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REPRESENTING THE CHARTERS OF FREEDOM ENCASEMENTS IN A DESIGN REPOSITORY: A CASE STUDY

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ABSTRACT

We report on a case study representing, in an evolving design repository, the design essence of new encasements for the United States Charters of Freedom (CoF)—namely the Constitution, the Declaration of Independence and the Bill of Rights. Specifically redesigned for the purpose of housing and preserving our national documents, the nine encasements each consist of three principal systems—a sealing system, a placement system and a safeguarding system. The encasements were needed to replace the ones manufactured in the early 1950s, because of glass deterioration; these newer encasements are designed to last 100 years. To populate the design repository, we represent engineering geometry, function and associated behavior. We model geometry with digital photographs and Virtual Reality Markup Language (VRML) models of actual Computer-Aided Design (CAD) drawings, and represent function with linked textual descriptions. Design rationale is represented explicitly. Through an evolving user interface, this representation serves to capture the more than 50 parts and systems of the encasements in such a way that the information relating to form, function, behavior and rationale is accessible *and* browsable to interested parties via the Internet. We conclude that such a representation, or ones similar to it, can provide the basis for a generic design repository, in which specific information—including design rationale—can be readily accessed by interested parties.

INTRODUCTION

Within the last decade, collaborative engineering (CoE) has become an established methodology for developing products and prototypes [1,2]. In general, design and manufacturing personnel have increased their CoE activities as technology has allowed them to do so. A prime example of this is the recent proliferation of Internet-Aided Design (IAD), where design and manufacturing personnel use the World Wide Web (WWW) for providing information services on the Internet [3-5].

In addition to *sharing* information, there is a need for, and an increased focus on, representing product knowledge in a way that facilitates storage, retrieval and reuse. This is a formidable engineering problem with over 20 billion CAD models in use [6]. In addition to providing an extensive database to improve the design process, it is also important to provide one in an easily accessible way. The Internet provides a widely accessible and usable platform for conveying information over long distances and to many people at the same time. Internet-related technologies that are beginning to address the accessibility issue include digital libraries [7,8], active catalogues [9], extended databases [10] and design repositories [11,12].

The most recent of these technologies is design repositories (DRs). DRs have extended the capabilities of traditional databases by being more robust in capturing function, behavior and models. In addition, DRs generally accept more heterogeneous information and incorporate more explicit representations than databases [12]. The National Institute of Standards and Technology (NIST) design repository, started in 1996, is a database that supports representing, capturing, sharing and reusing design knowledge. The NIST DR can be used to store much of the data created from a generic design and its associated processes so that the information can be shared with future designers and planners.

This paper describes a case study using the NIST design repository to capture the design and reasoning behind the development of the Charters of Freedom Re-encasements (CoFR). The subject of the paper is a case study in product knowledge modeling and representation, as opposed to a paper about the design repository project that uses the encasements as an example. Thus, the focus is in the information modeled, and not the implementation of the Design Repository system. Szykman et al [12, 13] provide more information about the implementation and technical detail about the design repository.

After briefly describing the need for a new encasement design, and the associated design and manufacture of them, we present how we populated the NIST DR with knowledge about the CoF encasements. We conclude with our assessment of the benefits of, and the bottlenecks to, the representation of CoFR in the DR.

NOMENCLATURE

CAD	Computer-Aided Design
CoE	Collaborative Engineering
CoF	Charters of Freedom
CoFR	Charters of Freedom Re-encasements
DR	Design Repository
NARA	National Archives and Records Administration
NIST	National Institute of Standards & Technology
URL	Uniform Resource Location
VRML	Virtual Reality Modeling Language

RE-ENCASEMENT DESIGN DESCRIPTION

As part of the millenium program to preserve America's heritage, the National Archives and Records Administration (NARA) commissioned NIST and others to redesign the encasements for the CoF. For more than a century, the CoF were stored without much regard to preservation—in government offices, safes and display cases [14]. As a result, these historical documents became among the most abused and deteriorated in preservation history. Realizing this in the 1920's, the government transferred the documents to the Library of Congress. In 1940, the Library asked the National Bureau of Standards (which became NIST in 1988) to design the encasements because of the technical expertise two NBS employees, Bourdon Scribner and Arthur Kimberly, had in paper conservation. The 1951 encasements were based, simply enough, on a thermopane window—two panes of glass soldered around the edge [15]. Between the panes, were the document, helium and "pure" cellulose paper backing. Visual inspections since 1952 revealed no deterioration in the encasements until 1995. At that time, experts determined that the glass was deteriorating and would need to be replaced within seven years. Hence, the re-encasement effort. Passaglia [14] and Kline [15] describe more of the history about the Charters and initial encasements; the URL, www.nara.gov/charters_reencasement/impact/reencasment.html complements and updates those reports.

Design requirements for the CoF re-encasement were similar to the requirement for the original encasements [15]. Since an atmosphere above 2% oxygen supports aerobic bacteria that can deteriorate paper, the re-encasements must be filled with an inert gas. Moisture fluctuation is also problematic; as a result, humidity needs to be controlled within the encasement. Methods for monitoring the environmental conditions in the encasement are required. The enclosure must allow viewing, while preserving the environment within and protecting the document from ultraviolet light radiation. Newer design requirements included specifications such as an environment of < 0.5% oxygen, a 100-year seal, a weight limit of 625 N (140 lbs) to allow for emergency removal, handicap viewing, and color, texture and sheen to match the aesthetics of the Rotunda, where the encasements will be housed. Additionally, the new encasements must overcome inadvertent abuse during maintenance and be able to withstand drop tests. The design team, consisting of representatives from four government agencies, and several companies and individual consultants, went through several conceptual designs and prototypes before finalizing on the design shown in Figure 1. The encasement consists of three principal classes of systems, of which ten systems are major. The three classes of systems are seal, safeguard and display. Within those classes, major system functions include pressurizing, monitoring, controlling, joining, supporting, transferring, securing, adjusting, and

Figure 1. The first prototype encasement, shown here with the transmittal page for the Declaration of Independence. Sized for the Bill of Rights, the encasement can accommodate the smaller document, albeit with asymmetric margins.

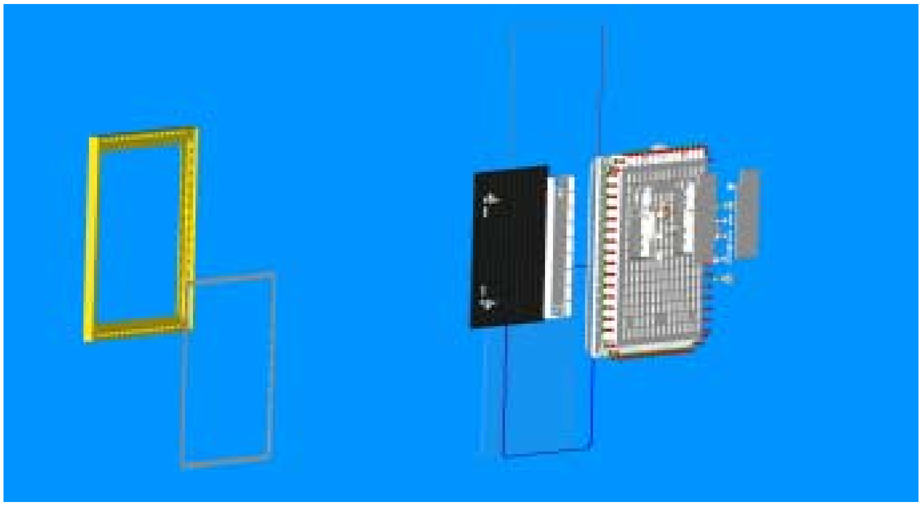


Figure 2. Exploded view of assembly. From left to right, shown components are frame, seal, platform, optics bench, base and plumbing.

covering. These systems were implemented into components, many of which can be visualized in Figure 2, which shows an exploded view of the encasement. The main parts include the base, the refill and rupture disc plumbing, the bolts that seal the encasement, the optics bench, document platform, handles, the main seal, the titanium frame, and the tempered laminated glass.

As part of this design, the new encasements have a monitoring system to help control the interior environment. This system includes an optics bench that detects changes in humidity and oxygen levels using a absorption spectroscopy, temperature and pressure gages. Adjustments to the interior environment are made through the plumbing system. A rupture disk, shown in Figure 3, is an original part of the plumbing system as a safety device to guard against overpressure. If interior pressure becomes unexpectedly large, the rupture disk is designed to break before the covering glass.

Figure 3. In case of an unexpected pressure differential The rupture disk is designed to fail before the main glass.

However, subsequent full-scale tests on the encasements revealed that the tempered glass withstood pressures on the order of 500 mm Hg. As a result, the rupture disk is being phased out for the final design.

These are some of the major components contained within the new design. We now discuss the design repository and how the charters of freedom were represented there.

DESIGN REPOSITORY

The NIST Design Repository project was formally started in 1996, after a NIST-sponsored workshop in the area [11]. The infrastructure is one where formal and explicit representation of design-artifact knowledge can be expressed and created using Internet-based tools. In addition, populated repositories can be browsed by others to view multiple types of design information.

In brief, a design repository is an intelligent, knowledge-based modeling system used to represent, store, display and retrieve specific design information. A DR is an extension of a traditional design database in that it captures function, behavior, in addition to drawings and CAD models that might well be represented in a database. At the most basic level, a DR captures form (geometry), function and behavior of artifacts [16]. While this top-level division into form, function and behavior has been espoused by many, Szykman et al have extended the notion by implementing Web-based interfaces, developing a core model with common terminology and developing mechanisms for representing rationale and process information [12, 13]. A typical format is shown in Figure 4.

For the Charters of Freedom project, we represented form, function, behavior and design rationale in the DR for many of the components. Form was captured, in part, through taking the geometry as represented by CAD drawings typically, and linking them or their VRML images and digitized pictures to the repository. A typical example is shown in Figure 5 and Figure 6, which represent a detailed drawing and VRML image of the rupture disc displayed in

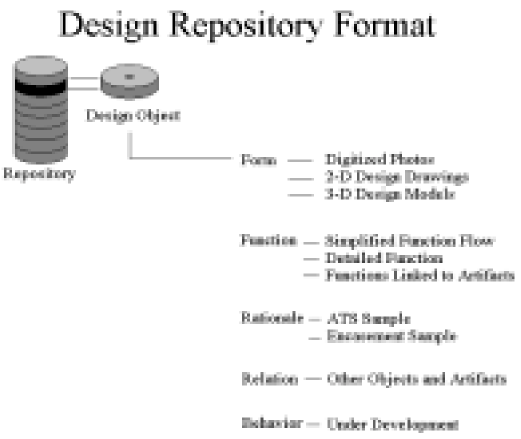


Figure 4. The design repository format. As indicated, multiple designs are represented in the same format.

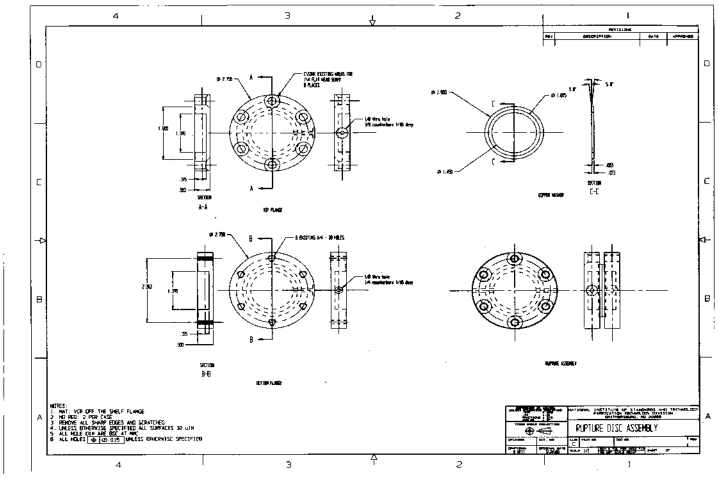


Figure 5. A 2-dimensional CAD drawing of the rupture disc. This is linked to the form artifact of the rupture_dic_object.

Figure 6. A VRML isometric image of the disc.

Figure 3 (as a digital photograph).

These forms were linked to function, behavior and rationale through a hierarchy of links at the functional level. As shown in Figure 7, for example, each of the principal functions of the new encasements are linked hierarchically to component artifacts and to assembly artifacts. These links allow the DR to be browsed by users interested in identifying components for a particular function, or for determining which function or functions a component contributes to. While many components are often associated with each function, some components or systems, such as the handle assembly, can also have multiple functions.

In its current configuration, design rationale for some artifacts is represented as an object with textual descriptions linked to artifact objects and function objects within the repository. For example, in the design of the rupture disc shown in Figures 3, 5 and 6, the membrane separating the inside of the encasement and the outside atmosphere is made of aluminum. The purpose of this membrane is to break in the event of an unexpected pressure rise or drop. This would allow the gas pressure inside the encasement to equalize with the outside atmosphere, thereby reducing the risk of front glass breakage that could damage the document protected. The original design called for an aluminum membrane, in part, because of its good seal characteristics and its mechanical properties (it could be made thin enough to rupture in the correct pressure range). The aluminum membrane began to corrode where it contacted the copper seal rings. As a result, designers evaluated different materials for the membrane These design decisions (and others), as well as associated rationale, are represented textually within the DR.

Figure 8 shows one user interface of the design repository browser [12, 13] for this application. In this view, there are three active windows. The upper right shows a VRML image of the encasement at hand; in this case, it is the entire assembly. The lower right window displays the information contained in the abstraction—description, form, function, behavior, subartifacts and parent. Each abstraction—being an object itself—is accessible to the user. The left window lists the system hierarchy, allowing the user to view other aspects of the design at his/her discretion. Although the encasement consists of more than 50 major components, the representation of the design in the NIST Design Repository includes many more data entities (objects and relationships). It is these additional objects that model artifact functions, associated flows, physical decompositions, and other relationships between parts of the artifact. These entities allow design repositories to capture a more comprehensive representation of an artifact than would be included in a traditional design database. The browser is continuing to evolve; a more refined user-interface is currently being developed.

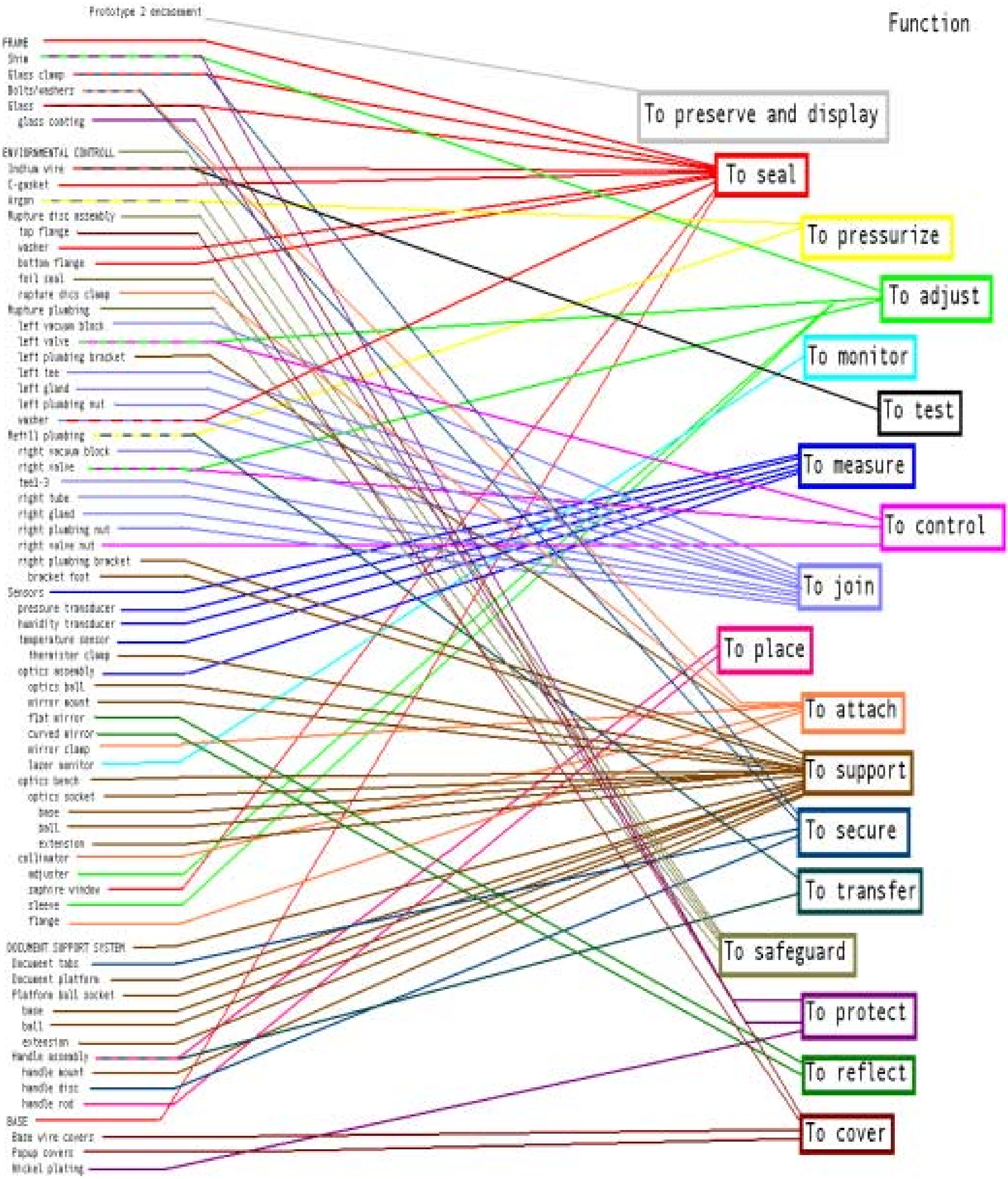
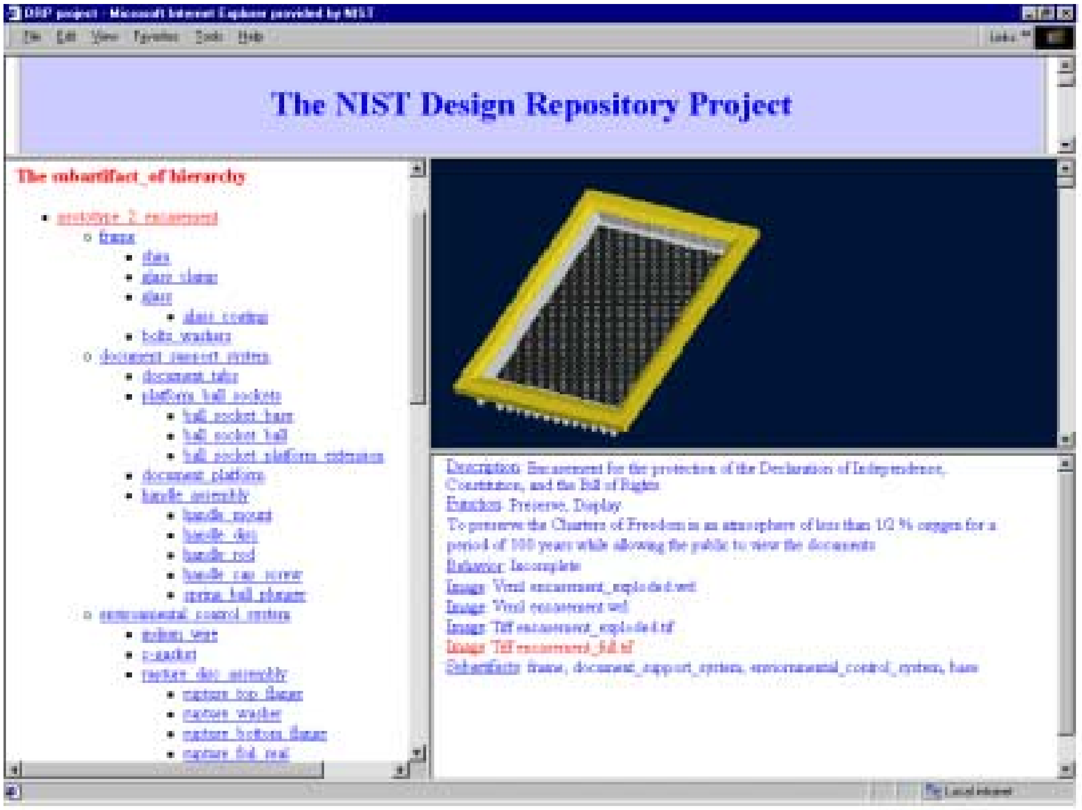


Figure 7. The hierarchy of encasement functions with links to associated components and systems.



The NIST Design Repository Project

The subartifact_of hierarchy

- prototype_2_encasement
  - frame
    - glass
    - glass_clamp
    - glass
      - glass_coating
    - bolts_washers
  - document_support_system
    - document_tabs
    - platform_ball_sockets
      - ball_socket_base
      - ball_socket_ball
      - ball_socket_platform_extension
    - document_platform
    - handle_assembly
      - handle_mount
      - handle_disc
      - handle_rod
      - handle_cap_screw
      - spring_ball_plunger
  - environmental_control_system
    - [illegible]
    - c-gasket
    - rupture_disc_assembly
      - rupture_top_flange
      - rupture_washer
      - rupture_bottom_flange
      - rupture_foil_seal

Description: Encasement for the protection of the Declaration of Independence, Constitution, and the Bill of Rights
Function: Preserve, Display
To preserve the Charters of Freedom in an atmosphere of less than 1/2 % oxygen for a period of 100 years while allowing the public to view the documents
Behavior: Incomplete
Image: Vrml encasement_exploded.wrl
Image: Vrml encasement.wrl
Image: Tiff encasement_exploded.tif
Image: Tiff encasement_full.tif
Subartifacts: frame, document_support_system, environmental_control_system, base

Figure 8. One proposed interface of the DR for the encasement assembly.

SUMMARY AND AREAS FOR FUTURE RESEARCH

We represented the function, form, geometry and design rationale of the encasements associated with the Charters of Freedom in the NIST Design Repository. The hierarchical abstraction of the designs can now be accessed and browsed via the Internet. Subsequent design teams can view and browse the design for specific instances of components or systems, for the rationale in selecting them, or for the specific details associated with one part. Preliminary data with the system suggests that having this information readily available can be useful to the conservationists at NARA.

Our purpose in this paper was to populate an existing design repository with the CoFR as a case study. There were three principal reasons for this. First, because of the nature of this particular design project, the DR representation has historical significance. In the distant future, when these encasements will need replacement, for example, designers can explore the rationale behind the current design, and perhaps use that knowledge in the development of a third generation encasement. Secondly, it is well established that considerable effort is needed for capturing design knowledge [17]. Because it is a structured environment, the design repository reduces the knowledge engineering effort associated with acquiring knowledge. There is still effort involved in populating the DR with design data and knowledge, but it is less than the effort needed in a less formal method [15-17]. Thirdly, because there are links among artifacts and functions, such as those shown in Figure 7, there is an inherent taxonomy within the DR structure. This provides the potential to search for an artifact through function and to search for function through an artifact. As with any new technology, the efficacy of the DR approach should be judged not only by the ability of the technology to search and browse existing design data, but by the additional effort necessary to achieve useful DR representation.

Another issue is the representation itself. To be useful to many, any representation scheme needs to be as standardized as much as possible to ensure that data can be reused and assimilated on successive projects. Doing so would also ease the burden of undue documentation on the designer while he or she is designing. Such standardization requires consensus with input from the design and research communities. Researchers at several universities are making use of representations developed for the DR project and are providing useful feedback. NIST is continuing its industry workshops to gather additional information regarding needs associated with engineering design data reusability.

Because of industry's increasing dependence on other types of knowledge in the design process, new classes of tools to support knowledge-based design, product data management (PDM), and concurrent engineering have begun emerging in the engineering software marketplace. When contrasted with traditional CAD tools, these new systems are making progress toward the next generation of engineering design support tools. However, these systems have focused primarily on database-related issues. In contrast, the focus of the Design Repository Project is on a more comprehensive representation of artifact knowledge. Once this work diffuses into commercial applications, it will still be important to address the database and product data management issues. Thus this work is not viewed as being in competition with ongoing efforts by others in the area of database and product data management, but rather is a complement to those efforts.

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