

## **AC 2007-292: 4D CONSTRUCTION VISUALIZATION: TECHNIQUES WITH EXAMPLES**

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# 4D Construction Visualization: Techniques with Examples

## Abstract

In recent years, science, engineering, and technology classes have begun to greatly assimilate IT technology as an effective tool for classroom reform. The widening breadth of IT applications has come to include the development of web based “virtual learner-centered classrooms,” allowing typical classrooms to reach more extensive student populations. Traditionally construction education, especially construction scheduling, has been dependent on bar charts and network diagrams. However, students can hardly comprehend the schedule-construction progress relationship using a CPM network or a bar chart. Using 4D visualization students can learn time-space relationship in construction schedule more effectively. Scheduling is based on task activities and 4D models can help understand this process better. This paper demonstrates various 3D visualization, VRML and walk-through animation of construction progress as a function of time (schedule). The techniques to develop 4D construction visualizations are meticulously demonstrated with examples. Considering the interest of youths in computer games these days, the use of a 4D visualization will develop a lot of interest amongst them, and will motivate them to try to better understand and retain important concepts of construction. The techniques demonstrated through 4D virtual construction models can potentially be a valuable tool not only in the classroom, but also as an effective self-directed tool for open learning by facilitating the expansive power of the World Wide Web.

## Introduction and Background

Traditionally students in Civil and Architectural Engineering programs learn to analyze project designs and plan their construction by reviewing 2D CAD drawings and developing Critical Path Method (CPM) schedules<sup>1</sup>. 4D models combine 3D CAD models with project timeline<sup>2</sup>. Experience from various projects has shown that combining scope and schedule information in one visual model is a powerful communication and collaboration tool for technical and non-technical stakeholders<sup>3</sup>.

4D model of a project helps in detecting the incompleteness of a schedule, inconsistencies in the level of detailing, opened ended activities and impossible schedule sequence. This also helps in anticipating potential time space conflicts and accessibility problems. “Automating schedule data preparation and 4D model generations in the design stages of a project can expedite 4D model development and use. Users need to be able to generate 4D models at multiple levels of detail, generate, and evaluate alternative scenarios rapidly”<sup>4</sup>.

The use of 4D models and their associated database on site results in an average of 5% savings in cost growth, 4% savings in schedule growth and 65% savings in rework. Use of these tools, by the project management personnel, pre project planning, design, procurement and material management, construction, start-up and commissioning phases of a project can result in unanticipated savings<sup>5</sup>.

One of the key benefits that can be gained from VR technology is that possibility for the 3D visualization of construction plans<sup>6</sup>. These visualizations enable an improved communication over the product and its constructional processes<sup>7</sup>. It would become much easier to get all the key individuals involved in an improved way and, in particular, to take advantage of their experience and knowledge. The potential problems relating to the efficiency of the current design solution and construction plan can be more easily identified<sup>8</sup>.

“As technology rapidly changes, the importance of educating and training diverse populations of civil/construction engineering/science students becomes more critical. With the advances in information technology (IT) over the last decade, the traditional teaching format of having an individual lecture to an audience has been supplemented, and in some cases, replaced by the rapid development and implementation of new distance learning methods. Classroom use of IT for teaching science, engineering and technology has increased dramatically in recent years and has proved to be very effective in various situations<sup>9, 10</sup>. Contemporary applications of IT allow us to develop learner-centered virtual design studios that can be reached to a large student population via the web.” It was also stated that the interactive computer aided learning allowed students to proceed at their own pace, motivated by a curiosity about “what happens” interactivity and “the need to know” the design/analysis principles<sup>11</sup>.

“Animation/visualization techniques provide virtual experiential learning when combined with interactive design animation and virtual design navigation. These activities are self-directed, experiential, and personalized for the autonomous self-directed distance learner. Web based teaching and learning has potential advantages compared to traditional education since it is less expensive, easy-to-access, easy-to-update and platform independent. Although multimedia is generally considered as an individual pursuit, authors' study suggests that its use in classes with a large audience can be accommodated, provided that it is linked directly to the achievement of a specific group of learning objectives.”<sup>9</sup>

Computer technology is giving students more to learn during their school years. For the education of current students, in order for them to be productive from the first day of work, it is important as educators to give them all the foundation knowledge for their chosen field, identify current trends in technological use in that field, show how the new technology might affect the industry- both benefits and troubles, demonstrate how to utilize the technology on-site, and last but not least- identify current technology used by industrial firms. A curriculum that shows the benefits and troubles from all aspects of industry comprising everything from knowledge, technology, and industrial standards might be more beneficial than introducing them to the latest and greatest<sup>12</sup>.

Although many advances have been recently made in the area of construction visualization the main focus has been the finished product (3D CAD) or on the product as it evolves through construction (4D CAD). Very little attention has been given to visualizing the construction process that leads to the end product<sup>13</sup>.

“The use of immersive virtual reality display technology can help revolutionize the educational techniques used in engineering education. Virtual environments provide an extremely rich learning atmosphere where students gain a ‘sense of presence’ within the virtual space. This

engages students to learn from the virtual experiences that they have within the immersive environment. Another significant benefit of this visualization technology over desktop graphical displays is that students can enter a space at full scale (1:1), which adds more realism to their virtual experience. Research has shown that students learn best from their own experiences and discoveries.”<sup>14</sup>

Some of the 4D software in the market:

1. Project 4D by Common Point
2. Visual Project Scheduler Visual Engineering 4D Builder by Virtual STEP
3. Graphisoft constructor by Graphisoft
4. Builder 4D Suite by Domos

The conventional method of teaching involves using bar charts and network diagrams, which at times leaves a lot to imagination and might not portray a clear picture, leading to a flawed understanding of the construction processes. 4D model when combined with a schedule offers a clear picture of construction processes and its duration. The study aims at making a collection of 4d models of various generic components of a structure i.e. foundation, drywalls, roofing, etc. This collection would be a valuable resource that would help students understand the various facets of construction technology without the conventional problems of the traditional teaching methods.

The aim of the research was to develop a collection of interactive 4D models starting with concrete slab foundations used in residential purposes, which would help to understand this process better thereby making it an effective tool for explaining this process. This can be used for educational purpose in construction schools and on site to explain the process to workers. Further, this research developed a user interface for the collection of the 4D models for better storage and accessibility. This process could be used to produce 4D models of different construction processes, and over a period of time, a collection of such models that could be used for reference purposes. Other advantage is that the realistic stimulations of the 4D models developed in this process can be used effectively for construction education.

## **Research Methodology**

The purpose of this study was to create a library of 4D models of concrete foundations used in residential construction that could be used for educational purpose by students and faculty in school and small subcontractors. To develop the database, 4D models of three different types of concrete foundations were created - 1. Isolated Footing, 2. Raft Foundation, 3. Strip Foundation. For the purpose of this paper, the methodology of creating isolated concrete foundation is explained.

### A. Procedure for creating 4D model using 4D Builder Suite:

The following step-by-step methodology was used for creating 4D models using 4D Builder Suite:

1. A particular type of concrete foundation used in residential construction (e.g. Isolated footing) was selected.
2. All the task activities and milestones associated with the construction of the foundations were identified.
3. A schedule was prepared based on these activities using Microsoft Project 2003.
4. Detailed 2D drawings for the concrete foundation (plan and elevations) were prepared using AutoCAD.
5. Using these 2D drawings, a 3D model of the foundation in AutoCAD was prepared (Figure 1). The AutoCAD drawing was developed in such a way that all the objects pertaining to a single activity on the schedule was in the same layer.
6. The 4D model was constructed using the schedule made in Microsoft Project 2003 and the 3D model developed in AutoCAD.
7. Using 4D Builder Suite all the activities in the schedule to the corresponding layers in AutoCAD were linked (Figure 2).
8. After all the layers and activities were linked, the file was exported to 4D Viewer where the 4D animation was produced.

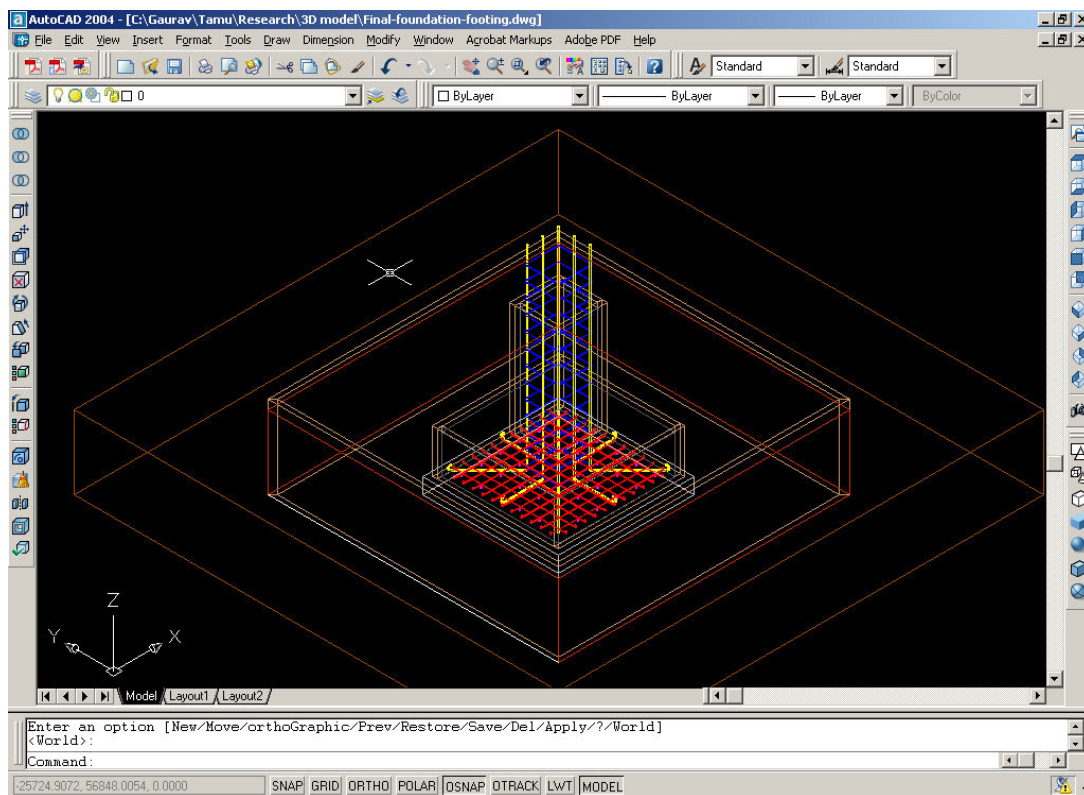


Figure 1: Creating the 3D model using AutoCAD.

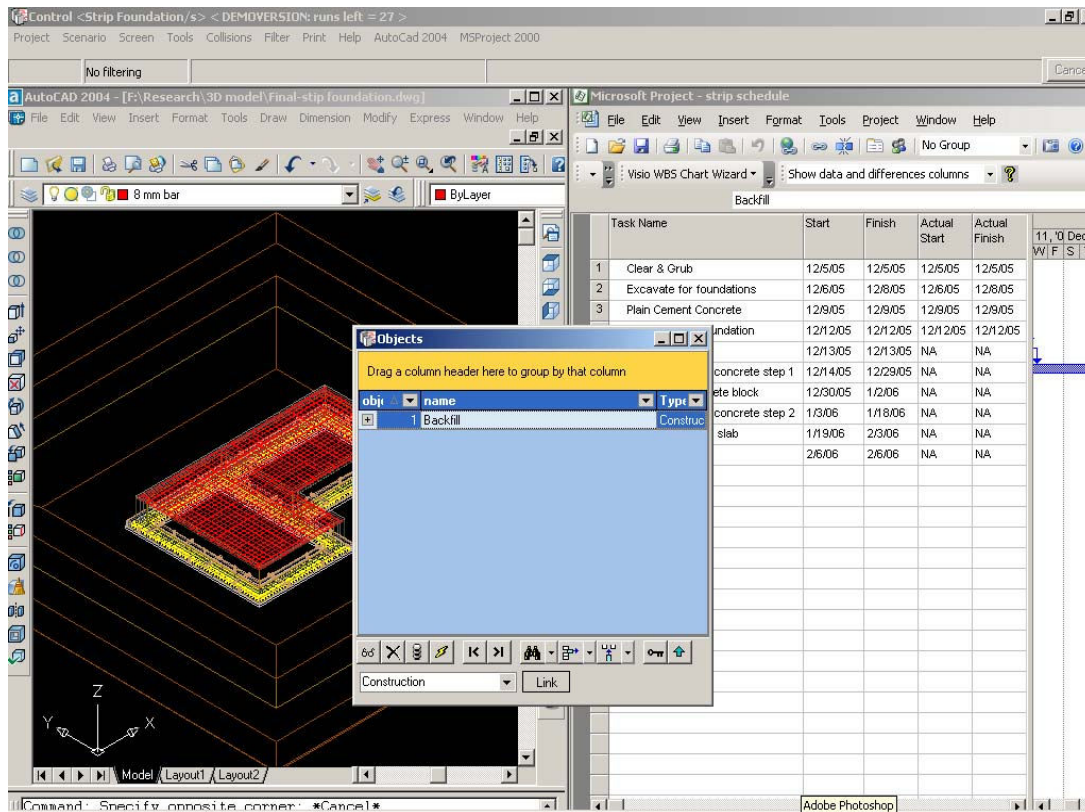


Figure 2: Linking the schedule and 3D model using 4D builder.

## B. Procedure for creating realistic rendering for the 4D model

These were developed for a better understanding of the 4D model. Due to the limited rendering capabilities of the 4D software, the output generated is mostly in wire frame. However, using this process one can create a more realistic animation of the construction process. Hence, it could be used in construction schools for explaining the construction steps in detail in order to achieve a better understanding of the process.

1. Steps 1 to 5 as mentioned previously were repeated to develop the 3D CAD model and schedule.
2. 3D model was imported into 3D Max for rendering purposes (Figure 3).
3. Materials were assigned to each layer and exported the model as a .wrl. The exported file was the VRML model, which could be viewed using any VRML viewer.
4. All the layers except the one associated with the first activity in the schedule were hidden; the image was rendered and saved as activity1.jpg.
5. The layer associated with the second activity was unhidden (keeping unhide the previous layer); this image was rendered and saved as activity2.jpg.
6. Similar steps were performed till all the layers were shown, and saved (Figure 4).

- Using Macromedia Flash an animation was created by assigning each image to the corresponding activity (Figure 5).

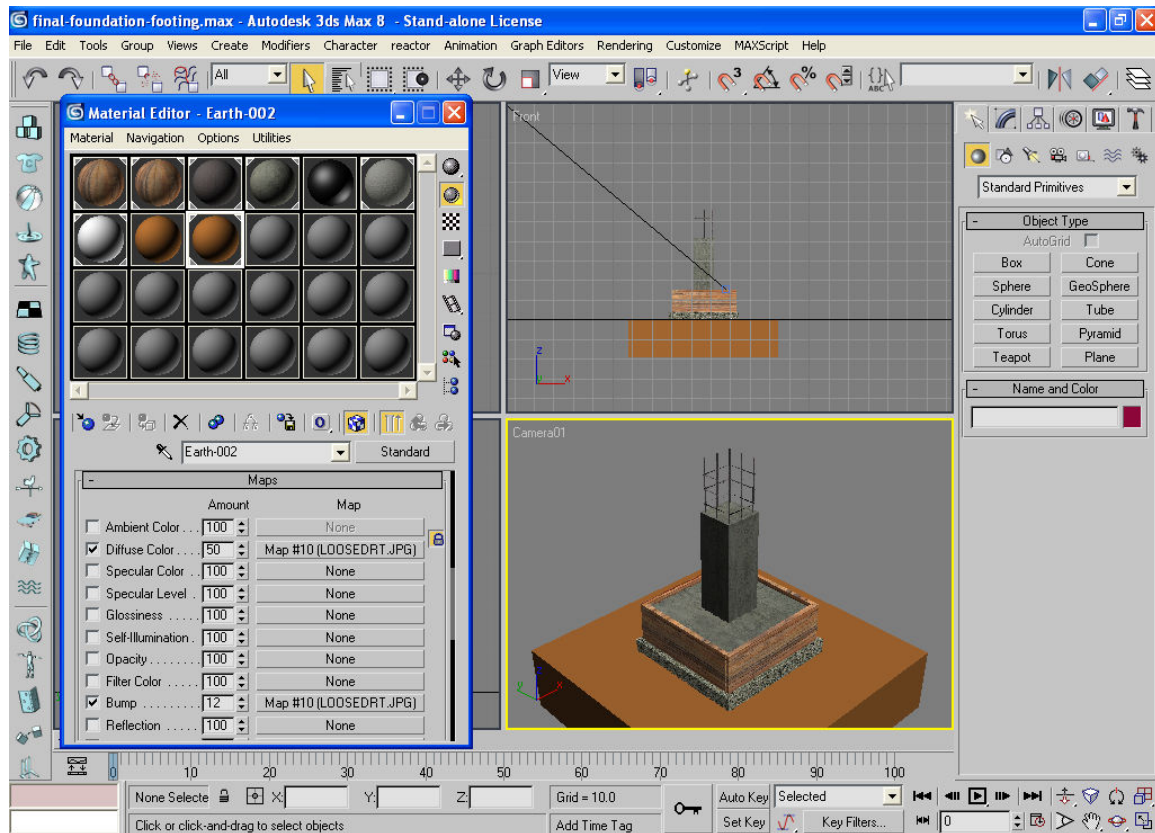


Figure 3: Creating a rendered image using 3D Max 6.

### C. Creating the user-interface for the model

The interface for this database was created in html, using Macromedia Dreamweaver, and was in a form of a website. The website comprised of all the following:

- 2D/3D drawings in .dwg format.
- Schedule – Project .mpp and picture .jpeg format.
- 4D models - 4D suite, 3D Max version and a VRML model
- The help files for creating all these models.
- Links to all the parent sites of every software and help file associated with each.



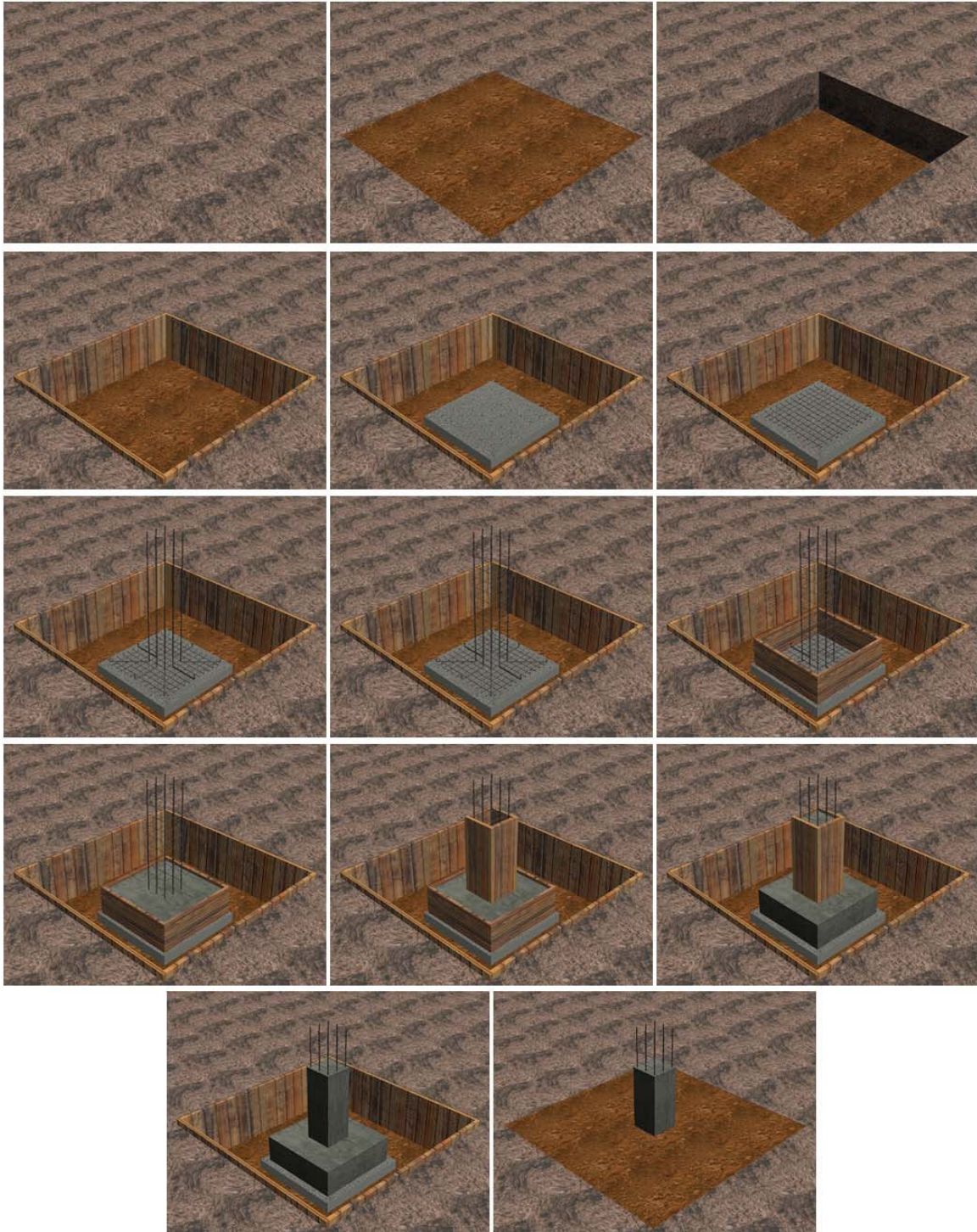


Figure 4: Rendering process of the isolated concrete foundation using 3D Max.



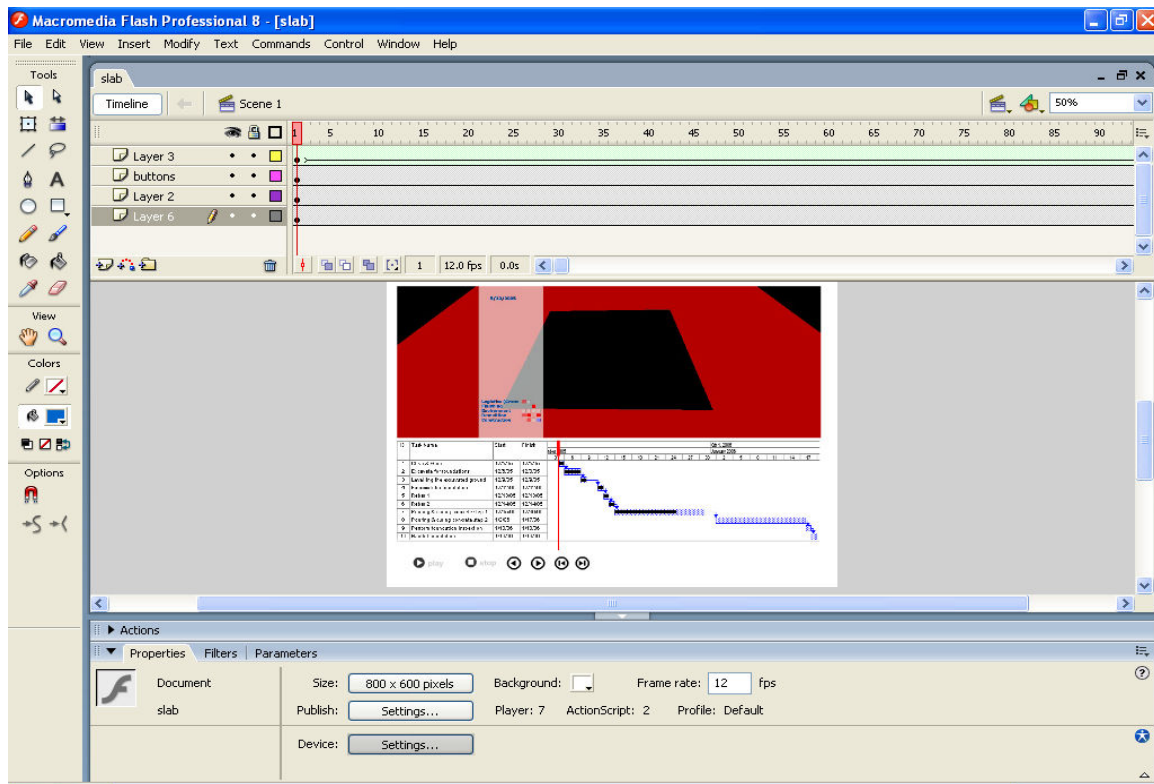


Figure 5: Creating the flash animation from the rendered images.

#### D. Creating the reference list for the 4D models

The reference list was created using Microsoft Word and this was saved as .html file using the save as command. This file can be updated using edit in Microsoft Word feature available in Internet Explorer. This reference list is used to keep track of all the files that are created while making the 4D model for future reference.

Once all the files are created they would be stored electronically and referenced appropriately. The continuous addition of new models to the database and modification of the existing would eventually build up a library of 4D models.

The methodology is illustrated on a 4D model of single-footing concrete foundation, and the Figures 6 – 8 are some of the snapshots of the procedures that were captured during the development of the model. Figure 9 shows the flow chart of the web interface structure.

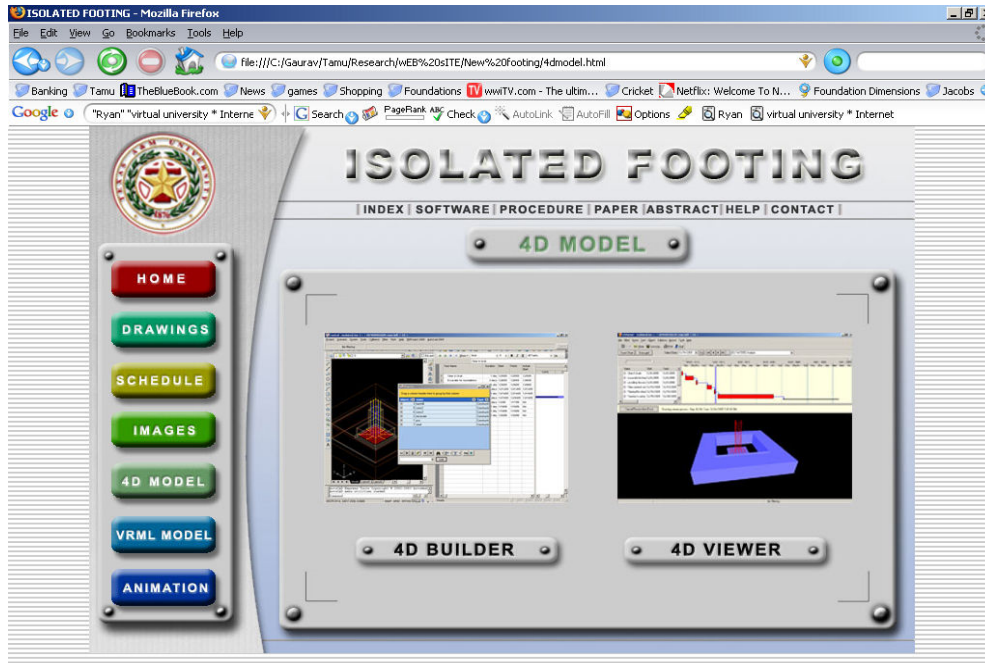


Figure 6: Development of Web Interface -1

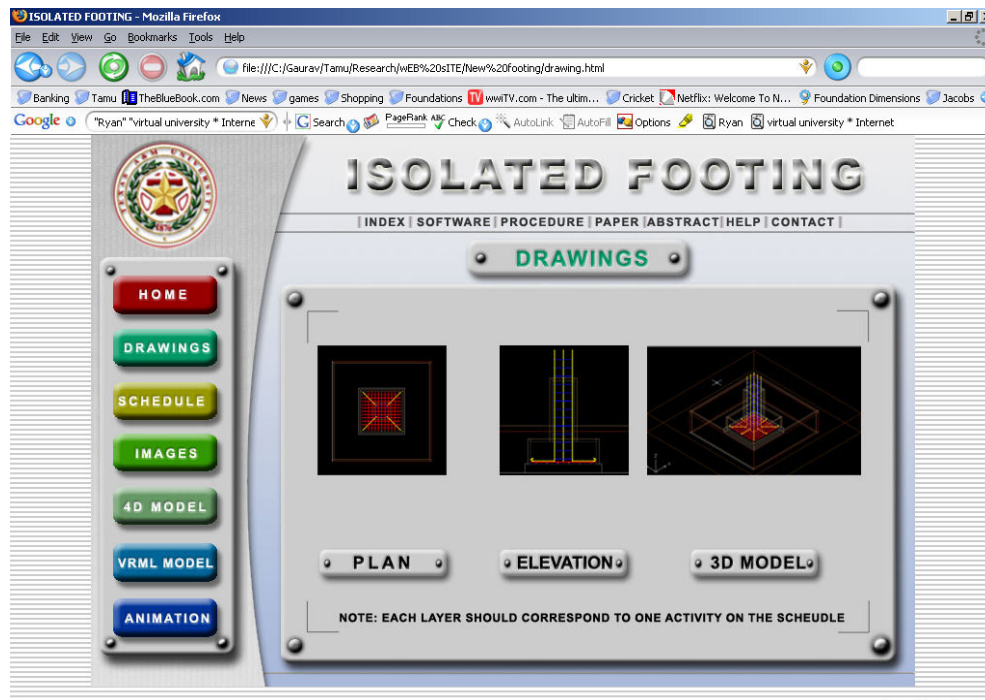


Figure 7: Development of Web interface-2

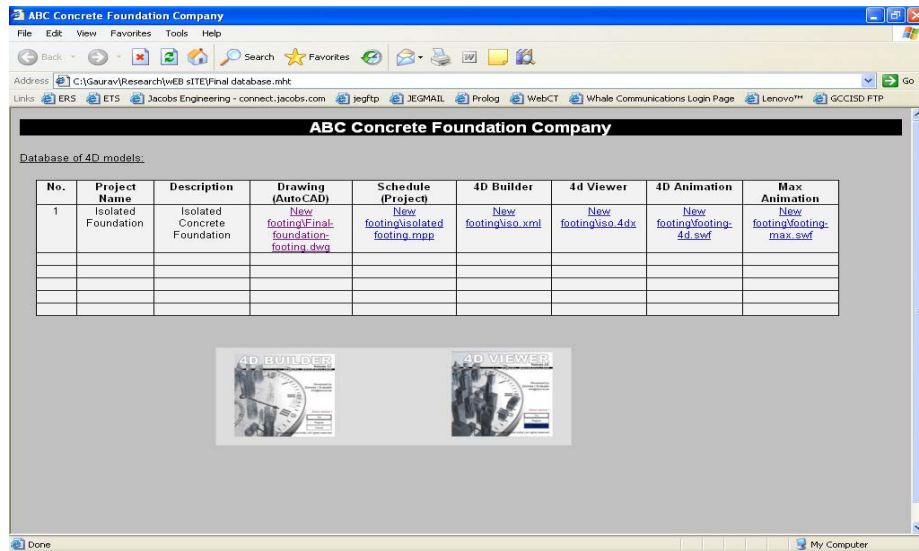


Figure 8: Creating the database

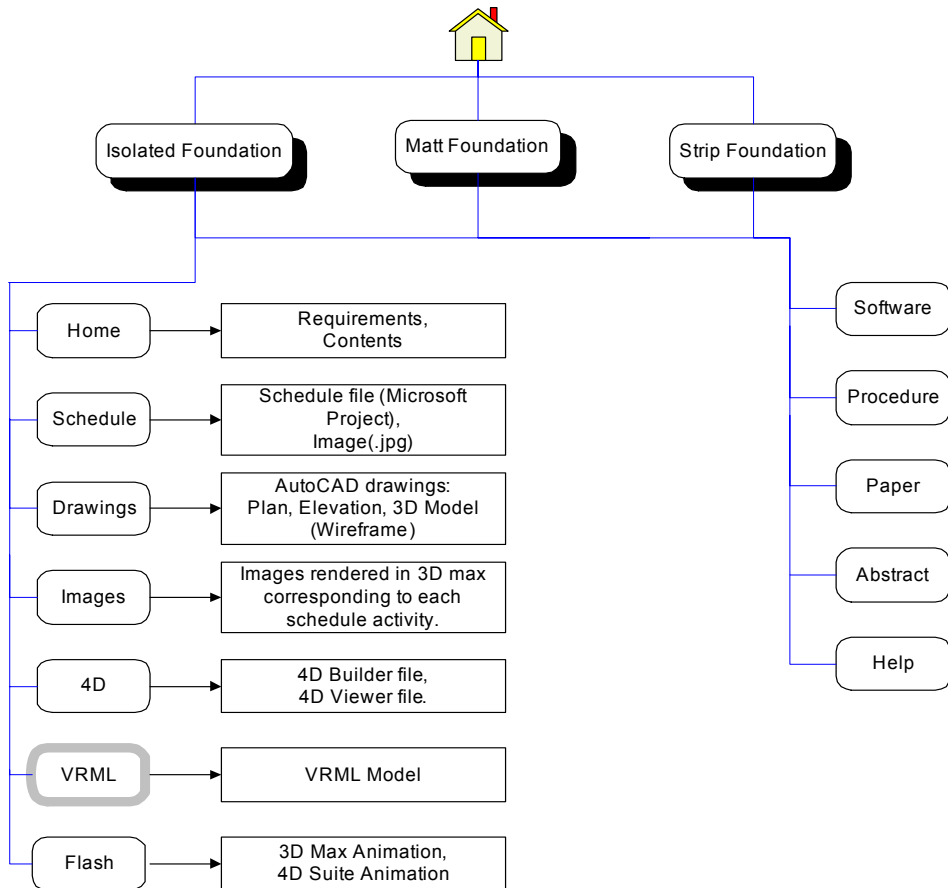


Figure 9: Flow Chart denoting the web interface structure

## **Significance of the Research**

This paper describes an online teaching tool for 4D visualization of construction process of concrete foundations. The model shows the construction sequence virtually with time. Considering the interest of youths in computer games these days the use of a 3-D computer animation with time model will develop a lot of interest amongst them and will motivate them to try to better understand and retain important concepts of construction.

The model could be a good planning tool to identify and resolve the various conflicts that might occur during the actual construction. The model could be an effective tool to explain owners, architects and subcontractors the scheduling and sequencing of construction. Construction models integrated with the schedule can be used to improve the design and planning process, which can lead to a more efficient construction process.

All the techniques that were used in this research employed a generic programming architecture, which was construction type independent, and could be adapted to other types of construction. These visualization techniques can be valuable aids not only in teaching in the classroom but also an effective self-directed tool for open learning via the web.

Finally since the instruction tool is available on a single CD or over the internet it becomes easy for students and small sub contractors to easily view it on their computers thereby increasing the potential reach of the tool. Moreover it becomes convenient for the faculty to integrate 4D into their curriculum as the CD can be distributed to each student for developing their own 4D project thereby improving their overall understanding. This will also help in the advancement of a scheduling course by adding the 4D element to it. With this tool faculty member can add this dimension to the course without much increase in their work load and at the same time impart important cutting edge technology training to students.

## **Evaluation of the Model**

In order to determine the effectiveness of the model by using it as an instructional tool was conducted in a small sample (graduate students). Initial feedback of the evaluation of the model was very encouraging. Evaluation of the model using a large sample of population (undergraduate students) will be conducted in future. This instruction model will be tested on a Likert scale of 1 to 5 to see whether the model achieves its aim or not. A survey will be developed and distributed amongst students and small sub contractors along with the CD of the model.

## **Concluding Remarks**

This study develops a collection of 4D models and animations of construction process of concrete foundations. The 4D models show the construction process as a function of time. There have been two types of 4D models developed, one using 4D Builder Suite and the other using 3D studio Max and Flash.

The first model can be effectively used to explain the construction schedule along with the scope of work to the workers on site. It enables them to have a clear picture about the scope of work and allotted time.

The second model is a realistic rendering of the construction process and can be used for educational purposes in schools. This method generates a stimulation that portrays a realistic image of the construction process. Considering the interest of the youth in 3D Games and computer stimulation, this method would generate a higher interest in learning these processes. The informal feedback from students has been very positive as being a self-learning mechanism.

These models also lead to a better understanding of the construction processes and to help identify any problems or issues that might occur during the actual construction. These also help in planning the resources appropriately so as to have the actual construction run as smoothly as possible.

A library of 4D models developed over the period can be used as a data bank for construction education. This type of data bank can eventually lead to better planning, scheduling and resource allocation for contractors and sub contractors.

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