equipment in Room 12306

Figure 3 shows a user in the IVE on the first level of Room 12306. A large, 2-level module (KB36) occupies much of the south end of the full scale virtual mockup. Piping, valves, and equipment for the passive containment cooling system dominate the first level of the module.



Figure 3: Module KB36 - First Floor

IMMERSIVE VIRTUAL ENVIRONMENT (IVE) DISPLAY SYSTEM

The Surround Screen Virtual Reality (SSVR) system is an Immersive Virtual Environment (IVE) display system designed and sold by Mechdyne Corporation. The SSVR system is a turnkey virtual reality platform, which includes the display, the projectors, and all of the required hardware. A high-end Silicon Graphics Onyx2 server drives the display. The computer has a separate graphics processor for each of the four walls and the floor. A High Bandwidth CRT-style projector from BarcoGraphics projects the image generated by the computer onto a Mylar mirror, which reflects the image on the back of each of the four wall screens. The mirrors allow for a relatively compact footprint for the display.

The typical footprint for a SSVR system is 3 walls and a floor, but the IVE display system at the SEA Lab at The Pennsylvania State University is a custom built system with four walls, which surrounds the user. A fifth display surface, a top-projected floor has recently been added to the SSVR system. This surface was added following the experiments described in this paper. A diagram of the IVE display system at The Pennsylvania State University's SEA Lab is shown in Figure 4 (Shaw 2002).

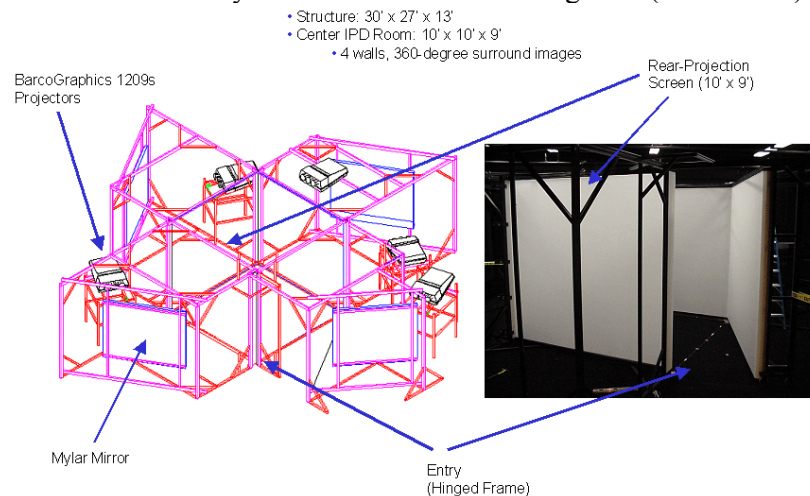


Figure 4: Immersive Virtual Environment Display System at the SEA Lab

EXPERIMENTS TO TEST THE APPLICATION OF 4D MODEL IN AN IMMERSIVE VIRTUAL ENVIRONMENT (IVE)

Two experiments were performed to test the 4D modelling applications for construction planning in the Immersive Virtual Environment (IVE). The objective was to help the construction professionals identify design, constructability, and safety issues by reviewing and generating an installation sequence in the IVE with the goal of developing an optimum construction plan. To perform the experiments, 4D model viewing and generation features were programmed into the IVE software applications (see Yerrathruthi (2003) for added details).

EXPERIMENT I – APPLICATION OF 4D MODEL IN THE IVE FOR SCHEDULE DEVELOPMENT

The primary purpose of Experiment I was to test the operation of the case study project in the IVE prior to construction superintendents and other trade personnel interactively using the system to create installation sequences in the IVE.

Two teams of two graduate construction management students participated in the experiment. The participants had a combined construction experience of 8 years. The participants had no prior knowledge of the area under study. Each team was immersed in Room 12306 in the IVE and was given a scripted tour. The students were then asked to develop an installation sequence for Room 12306 in the IVE. The participants were given the freedom to recommend changes to the design and module boundaries.

Each step of the installation sequence generated by the participants was manually recorded. The researchers entered the participant's installation sequence into the table-based data file to allow viewing of the construction schedule in the IVE. The teams were able to visualize their schedules in the form of a 4D model and review their installation sequence.

EXPERIMENT I - RESULTS

Each team presented a clear strategy for their work plan; although both sequences were different. The sequence was played back and critiqued by the users. Team 1 took approximately 120 minutes and Team 2 took approximately 90 minutes to develop the installation sequence in the IVE and review their sequences. The playback allowed the participants to find additional places where parallel activities could be performed, as well as places where the schedule they had developed could be improved. Standing in the room before and during construction fostered discussion of the actual methods of construction that would be used. For example, the participants discussed the use of spreader beams for lifting pipes into place. They also mentioned module size limitations and accessibility issues for some of the field weld locations. The enhanced spatial perception offered by the IVE allowed the participants to take workspace interference between trades into account while planning a number of parallel activities. The participants rated the development of the installation sequences using the IVE, an average of 8.37 out of 10 in ease of use. The participants rated their confidence in the schedule they had developed an average of 9.1 out of 10.

EXPERIMENT II – APPLICATION OF 4D MODEL IN THE IVE FOR PROJECT PLANNING

The objective of this experiment was to test the use of the IVE as a construction planning tool by industry practitioners. The ability of the IVE to help construction planners identify critical issues of a project by reviewing and generating schedules in the IVE was tested in this experiment.

Two teams of two experienced construction superintendents participated in the experiment. Each team was provided with 3D drawings of the modules, assemblies and makeup pieces in Room 12306. The 3D drawings identified the pre-set module boundaries and weld locations for the makeup pieces. After spending less than one day reviewing the 3D CAD drawings provided by the designer, each team developed a construction schedule for Room 12306. One team documented the schedule in a Microsoft® Excel spreadsheet with activities broken down by man-hours while the other team created their schedule using Primavera P3® and allowed one day for each activity.

The superintendents were then placed in the IVE and each team viewed their sequence in 4D. After the sequence was played back from start to finish, each team advanced

through the sequence step-by-step and evaluated their performance, while discussing their construction strategy with the researcher. A detailed description of the discussions and issues identified is provided in the results.

EXPERIMENT II - RESULTS

The value of the IVE to help develop robust schedules and sequences was assessed by measuring the number of constructability issues identified and by measuring the number of issues identified that would impede schedule reliability. Constructability issues were divided into the number of module boundary changes and the number of weld locations changes. Schedule reliability issues were divided into out-of-sequence activities and schedule confidence.

Number of module boundary changes – Figure 5 illustrates the number of module boundary changes made before and after the review of the construction schedules in the IVE by each team. This data shows that the construction planners were able to identify more module boundary changes after reviewing the schedule in the IVE. This suggests that the construction planners had a better understanding of the constructability issues when using the IVE.

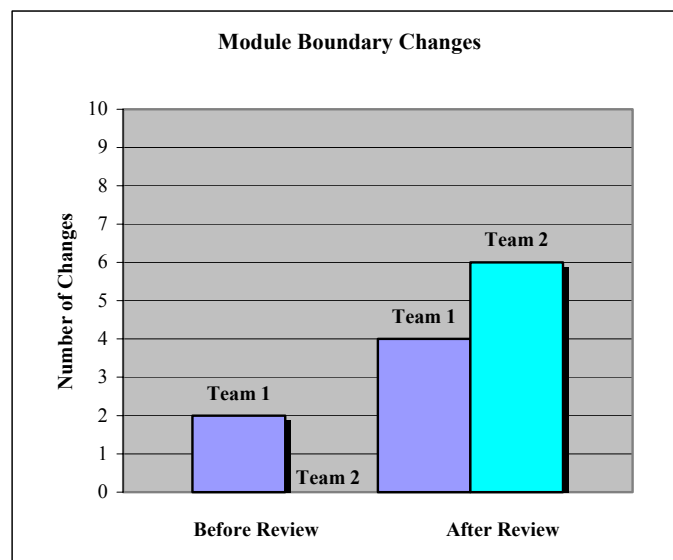


Figure 5: Changes in module boundaries

Changes in weld locations – Figure 6 illustrates the number of changes made to the weld locations before and after the review by each team. This data shows that the IVE helped the construction planners identify weld locations. The planners also mentioned the need to involve pipe fitters and welders into the planning process. According to the planners, this could be very valuable to avoid delays during the actual construction. The construction planners did not identify any such changes while developing the schedule on paper.

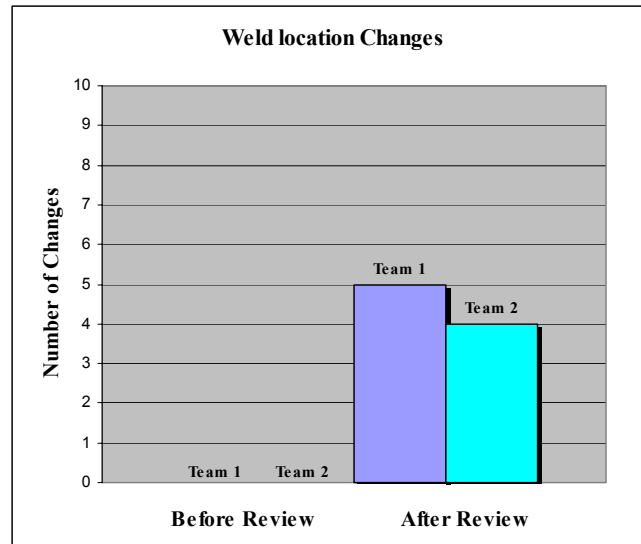


Figure 6: Change in Weld locations: average

Sequence changes – During the review, each group found a number of issues with their construction sequences. The construction planners were able to identify out-of-sequence activities in the schedule that they developed in at least four instances.

For example, Figure 7 below shows the Team 1's schedule for 11/22/2002 before review in the IVE. The figure shows the objects already installed in their original color and the objects being installed in black. Figure 8 shows the schedule for 11/22/2002 of Team 1 after review in the IVE. The figures clearly show that Team 1, after reviewing their schedule in the IVE, realized that they could have installed more objects by that date. Even though this did not change the total number of schedule days, it eliminated a potential field schedule conflict and improved the schedule reliability.

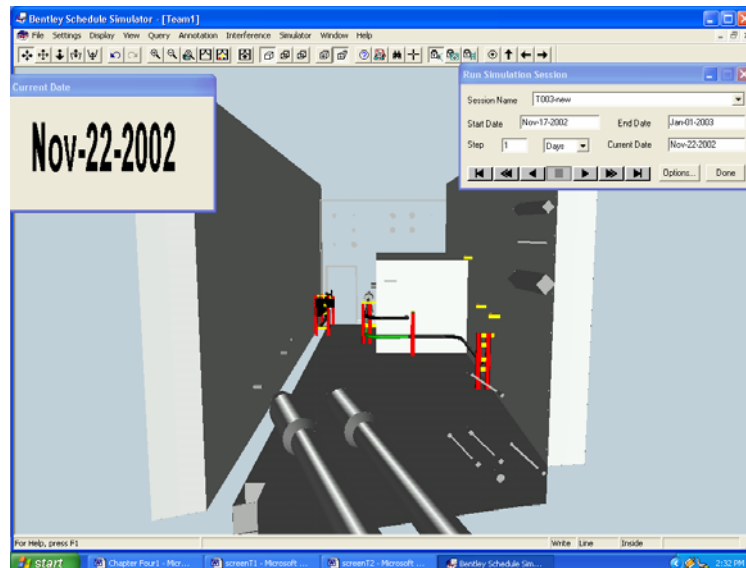


Figure 7: Team 1 – Schedule for 11/22/02 before review in IVE

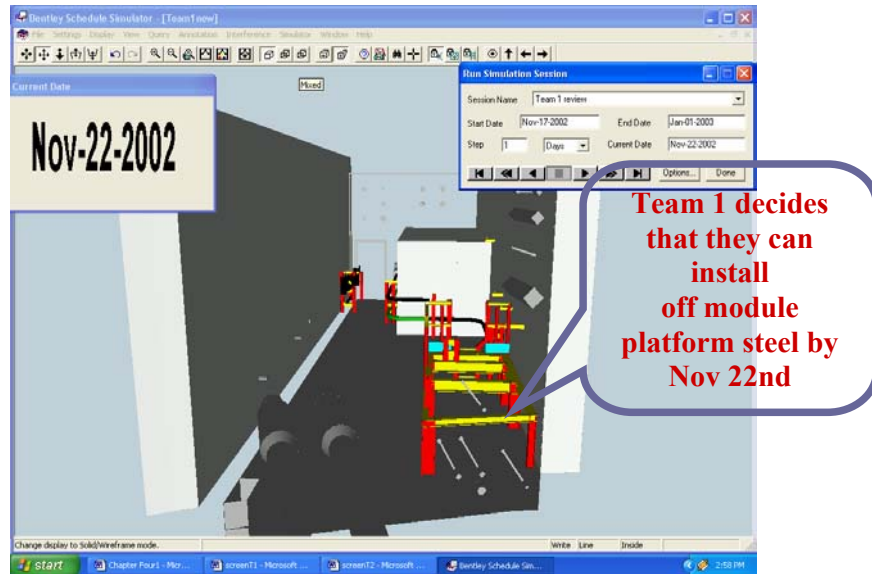


Figure 8: Team 1 – Schedule for 11/22/02 after review in the IVE

DEVELOPMENT OF AN INSTALLATION SEQUENCE IN THE IVE

After the review, the two groups were combined into one and were given the opportunity to develop an installation sequence in the IVE using the interactive scheduling technique. The team spent less than one hour developing a final sequence using the IVE.

The planners mentioned two points while developing the sequence. First, the IVE gave them a good spatial understanding of Room 12306. This allowed them to develop parallel crew assignments. Second, they gained valuable insight into possible constructability issues. They mentioned several alternatives for field weld locations.

Figure 9 shows the number of schedule days each team planned for the installation of Room 12306 during: (1) the paper based schedule development, (2) review in the IVE, and (3) schedule generation in the IVE.

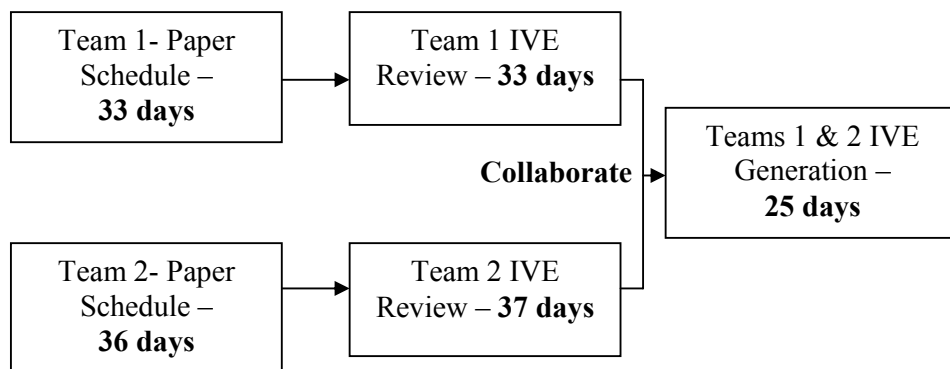


Figure 9: Schedule review and generation process

PROCESS MODEL FOR DEVELOPING CONSTRUCTION PLANS IN IMMERSIVE VIRTUAL ENVIRONMENTS (IVE)

Much was learned from these results and from the IVE collaborative planning approach. Consequently, a process model was developed to assist construction planners and future researchers develop their construction plans in the Immersive Virtual Environment (IVE). The model contains processes that need to be performed by construction planners and/or researchers to develop construction plans in the IVE. The model is organized to help planners/ researchers identify the resources, mechanisms and constraints to perform each process. The model uses the IDEF₀ modeling method (ICAM 1981). The process model for generating construction plans in an IVE is shown in Figure 10. The figure depicts four sub processes of this model. These sub processes are interdependent and can be performed in a sequential order. A detailed breakdown of the third process “Develop the 4D construction plan” is shown in Figure 11.

CONCLUSION

Construction professionals who used the Immersive Virtual Environment (IVE) for construction plan review and generation were able to reduce their planned schedule by 28%, develop a more detailed understanding of schedule dependencies, identify more constructability issues (e.g., clearances, weld locations), and improve their overall schedule confidence. One of the significant benefits noted throughout this research was the value of the IVE as a tool to foster collaborative planning with improved communication among the various project planners.

This research analyzed the use of an Immersive Virtual Environment (IVE) to improve the project planning process. By performing an exploratory study, it was possible to identify how the IVE could potentially improve project planning. The experiment results show that the IVE was an effective schedule review and generation tool, as well as a robust communication tool. It is important that further research into the added benefits of planning within a full scale immersive environment continue to be explored.

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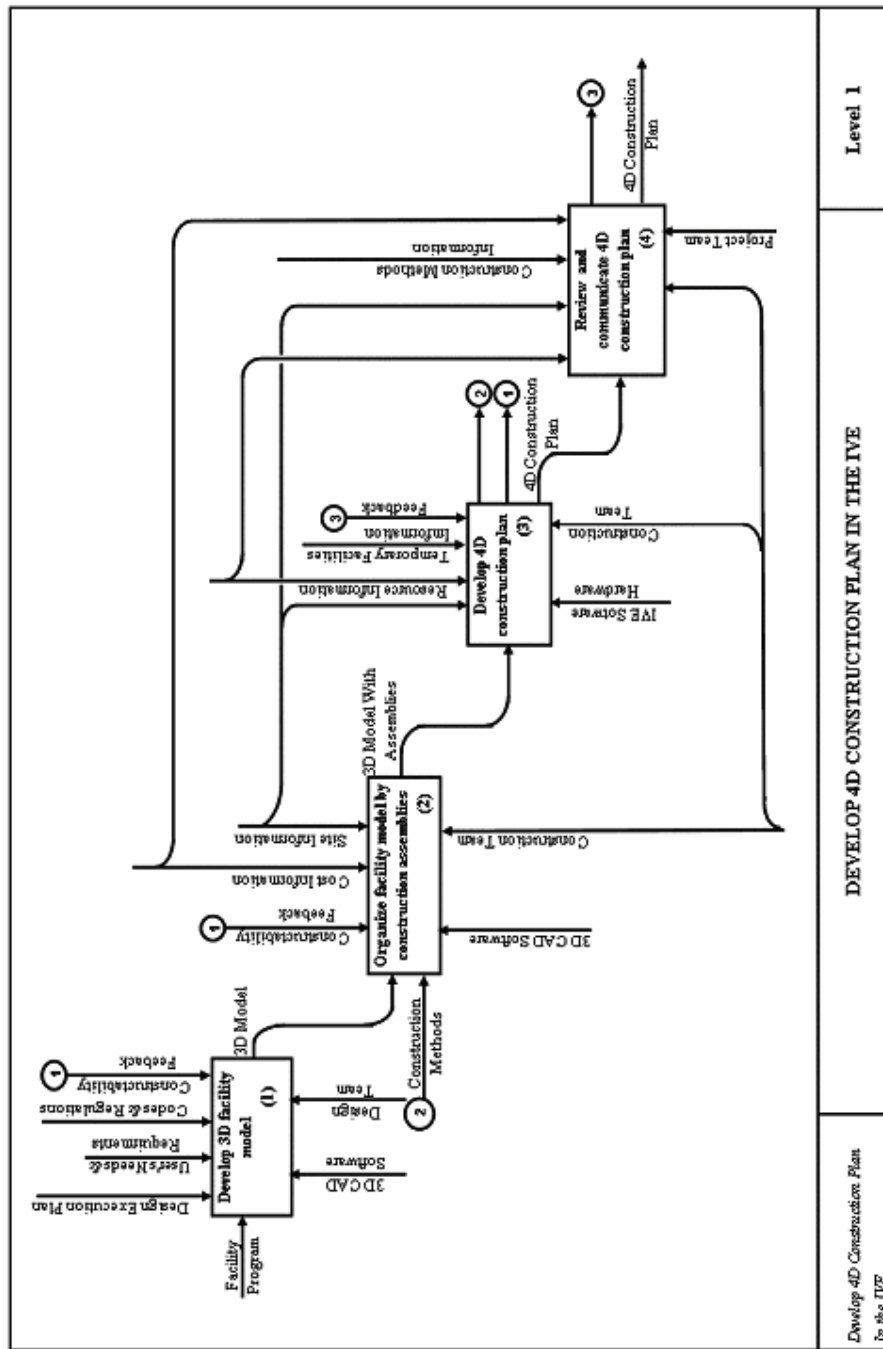


Figure 10: Develop 4D Construction Plan in the IVE Process

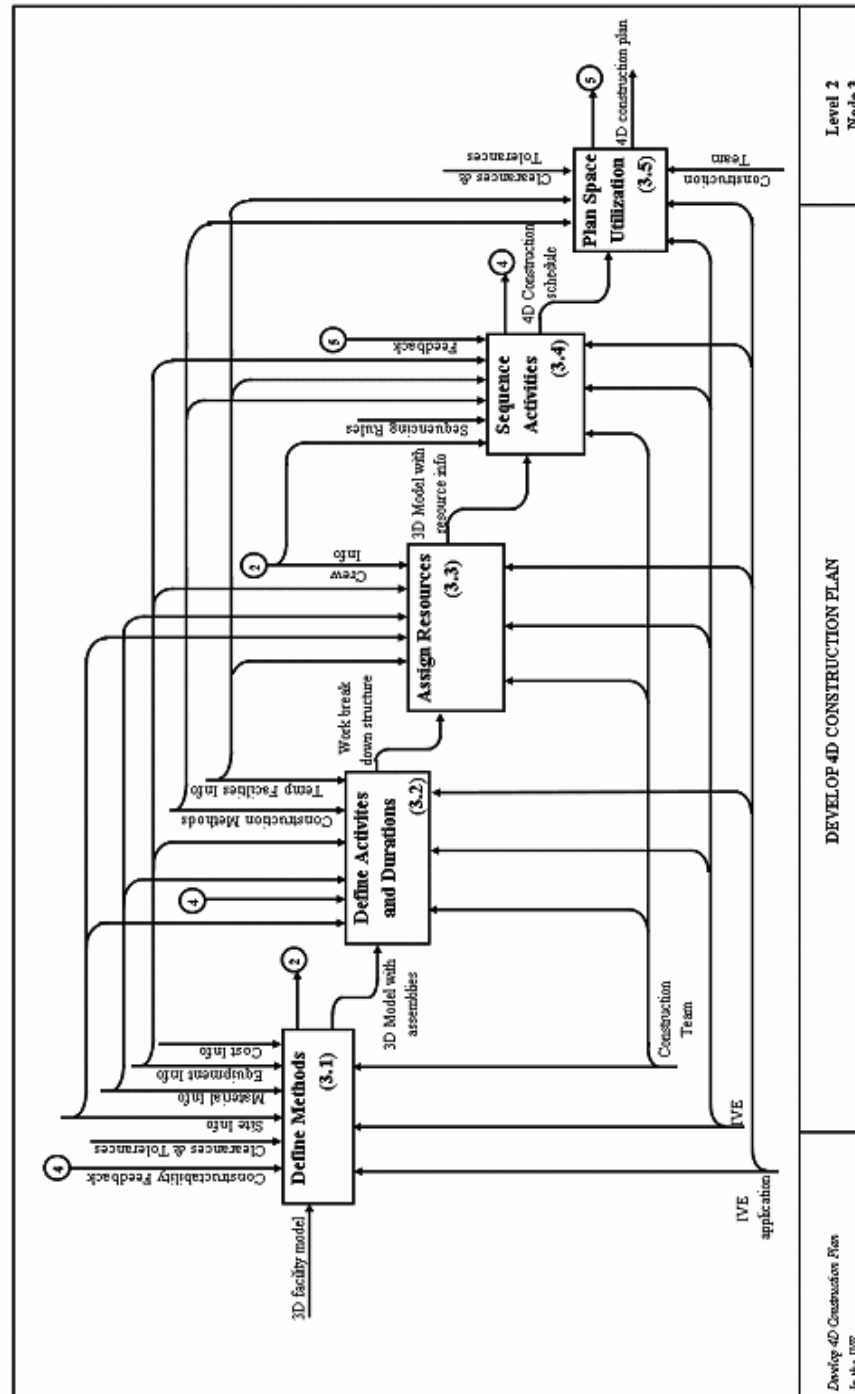


Figure 11: Develop 4D Construction Plan Process

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