Building Internet-Based Virtual Environments Collaborative Design

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1 Introduction

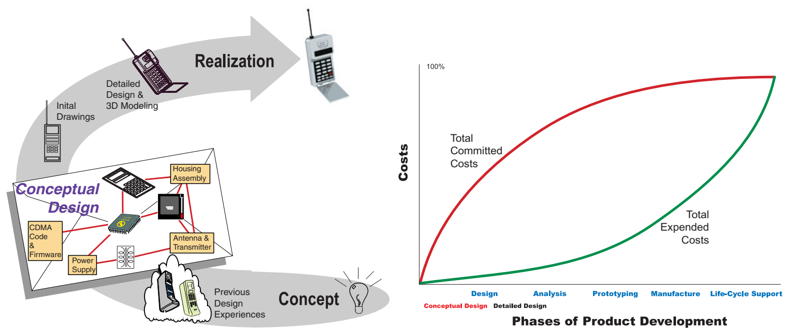
This paper presents an overview of our system to support computer-aided conceptual design of mechatronic assemblies in a collaborative, multi-user environment. CUP (Conceptual Understanding and Prototyping) allows design engineers to develop a high-level structure-behavior-function (S-B-F) descriptions of an assembly in a Java3D/VRML-based virtual environment. Our goal is to enable users to navigate intricate product data management (PDM) and case-based design knowledge-bases, providing the ability to perform design at the conceptual level and have intelligent CAD tools that can access details from large repositories of previous designs.

Conceptual design, as shown in Figure 1 (a), is the initial phase of the product design process, when product development teams (consisting of design engineers, manufacturing engineers, marketing and management personnel) perform the "back-of-the-envelope" calculating, sketching and planning—fleshing out—of their initial product concept. Figure 1 (b) shows that the design phase of the product realization process has a tremendous impact on the life-cycle cost of a product.

This work furthers research efforts in supporting collaborative design, in particular drawing on work in Computer-Aided Design (CAD) and Computer Supported Collaborative Work (CSCW). We envision CUP to be a network interface to next-generation engineering PDM systems and CAD databases. We are currently planning to deploy CUP as the query interface to the National Design Repository (`http://repos.mcs.drexel.edu`). This will enable CAD users to interrogate large legacy databases (models and assemblies) and identify artifacts with structural and functional similarities, aiding designers during case-based and variant design.

2 Background

The sources in literature most relevant to our efforts come from two areas: Collaborative Work and Computer-Aided Conceptual Design. At Stanford [4], collaborative production modeling and planning has been performed using virtual environments. Much research has focused on information requirements



(a) (b)

Fig. 1. (a) The role of Conceptual Design in the product lifecycle: capturing design structure and function and generating ideas from previous design experience. In the above example, designers creating the next-generation model of cellular phone draw on past design experience and perform conceptual design. (b) Decisions made at the conceptual design phase have great impact on product viability and cost. However, there are few software support tools for conceptual design.

for synchronizing shared realities [9] and managing networked bandwidth requirements [2]. There has been a realization in the CAD community that digital support for conceptual design is an increasingly critical component of software environments for designers [12]. Wallace and Jakiela [16] developed an experimental conceptual design tool for industrial designers capable of generating alternative design suggestions based on user input. The Virtual Assembly Design Environment (VADE) of Jayaram et al. [8] creates an immersive 3D world for assembly modeling and prototyping. Research in CACD also includes systems for “conceptual sketching” [7] in Human-Computer Interface design as well as CAD [3]. Most relevant to our work is the CONGEN system of Gorti and Sriram [6,5]. In this approach to conceptual design, the design process consists of two stages: a symbolic aspect which leads to a logical product description, and a geometric aspect which leads to a physical description.

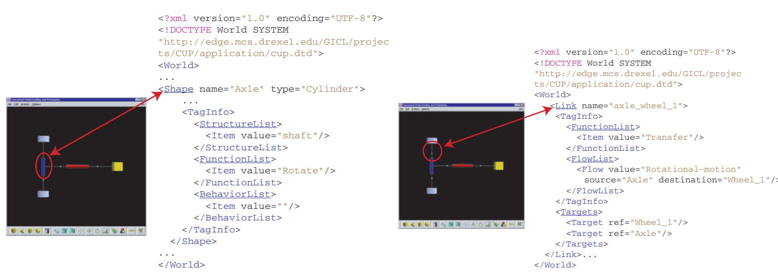
3 Research Approach

CUP allows a user to specify a spatial layout of components and sub-assemblies, provides means for the user to specify **structural**, **behavioral**, and **functional** (S-B-F) information about components and sub-assemblies, and possesses mechanisms for capturing textual information about the designer’s intent and preferences. In this way, CUP serves two needs:

1. CUP enables users to quickly capture structural information in a top-down fashion and record the function and behavior of the intended artifact and its sub-components.
2. CUP is a query interface for *Design Repositories*—enabling access to knowledge-bases containing legacy engineering design data [13,11].

Other researchers have approached conceptual design as a **freehand sketching** problem [3]. A novel aspect of CUP is that we have developed a three-dimensional modeling approach to conceptual design that enables teams of designers to embed semantic **structure-behavior-function** (S-B-F) information in their models. Our approach offers several benefits. First, it is the structure-behavior-function knowledge, more than the geometry and topology, that encodes the designers' intent. Second, this approach liberates the designer from the usual restrictions of exact measurements, or precise positioning and orientation. CUP will allow the designers to create a three-dimensional "freehand" sketch and the general structure of the artifact without performing detailed CAD.

Embedding structure-behavior-function [15,14] information in CUP's model files enables user to add design intent and purpose to the simple concrete objects and groups represented in each design world. Our design data representation is based on a taxonomy proposed by Szykman et al. [15] of the National Institute of Standards and Technology (NIST) regarding the representation of function in engineering design. In this standard, **function** and **flow** are defined as the two main quantities that are necessary in order to properly represent design intent.



(a) (b)

Fig. 2. Snippets of XML code from an assembly modeled in CUP (specifically, a simplified drive train).

CUP store models with the eXtensible Markup Language (XML) [1], a dynamic language which allows the structured representation of data with user-defined tags. Figure 2 shows two pieces of actual XML code that were created by CUP for a drive train assembly.

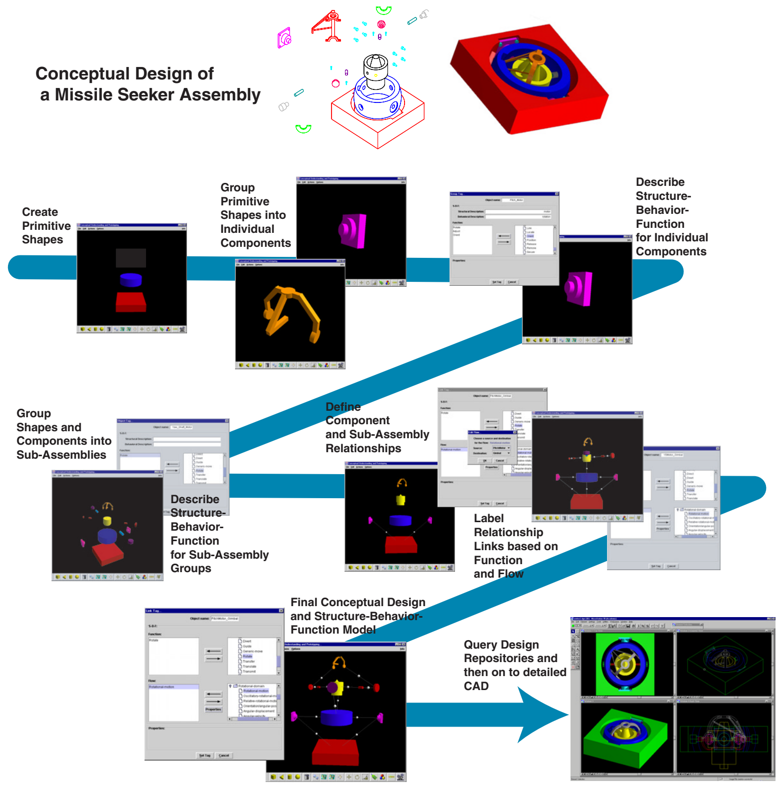


Fig. 3. The conceptual design process of the missile seeker within CUP, from component design to functional description to final conceptual assembly. This conceptual design then becomes the basis for detailed CAD.

4 An Example

CUP is primarily concerned with the creation of conceptual designs of *mechatronic systems*: electro-mechanical systems that combine electronics and information technology to form both functional interaction and spatial integration in components, modules, products, and systems, such as the CAD model (simplified) of a missile seeker assembly pictured in Figure 3. This simplified seeker assembly might be one of many dozens stored in a corporate design data/knowledge-base. A design team, faced with the task of creating a new seeker, might want to interrogate the CAD knowledge-base and examine previous design cases that might be relevant to this new problem. Examining this legacy data can prove time-consuming and tedious.

The design scenario shown in Figure 3 demonstrates how CUP allows a designer to quickly sketch out, in 3D, the major components and structural relationships in the assembly. Rather than performing detailed CAD modeling to create a draft design, which for this model took several days, designers can, in a matter of minutes, build a conceptual design. This conceptual design can then be used as a starting point for further refinement or as a query to the design knowledge-base. CUP also, via the attributing, tagging and labeling features, helps designers capture the design intent and build a structure-behavior-function (S-B-F) model of the artifact.

5 Conclusions

This paper presented CUP, a system for the computer-aided conceptual design of mechatronic assemblies. We are extending CUP in several significant ways:

- **Multi-User Conceptual Design:** Building multi-user collaborative design functionality via CUP's network-based Virtual Reality environment could prove to be a powerful supplement to traditional CAD and CSCW tools.
- **Access to Design Repositories:** Increasingly, engineers depend on Product Data Management (PDM) systems, large-scale engineering digital libraries, and knowledge-bases of CAD solid models to perform their job [11,10]. This involves searching through vast amounts of corporate legacy data and navigating manufacturers' catalogs to retrieve precisely the right components to assemble into a new product. It is our eventual goal to integrate CUP with the National Design Repository[1] and provide facilities for users to add their own ontology information to the repository's knowledge-base.
- **Evaluation:** As a complement to our approach to conceptual design, we plan to undertake studies to rate efficiency of this design tool.

Acknowledgements. This work was supported in part by National Science Foundation (NSF), Grants CISE/IIS-9873005 and CISE/IRIS-9733545. Additional support was provided by AT&T Labs. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or the other supporting government and corporate organizations.

[1] `http://repos.mcs.drexel.edu`

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