Designing and Evaluating Visualization Techniques for Construction Planning

Kathleen Liston\textsuperscript{1}, Martin Fischer, and John Kunz\textsuperscript{2}

Abstract

Construction project teams view project information with traditional paper-based methods that have remained largely unchanged with the advent of computers and electronic project information. Observations of project teams show that these methods fail to support critical group decision-making tasks because they do not communicate relationships between project information. There is an opportunity to design and evaluate the use of visualization techniques to visually communicate relationships between project information. This paper discusses our research efforts to prototype and evaluate two visualization techniques - highlight and overlay - that visually relate project information.

Introduction

Today, AEC professionals produce project information in electronic form with discipline-specific tools. Much research has focused on developing methods to integrate this information and standardize how AEC data and their relationships are modeled [IAI 1998]. Large scale displays to view these information models are becoming economical. However, no tools provide functionality to visually communicate the relationships between project information. Consequently teams must spend a lot of time mentally relating project information to support decision-making tasks [Fischer et al. 2000]. Visualization techniques that visually communicate the relationships between project information can potentially improve a team's ability to relate project information and improve the overall decision-making process. Consider the following hypothetical scenario in which a project team uses a CIW with two visualization techniques -highlight and overlay - to review a project schedule (Fig. 1):

\textsuperscript{1} Ph.D. candidate, Department of Civil and Environmental Engineering, Stanford University

\textsuperscript{2} Associate Professor of ….
On the walls of the room are electronic views and icons representing various project information such as the schedule, the 4D model, and project status information. Instead of a paper agenda, there is an interactive electronic agenda. When a team member selects an agenda item the relevant project information is highlighted. The CIW also displays all of the available project documents and information. In the CIW the project team can overlay any project information onto a spatial or temporal view, thus enabling team members to quickly view relationships between project information. For example, when the general contractor asks "When can we have access to Area C?" the team can easily compare contract requirements against current project information by overlaying information onto other information. Thus, the team doesn't have to spend much time on these comparative tasks and can spend more time reviewing and evaluating the information. The team can easily view critical relationships between the information views because related items in the 4D view, Gantt chart view, cost view, and resource view are highlighted. As problems are identified, the team can quickly understand the constraints and rationale and explore solutions by making changes to project information and quickly view the

Figure 1: Comparison of Paper-based Project Information Today with Future Construction Information Workspace. Project information today with no visual relationship between project information and a Construction Information Workspace with highlighting functionality to show relationships between project information.
impacts of those changes on other project information. The team leaves the meeting with a shared understanding of the issues discussed and is satisfied with their solutions.

The two visualization techniques - highlight and overlay - enable the team to focus on the relevant information, productively interact with the information and visually relate information. The team can better describe and explain relationships between information and compare or evaluate the project information. The project team can spend more time performing predictive tasks and more efficiently evaluate design or schedule alternatives. In the following sections we describe these techniques in more detail and present methods to evaluate their effectiveness for team decision-making. The goal of this research is to quantify to what extent these techniques improve the overall decision-making process.

Use of Highlighting to Visually Relate Project Information

Generally, highlighting is the process of emphasizing information. We define highlighting as the process of emphasizing, through visual annotation, related sets of information within a view and across multiple views (Fig.2). Highlighting is tightly coupled with the specific task and context. Thus, the process of highlighting has two parts: the interaction that defines the task/context and the visualization of the specific project content. The proposed work envisions the following types of 'highlighting' actions:

- **Selection of an object (building component, construction activity, resource, specification or contract item, cost item, etc.)** → highlight all related project information. For example, the selection of a specification item would result in the highlighting of related items, such as Area C, and activities related to that item.

- **Selection of spatial region** → highlight project information related to a spatial region, e.g., all components that occupy that space, all activities occurring in that space, all resources occupying that space. For example, the selection of Area C would highlight all activities that occur within that region.

- **Selection of temporal region** → highlight related project information within a temporal region (time frame), e.g., all activities that occur during that time frame, all resources performing work during that time frame. For example, the selection of a one week time frame would result in the highlighting of the building components that have activities being performed on them during that time frame.

- **Selection of an object (building component) → Apply Highlight Filter (i.e., choose to only highlight specific types of project information)** → highlight selected types of related project information. The selection of a building component and then a filter selection of specification items, would result in the highlighting of specification items related to that component.
Use of Overlaying to Visually Compare and Relate Project Information

Overlaying is the process of placing one set of information onto another set of information that results in one 'merged' view (Fig. 3). The proposed work will implement the following types of overlaying actions:

- **Document to document of same type:** e.g., placing a Gantt chart onto another Gantt chart. For example, overlaying the general contractor's schedule onto the owner's milestone schedule would result in 'lining' up the general contractor's milestones with the owner's milestones enabling the project team to visually see differences between those milestones in one view.

- **Object(s) to document of same type:** e.g., placing a set of activities onto another Gantt chart. The team could overlay the milestone activity for turnover of Area C onto the general contractor's schedule to quickly see potential problem.

- **Document to document of different type:** e.g., placing a 3D model onto a Gantt chart. This might result in small images of the components related to specific activities.

- **Object(s) to document of different type:** e.g., placing a building component onto a Gantt chart. The team could overlay Area C onto the schedule to identify activities related to that area.

Today, documents and objects can be 'drag and dropped' into other documents as long as the underlying document supports some mechanism to represent that object within the application. Typically the object is placed in the document without changing its original form and the underlying document and its contents are only changed to allow the insertion of the new object. Overlaying, however, will change the form of the overlaid object or document to the underlying document's form where necessary and add content to the underlying document. For example, if a schedule document is overlaid onto another schedule document, the form of the overlaying information will not change, but annotative content will be added to the underlying information to communicate the differences between the two schedules. If a 3D model is placed on a Gantt chart, the 3D model will change from geometric-based form to textual or iconic form to show relationships between 3D model components and activities in the Gantt chart.
Prototyping Overlay and Highlight Techniques

The scope of the research involves prototyping visualization techniques in a Construction Information Workspace environment. That is, this research is not directly involved in the implementation of these techniques. Instead, we leverage, where possible, other research efforts such as those described in Froese and Yu [2000] and the Interactive Workspace technologies [Winograd and Hanrahan 1999]. The prototyping uses the following technologies:

- **Workspace event heap**: this enables messaging between views in the workspace. For example, when an item is selected in one view, a message is sent with specific instructions, such as, 'highlight' all items related to Area C.

- **HTML/Flash**: These technologies enable the production of interactive visual interfaces.

- **Workspace XML database**: The database stores the types of project information available, relationships between objects, current views, and available types of viewers.

This prototyping strategy enables us to quickly generate a variety of examples to test and explore their effectiveness.
Evaluation of Overlay and Highlight Techniques

We are evaluating these techniques using a set of test trials to compare these two techniques. The goal of these test trials is to identify 'fits' [Vessey 1991] between visualization techniques and decision-making tasks (Fig. 4). These fits map characteristics of visualization techniques to characteristics of decision-making tasks and assess to what extent the visualization techniques improve the performance of those tasks. For example, we may find that for descriptive tasks that require project teams to relate three or more types of project information, the overlay technique yields the best performance.

The two main test hypotheses are:

- Overlay and Highlight techniques will reduce time spent performing descriptive, evaluative, and explanatory tasks
- Overlay and highlight techniques will reduce the influence of task complexity on task accuracy and task completion

The test trials are based on the Charrette Test Method [Clayton et al. 1996] in which users perform a specified design task within a specified time period, using two different processes. In the test trials users are asked to perform a set of tasks. Test participants are given a specified amount of time to read a description of the project, their role in the project, and the questions that they will ask during the 'test meeting.' All test participants perform the test in either the CIW room or CIW web-based environment.

Each group is given the same set of twenty pre-defined questions and tasks to perform (See following table), designed as follows:

- 5 questions of each task type: 5 descriptive, 5 evaluative, 5 explanatory, and 5 predictive
- The predictive questions will be designed to incorporate the results of a descriptive, evaluative, and explanatory question. The questions will be organized into five sets.
- For each task type, the tasks will represent three levels of task complexity, as measured by number of types of inputs and types of relationships between project information. For example, the task, "When do I have access to Area C", requires four types of input and requires the team to relate time to space and to textual information.
- The tasks will use spatial, temporal, semantic, quantitative, and symbolic information
- The tasks will use temporal charts, 2D, 3D, 4D, text, and charts

Figure 4: Example of A Fit between a visualization technique and a Decision-making Task Type
<table>
<thead>
<tr>
<th>Question</th>
<th>Information Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Who asks, Owner or GC) Question</td>
<td>Form type</td>
</tr>
<tr>
<td>(O) What milestones have changed in revised schedule?</td>
<td>2 Temporal Schedule</td>
</tr>
<tr>
<td>(O) How is the GC sequencing work in the lagoon?</td>
<td>3 Spatial Temporal Textual 4D with zones Work assignments</td>
</tr>
<tr>
<td>(GC) Why is the lagoon work broken into 6 zones?</td>
<td>2 Spatial Textual Resources Drawings/3D</td>
</tr>
<tr>
<td>(O) Why are they sequencing the work in that direction?</td>
<td>4 Text Spatial Temporal Resource constraints Workspace constraints Milestone dependencies Procurement Information</td>
</tr>
<tr>
<td>(O) Do they adhere to the specification that they need 5-7 days curing for all lagoon walls?</td>
<td>2 Text Temporal Specification Schedule</td>
</tr>
<tr>
<td>(O) Does revised lagoon construction meet specification for test and adjust envelopes?</td>
<td>4 Text Temporal Spatial Specification workspace 3D Schedule</td>
</tr>
<tr>
<td>(GC) Can we get access to the lagoon area #4 a week earlier?</td>
<td>3 Temporal Spatial Textual Schedule Specifications Contract</td>
</tr>
</tbody>
</table>

The only testing variable is the visualization technique: no annotation, highlight, or overlay. That is, one group will answer these questions with traditional views of project information and the other groups will perform the tasks using either highlight or overlay visualization techniques.

As the test participants try to answer each question, the following information is recorded:

- **Time to answer each question.** This will determine how much time they spent on specific types of tasks. Time will be recorded via the computer.

- **Questions they ask as they are trying to answer/complete the task.** This will figure into the overall analysis of types of tasks users perform. This data will be recorded manually.

- **Answer to question.** This will be entered into the computer and recorded electronically.

By recording this observational data we will perform the following types of analysis tasks:

- Average time/task for each visualization technique
- Average time/type of task for each visualization technique
- Average time/information type for each visualization technique
- Time/# of targets for each technique
- Average Accuracy/visualization technique
- Average task completion/visualization technique

Based on these results and further analysis, we will test the hypothesis and identify potential fits.
Conclusions
The two main contributions of this research are:

- empirical evidence demonstrating the usefulness of construction information visualization techniques. This evidence could be used to produce a ‘wishlist’ of visualization functionality to support those techniques.
- demonstrate and quantify benefit to the use of AEC data models. Since the implementation of these techniques is dependent on an underlying data model, this research will provide examples of the value of implementing a standard AEC data model.

The first set of test trials will be performed in May 2000 and results available online in July 2000 at fourd.stanford.edu/test-results/main.htm.

Acknowledgements
We thank the Center for Integrated Facility Engineering at Stanford University and the Interactive Workspace team from the Department of Computer Science [Winograd and Hanrahan 1999].

References