A Proposal of the Activity Chain Model and Its Application to Global Design

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Abstract

In this paper, the "Activity Chain Model", a new design information model necessary for the knowledge medium which realizes "Global Design" is proposed. In order to realize "Global Design", the knowledge medium must provide both intent-capturing and intent-explanation capabilities sufficiently. To provide these capabilities, the "Activity Chain Model" not only integrates both the product and the process based on the activity description, but also introduces a chained structure into the activity. Consequently, this model exceeds the capabilities of conventional media in terms of the range and methods of handling information. For example, this model can capture design process information, including design intent, according to the level of detail of the process information, and the designer's input overhead can be mitigated. The authors implement the model in a computer system called "POET Knowledge Medium". From the results of the evaluation of the "POET Knowledge Medium" through design simulation, the effectiveness of the "Activity Chain Model" was confirmed, not only in the case of capturing and transferring the design intent, but also in reminding the designers themselves of the design process.

1 Introduction

1.1 Globalization of design

Today's computer network technology enables industrial activities without the restrictions of physical distance or time, and many enterprises have adopted a global production style based on international cooperation. However, when design and manufacturing in a production process are considered separately, the design process is still performed locally by direct face-to-face communication even though globalization of the manufacturing process has become common. It is an important issue in future production industries to attain globalization of design.

The authors consider the globalization of design as follows. One is "spatial globalization" of design. This includes cooperation among designers with various abilities to design various product families. This also includes international division of the design process into overseas markets or factories to realize short-term development of products.

Another is "time globalization" of design. This includes the reference and the reuse of past designs as examples. This also includes accumulation of design expertise for succession of designers' skills. In this paper, the new design style suitable for the globalization of design as stated above is called "global design".

1.2 Necessity for new design-support technologies

From the viewpoint of an information system, most design information treated by the system is not for design but for manufacturing. There are no established criteria on what information should be managed and provided in what way to support creative design.

Advancement of design-support tools, such as 3-dimensional CAD, makes it easier than ever to describe geometric information or attribute information based on a result of a design. However, it is difficult to express the designer's own ideas and recognition of problems using these design-support tools. There is still no tool that can support the designer's work itself. Moreover, industrial standards, such as CALS and STEP[1], are the minimum necessary framework for sharing product information among the users of such information, and are not aimed at information sharing for the sake of creativity and efficiency in the design process.

It can be said that the realization of an information-sharing framework to make design work global is one of the most important future research subjects.

2 Objectives

In this paper, the computer medium for supporting global design is called the "knowledge medium". The knowledge medium for supporting global design must provide an information-sharing mechanism that exceeds the ability of conventional media in the range and methods of handling information.

First, in the range of information that the knowledge medium handles, not only product information such as drawings, but also the histories and the intent of the design, which have been difficult for conventional media to handle, should be contained. Next, as a method by which it handles information, the knowledge medium must perform simultaneous capture, accumulation and distribution of design information through one medium; conventional media perform those processes separately. In other words, the knowledge medium must accumulate design information, which can be referred by other designers, based on the interaction with the designer in the design process, without the addition of extra operations by the designer. In particular, it is important that the knowledge medium is able to mitigate the designer's overhead of inputting information by capturing support concerning the history and the intent of the design.

The objectives of this research are to define the design information model necessary for realizing the knowledge medium, focusing on a model of design processes, to implement it in a computer system, and to confirm the validity of the model.

3 Proposal of the “Activity Chain Model”

Now, toward the realization of the cooperative design-support environment through information sharing, utilization of the information technologies, including the PDM system, has become more common than ever before in design work[2]. However, in PDM, management of design output (drawings, CAD information, design documents, etc.) is considered important, and the information on the history and the intent of the design are restricted to the range necessary for the management of the design output.

Concerning the design intent Garcia et al.[3] classified the cooperative design-support environment into three methods based on the manner of intent expression:

(1) the knowledge-model-based method,
(2) the argument-based method,
(3) the action-based method.

They compared these three methods from the viewpoint of intent-capturing capability and intent-explanation capability. Their comparison showed that the explanation of the design intent is better in the knowledge-model-based method, the argument-based method, and the action-based method, in that order. In addition, it is shown that capturing the design intent is easier in the action-based method, the argument-based method, and the knowledge-model-based method, in that order.

In SHARE[4], SHADE[5][6] and n-dim[7], when realizing a cooperative design-support environment, the focus is on the utilization of information technology such as knowledge engineering. The description model of the design intent in SHARE, SHADE and n-dim assumes the use of the conventional method that includes the knowledge-model-based method or the argument-based method. In the description model of the design intent using the knowledge-model-based method, although the intent-explanation capability is better, capturing the design intent is difficult. In particular, in a creative field in which the designers themselves cannot denote the knowledge or the rule on the design, there is the problem that it becomes harder to capture the design intent in a knowledge model.

It is possible for gIBIS[8][9][10] and PHI[11][12][13], which are based on the description model of design intent using the argument-based method, to describe the design intent, even in a field in which it is difficult to describe a knowledge model, and to give an explanation based on the intent. However, in the argument-based method, capturing the design intent is not necessarily easy since designers must register proposals, arguments, opinions, and the relations among them into the system during design work. The description model of the design intent based on the decision can also be considered to be a kind of argument-based method, and it is necessary for designers to register the contents of the decision in order to capture the design intent for the system. ADD[3], JANUS[14], AIDEM[15], the system of Ganeshan et al.[16], DESIGN SCRIBE[17], and DRIM[18] study active capturing support of the design intent by the computer using the argument-based method. However, since the system needs to recognize the designer's intent according to the argument-based method to support capturing of the design intent, it is difficult for the system to support capturing unless the system can understand the designer's knowledge or rule concerning the domain of the design. Moreover, from the viewpoint of the explanation capability of the intent according to the classification of the process explanation by Wright[19], although the intent-description model using the argument-based method is suitable for "teleological explanation", which is an explanation of the reason for an action according to the future state to be satisfied, it is not necessarily suitable for "causal explanation", which is an explanation of the reason for an action according to the past state.

In the preceding study by some of the authors[20], a new intent-description model using the action-based method, which extends the explanation capability of the intent-description model using the argument-based method to "causal explanation", was proposed. Generally, in the intent-description model using an action-based method, such as Electronic Notebook[21], since the action itself serves as the explanation of the intent, although capturing the design intent is easy, the intent-explanation capability is not satisfactory. This paper proposes a design information model that introduces the chained structure into the action in order to improve the explanation capability based on the intent, and which employs easy and efficient capturing of the design intent in the action-based method. This model is called the "Activity Chain Model". In the following, the description method of the history and the intent of the design based on the Activity Chain Model are explained in detail. We define the following terms.

(1) "Product Information" means the information on the result of the design (an intermediate result is also included) such as drawings, CAD information, or design documents.

(2) "Design Process Information" consists of the information on the history and the intent of the design.

(3) "Product Unit" means the unit of product information that corresponds to a part or an assembly.

(4) "Design Activity" means the external action that can be described as operations on the product information. Inner (mental) action of the designer is not included.

(5) "Activity Unit" means the unit of design activity that corresponds to each decision on the specifications or the shape of the product by the designer.

3.1 Description of the history of the design process by the Activity Chain Model

In the Activity Chain Model, the information on the history of the design processes includes product information as an attribute, and the design process information and the product information are integrated with the focus on the design process information.

First, for the product information, we consider a "composition relation" (the relation between the part and the whole) including "child-parts and a part" or "parts and a product" relation. The product information is described by the product units that are associated with each other through the composition relations.

Next, for the design activity, we consider a "sequence relation" according to the order of execution of design activities along the time axis. The information about the history of the design is described by the activity units associated with each other through the sequence relations.

Between a product unit and an activity unit, we consider the "object relation" which means that the object of the design process denoted by the activity unit is the product unit. Two or more objects can be considered for one activity unit. The product unit changed by the execution of a certain activity unit can be considered an object of the activity unit.

In this way, the Activity Chain Model describes the history of the design by means of the product units and their composition relations, the activity units and their sequence relations, and the object relations between them (Fig. 1).

3.2 Description of the design intent by the Activity Chain Model

In the Activity Chain Model, we also consider a "constraint relation" and an "alternative relation" between the activity units as the relations concerning the design

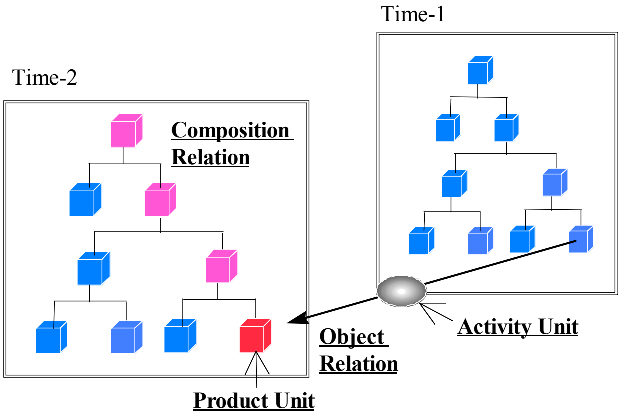

Fig. 1 Product Units and Activity Units

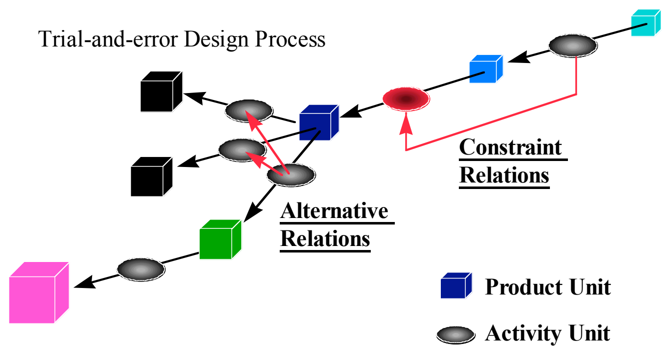

Fig. 2 Constraint Relations and Alternative Relations

intent (Fig. 2). Moreover, a "reason" is described as an attribute of these relations. The "reason" here denotes not the reason for the activity but the viewpoint of the designer in determining the constraint relation or the alternative relation. The reason for the activity is expressed by the entire structure of the constraint relation and the alternative relation, which are related to the activity unit, including "reason (viewpoint)" as their attribute.

The "constraint relation" denotes that a certain activity unit in the past is a constraint of a succeeding activity unit, and it is described as a multiple-to-multiple relation. Using the "causal reason", which is an attribute of the constraint relation, the designers can describe the reason why they consider the activity unit to be a constraint. The "alternative relation" denotes that a certain activity unit is an alternative of another activity unit, and it is described as a multiple-to-multiple relation. Using the "teleological reason", which is an attribute of the alternative relation, the designers can describe the reason why they actually adopt (or do not adopt) the activity unit in comparison with its alternative. This "teleological reason" can express the designer's teleological explanation in the design processes.

Thus, the Activity Chain Model describes the design intent by means of association between the activity units using the constraint relations, their causal reasons, the alternative relations and their teleological reasons. The hypothesis underlying the Activity Chain Model is that the designer's inner (mental) process which forms the design intent can be represented as a chain structure of the external activity units. The class diagram of the Activity Chain Model is shown in Fig. 3 according to the UML (unified modeling language) notation[22].

4 Method of handling the design process information

4.1 Support for capturing design process information

Since it is important for the argument-based intent-description model to capture the design intent efficiently, ADD[3], JANUS[14], AIDEM[15], the system by Ganeshan et al.[16], DESIGN SCRIBE[17], and DRIM[18] provide active support for capturing the design intent using the dependence among the decisions, the knowledge and the rules on the domain of the design. On the other hand, active capturing support of design process information, including the design intent, by the Activity Chain Model focuses on the derivation of relations between design activities and attributes of the relations. The details are described in the following.

First, in order to support the capture of the design history, it is sufficient to generate, without extra input from the designer, the activity units corresponding to the designer's operations, the sequence relation between the activity units along the time axis, and the object relation between the activity unit and the product. Next, when a designer inputs the constraint relation and the alternative relation explicitly, it is effective to choose the constraint relation from the activity units in the past designs, and the alternative relation from the activity units in the past trial-and-error histories. In the Activity Chain Model, the structure of the chains between the activity units described by the constraint relation or the alternative relation primarily expresses the designer's intent, and the causal reason and the teleological reason are supplemental attributes of the chains. Therefore, even if the causal reason and the teleological reason are omitted, the design intent can be understood to some extent from only the constraint relation or the alternative relation. Furthermore, when the designer inputs the causal reason for the constraint relation or the teleological reason for the alternative relation, only simple vocabulary without structure need be prepared beforehand in order to support the capture of the design intent more clearly. Thus, because the reason itself can be expressed by simple vocabulary without structure, it is possible to choose appropriate words as the reason, by the simple estimation mechanism based on the ontology dictionary.

As stated above, in the Activity Chain Model, it is possible to support the capture of the design process information, including design intent, according to the level of details of the process information. In addition, it is possible to support the designer's input of the design process information at each level of the details, and to mitigate the input overhead.

4.2 Integration of capture, accumulation, and transfer of the design process information

In the accumulation of the design process information according to the Activity Chain Model, it becomes easier to capture the design process information because the design activities performed by the designer in the design process need only be expressed as the activity units along

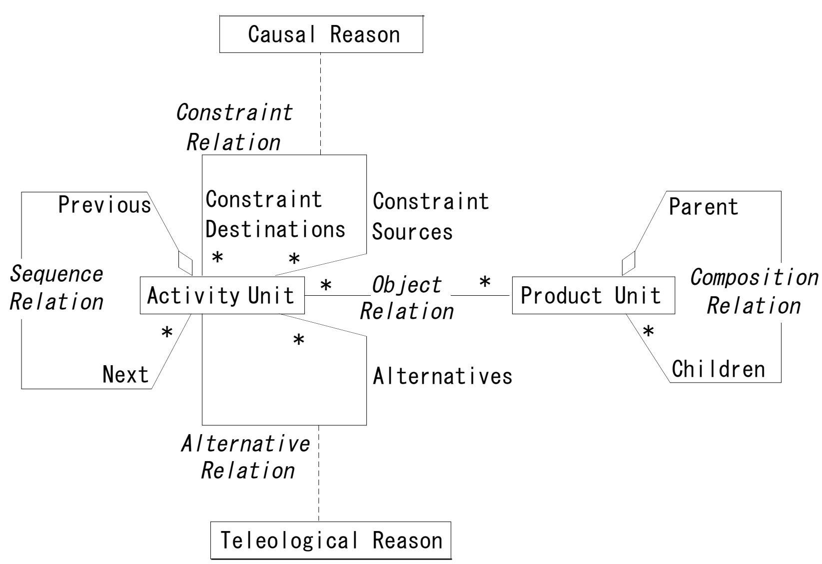

Fig. 3 A class diagram of the Activity Chain Model

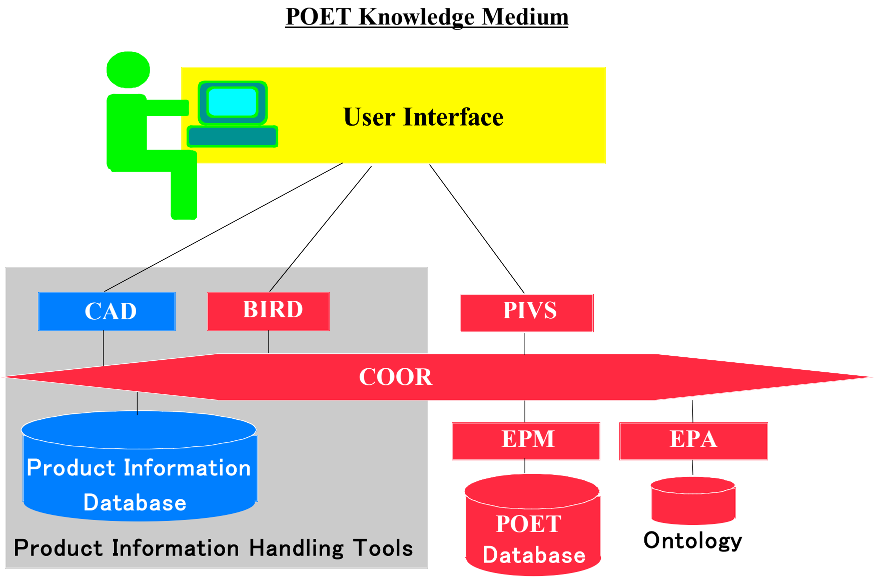

Fig. 4 POET Knowledge Medium system architecture

the time axis, and the constraint relation and the alternative relation are added between these activity units. Also it becomes easier to transfer the design process information because a designer can receive another designer's past design activity as activity units along the time axis, along with the constraint relations and the alternative relations between these activity units, which enable the designer to understand the design history and the design intent.

Thus, since the Activity Chain Model is suitable for both the capture and transfer of the design process information, it is possible to use the same integrated model in order to capture, accumulate, and transfer the design process information simultaneously with the propagation mechanism from the capture system to the visualization system through the database. This integrated model also enables the designer to combine the functions of capturing, accumulating, and transferring the design process information.

5 Architecture of the POET Knowledge Medium

POET (Process-Oriented Engineering Technology) Knowledge Medium implements the knowledge medium based on the ideas mentioned above as a system, and it consists of the following five subsystems (Fig. 4).

(1) Design process information database management system: EPM (engineering process manager)

(2) Design process information capturing support system: EPA (engineering process assistant)

(3) Design process information visualization system: PIVS (process information visualization system)

(4) Simulation support system: BIRD (behavior information reusable and distributed environment)

(5) Software coordination control system: COOR (coordinator)

In the POET Knowledge Medium, the information unit that denotes a product unit is called "PDU (product unit)". The information unit that denotes an activity unit with the relations between the activity unit and other activity/product units is called "PCU (process unit)". The PCU consists of ontology words and links to other PCUs or PDUs, which express actions, objects, constraints, alternatives, and reasons. The POET Knowledge Medium implements the Activity Chain Model by extending the model based on these information units. First, in the POET Knowledge Medium, constraints of an activity unit are extended so that they can include not only activity units of the past but also other kinds of design information such as catalogs and documents which are referred to by the designer during the design process. These constraints are described in PDUs. Next, in the POET Knowledge Medium, the change of the PDU is managed by using the concept of the "stage" which is the time section of the design process based on the declaration by the designer. The designer's trial-and-error histories are described as branches of the stages parallel to the time axis.

5.1 Design process information database management system: EPM

The database management system for accumulating and

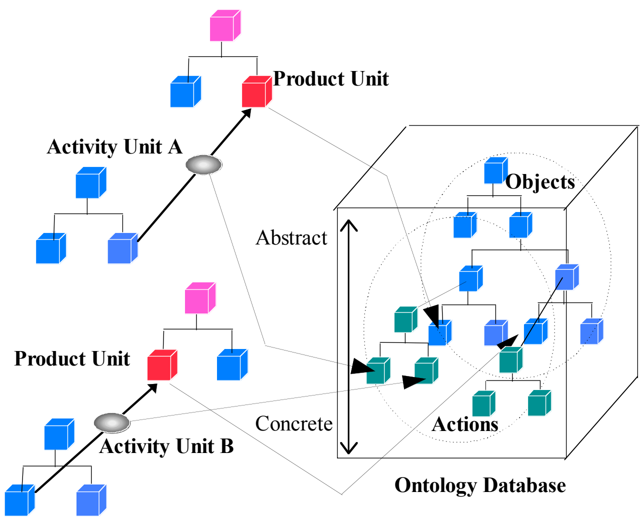

Fig. 6 Relations between design processes and ontology database

sharing the design information in the POET Knowledge Medium is called EPM. Since the EPM is implemented using the ODBMS (object-oriented database management system), the PDU and the PCU which describe the Activity Chain Model are stored in the database without schema transformation, and can be searched and traced efficiently by navigating of the relations between them. It is possible for the EPM to store and manage the product information created by the product information creation tools, such as the existing CAD systems and the simulation tools, related to the design process information, such as CAD operations and the design histories.

5.2 Design process information capturing support system: EPA

The input support system for design process information capturing is called EPA. The static knowledge on the design domain obtained in advance is described in the EPA's ontology database as an extendable vocabulary with relations. The vocabulary stored in the ontology database is classified into the "action word" which denotes the action of the activity unit, the "object word" which denotes the object of the action, the "constraint word" which denotes the constraints affecting the activity unit, and the "reason word" which denotes the reason for the constraint and the alternative. The relations in the vocabulary are classified into the general relations which include an "abstract-concrete relation" and a "whole-part relation", and the action-based relations which include an "object-action relation" and a "constraint-action relation".

The degree of the relation can be defined for each relation in the vocabulary of the ontology database. Between two ontology words associated indirectly by navigating relations in the ontology database, the degree of the relation is also defined based on the combination of the degrees of the relations involved in the navigation. For the graph obtained by considering an ontology word as a vertex, the relation between the ontology words as an edge, and the degree of the relation between these words as the weight of the edge, the EPA computes the degree of the relation between 2 ontology words as the distance based on each edge weight on the minimum weight path between the corresponding 2 vertices in the graph. By associating the design process information and the product information with the ontology word on the database, the EPA enables designers to not only locate the activity unit on the standardized domain knowledge but also evaluate the degree of the relation between the activity units or the product units according to the degree of the relation between ontology words. The EPA estimates the degree of the relation between the activity units or the product units based on the degree of relation between the ontology words associated with them (Fig. 6).

The information that the designer referred to in the design process is recorded as operation history information, and can be regarded as the information that the designer took into consideration in the design work. It is probable that the ontology words relevant to them are used in the registration of the design process information. It is also probable that the ontology words relevant to the activity units registered in the past or the product unit changed by those activity units are used in the registration of the

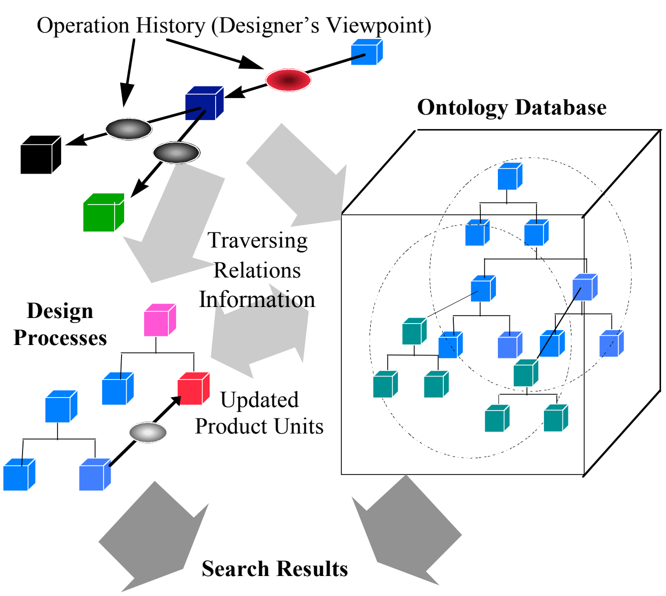

Fig. 5 Navigational search using ontology database

design process information. The EPA predicts the ontology words which the designer is going to input based on the activity units and the product units mentioned above, by searching the activity units and the product units which have a high degree of relation to these units, the ontology words associated with these units, and the ontology words which have a high degree of relation to these words (Fig. 5).

At the time of registration of an activity unit, EPA supports the designer's input of an activity or its reason by listing the ontology words in a suitable order from which the designer's input can be easily chosen. The ontology words listed by EPA not only mitigate the designer's input overhead of the activity unit, but also remind the designer of relevant knowledge or relevant design examples in the past. Consequently, the EPA enables the designer to avoid oversight and to find a new viewpoint in the design process. Moreover, the designer understands the history and the intent in the design by other designers, by re-experiencing past design examples relevant to those ontology words, so that it becomes easier for the designer to acquire knowledge and know-how in the design.

5.3 Design process information visualizing system: PIVS

In the POET Knowledge Medium, the visualization system is called PIVS, which displays the design process information visually. The PIVS visualizes the design process information in a design process space that is the virtual 3-dimensional space, and provides a graphical user interface through which to refer and edit the design process information in the space. In registering an activity unit, the designer receives various feedback not only from the knowledge and past design examples based on the ontology words listed by the EPA, but also from the past design process information visualized by the PIVS. The PIVS enables real-time interaction between the designer and the design process space. To achieve an efficient design, the PIVS is useful for the designers to be aware of their own design process as well as to share the design process space visually with other designers.

5.4 Simulation support system: BIRD

In the POET Knowledge Medium, the 3-dimensional simulation support system is called BIRD, which express "motion" information in the product information related to the design process information. The BIRD is one of the product information creation tools in the POET Knowledge Medium, and provides an environment in which to reuse the simulation information in order to support trial and error. By using BIRD, the simulation information can be associated not only with the product information, such as CAD information, but also with the design process information, so that the simulation information can be used to express the design intent. Thus, BIRD is a new simulation tool that extends the expression technique of the designer in the design process space, which is unlike the conventional simulation tools that check the design result.

5.5 Software coordination control system: COOR

In the POET Knowledge Medium, the software coordination control system is called COOR, which connects the 4 systems mentioned above and the product information creation tools on the market, such as the CAD system. The COOR enables the connection of systems that have different interfaces while retaining their independence, by performing the interface conversion and the data complement between the systems. The COOR integrates the design process information expressed by the Activity Chain Model and the product information created using the existing CAD systems, the simulation tools, and the documentation tools. Thus, the COOR enables the design process information to be referred to using the navigation from the relevant product information, so that it is understood easily by the designers. The COOR enables the designer to use the POET Knowledge Medium as the integrated seamless design support environment that includes the existing design support tools.

6 Design simulation

In this research, the authors chose the mechanical design field as the target domain of the design simulation using the POET Knowledge Medium, and the design of a DAT (digital audio tape) deck as an example. The screen of the design simulation when the EPA is supporting the input of a PCU in the PIVS is shown in Fig.7. As one scenario of DAT design, the authors consider the following procedures corresponding to part of the actual DAT design process.

(1) A control board, a cassette compartment cover, and a button are created as parts.

(2) A cover assembly is created, using the cassette compartment cover and the button as children.

(3) A cassette cover assembly is created, using the control board and the cover assembly as children.

(4) An upper cabinet assembly, a lower cabinet assembly, and a mechanical deck assembly are created by reusing data for an existing model.

(5) A main body assembly is created using the upper cabinet assembly, the lower cabinet assembly, and the mechanical deck assembly as children.

(6) The BIRD carries out the simulation on the mechanical deck assembly.

(7) The shape of the guide channel of the loading link is changed based on the result of the simulation.

(8) The holes for buttons are made on the cassette compartment cover.

(9) The shape of the leaf spring of the button is changed by trial and error.

Consequently, 3 trial-and-error branches and 8 declared stages were created, and 7 representative PCUs were registered concerning the design changes. About 200 PDUs were generated in the design history information. The following were registered into the ontology database.

(1) Activity words: about 40

(2) Object words: about 60

(3) Constraint words: about 50

(4) Relations between these words: about 160

The authors confirmed the ontology words listed via the input support functionality of the EPA. The authors also confirmed to what extent the designer could understand the design history and the design intent based on the design process information, by simulating a case where another designer continues the work in response to a request to change the position of the button. The evaluation of the design simulation result shows that the information on the design history and the design intent can be expressed generally, and that the ontology words listed by the EPA were appropriate. The evaluation also shows that the design history and the design intent can be understood in a short time by re-experiencing the design process information. Furthermore, in the case where designers carry out mutually dependent designs concurrently using the Activity Chain Model as a work space, the evaluation shows that it is useful to integrate capture, accumulation, and transfer of the design process information in order to understand each designer's viewpoint in real time based on design process information.

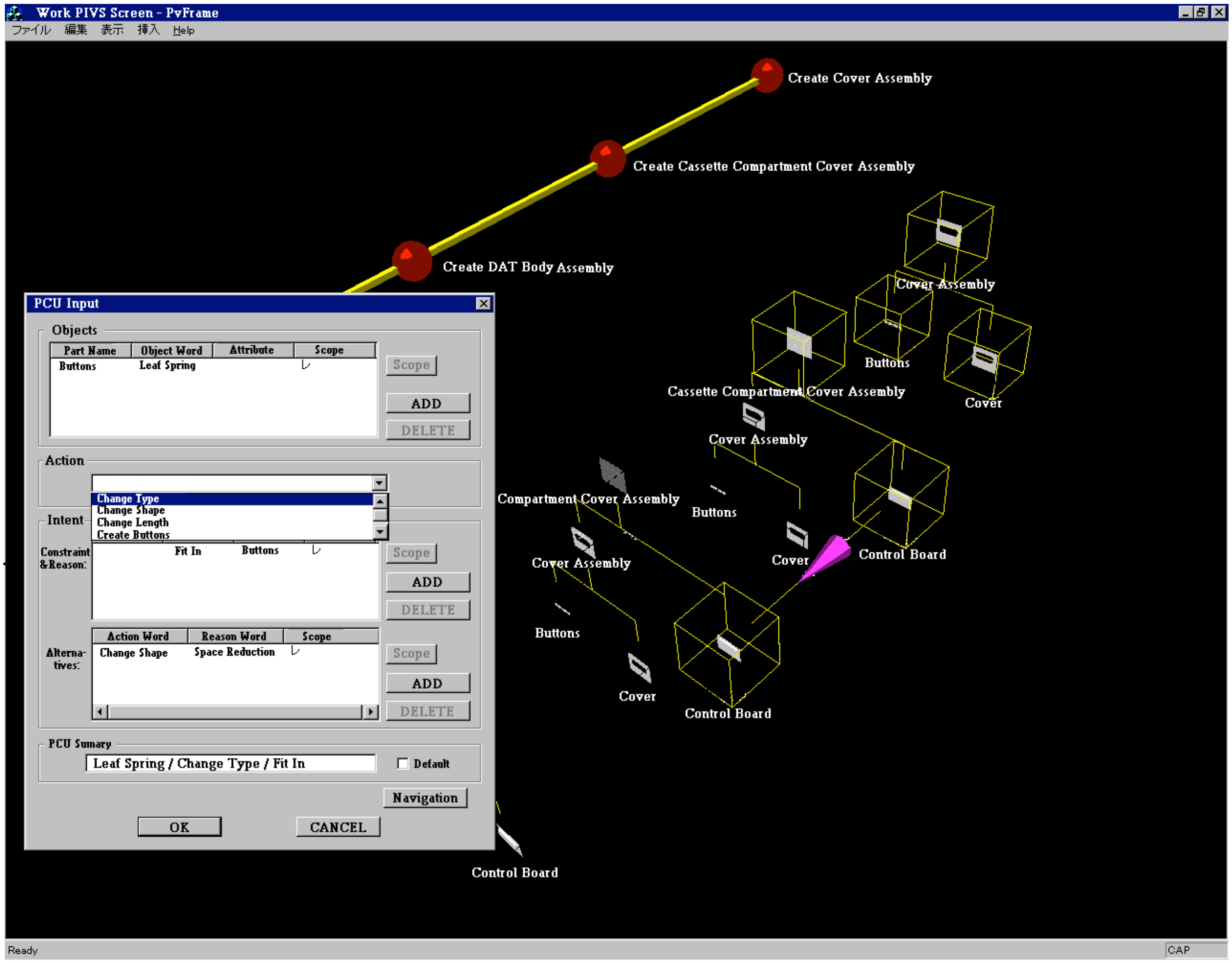

Fig.7 GUI screen image of PIVS and EPA

7 Conclusions

In this research, the authors proposed the "Activity Chain Model" that realizes a new design style based on collaboration between designers beyond the physical restrictions of time and space. The POET Knowledge Medium implementing the Activity Chain Model was developed as the knowledge medium for the global design. From the evaluation of the POET Knowledge Medium through design simulation, the effectiveness of the Activity Chain Model was confirmed, not only in capturing and transferring the design intent, but also in reminding the designers themselves of the design intent when used in combination with product information creation tools such as CAD systems. The evaluation shows that the Activity Chain Model can provide practical capturing and explanation capabilities of the design intent.

In the future, by using knowledge media such as the POET Knowledge Medium, it is expected that a flexible design team for overseas projects can be organized dynamically, and that a global design organization can be realized. Moreover, it also is expected that knowledge and know-how concerning design can be shared on an organizational level, and that creative design using ideas from past excellent designs and high-quality architecture-driven design referring to similar past designs will be realized. Furthermore, the POET Knowledge Medium in this research is considered useful for solving the designer's current problem of communication and adjustment with other designers, and for organizing an efficient design team which is flexible against changes through quick adaptation of the design to various business environments and through the utilization of the distributed design resources.

In this research, the "Activity Chain Model" is used a priori in the POET Knowledge Medium to capture the design intent. As a future research subject, it is considered important to apply the "Activity Chain Model" to improve project monitoring and to develop the POET Knowledge Medium into more practical knowledge medium by enhancing the user interface and the information description model in the database, through its use in actual design work involving many designers.

Acknowledgement

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