KISS: KNOWLEDGE AND INFORMATION SLIDER SYSTEM

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ABSTRACT: Computer-based representation, capture, linking, visualisation, navigation, and use of the information and knowledge created in a multi-disciplinary project environment during concept development, design, and construction remains a difficult problem. This paper presents a prototype environment, Knowledge and Information Slider System (KISS), for knowledge management and navigation of heterogeneous information that constitutes a building project memory. KISS proposes a product-based and context-based approach for project, product, and process evolution capture, organisation, and navigation. The prototype formally articulates and links the following four knowledge network levels: people knoweldge network, design informal knowledge network, design and construction formal knowledge network, and construction site knowledge network. KISS enables key stakeholders involved in "building a building" to metaphorically slide among the different knowledge networks to retrieve and re-use information in support of their decision process.

KEYWORDS: Knowledge Management, Knowledge Networks, Project Memory

1. INTRODUCTION

In many A/E/C enterprises today, product development and process management is done by large geographically distributed multi-disciplinary teams. Past decades have seen revolutionary increases in the complexity of products and the power of tools used to describe and analyze them. However, the fundamental tools of collaboration and project memory management have remained unchanged. The limitations inherent in these tools actually limit the quality and performance of the products they describe, while adding to their cost and time to market.

Based on our research experience, our findings show that:

1. One of the key factors in reducing life-cycle cost is improved communication, collaboration, and coordination among the stakeholders engaged in design, construction, maintenance, and operation of a building.
2. Information, knowledge, and product models are valuable assets created by a multidisciplinary team over the life-cycle project.
3. Computer-based representation, capture, sharing, and re-use of these assets remains a difficult problem when stakeholders are distributed over time and space.

This paper presents a prototype environment, Knowledge and Information Slider System (KISS), for knowledge management and navigation of heterogeneous information that constitutes a building project memory. KISS accommodates and integrates many perspectives throughout the design and construction teamwork and allows the different stakeholders to:

- Keep track of the human resources during the design-build process,
- Capture, link, navigate, and use knowledge, information and product in the four different knowledge networks,
- Augment shared design-construction models with the team members' intents, interests, and responsibilities,
- Track team interactions in a shared Web workspace environment, and
- Link the construction site information with the formal and informal knowledge and models created by the different stakeholders.

2. SCENARIO

Consider the following scenario: A new facility is designed to have a core and two building wings, i.e., east and west wing. An owner and a multidisciplinary team of designers, engineers and contractors interact on a continuous basis to identify their objectives, constraints, and marshal their resources. Each team member needs to access, retrieve, and manipulate different information and knowledge resources of the building product model. Examples of information requests are:

What was the initial concept for the west wing entrance?
How does the current construction status relate to the initial concept?
What was the evolution of the west wing spatial layout of the facility?
What were the evolution, corresponding rationale, and decisions for the west wing structural system design and construction?
How does the west wing structural system design relate to the initial architectural concept?
What was the design evolution of the west wing design?
What were the vendor's operation specifications for the cooling system?
Why was a specific alternative design for the west wing rejected?
Who was responsible for the decision to locate the crane in its current position?
How does the construction status relate to the construction schedule and the product model?
How does the current construction delay relate to the initial design concept and design development decisions?

These information and knowledge requests target:

- formal (e.g., *vendor's operation specifications*) and informal information *(design rationale for structural system design*) related to specific components in the facility (i.e., *cooling system*),
- evolution over time of the design of specific parts of the facility (e.g*., east wing, west wing*) in a specific discipline context (e.g., *architecture, structural engineering*), or in an overall perspective of the project,
- need of information at different stages of the life cycle of the product, i.e., concept generation, design, construction,
- visualization and navigation through a specific subset of information related to the product and construction site.

The result to such requests in today's state-of-practice project information development and management process requires to:

1. Recreate conceptual models and rework a rationale,

2. Collect documents captured in heterogeneous media, such as electronic CAD drawings files, and paper documents, e.g., memos, faxes, reports. All these paper and electronic project documents include vast amounts of information, beyond the one requested. Consequently, collecting and filtering this information, and compiling the response to the specific request becomes a time consuming process. To date, product documentation tools offer a file-based approach to archive, access, and retrieve the evolution of formal information only. Referencing a specific design version in such documentation systems means referencing a specific file or group of files. Time-stamps, filenames, and directory hierarchies provide document organization, but provide limited information about the file contents.
3. Inspect the construction site and manually/mentally link and compare the existing construction status with information captured in project documents, such as design drawings, and schedule charts.

3. OSERVATIONS OF STATE-OF-PRACTICE PROJECT INFORMATION DEVELOPMENT AND MANAGEMENT

We conjecture that design intent and knowledge capture, representation, sharing, and team interaction tracking is far less costly than the re-invention of comparable design and/or knowledge. We have observed over the past eight years more than two dozen multidisciplinary teams at work. We studied the traditional teamwork activities and the current project information development and management process. Our observations indicate that:

- Team members develop their solutions independently as well as collaboratively.
- Each team member develops multiple alternatives. Evolution of discipline solutions and interactions among professionals are hard to document and track.
- Most of the concepts generated in the early phases of the project as well as the rationale behind these concepts are not captured. These concepts are hard to communicate to the stakeholders of the project and re-use in future projects. Consequently, a large rework time and effort are involved in recreating these concepts and linking them to the later stages of the project, such as design, design development, and construction.
- Unsatisfactory changes prompt team members to backtrack to earlier solutions, which many times have to be recreated.
- Different discipline solutions interact with each other. The process of identifying shared interests is ad-hoc and based on participants' imperfect memories. This error-prone and time-consuming process rapidly leads to inconsistencies and conflicts.
- Meetings are usually the forums in which inconsistencies are detected and resolved before the project can progress.
- Individual notebooks record background information and results of reasoning and calculations. Notebooks are private documents and are not shared with the team.
- Memos, generated by computers but handled as paper documents, distributed to selective team members, and filed. Paper memos can not be easily updated and are hard to retrieve.
- Graphics and other data, indexed by drawing number and date are generally hard to recover and in their paper form laborious to annotate and update.
- Documentation, in the form of successive approved versions under configuration control often is filed as signed off paper documents.
- Project documents that are captured in heterogeneous media preclude team members and clients to have a global project memory that they can access, visualize and navigate through.

- Distributed teamwork is more than archiving documents in a central Web repository that is tagged by originator and date/time stamp, or passing documents back and forth, typically offered by new e-commerce collaboration services like Bidcom, Buzzsaw, Cephren, Bricksnet, etc.
- Project documents are not linked with the information on the construction site. This precludes the design-build team to quickly assess the status of the project, identify current delays, and act in an informed fashion.
- The construction industry has many problems of efficient monitoring and control as a consequence of the scale of operations undertaken. Visualization of progress of construction requires representation of changes in the geometry of a building or structure. Such changes prevent efficient use of existing 3D architectural and structural models for planning purposes. Moreover, geometrical representation of construction activities is not always 'compatible with' or even presented by design models. Therefore, integration of real images of a construction site with simulation of and interaction with a construction process will require the ability to model dynamic changes to the site geometry.

4. POINTS OF DEPARTURE

The points of departure for this research are the following domains: design theory (Schon 83) (Cross 94), collaboration technologies, construction visualisation, augmented reality and telepresence, and design rationale and documentation.

Collaboration Technologies. Communication of intents, problems, and decisions is critical in achieving better cooperation among professionals across organizations. Collaboration technologies provide computer support for (1) software data interchange, (2) cooperative distributed problem solving, and (3) capturing, accessing, sharing and exchanging graphic and non-graphic information representing the product models, data and knowledge among project participants. Two recent projects address issues of integrating multi-criteria and multi-disciplinary semantic representation and reasoning (Fruchter 96), (Saad 95). Other research directions have proposed different integration frameworks to address the information exchange needs for collaborative work, such as, blackboard architecture to link CAD with expert systems (Fenves 90), (Phol 90), blackboard object-oriented database framework (Sriram 91), and federated agent architecture (Cutkosky 93), (Khedro 93), (Khedro 95). The prototypes developed in these studies do not include capabilities for content-based evolution capture and documentation of design rationale linked to the product models. Commercial PDMs (e.g., Autodesk's WorkCenter) address some the key issues of version and document management.

Virtual Construction Simulation, developed at Strathclyde University (Retik et al 98) is an approach that enables the visualisation and simulation of construction processes, i.e., the final stages of construction project planning which are scheduling and site production. These tasks represent *process* design (called planning) and are not explicitly supported by existing visualization tools developed for *product* design. Existing software tools have been developed for designers to work with a *product* design and visualization (i.e. 3D modeling of a building and 'walk through' it), while the construction planning tasks (e.g. scheduling, progress monitoring, etc.) focus on *process* design. Several complementary studies undertake the modeling and simulation of the construction process that address either the construction tasks sequencing or 3D animation of the construction progress over time (Fisher 96, Collier et al. 96). Visualization of the project progress requires changes in the geometry of a building or structure during the construction process. These changes prevent efficient use of 3D architectural and structural models for planning purposes. Moreover, geometrical representation of construction activities is not always 'compatible' or even presented by these design models. The visual simulation of and interaction with such a construction process also require the ability to produce dynamic changes to the project geometry.

Augmented Reality and Telepresence integrates state of the art Virtual Reality (VR), Telepresence (TP), and mobile video telecommunications technologies. VR involves the impression of participating in a computer generated synthetic environment, TP the impression of being present at a remote real world location. VR and TP can each be categorised into immersive and non-immersive systems. Imersive systems in principle allow the user to feel completely present in the virtual or remote location through the use of 3D displays etc. Non-immersive systems leave the user aware of his or her immediate environment but able to observe the virtual or remote site through some such device as a computer monitor or video display. These modelling methods and communication technologies will enable us to explore the link between the construction site, scheduling and planning, with formal and informal design knowledge.

Design rationale. Three major approaches to design rationale have been proposed in the past decade:
(1) history-based rationale, that records arguments and issues raised during design, such as the electronic notebook (Lakin 89) and EDN (Karinthi, 92) documents design by recording the sequence of events that happen during design.
(2) argumentation-based, that record the justification during design, such as, IBIS (Kunz, 70), PHI (McCall, 87) is derived from hypertext research, where the goal is to provide uniform structure to a potentially diverse medium.
(3) device model based rationale, that records the device behavior model, such as, (Gruber 91), (Baudin 89), attempts to make much of the design knowledge reusable across related design tasks. It takes a model-based approach used in diagnosis expert systems. The key in this approach is to develop reusable devise models. This approach does not address the requirements posed by teamwork, such as shared interests, notifications, and negotiation. Consequently increases the designer's overhead in documenting the design and is unrealistic during conceptual design.

5. KISS ENVIRONMENT

The KISS prototype environment enables the stakeholders to represent, capture, link, visualize, navigate, and use the information and knowledge created and needed in the different stages of a project, i.e., "*from concept to construction site*." During the formalization and development of KISS we posed the following research issues:

- What are key knowledge and information networks in a design-build project?
- How do these four networks relate and interface to each other? How do we integrate them to effectively formalize, implement and use a buildig project memory?
- What are appropriate levels of granularity for context-based archival, retrieval and visualisation of project, product, and team interaction?
- How can we dynamically monitor the *project evolution* to examine the states of the project as it is being captured to benchmark team performance and expose bottlenecks in real-time?

5.1 Knowledge Networks

We propose the following four knowledge and information:

People Knowledge Network is composed of the stakeholders engaged in building a building, such as, developer or owner, architect, engineering team (e.g., structural engineer, mechanical engineer, electrical engineer, etc.), construction team (e.g., general contractor, subs, etc.), their working relationships, their responsibilities, and interests. It is these people who create, own and manipulate the knowledge, information, and building models and product. This information is usually tracked by each team member and is disjoint from the building model, product and process.

Informal Knowledge Network includes sketches, annotations, back of envelope calculations on a paper napkin, verbal explanations of concepts created during concept generation, development, and formalization. This information is usually tacit knowledge and is not captured in a disciplined, structured fashion.

Formal Knowledge Network includes memos, notes, reports, CAD drawings, fabricator specs, code requirements, schedules, RFIs, etc. created during design development, scheduling and planning. This knowledge is captured in disjoint and heterogeneous documents created with diverse software applications.

Construction Site Knowledge Web is represented by the actual product under construction, materials, equipment, and their location on the construction site.

5.2 KISS Building Blocks

The development of the KISS prototype leverages the R&D efforts of the Stanford and Strathclyde research teams. More specifically,

- *Recall* (Yen, Fruchter, Leifer 99) and *ProMem* (Fruchter et. al. 98) collaboration technologies developed at Stanford to support the concept and rational generation, and multi-disciplinary team interaction and design intent evolution capture, respectively; and
- *Virtual Construction Simulation* and *Construction Site Telepresence* information technologies developed at Strathclyde University to facilitate virtual reality modeling of the design and construction process, and mobile telecommunication to capture and link the construction site information with the office, respectively.

Figure 1 illustrates these information and collaboration technologies as building blocks that cover the spectrum of knowledge and information, from informal to formal, during design and construction. KISS explores a methodology to link and manage the knowledge and information captured by these technologies. It can enable the stakeholders to metaphorically slide through the informal and formal knowledge created over time on-an-as-need basis.

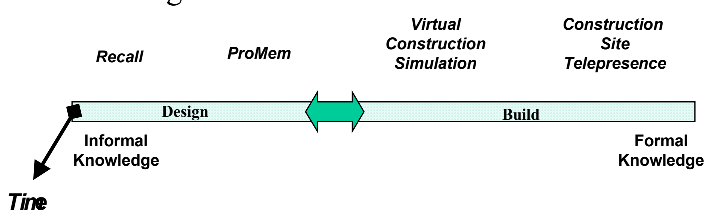

Figure 1: KISS Building Blocks

We provide a short description of these four information and collaboration technologies.

RECALL is a prototype that facilitates the user or team to capture, index, retrieve, and replay the concept generation over time in the form of a sketch and the corresponding audio and video rationale (Yen, Fruchter, Leifer 99). RECALL provides an accurate environment to capture knowledge created in the Informal Knowledge Web.

Sketching is a natural mode for designers, engineers, or contractors to communicate in highly informal activities such as brainstorming sessions, lectures, or Q&A sessions. Often, the sketch itself is merely the vehicle that spawns discussion about a particular design issue. Thus, from a design capture perspective, capture of both the sketch itself and the discussion that provides the context behind the sketch are important. It is interesting to note that today's state-of-practice neither is captured and knowledge is lost when the whiteboard is erased.

RECALL is a drawing application written in Java that captures and time stamps each individual action on the drawing surface. The drawing application synchronizes with audio/video capture and encoding through a client-server architecture. Once the session is complete, the drawing and video information is automatically indexed and published on a web server that allows for distributed and synchronized playback of the drawing session and audio/video from anywhere at anytime. In addition, the user is able to navigate through the session by selecting individual drawing elements as an index into the audio/video and jump to the part of interest. RECALL was tested in is used as a regular tool in the "Computer Integrated A/E/C" CEE222/122 learning environment (Fruchter 99).

The RECALL is aimed to improve the performance and cost of knowledge capture, sharing and re-use. It provides the following benefits:

- Transparent Graphical, Audio/Video indexing
- Zero overhead for production i.e., editing/indexing.
- Zero overhead for publishing Web content
- Immediate access and retrieval of knowledge and information, i.e., sketch, audio/video on demand.

ProMem (Fruchter et.al. 98) accommodates and integrates many perspectives throughout the design and build team work and facility management. It proposes a product-based, content-based, CAD-Web mediated approach for project, product, and process evolution capture, access and visualization.

ProMem provides direct support for linking the *People Knowledge Network, Informal Knowledge Network,* and *Formal Knowledge Network*. It enables team members to:

- augment a shared graphic design model design with the team members' design intents, interests, and responsibilities,
- capture versions at different levels of granularity, such as, feature level, discipline perspective level, and project level,
- create private, public, and consensus versions in a hierarchical archive,
- detect shared interests and route change notifications with regard to a modified feature or perspective,
- visualize the design evolution of features, discipline perspectives, and the overall project, and
- track and backtrack through archived team interactions.

The design modeling paradigm of ProMem is based on design theory (Asimow 62), (Schon 83). ProMem was implemented using AutoCAD as a geometric engine, Informix ORDBMS, C, DCL, and AutoLisp. We developed a semantic modelling engine that proposes three product object types: *Manager Objects (MOB)*, *Interpretation Objects (IOB)*, and *Feature Objects (FOB)*. *Manager Objects* provide a means by which a person or team can group multiple discipline models or interpretations of the design. *Interpretation Objects* encapsulate features for a particular perspective. They have two primary attributes: a list of *Feature Classes* and multiple *Feature Objects*. *Feature Classes* provide an ontology to describe the semantic meaning of the graphics within a design context. The user edits the list of *Feature Objects* to contain the instances from a particular graphic model that are relevant to an interpretation. The basic components of a *Feature Object* are a *Feature Class*, a *Feature Name*, and a *Graphics Object(s)* (*GOBs*). *Feature Objects* allow graphic entities to have multiple meanings within different interpretations. The designers on a multidisciplinary team use these objects to declare their interests and identify components of the design. The shared, central *Graphic Objects* serve as translating links among the many design perspectives.

The knowledge modelling objects that capture the personnel, negotiations, decisions, and rationale are accomplished with four additional modelling objects:

- *Person Objects* record the project participants, their roles and their interests. *Person Objects* are used to (1) associate the product model with the team members, (2) infer routing of *Notification Objects* (described below), and (3) determine user privileges.
- *Note Objects* record text written by the project members. They are used to capture the design rationale, short descriptions, decisions, product specifications, part numbers, etc. that a designer traditionally records on napkins, notebooks, blue prints, etc.
- *HyperLink Objects* provide a mechanism to link a *Feature Object* to formal information sources outside of the graphic and semantic models (e.g. component specification sheets available on the Internet). The hyperlink references can contain any format supported by Web documents, e.g. text, images, video, audio, RECALL sessions.
- *Notification Objects* record the communications among the designers and are routed in an asynchronous communication mode. They can be used to solicit feedback, to give approval, to broadcast change notifications, or to initiate negotiations. *Notification Objects* tie together three key portions of the project: the people, their communications, and the product model.

We hypothesize that ProMem's data models are (1) suitable for real-time knowledge capture and (2) solve the problem of integrating disparate information sources. The basic approach to modeling in ProMem is centered on the graphic model, which follows from observational studies of the role of artifacts in design (Perry et al.98).

The ProMem prototype has been tested with Architecture/Engineering/Construction education and industry projects.

The *Virtual Construction Simulation* system combines knowledge based planning with virtual reality to produce a novel approach which allows visual planning and interactive simulation of the construction process. The principal innovation is in the development of a graphical library of virtual activities, on-site facilities and equipment, and an intelligent system-interface between existing scheduling and visualization tools. The prototype was developed to demonstrate automated creation of a 'virtual construction site' from a schedule (and vice versa) and subsequent visual monitoring of, and interaction with, the progress of the simulation project. This allows users to:

- investigate interactively in a collaborative manner several alternatives for both construction sequence and site organization by employing knowledge-based simulation of the construction process;
- verify and refine the construction plan, integrating dynamically construction progress with on site activities and plant.

Testing of the prototype used a real project environment and different projection techniques.

Construction Site Telepresence uses mobile, real-time, 3D hybrid VR/TP system that permits the user to integrate telepresence images with computer generated virtual environments superimposed over the remote real world view. This integrated system incorporates emerging mobile telecommunications technologies to give rapid and easy access to the real and virtual construction sites from arbitrary locations. This system allows remote surveillance of the construction site, and integration of real world images of the site with virtual reality representations, derived from planning models, for progress monitoring (Meir et al 98).

The knowledge and information evolution captured in the KISS will be only as useful as the visualization and retrieval mechanisms that will allow users to revisit portions of the design evolution. KISS will support navigation by allowing the user to slide through the project evolution based on its content and context, as well as its knowledge network levels. Figure 2 illustrates links among the four building blocks of the KISS prototype environment.

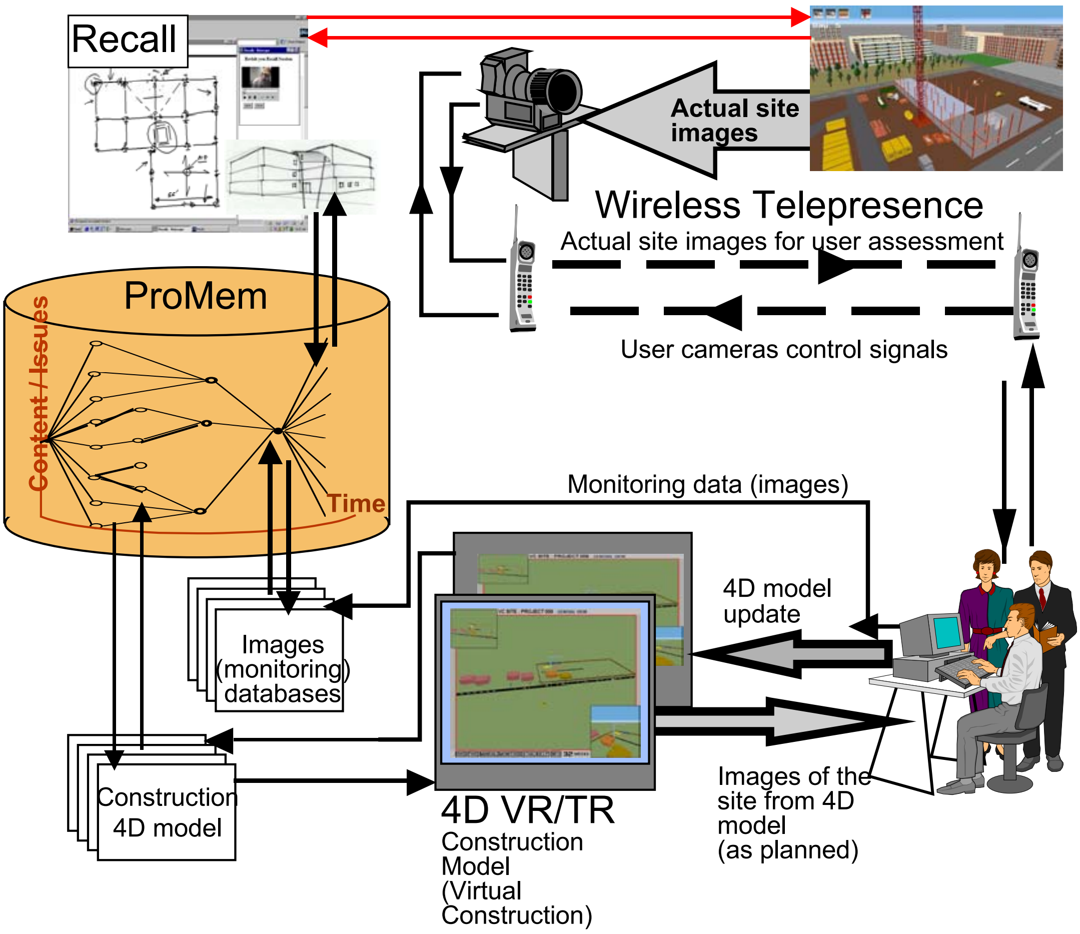

Figure 2. KISS Prototype Environment

6 SUMMARY

This paper reports on an on-going effort to define, develop, and test a prototype environment, KISS, that supports representation, capture, linking, visualisation, navigation, and use of the information and knowledge created in a multi-disciplinary project environment during concept development, design, and construction. KISS offers the stakeholders engaged in "building a building" a communication, collaboration, and coordination forum through which:

- by improving *how* people design, they can improve *what* is designed,
- design knowledge capture, sharing, and re-use is *less costly* than its re-invention,
- well informed engineers and managers will make *better decisions* and higher *quality buildings.*

We plan to further test and validate the KISS prototype in both education and industry pilot projects.

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