Visualization of repetitive construction activities in Excel

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Abstract

Construction visualization provides ample benefits to planning, scheduling, and forensic analysis of repetitive construction activities. Efforts have been directed toward using state-of-the-art technologies for providing a virtual realism to the visualization of construction processes. This paper addresses the benefits that can be provided by two-dimensional animation sequences on a widely used programming environment; Excel. Examples are presented.

The system uses discrete event simulation and Visual Basic for Applications (VBA). The visualization is presented in an Excel worksheet. The work performed can be visualized dynamically during the simulation period.

The first example presented illustrates the actual construction of a residential development where the lots were made available on time to the contractor. The second example is a simulation of this same project assuming that the residential lots were not available on time.

INTRODUCTION

Visual aids are very useful in construction planning, scheduling, design and forensic analysis of construction projects (Kang, Anderson and Clayton 2007), (Fisher, Haymaker and Liston 2003), (Issa, Flood and O'Brien 2003), (Vineet R. Kamat and Julio C. Martinez 2003). Four-dimensional technology using three-dimensional CAD and time are advancing rapidly producing visualization tools that are approaching visual realism. On the other hand, great benefits can be obtained from visualization using readily available software tools. This paper addresses a model and program for the dynamic visualization of repetitive construction activities using the spreadsheet (Excel). The creation of this model requires basic knowledge of Visual Basic for

Applications (VBA). The use of the model only requires knowledge of Excel. The model presented can be applied to other repetitive processes with similar characteristics to the process demonstrated below.

REPETITIVE CONSTRUCTION ACTIVITIES TO BE VISUALIZED

There are many types of construction projects that involve repetitive activities and can be visualized with the proposed system, for example, the construction of high-rise buildings, single family residences, tunnels, pipelines, industrial buildings and others. The model presented is designed to provide dynamic visualization of the progress throughout construction.

THE VISUALIZATION MAP AND THE SAMPLE PROJECT

The two dimensional visualization model is made of a transparent image located over the spreadsheet. Figure 1 shows a residential subdivision where lot numbers are cell values in Excel. An area has been reserved in the spreadsheet for the cells with the image so that the system is generally applicable. When visualizing a different process, the image can be placed in this area of the worksheet. These cells and the image will be referred to as map-cells. The size of the cells can be as small as practically desired to obtain the required effects. Cells can be merged so that items can be properly identified. In this example, various cells are merged and the lot number shown is the centralized cell value of merged cells.

Figure 1. Lot subdivision image superimposed on Excel spreadsheet.

The sample project consists of a single family residential development. The project will be built using a different crew for each type of activity. That is, the crew working on the site will complete the first lot and move to work on the site of the second lot. Other activities will proceed in a similar fashion. A partial CPM network representation of the construction plan is shown in Figure 2.

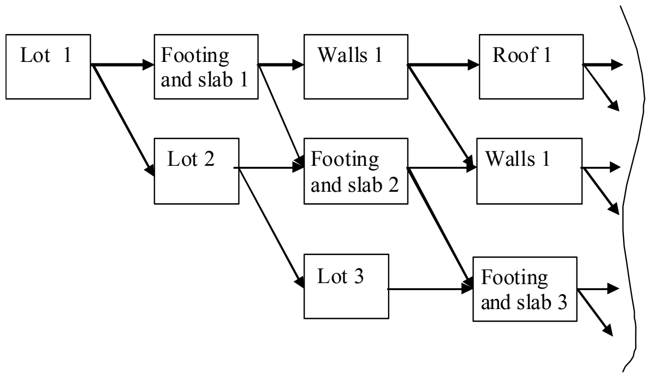

Figure 2. Partial network representation of a residential construction project.

The activities in this example are the following: Delivery of a lot to the contractor (Lot), Footing and Slab, Walls, Roof, Ceiling Plaster, Concrete Blocks, Other Plaster, Finishes (including electrical, plumbing and finish carpentry), and Punch List. It should be noted that the finishes, including electrical, plumbing and woodwork, have been grouped for simplicity. Figure 3 shows work on the concrete walls. Figure 4 shows work on the concrete roof.

The dates in this example represent the finish date for each activity and will be referred to as the data-dates. Each row starts with a lot number and continue with the finish date for the activities as shown in Figure 5, for example, lot one was made available to the contractor on Jan 12, 2009, the footing and slab for this lot finished on Jan 21, 2009, the walls were done on Feb 1, 2009, and the roof was finished on Feb 15, 2009.

For general applicability, the data-dates should always follow the format shown in Figure 5. The first cell in a row contains a label corresponding to a physical location in the map-cells. The other cells in a row correspond to event dates for activities whose description is found at the top of each column.

SOURCES OF DATA

Planned or actual data can be used with this system. Actual data-dates can be obtained from project reports or from modern remote data acquisition methods. If a scheduling system such as Primavera or Project is being used, the planned data-dates can be obtained from that program, for example, from the early start or finish date for the corresponding activity in the network.

The system provides dynamic visualization of the progress of the project as the visualization date is incremented from project start to project finish date. In our example, these dates initially represent planned dates. The second run is made with actual dates.

Figure 3. Work on concrete walls for a residence

THE SIMULATION ENGINE

A discrete event simulation program using VBA is the simulation engine. The discrete event simulation consists of starting the simulation at the start date and performing the visualization of the events that occur on that date. The simulation date is advanced and the events that occurred at the new date are visualized. This routine is repeated until the simulation time reaches the finish date. The simulation routine is shown below in pseudo code.

```
Establish the visualization period: Start Date and End Date
Start with TNOW = Start date. Start loop.
        Go over all data-dates
        When activity-date = TNOW then note the lot number and search
                map-cells for corresponding lot number.
                For each lot number found in the map-cells perform the
                corresponding visual effect in the map-cell
Increment TNOW by 1 day and loop until Finish Date
```

Figure 4. Work on residence concrete roof.

Lot #	Lot Delivery	Footing and Slab	Walls	Roof
1	12-Jan-09	21-Jan-09	01-Feb-09	15-Feb-09
73	12-Jan-09	28-Jan-09	02-Feb-09	23-Feb-09
2	12-Jan-09	29-Jan-09	09-Feb-09	04-Mar-09
74	12-Jan-09	31-Jan-09	12-Feb-09	19-Mar-09
3	12-Jan-09	03-Feb-09	19-Feb-09	27-Mar-09
4	19-Jan-09	08-Feb-09	26-Feb-09	11-Apr-09
5	19-Jan-09	11-Feb-09	08-Mar-09	24-Apr-09
75	19-Jan-09	14-Feb-09	18-Mar-09	04-May-09
6	19-Jan-09	22-Feb-09	24-Mar-09	18-May-09
76	19-Jan-09	23-Feb-09	25-Mar-09	23-May-09

Figure 5. Part of the data-dates for the sample project.

The program contains additional routines to control the start and finish dates and user selection of data to visualize. It allows the user to visualize one activity by itself through the simulation period or to include some or all other activities at the same time. This feature allows the user, for example, to visualize only lot delivery and illustrate the lot delivery pattern. Additionally, the program contains controls to make the simulation continuous or to stop at every day.

Visualization is achieved by producing visual effects on the map-cells as time progresses. In the example project shown below, the visual effect is to change the cell fill color to the color corresponding to the activity being executed. Other visualization effects available in Excel for every map-cell are the fill color, fill effects, pattern color, and the pattern. Additional visualization effects are related to the font of the identifier in the map-cell, for example type of font, font size, font color, and others.

Other effects can be created with VBA including moving objects such as a photo or diagram, creating graphics and others.
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The control and information panel is located to the right of the map-cells as shown in Figure 6. It provides for user input and for real time information as visualization progresses, including Time Now, which is the date corresponding to the progress visualized at a particular point in time. The user input items included in the panel are the following:

- Start and Finish Date
- Run which indicates the activities to include in the visualization. Activities are identified by a number in the box titled "Available Runs" in Figure 6. For general applicability, these correspond and are copied from the activity description at the top of the date-dates in the same order of the columns. The system also allows the user to visualize the progress of any two activities in the same simulation run by entering two activity numbers as input for Run. This can be used to pinpoint changes in the pattern of work between the activities.
- Manual or Automatic, which indicates if the user wants the visualization to stop at every data date and wait for the user to press "Enter" to continue, or to run automatically up to the finish date.

The data shown on the screen during the visualization are the following:

- Date as time progresses through the visualization called Time Now.
- Activity Actual and Previous: This information is additional to the effect shown in the map-cells. It includes the number of the lots with an activity finishing at date Time Now. It also shows the lot number for the previous event. It is a ready reference of the previous event shown. There is space for two activities to be tracked in the same visualization run.

The program collects statistics for each visualization run including the time between the execution of each activity and the lag time between the execution of its predecessors.

The sample project is run first with planned data. The start date of the sample project is January 12, 2008. Initially Time Now is set at the start date and is incremented up to the first event, when the corresponding progress is shown in the map-cells. If it is in automatic mode it continues incrementing Time Now and updating project progress. This dynamic visualization is very valuable in understanding how the project is to be built. For illustration purposes, the screen is shown when Time Now is May 9, 2008 in Figure 7. The status of work in each lot is visualized by different colors. The color legend is shown within Figure 7. The seventeen lots that have not been delivered to the contractor are not colored. There are two lots that have reached Punch List: Lots 3 and 74. There are three lots with the finishes completed: lots 9, 75,

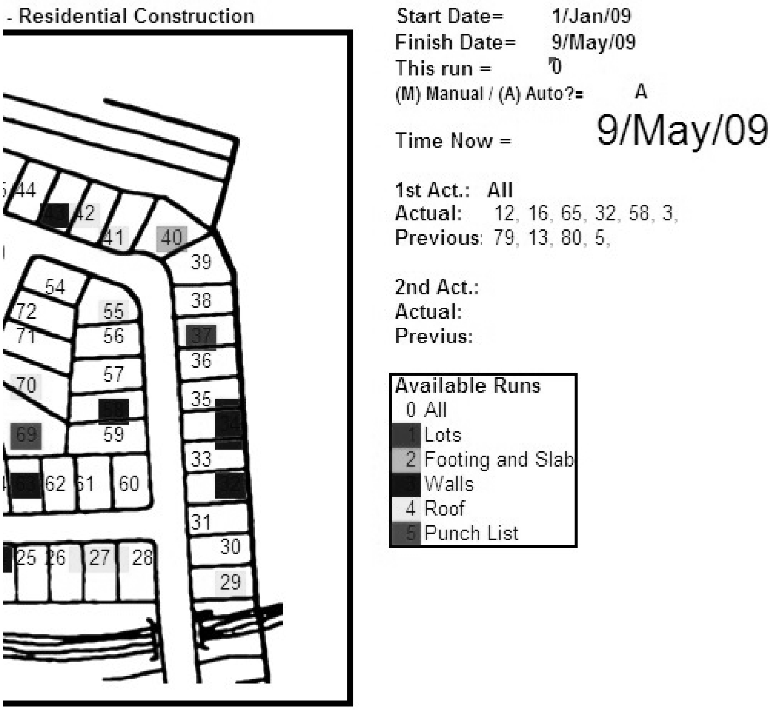

Figure 6. Part of the map-cells with the Control Panel to the right

77. There are twelve lots with the concrete blocks in place: lots 6, 7, 10, 12, 15, 18, 76, 78, 79, 80, 81, 82. There are twelve lots with ceiling plaster in place: lots 11, 14, 16, 17, 19, 20, 22, 23, 24, 26, 62, 63, 64. There are twelve lots with the concrete roof in place: lots 21, 25, 27, 28, 29, 30, 31, 32, 33, 61, 65, 66. There are seven lots with the walls in place: 56, 58, 59, 60, 34, 36. There are six lots with the footing and slab in place: lots 35, 37, 38, 40, 54, 55, 57. As seen in Figure 7, the project plan is to work with lots along the streets close to each other.

Color is key in providing visualization in this system. The figures in this paper will be published in grayscale and the reader may not appreciate the full value of the visualization. Color will be used during the presentation. The author will provide electronic copies of this paper in color by e-mail. Send request to jlluch@uprm.edu.

The second run was made with actual dates to visualize the problem created by the delivery of lots to the contractor with delays and in a sequence very different from the sequence initially planned. To continue working in the out-of-sequence lots, the contractor incurred productivity losses resulting in delays.

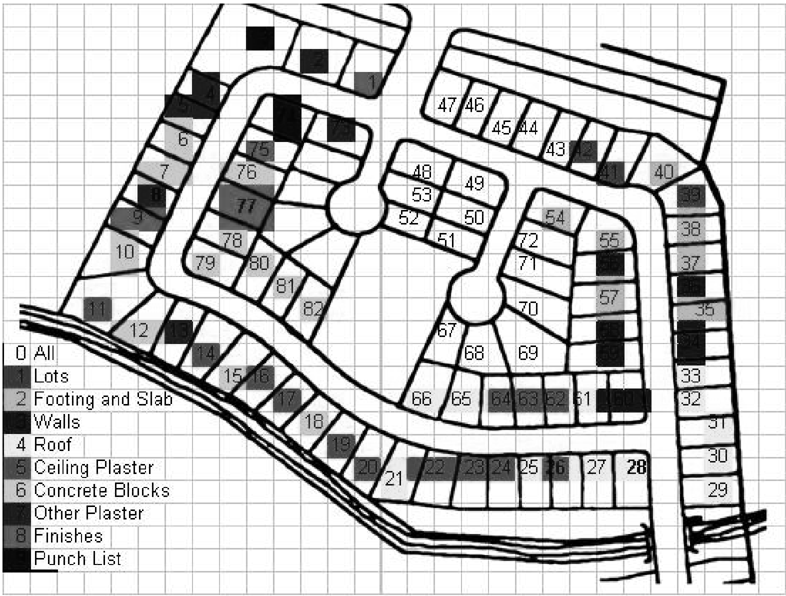

Figure 7. Planned project status on May 9, 2009

Figure 8 illustrates the actual progress of the work on May 8, 2009, the same date as in the previous figure. There were 41 lots to be delivered to the Contractor. The actual progress in each lot at the specified date can be obtained directly from this figure. The dynamic visualization while the program is running clearly shows the irregular delivery of lots and the pattern of work followed by the contractor to avoid further delays. The productivity delays occur due to learning curve effects, increased travel distance, problems with communication and supervision, material location and handling problems among others.

The system is being used in an arbitration procedure in a case similar to the sample project.

FUTURE WORK

This visualization program was created with general applicability for repetitive construction processes that can be modeled by changing cell color in the map-cells, with the visualization time increment equal to one day, and with a capacity of fourteen activities. These limitations can be overcomed with more VBA programming. Another improvement to the system could be features to collect statistics on idle time when visualizing the start and finish date of activities.

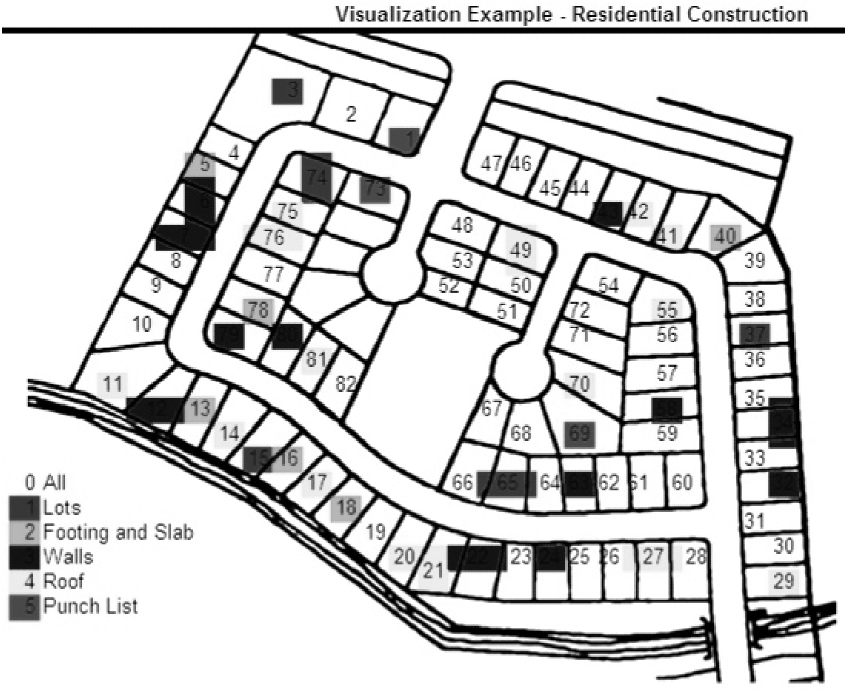

Figure 8. Actual project status on May 9, 2009.

This system can also be used for visualizing repetitive earthmoving operations if the image placed over the map-cells corresponds to the area where the cut, fill and travel path of the equipment take place. This requires that the system be modified so that the simulation time is in minutes instead of days. The activities are loading, traveling, unloading, returning, and waiting to load, among others. The data-dates would represent event times for the activities. An event time can be the start or the finish time of the activity, and each event is represented by a different color. A white cell background can represents no activity. Images of typical construction operations could be included in the system for user selection.

Planned data for earthmoving operations can be developed using techniques for specifying activity durations in CYCLONE simulation (Halpin and Riggs 1992), (Lluch and Halpin 1982). It could include Monte-Carlo simulation techniques where activity durations are derived from ramdom sampling a probability distribution that has been fitted to sample data. The beta probability distribution has been used for this purpose.

Future work could include making this tool part of a construction planning, scheduling and control system. Extensions such as cost and other resources could also be added.

This system can be used as a teaching tool in the education of construction professionals and in training field personnel at the job site.

CONCLUSION AND RECOMMENDATIONS

The system created using the Excel spreadsheet and VBA provide a very powerful visualization tool. The system can be used for different types of construction projects including high-rise buildings, single family residences, tunnels, pipelines, industrial buildings and others, and can be adapted for construction operations such as earthmoving. The visualization provided is valuable for project planning, scheduling, and control. The system is actually being used in the forensic analysis of a project for delay identification.

If "an image is worth a thousand words," then this visualization program multiplies these since it provides dynamic visualization of the project status as time progresses. The system presented is worth many millions of words.

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