EEN: A Pen-Based Electronic Notebooks for Unintrusive Acquisition of Engineering Design Knowledge

Jacek Gwizdka, Jim Louie, Mark S. Fox

Department of Industrial Engineering, University of Toronto, 4 Taddle Creek Road, Toronto, Ontario, M5S 1A4, Canada
tel: +1-416-978-6823 fax: +1-416-971-2479
email: {jacek, louie, msf} @ie.utoronto.ca
http://www.ie.utoronto.ca/EIL/eil.html

Abstract

Capturing design information and decisions is critical to supporting re-use of designs and coordination in engineering teams. Most of this information is currently not recorded at all. In this research we focus on the role of electronic engineering notebooks in the capture, storage and dissemination of design information and decisions, and on their role in integrating and managing design decisions and processes. We propose EEN as a tool ultimately leading towards replacement of traditional paper engineering notebooks and assisting engineers in information related tasks. This paper presents requirements, design and implementation of EEN as well as initial experiment results.

Keywords: *Electronic Notebooks, Knowledge Acquisition and Access, Collaboration, User Interface Design, Pen-based Computing.*

1 Introduction

The Knowledge Aided Design (KAD) research at the University of Toronto in collaboration with Spar Aerospace's Advanced Technology Systems Group is focusing on engineering projects requiring the services of many engineers (Design-in-the-Large) [7]. The goal of the KAD project is to meet the information and knowledge needs of engineers thereby maximizing coordination and enabling re-use and sharing of engineering knowledge. The project has two thrusts: (1) the development of a Knowledge Network (KN) with an associated set of collaboration tools, (2) the development of a tool that reduces the problem of transferring information and knowledge from engineers into the system and allows for an easy access to it. We call this tool electronic engineering notebook (EEN) and present it in this paper. Other parts of the KAD project are described elsewhere ([2],[9]) and here only a brief description of the KAD architecture is given.

Architecture of the KAD system (Figure 1) centers on a knowledge network for storing design knowledge and providing services for the management of shared design, a case-based retrieval module for engineers to retrieve and re-use past design experience, and a systems management agent that monitors the system engineering process. The system has two interfaces for knowledge acquisition and access, WWW and the EEN. The knowledge network is an information system providing tools for accessing and updating this knowledge, and services that support collaborative and concurrent design. EEN uses the services provided by the KAD system.

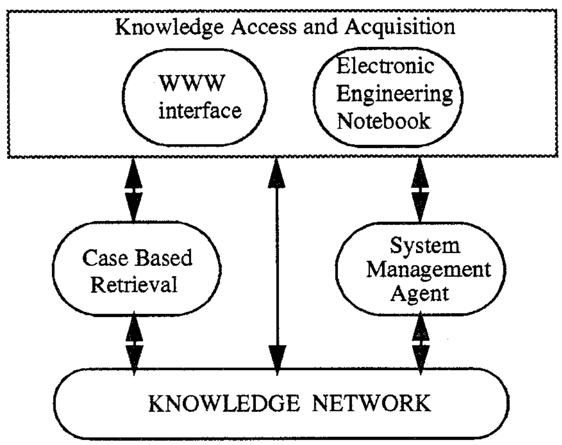

Figure 1. KAD Architecture.

Engineering design is an information intensive process. Engineers in design process make an extensive use of their past experiences, of similar previous designs and of design rationale lying behind them. This kind of information is for the most part generated during the conceptual stage of design. In current design practices, the conceptual design information is either not recorded at all, or recorded on paper, for example, in individual paper

1080-1383/96 $5.00 © 1996 IEEE
Proceedings of WET ICE '96

engineering notebooks, and thus, practically not available to other designers. The reuse of past design information relies currently on human memory and on communication with experienced designers, and hence, it is time consuming, not reliable, or not possible at all. Improving capturing design information during the conceptual design phase and making it available to all engineers is thus very important. Tools existing today record engineering design usually only in its final form. Furthermore, complex engineering design projects, which involve hundreds of participants, are commonly faced with communication and coordination problems. The ability to effectively communicate and share the design information can enhance coordination and design efficiency by reducing delays and improving decision making.

In the EEN research we focus on unintrusive acquisition of design information and decisions for their re-use and sharing, and on providing support for collaboration. This paper presents the initial results of this effort. In Section 2, we describe EEN requirements, in Section 3, functionality and design of EEN, in Section 4, results of initial experiments, and in Section 5, the implementation of EEN.

2 Requirements for EEN

A first step in improving information access, and ultimately coordination, is to make information available to those who need it, when they need it, and where they need it. For this to happen, more information must be captured onto systems and better methods for organizing and structuring this information must be provided to make it accessible to others. To achieve this, we need to (1) provide easy-to-use tools that will encourage engineers to capture more design information, (2) provide engineers with the capability to organize and structure this information in ways that make it accessible, and (3) provide them with the capability to browse and retrieve this information efficiently.

We design EEN as a tool meeting these goals and ultimately leading towards replacement of traditional paper engineering notebooks. If EEN is to replace paper it should provide agility and quickness of writing [10]. Furthermore, EEN cannot interfere with the design process but rather has to be its natural part; it cannot limit designer's creativity during the conceptual phase of design, any additional actions required from designer to use EEN should bring her clear benefits in the design process.

We identified the following EEN requirements:

1. Provide user friendly interface to support freeform writing, sketching, drawing; provide support for scanned pictures, text/tables, and possibly voice annotations.
2. Provide support for the specification of: definitions, synonyms, variables, constraints, values, geometry, features, versions, requirements, assumptions, deductions, revisions, decisions, rationale, dependencies, beliefs, source, importance, context, activities, resource, goals, milestones.
3. Provide for linking based on content (manual and automatic), maps of content, browsing (domain specific), and parametric search.
4. Provide the engineer with a natural, uniform access to relevant information; support importing of information/results into EEN, and exporting of new data and knowledge to data and knowledge bases.
5. Provide for a shared product definition and management, shared structure definitions: variables, constraints, values, etc., the distinction between public and private information (designer designated), public information extracted and organized (automatically) for ease of use, and links back to individual EEN structures.
6. Support meetings and capture decisions by providing the representation and visualization of a project model, shared variables and constraints, and alternative exploration.
7. Provide links between the EEN and external analysis and visualization routines, embedding of results directly in EEN, and automatic extraction of rules and constraints.
8. Provide, via the constraint management systems, the ability to monitor for changes; provide protocols and management tools for asking and answering questions.
9. Provide computer protocols for considering, proposing, negotiating and accepting/rejecting changes to structures, and representations of change history and rationale, versions, revisions.
10. Provide engineers and managers with activity management. This includes the ability to interactively generate and critique plans, monitor plan execution, re-plan, alert people when relevant changes occur.

3 Electronic Engineering Notebook Design

The EEN project is divided into 10 phases: 1. Basic EEN, 2. Structured EEN, 3. Hyper EEN, 4. Knowledgeable EEN, 5. Shared EEN, 6. Group EEN, 7. Analyzable EEN, 8. Active EEN, 9. Dynamic EEN, 10. Managed EEN. Each phase builds functionality on the previous and satisfies the corresponding requirements as outlined in the previous section. The first four phases roughly constitute the scope of our current design and implementation which we describe in this and in Section 5, respectively.

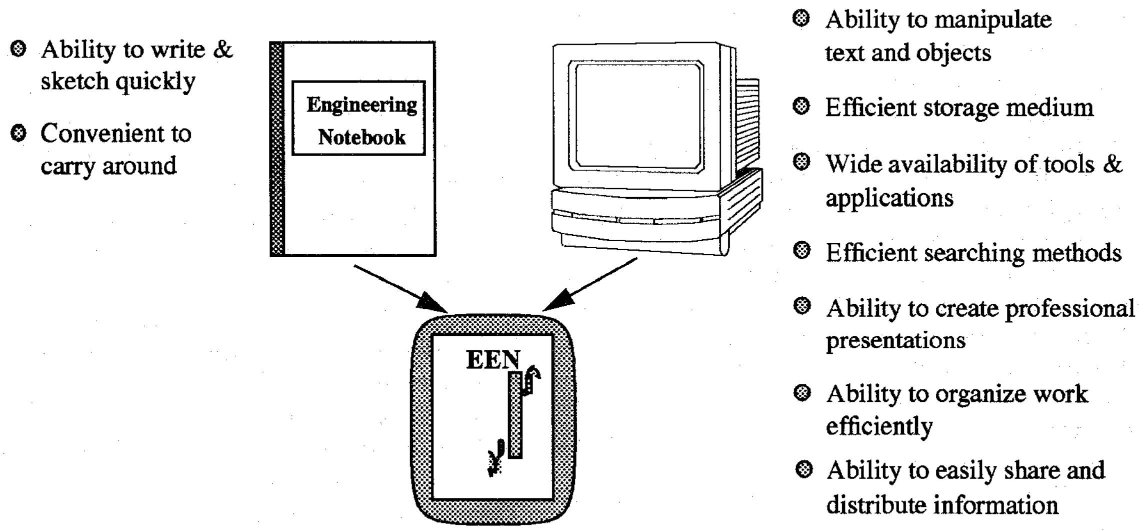

Figure 2. EEN as an integration of paper engineering notebook and computer

The main functions of the current EEN are information acquisition, authoring, browsing and navigation, and information transfer. Functionality of an electronic notebook can be generally seen as an integration of a paper notebook with a computer (Figure 2). Therefore, in the design of user interface for EEN we incorporate many elements from paper notebook. We employ the familiar notebook metaphor including well known methods of organization information (table of contents, indexes, pages). Support for natural user interaction is complemented by using pen-based input.

User interface design alone can fulfill only part of the requirements for unintrusive information acquisition, hardware technology is the other, and very important factor here. The EEN is designed to use a light-weight, pen-based, mobile computer with wireless communication. In the EEN research, however, we do not aim at developing new hardware, instead we rely on the commercially available solutions.

Users enter information employing the pen input. The recorded information is stored by the system as *digital ink*, which provides internal representation of pen strokes entered. The entry is *freeform*, that is, users can enter anything, anywhere on the electronic notebook page, and they don't have to change the mode of operation to record a different kind of information. For example, they do not need to switch between handwriting and sketching modes, nor do they need to select a different tool.

Once the content has been created in the process of capturing information, it has to be organized and structured to facilitate efficient access. This process is called *authoring*. We believe that acquiring information and authoring cannot be fully separated in time. If they are, loss of information may occur. We use the term *semi real-time authoring* for our approach. The authoring is dependent, in the first place, on the user interface design. *Tags*, *links* and *forms* are the main UI elements used in EEN for authoring. Information entered to the notebook is tagged. Each tag has a form associated with it which is filled out for inclusion in the KN.

Tags and forms play an essential role in making the EEN content understandable, in capturing the design information, and in sharing the recorded information. Section 5 describes their usage in the current implementation in more detail. The next organizational element employed in the EEN are *annotated hyper-links*. Links can be created between any two notebook pages creating an annotated, directed graph with notebooks pages as nodes. Tags and hyper-links allow for organizing and structuring of design information recorded by engineers during the design process. They provide the means for the specification of definitions, parts, features, alternatives, requirements, assumptions, decisions, goals, constraints, functions (as described by the requirement 2 in Section 2) and provide the necessary basis for browsing and navigation as well as for search. Furthermore, forms can be transferred between knowledge network and EEN, providing for information export and import, and at the same time facilitating information sharing through the KN.

Based on our design we implemented two prototype EENs, the first one based on PenPoint operating system running on a desktop computer, and the second one based on Apple Newton. The details of the former are presented in [13], while the latter is presented in Section 5.

4 Initial Experiments and Results

The focus of our research is unintrusive design information acquisition. It is thus very important to determine whether engineers can effectively use the EEN to capture design information. The basic skills involved in capturing information include writing, reading, and sketching, and these were the criteria we used to measure the EEN's effectiveness. We compared the engineer's ability in performing these tasks on an EEN to a sheet of paper (our benchmark) [13]. The following are our hypotheses:

H1: Engineers can write on an EEN just as effectively (quickness and quality) as they can write on a paper.

H2: Engineers can read from an EEN just as effectively (quickness) as they read from a sheet of paper.

H3: Engineers can sketch on an EEN just as effectively (quickness and quality) as they can on a sheet of paper.

We also studied the effect of EEN screen size on reading, writing, and sketching. Two EEN screen sizes were compared: 9x6 inches, 4x3 inches. The 4x3 inch EEN was tested in two variations, one with the screen placed in a larger surface area box, and the other with outside dimensions only slightly larger than the screen size (Apple Newton MessagePad).

Two usability studies and one controlled experimental study were conducted. The objective of the first study was to evaluate the designer's ability to use the EEN to solve design problems. Subjects were given a design problem with a set of requirements and constraints and were to create a complete design solution. In the second study, the objective was to evaluate the engineer's ability to use the EEN to perform project/time management tasks. Subjects were given four tasks to carry out.

In the third study, the goal was to determine whether engineers can effectively use the EEN to capture basic information. Subjects were to perform three performance tests on the EEN that evaluate writing, reading, and sketching. As a result of the studies hypothesis ***H1*** was rejected, while ***H2*** and ***H3*** were not.

In summary (Table 1), paper was a better medium for writing, however, for reading and sketching, the EEN worked just as well. Overall, users were able to write legibly without any difficulty on the EEN. Users, however, had to concern themselves with extra factors like page scrolling and view angle adjusting that were not issues with the paper medium. These extra factors consumed additional time what could explain why users spent more time writing on the EEN. Other factors that effect writing on the EEN are lighting conditions, parallax problem, and type of writing surface. We found that users were less comfortable writing on the EEN because writing on hard glass surfaces feels differently (etched glass is better) than writing on paper; the EEN provides also less control over the appearance of the writing.

In comparing the EEN to the smaller screen versions, the large screen was clearly a better medium for reading and sketching. For writing, it was not definite whether large screens were better than smaller ones because the Newton fared relatively poorer than the EEN while the 4x3 EEN showed no signs of being inferior to the larger screen EEN. A possible explanation is that with the 4x3 EEN, users had the additional comfort of being able to write with their hands rested on a bigger surface area. This would have provided users with more stability in writing and as a result would allow them to write quicker. Our interpretation of these results is that people need a comparatively large working space for writing, reading, and sketching.

Medium	Tasks	Significant Difference Observed	Difference between the first and the second in %
Paper vs. EEN	writing	yes	20%
	reading	no	
	sketching	no	
EEN vs. Newton	writing	yes	22%
	reading	yes	13%
	sketching	yes	61%
EEN vs. 4x3 EEN	writing	no	
	reading	yes	22%
	sketching	yes	18%
4x3 EEN vs. Newton	writing	yes	8%
	reading	no	
	sketching	yes	41%

Table 1: Summary of Experiment Result Analysis.

5 NewtEEN: Current EEN Implementation

We use Apple Newton™ MessagePad for the EEN prototype implementation. The implementation is called NewtEEN.

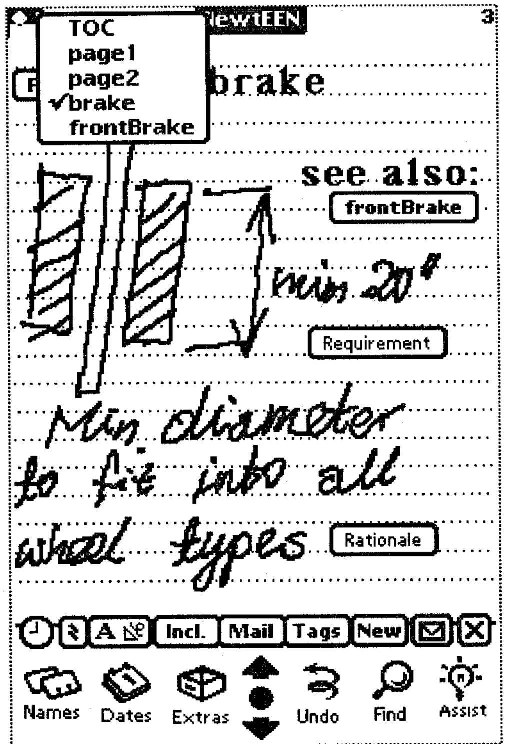

Figure 3. An example of NewtEEN page.

As described in Section 3, EEN uses notebook metaphor. The notebook consist of pages, page contains objects. NewtEEN page (Figure 3) accepts handwritten (text and sketches) and typed (on-screen keyboard) user input. Objects can be edited (resized, copied, deleted, moved, etc.); handwritten text can be recognized while it is entered or later. Objects are created by user input, by drag and drop between notebook pages and Newton built-in programs and by linking and embedding of data from specific applications (currently, we support a spreadsheet program). Objects are stored in a persistent object storage within NewtEEN. Each object on a notebook page has several attributes, some are automatically generated (date, time, author, page name) while other are manually entered by users, these include tags. Entering tags automatically adds corresponding entries to tag indexes. Notebook content can be searched by any of the object attributes. To link notebook pages we use annotated hyper-links. Tags are of two types, ontology tags, based on our TOVE ontologies [6] (e.g. part, parameter, feature, requirement, constraint, function), and organizational tags (e.g. objective, meeting, to-do, milestone, action item, proposal). Tags define type of recorded information. The selection of tags is, in part, based on our studies of engineering notebooks content in a large aerospace company [13].

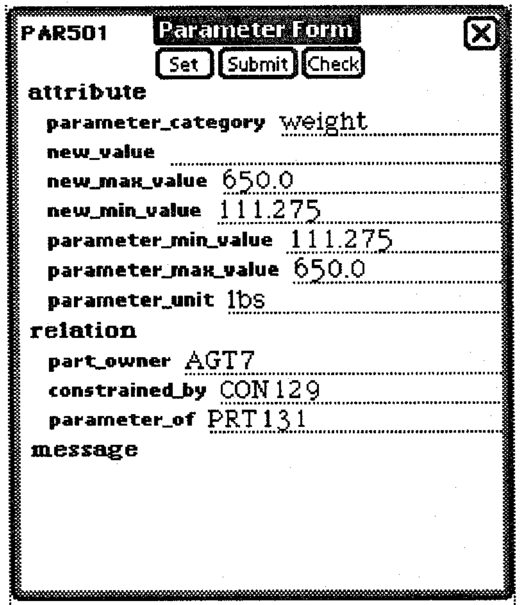

Figure 4. A form associated with parameter tag.

NewtEEN has several communication capabilities. It can receive e-mail notifications, related, for example, to the design changes, and it can communicate with the KN (Figure 1 and Figure 6). Communication with KN is possible in two modes. First, the KN can be queried and its contents changed by executing a generic Prolog predicate (The KN is currently implemented in an object-oriented manner using Eclipse Prolog). This is a powerful feature, but it does not have a specialized user interface for presentation of results. Second, and more interesting, is transmitting of forms.

Each tag has a form (Figure 4) associated with it; the structure of the form corresponds directly to the attribute and relation slots contained in frames in the KN. Tags are entered during the concept time while engineers are writing and sketching on their EENs. We expect cost of tagging to be relatively small [11] and to decrease with the increase of EEN screen size. At the review time, after the information has been recorded in the EEN, user fills out forms corresponding to the entered tags, and then submits them to the KN (Figure 5). In this way we avoid post-hoc tagging, which may lead to loss of information, and at the same time we avoid the "garbage-in/garbage-out" syndrome, by transmitting to the KN only post-processed information.

NewtEEN is connected to proxy server using RF communication link. The proxy server communicates with the

KN over the Internet. The communication architecture is presented in Figure 6. Content of the EEN is transmitted to the KN by means of forms, and in this way it can be accessed by other designers. The KAD system also provides a WWW user interface (Figure 1); information generated from EEN can be thus accessed through the World Wide Web.

intrusive. VNS [5] has a pen-based interface option, but its role is not emphasized. PENS [8] runs on a portable notebook computer (Mac PowerBook), but only the keyboard text input is supported. The authoring process is often not performed in real-time [15]. Most of the systems require powerful or even specialized workstations to run (e.g. [12], [15]). These notebooks primarily focus on providing

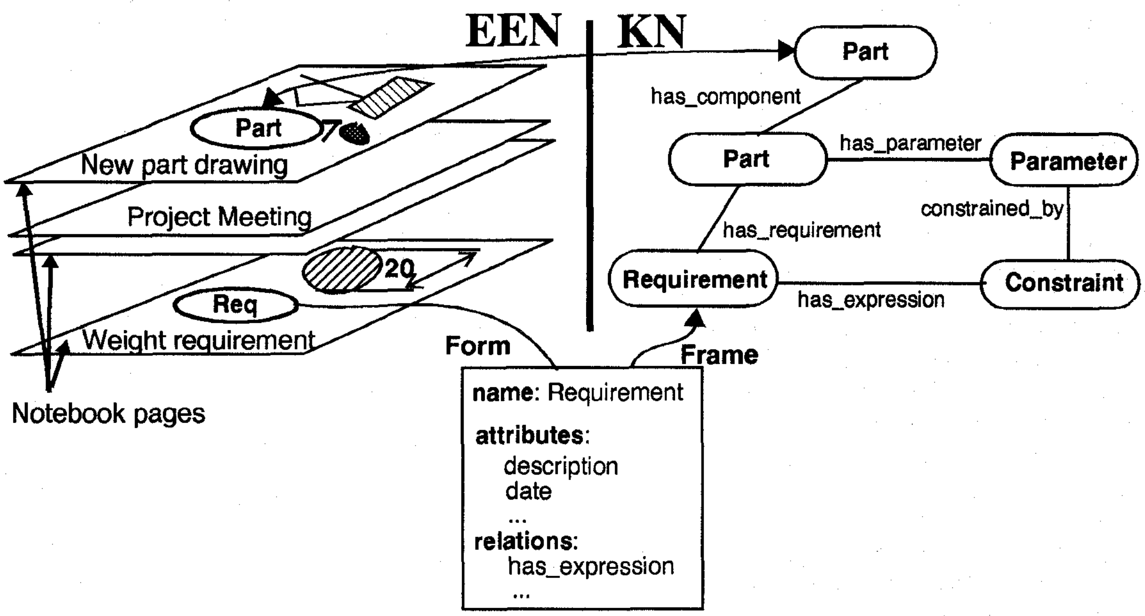

Figure 5. Relation between the content of EEN and KN

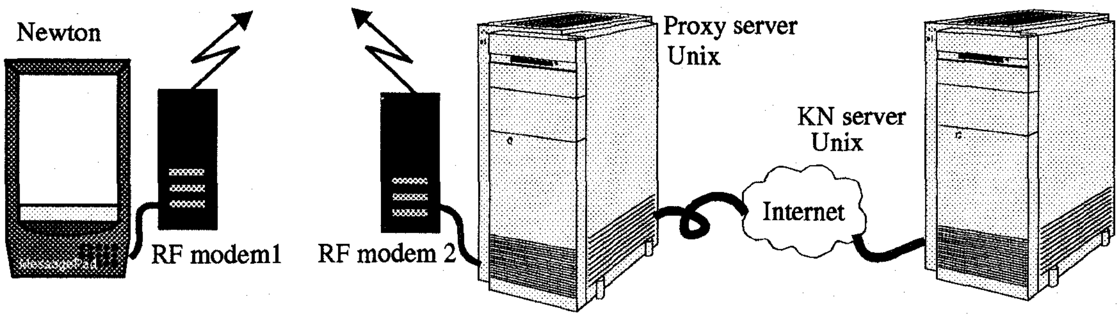

Figure 6. NewtEEN communication architecture

6 Related Work

There are a number of efforts aiming at the creation of an electronic design notebook [5],[8], [11],[12],[15],[17],[18]. They differ from our approach in various aspects. The conceptual design phase is not well supported as most of these systems are keyboard-based, run on desktop platforms, and thus, using them during the creative design stages is users with functionality for organizing and retrieving information and provide framework for integration of various engineering design tools. There are also efforts pursuing the opposite direction - paper is not replaced by, but augmented with computer tools [14]. These systems are not portable, their setup is complicated, and transferring paper notes into computer is difficult.

Our effort distinguishes itself in a number of ways. We focus on acquiring design information unintrusively by exploiting natural user input methods and using pen-based notebook computers and personal digital assistants (PDAs) to implement EEN. Our EEN provides engineers with the ability to capture design information quickly and efficiently anywhere they go.

7 Conclusions and Future Work

In this paper we presented our approach to electronic notebooks for engineers and described requirements for EEN, its design, prototype implementation, and initial experiments.

The development of EEN is dependent on the advances in various areas of computing and communication technology. Currently used hardware platform limits practical applications of our EEN, mostly due to the small screen size. We expect, however, that in the near future new tablet-like devices will become available.

We will conduct usability and usefulness studies at industrial sites to gather data validating our approach. In particular, we need to answer whether ontology terms can be used by designers for tagging notebook content and whether forms are an effective and sufficient means of transferring information captured in EEN to knowledge network. To support design rationale capture, we will extend TOVE ontologies [6] to include design knowledge and rationale representation and develop the corresponding elements of user interface. Described design and implementation constitute the first four phases of our EEN project, we will continue the development as outlined by subsequent phases.

We expect that with the development of computing technology paper and pencil will no longer be the most agile and the quickest way to record ideas, and that EEN will ultimately replace paper engineering notebooks.

Acknowledgments

This research was, in part, supported by Spar Aerospace Limited and PRECARN Associates.

References

[1] Baya, V., et al., A Study of the Information Handling Behavior of Designers During Conceptual Design, *in DE-Vol. 68, Design Theory and Methodology'94, ASME 1994,* pp. 153-160.

[2] Bilgic, T., Fox, M.S., "Constraint-based Retrieval of Engineering Design Cases: Context as constraints", in *Gero J. and F. Sudweeks (eds.) Artificial Intelligence in Design '96,* pp. 269-288, Kluwer Academic Publishers, 1996

[3] Crabtree, R.A., Baid, N.K., and Fox, M.S. An Analysis of Coordination Problems in Design Engineering. *In Proceedings of the International Conference on Engineering Design*, 1993

[4] P.F.Culverhouse, Product Books: archiving for information use and reuse, a replacement for CAD databases, *Journal of Design and Manufacturing*, 5:13-24,1995.

[5] Jerry Fowler et al, Experience with the Virtual Notebook System: Abstraction in Hypertext, *Proceedings of ACM Conference on CSCW*, October 1994, pp. 133-143

[6] Fox, Mark. S., Chionglo, J.F., Fadel, F.G., A Common Sense Model of the Enterprise, *in Proceedings of the 2nd Industrial Engineering Research Conference*, pp.425-429, Norcross GA, Institute for Industrial Engineers, 1993

[7] Fox, Mark.S, Design-in-the-Large - A project description, *Internal document*, 1994

[8] Hong, J., et al., Personal Electronic Notebook with Sharing, *Proceedings of the Fourth WET ICE'95*, IEEE Computer Society Press 1995, pp 88-94

[9] Gupta, L., Chionglo, J., Fox, M.S., A Constraint Based Model of Coordination in Concurrent Design Projects, *in the same volume*

[10] Lakin, F., Wambaugh, J. et al., The Electronic design Notebook: Performing medium & Processing Medium, *in The Visual Computer*, Springer Verlag, 1989

[11] Lakin Fred, et al, Mapping Design Information, On the Web: http://www.pgc.com/pgc/home-stuff/papers-archive/mdi-abstract.html, *AAAI 92 Workshop on Design Rationale Capture and Use, June 21, 1992.*

[12] Leifer Larry, Instrumenting The Design Process, *International Conference on Engineering Design, ICED 91' Zurich, August 1991.*

[13] Louie, Jim, An Analysis of a Pen-based Tool for Acquiring Engineering Design Information, *EIL Technical Report*, TRE-EIL-95-1, January 1995

[14] Mackay, W.E et al., Ariel: Augmenting Paper Engineering Drawings, *Video from CHI'95*, May 1995.

[15] Multimedia Engineering Collaborative Environment Project (MECE/DICE), Stanford CDR/Lockheed AI Lab/Enterprise Integration Technologies, *URL: http://www/hitchhiker.space.lockheed.com/pub/aic/dice/README.html*

[16] Moran, T.P., Chiu, P., van Melle, W., Kurtenbach, G., Implicit Structures for Pen-Based Systems Within a Freeform Interaction Paradigm, in *Proceedings of the CHI'95*, May 1995.

[17] Toye George, et al, SHARE: A Methodology and Environment for Collaborative Product Development, *in Post-Proceedings of the IEEE Infrastructure for Collaborative Enterprises, 1993*

[18] Uejio Wayne H., et al, An Electronic Project Notebook from the Electronic Design Notebook (EDN), *In Proceedings of the 3rd National Symposium on Concurrent Engineering. CERC, West Virinia University, February 1991*