Designing and Evaluating Construction Information Workspaces

1.0 Introduction

The proposed work envisions a new type of construction information technology (CIT), an interactive environment called a *construction information workspace* (CIW), that visually communicates construction information and their inter-relationships to support group tasks, such as project review and project coordination and most importantly decision-making. Today, construction project teams must manage ever-increasing amounts of construction information, spending more time producing, changing, organizing, and reviewing project information and trying to understand how project information relates (Fig. 1), than using project information to optimize and achieve project goals. Current research efforts in CIT at the Center for Integrated Facility Engineering (CIFE) and similar research centers focus primarily on the back-end functionality of large information spaces, such as data modeling [1], integration technologies, and information brokers [2]. The proposed research focuses on the 'front-end' or the user interface of an *information workspace* [3, 4]. The primary goal of this research is to identify characteristics of workspace visualizations that are useful to project teams and improve the utility of the already existing project information and to measure the *value* of these visualizations.

To date, research at CIFE related to CIW [12] has involved prototyping workspace environments to support various project team scenarios. While this work demonstrates a 'proof of concept' for CIW, there is a need for identifying what types of CIW functionality can improve a project team's ability to make decisions. To do so, this work will evaluate two types of visualization techniques - highlighting and overlay - in a CIW environment through a set of test trials. For each test trial we will use two sets of metrics: 1) performance-based metrics, e.g., number of tasks teams can perform, types of tasks, and completion and accuracy of tasks to measure how the techniques improve task performance
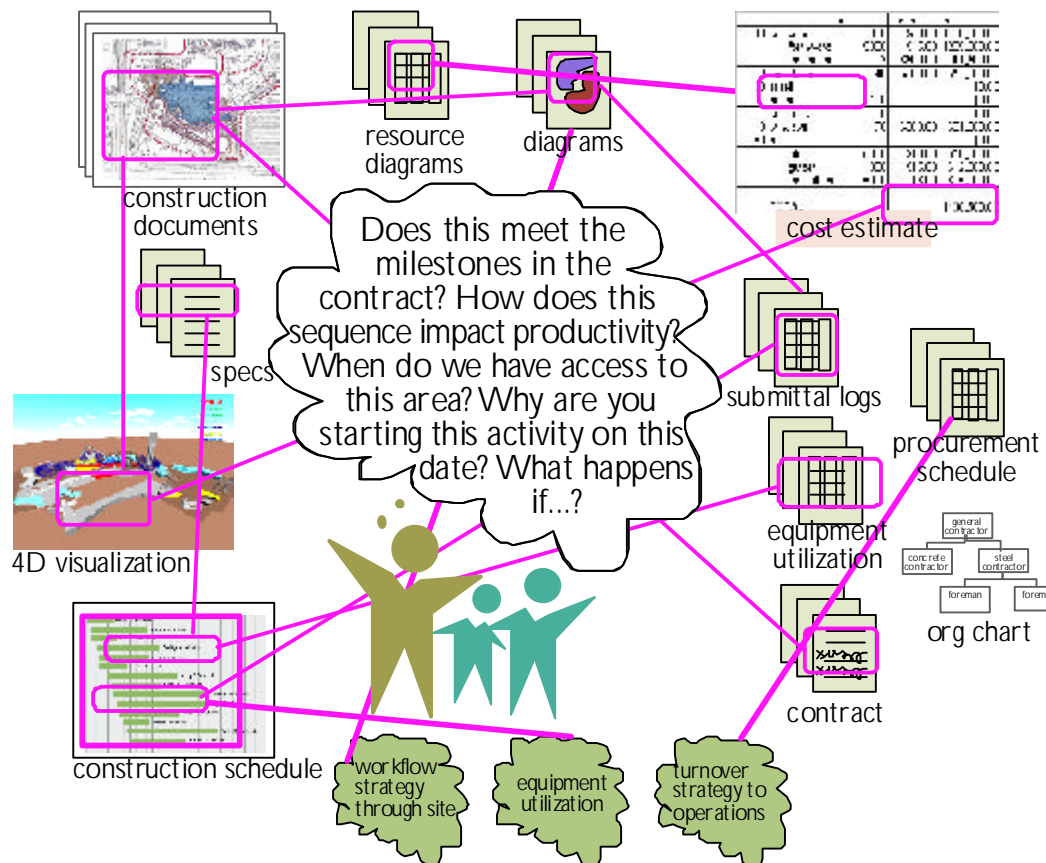

Figure 1: **The Decision making process as a set of tasks/questions to describe project information, explain relationships between project information, evaluate relationships between project information and predict impacts of changes on project information**

2.0 Motivation

Construction project teams must consider a wide variety of information when making project decisions. Much of this information is produced electronically and visual in nature, yet teams primarily use paper-based views of project information that do not communicate critical relationships between project information or adequately highlight the important and critical information. Consequently, project teams spend far too much time trying to understand and describe project information to one another and little time actually using information to support decision-making and solve problems. To illustrate this, consider the following observation of a schedule review meeting:

> *On the walls of the conference room are 2D construction drawings and the project Gantt chart (Fig. 2). Each meeting participant has handouts consisting of the schedule, which contains 8,000 activities, and the meeting agenda. Participants have brought other types of documents to the meeting such as 'marked-up' schedules, some contract documents, and construction drawings. The meeting begins with the first agenda item, 'Schedule Comments.' This discussion involves the owner asking questions such as: Does the schedule meet contractual milestones? Do these activities adhere to project specifications? Why are you finishing this facility on this date? What if we change this milestone date? What if the equipment is late? Throughout the meeting, project participants are distracted as they shuffle through the schedule sheets searching for activities or as they scan the walls searching for relevant information, trying to understand the schedule and the issues at hand. Meeting participants come and go. Some leave to get information such as project specifications or to get updated information. In some cases, a document is passed around for participants to review. By the end of the meeting, twenty types of documents have been referred to or used as participants try to describe, understand, review, and evaluate the schedule. Various people have marked up their schedules or other documents, but no one leaves with the full documentation of the comments, to do items, or issues addressed in the meeting. More importantly, although several problems were noted, no problems were resolved during this meeting nor during the successive three meetings.*

Did the information aid their decision process and did the team fully utilize the information they produced? The team covered many of the agenda items, but at a cost to the project because the team spent no time solving problems or making any decisions. Further analysis showed that only 10% of the time in these meetings were spent performing predictive tasks (Fig. 2) and when teams engaged in such "what-if" tasks they never completed the task . Instead, the team spent most of their time managing and trying to understand the project information rather than using the information because the:

•   **information is not interactive.** Requiring team members to manually navigate information and change informa-
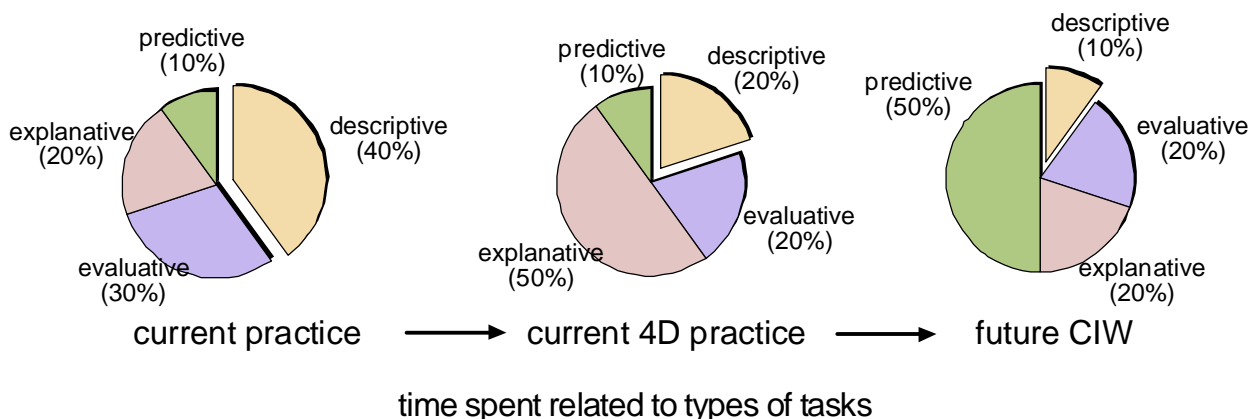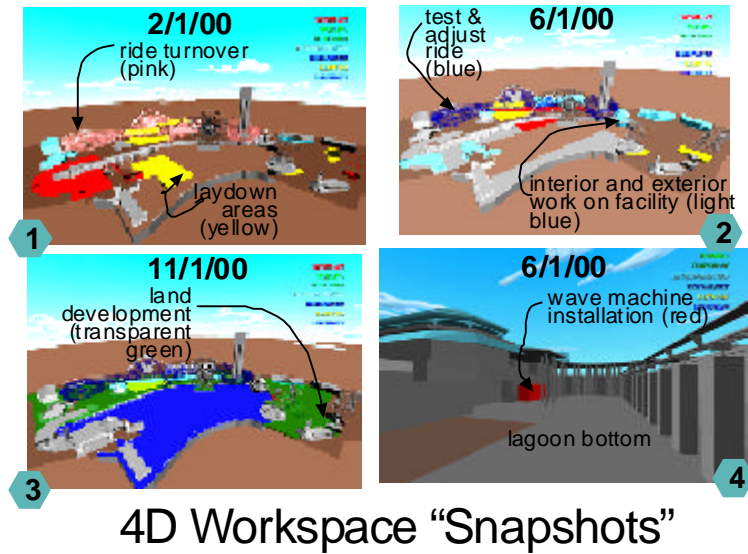

Figure 2: Analysis of time spent performing tasks in current practice and current 4D practice and goal

Figure 3:4D Workspace Meeting with Snapshots of 4D Visualization

tion and manually predict the impact of those changes.

- <mark>focus of information is not shared.</mark> Since much of the information that the team used or referred to during the meeting, such as the project specifications, diagrams, detailed schedule, was private the whole team rarely focused on the same information. Even the shared information, the 2D drawings and schedule provided no visual cues to guide the focus of the team. Consequently, people were easily distracted.
- <mark>views are inappropriate for group use.</mark> The Gantt chart provided an overall context, but was unusable for any group task. Instead, team members stood in front of the chart, searching for relevant activities and pointing to activities that then caused other members to search through their own personal schedules for the information. Current printed views of project information are designed for individual review and not group review.
- <mark>views don't visually represent critical relationships</mark>. During the meeting, as a team member described certain activities, the member would walk to the 2D view of the project and point out 'where' the work was taking place. Similarly, when the team wanted to compare information in the schedule to contract requirements or project specifications, various team members had to search through documentation to identify the related items. Relationships between time, space, resources, project requirements, cost are not captured or communicated in today's traditional graphical representations. This forces the team to spend time comparing and trying to understand how the information is related, when simple visualization techniques might easily communicate this information.

The proposed research focuses on this last problem. CIW that communicate critical relationships between project information will inherently address some of these problems. For example, on the same construction project, we participated in an R&D project using a 4D-CAD environment (Fig. 2) that enabled the team to visualize the relationships between time (construction activities) and space (3D model of the project) [5]. Several project review meetings took place in this 4D workspace, a CAVE environment [6]. During these 4D meetings, the team spent more time explaining the information than describing it, an improvement over the traditional paper-based meetings. They were able to quickly identify several problems and solve some of them. This environment demonstrated:

- *improved focus* since the project team focused on the 4D visualization and were not distracted by twenty types of documents.
- *improved ability to describe and explain project information* because the large-scale views were more appropriate for group tasks.

These improvements from using a workspace environment that communicated time-space relationships is further motivation to continue to research how new ways to visualize project information will improve group tasks.

3.0 Research Vision and Objectives

The proposed research envisions a new type of CIT - Construction Information Workspace (Fig. 4) that enables project teams to interactively visualize a variety of types of project information and their inter-relationships through annotative visualization techniques. The CIW will improve:

- *a team's ability to make critical project decisions.* With useful views of information teams will improve their ability to describe, explain, and compare project information. Once teams can perform these tasks more efficiently, they will be better equipped to make decisions and leverage the team members' expertise and creativity

- *the utility of project information* since relevant information and needed information will be available to project teams in the decision making process

Consider the following hypothetical scenario in which a project team uses a CIW that supports two types of visualization techniques, highlight and overlay (Fig. 6):

> *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 electronic agenda that associates each item with the relevant information, that when selected highlights the relevant project information. The CIW also displays all of the available project documents and information. In the CIW any project information can be overlayed onto a spatial or temporal view, thus enabling team members to quickly view relationships between project information. For example, 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 viewing the impacts of those changes on other project information. The team leaves the meeting satisfied with their solu-*
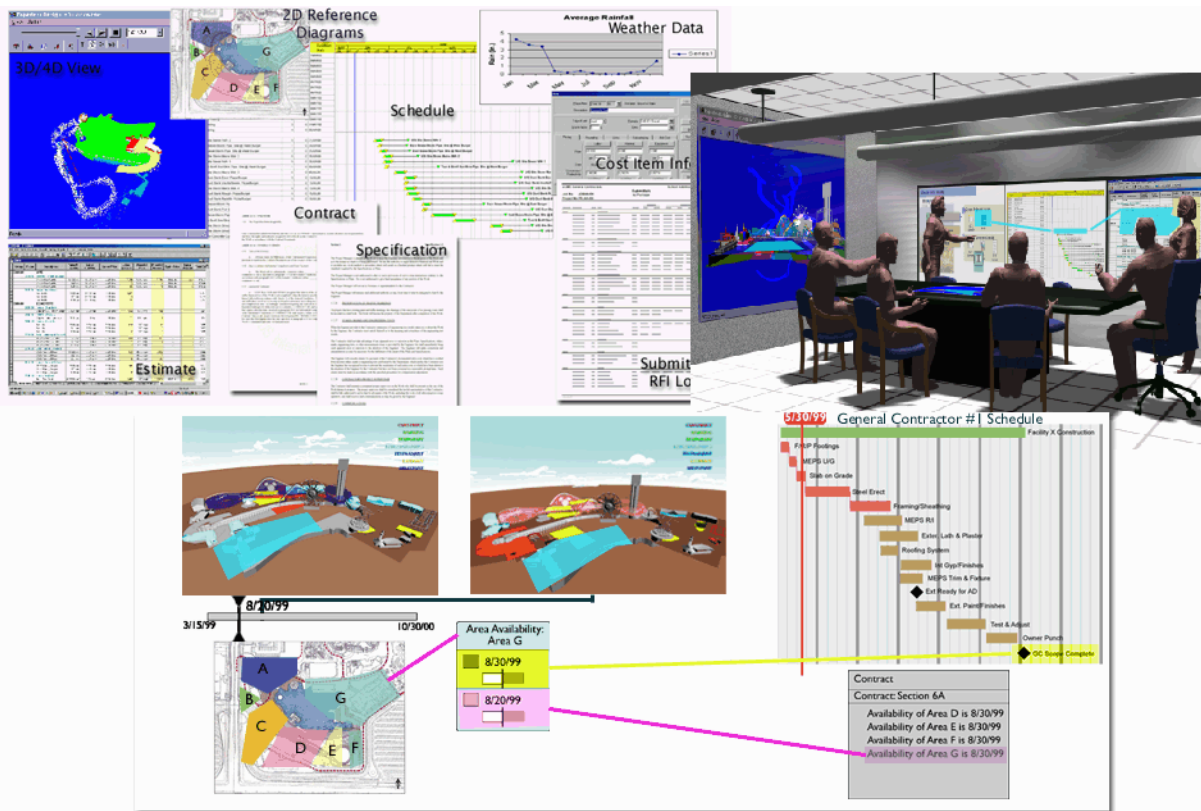

Figure 4:Examples of CIW Workspaces: Past, Present, and Future

tions.

To make this vision a reality this research builds upon and integrates research efforts and innovations in computer science, human computer interaction, and information visualization. Research projects such as The SAGE Visualization Project [3], Information Visualizer [4] and Snap-Together Visualization [7] demonstrate the visualization techniques and visual mechanisms necessary to implement the described functionality. Instead, this work will provide innovative research in two areas:

- **construction information visualization:** Research in information visualization typically is not domain specific. In this work we will identify characteristics of CIW visualizations that best support construction project decision-making tasks.
- **evaluation of CIT:** Empirical studies and evaluations of visualization techniques are either fine-grained, e.g., test performance relative to very specific tasks [8, 9] or domain-specific, e.g., comparative evaluation of visualization techniques for biomedical users [10] or airplane pilots [11]. Typically these evaluations are based on well-definable performance metrics. Such metrics do not exist in CIT and we will propose and apply a set of metrics for CIW.

Our objectives are:
- to identify visualization techniques that improve a team's ability to perform decision making tasks
- to define an initial set of metrics for evaluating CIW in the context of construction project team decision-making

In the following section we discuss the proposed research methods and related research.

4.0 Research Methodology and Related Research

To meet these research objectives we will perform four research tasks: definition of testing metrics, data collection, prototyping, and testing (Fig. 5). In the following sections we describe for each area the proposed methods, any results to date based on prior CIFE research, and related research.

4.1 Definition of Testing Metrics and Variables

Defining the testing metrics and variables is the most critical part of this research because they define the scope and expected contributions of this work. The metrics must enable us to map characteristics of the CIW environment to specific decision-making tasks or tasks necessary to make decisions. The proposed research defines four types of tasks in the decision-making process:

- *Descriptive*: Describing the 'who', 'what', 'where', 'when', and 'how' of the project. Traditional schedule methods, such as Gantt charts, use temporal relationships there aren't any explicit temporal relationships between activities in a Gantt chart between construction activities to describe 'when' and 'what'.' Some schedule tools allow teams to relate activities to resources, thus describing 'who' and partially 'how.' 4D visualizations relate the spatial and temporal aspects of a project, thus enabling teams to communicate the 'when' and 'where' of a project.
- *Explanative:* Explaining project decisions or the schedule rationale - the 'why' questions. Most tools do not enable teams to capture or document 'why' decisions are made. Typically this information is expressed as a constraint, such as resource constraints, contract constraints or procurement constraints.
- *Evaluative:* Evaluating project goals and checking that project requirements are met, e.g., 'does this meet this requirement?' or comparing one set of information against another set of information.
- *Predictive:* Predicting impacts of changes or specific decisions on project goals - asking 'what if' or 'what happens to' questions.

All of these are critical tasks necessary to enable project managers to make a decision. The proposed work assumes that the ability to make decisions is directly related to a team's ability to perform these tasks. More importantly, making good decisions is most directly influenced by the team's ability to perform predictive tasks. However, our observations of project meetings show that teams spend most of their time performing descriptive, explanative, and evaluative tasks. Therefore, the goal is to identify visualization techniques that support those tasks. For the one year project we will look at two types of visualization techniques - overlay and highlighting. Overlay maps information onto the same view and highlighting highlights related items either in the same view or independent views. This leads to three main hypotheses of the proposed work:

- **Hypothesis #1:** CIW using overlay and highlight techniques will improve the ratio of predictive tasks.
- **Hypothesis #2:** CIW using overlay and highlight techniques will reduce the amount of time needed to perform descriptive, evaluative, and explanative tasks.
- **Hypothesis #3:** CIW using overlay and highlight techniques will impove the accuracy of evaluative and predictive tasks.

Proposed metrics to test these hypotheses:
- # and type of tasks
- Time spent performing task
- Accuracy of task
- Completeness of task
- Types of tasks necessary to perform to complete tasks

The second set of metrics must measure the utility of the information in the context of decision-making is improved.
- **Hypothesis #4:** Overlaying and highlighting will improve a project teams' ability to identify relevant information.
- **Hypothesis #5:** Overlaying and highlighting will improve a project teams' ability to 'target' more types of information.

Target refers to the type(s) of project information needed to perform the task. These metrics will also help in our analysis of our test results by enabling us to measure whether certain techniques are best suited for specific tasks, in terms of the number of targets required, form of the targets, etc. Proposed metrics to test these hypotheses are:
- # of types of information accessed/referred to to support task
- was target information used to support a task
- was target information needed for a task not used
- # of targets
- # of types of targets: e.g., construction schedule, specification, construction drawing, submittal
- # of target form: since a type of target can be represented in different forms we need to also catalog the types of target forms used, e.g., spatial, temporal, textual, as well as verbal and physical

4.2 Data Collection

In addition to data collected from the testing trials, we will observe two types of project meetings throughout this research as a baseline for CIW validation:
- traditional practice where teams use paper-based information
- current 4D practice where teams use a 4D environment to support group tasks

We will use a observational template to document the metrics described in the previous section.

4.3 Prototyping and Designing CIW Visualizations

The third task in the research process is to design and prototype the CIW functionality. The primary goal of the prototyping is to support the validation task. However, the prototyping will also help to identify implementation issues. For example, to perform the prototyping we will use workspace technologies developed by the Stanford computer science department during the CIFE Seed Project Titled "Interactive CIFE Workspace" [12, 13]. We will extend these efforts and implement a CIW XML database. This database will store workspace-specific information such as types of
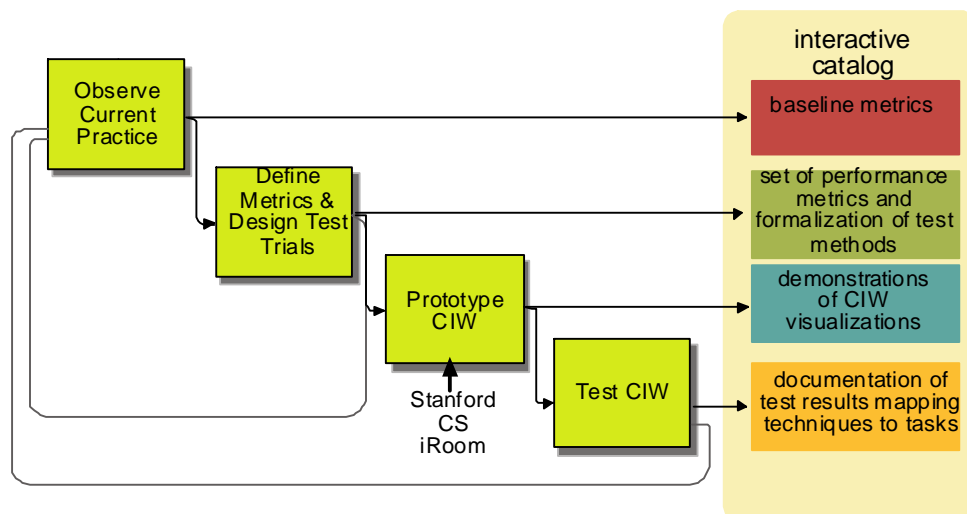

Figure 5: Diagram Showing Research Process Tasks and Expected Deliverables
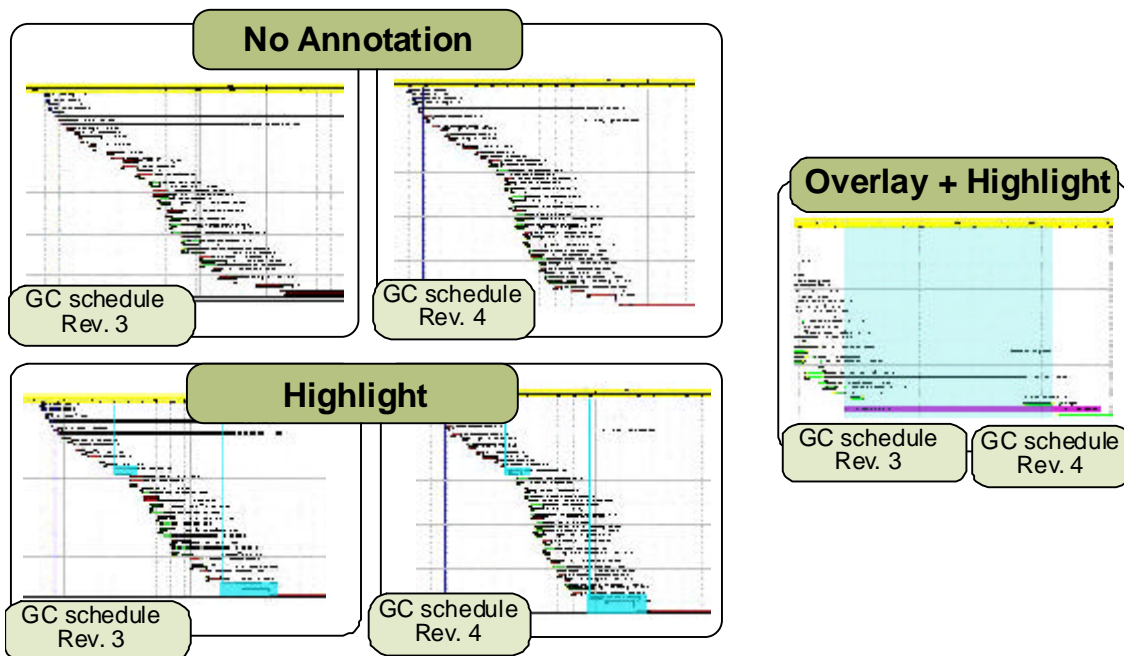
Figure 6: Comparison of CIW Visualization techniques we propose to prototype and evaluate

project information the team can access during the trials or project meeting. The database will also store a simple project model with the needed relationships between project components to support overlaying and highlighting.

4.4 Validation and Testing

The test trials are based on the Charrette Test Method employed by former CIFE Researcher Mark Clayton [14]. In the Charrette Test Method, users peform a specified design task to solve within a specified time period , using two different processes. In our proposed trials the users will be asked to perform a set of tasks in the form of questions presented to them by the other team member. A time-limit will not be imposed except when scheduling constraints exist. The trials will be performed in groups of 2-3, with each participant assuming the role of 'owner' or 'GC.' Test participants will be 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 will perform the test in a primarily in a CIW. Each group will be given the same 'agenda' for the meeting and will be given the same set of pre-defined questions/tasks to perform (See Table 1). These questions will represent different types of decision making tasks. However, the groups will perform these tasks with different visualization techniques.

5.0 Industry Involvement

Walt Disney Imagineering is currently providing opportunities for researchers at CIFE to observe project meetings for the data collection tasks in this research. We solicit other companies to allow researchers to document project meetings or to document their own meetings using a template posted on-line. We also ask interested companies to either participate in one of the test trials.

6.0 Expected Research Milestones and Deliverables

For each quarter of the project we plan to perform one set of test trials. Additionally each quarter we will formalize our testing methods and document the results of our evaluations. The following table summarizes the proposed milestones and deliverables for this project:

	Milestone	Deliverable
Quarter 1	• *Test #1:* Compare 'non-annotation' workspace to 'highlight'	• Meeting Observation Template • Working Paper describing proposed performance metrics and testing method

Quarter 2	• *Test #2:* Compare 'non-annotation' to 'overlay' technique • Online form to review testing metrics	• Online test for CIFE members • Online demonstration of visualization techniques
Quarter 3	• *Test #3:* Compare 'highlight' to 'highlight + overlay'	• Initial analysis of test results (Journal Paper) • Mapping of techniques to tasks • Potential implementation issues
Quarter 4	• *Test #4:* at CIFE Summer Program	• Documentation of test methods and metrics (Journal Paper)
Quarter 5	• Technical Report Submission	Technical Report/Interactive Online catalog documenting: • All Test Results • Analysis of results • Implementation Issues for CIW

7.0 Efforts to Minimize Research Risk

We foresee the following potential risks with respect to the research tasks:

- **prototyping in the Information workspace:** the prototyping and testing will be performed using Stanford's Interactive Workspace [13] technologies. To date, we have successfully prototyped CIW functionality in this environment. However, we will also prototype and test online to mitigate potential problems with the workspace technologies.
- **defining metrics that will yield significant results:** Our initial set of testing metrics is a mix of our 'intuition' based on observation analysis and surveys of metrics used by other researchers. To minimize the risk of using metrics that are not valuable to industry we will solicit feedback and review of these metrics after each testing trial.
- **feasibly performing the proposed number of tests:** The challenge is to find potential test participants and train several CIFE researchers to perform the tests and data collection. To minimize this risk we will include these tests as an assignment in CIFE related courses and produce testing documentation templates and observation templates to enable other CIFE researchers to perform the tests and data collection tasks.

8.0 Future Research Opportunities

Future research should continue to validate the usefulness of CIW's and prototype and evaluate additional functionality of CIW and extend validation to other types of visualization techniques and interaction techniques. Additionally, the prototype implementation architecture used for this research is only a starting point for research at the data store level of CIW. We have submitted two NSF proposals for funding to extend research at all levels of a CIW:

- **User level:** The use of CIW will need to be extended to other tasks in the AEC project life-cycle, such as conceptual design, procurement, facility management. The construction planning phase is probably the phase that combines the largest number of different types of information. Hence what we learn with respect to the types and value of visualization for the construction planning phase is likely to transfer to a large extent to other phases.
- **Graphics level:** This research will provide a starting point for more serious graphics research that would study generally useful types of visualizations and corresponding techniques and mechanisms. Such generally useful visualizations would enable all project stakeholders and teams in other industries leverage the investments in data models and stores.
- **Data store level:** Currently, many firms are struggling to integrate the various sets of data created for various business functions in the context of a project. More intuitive and valuable visualizations would create demand for better data store solution, complementing the current data integration push with actual user demand.

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Table 1: Sample Questions for Test Trials
Examples of each type of question with increasing # of targets and types of form for each taskt ype

Question			Target		
Type	(Who asks, Owner or GC) Question	#	Form type	Target type (domain specific)	
Desc	(O) What milestones have changed in revised schedule?	2	Temporal	Schedule	
Desc	(O) How is the GC sequencing work in the lagoon?	3	Spatial Temporal Textual	4D with zones Work assignments	
Expl	(GC) Why is the lagoon work broken into 6 zones?	2	Spatial Textual	Resources Drawings/3D	
Expl	(O)Why are they sequencing the work in that direction?	4	Text Spatial Temporal	Resource constraints Workspace constraints Milestone dependencies Procurement Information	
Eval	(O)Do they adhere to the specification that they need 5-7 days curing for all lagoon walls?	2	Text Temporal	Specificaton Schedule	
Eval	(O) Does revised lagoon construction meet specification for test and adjust envelopes?	4	Text Temporal Spatial	Specification workspace 3D Schedule	
Pred	(GC) Can we get access to the lagoon area #4 a week earlier?	3	Temporal Spatial Textual	Schedule Specifications Contract	
Pred	(GC)What if milestone for filling lagoon is moved ahead 2 weeks? What impacts on cost and surrounding work?	4	Temporal Spatial Textual	Schedule Budget/Estimate Resources Workspaces	