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Abstract: This paper aims to describe a particular role of annotations as co-operative artefacts in engineering design. In co-operative processes, where achieving a shared understanding between the participants from different domains is crucial, sharing the decisions and argumentations which lead to a solution is as important as sharing the solution itself. In our case study, we describe what we call an "information gap" between the asynchronous phase, when individual decisions are made, and the design review, when the solution is evaluated, and collective thinking influences the decisions. Then, within a conceptual design scenario, we show how semantic annotations can create a shared environment to help to reduce this gap, where all actors are able to elicit domain-specific constraints and engage discussions on design solution during the asynchronous phase.

Key words: semantic annotation, engineering design, design communication, collaborative tool.

1- Introduction

An important part of CSCW (Computer-Supported Collaborative Work) research today is to develop annotation systems to support collaborative work. The International Workshop on Annotation for Collaboration, realised in Paris on 23-24 November 2005 provided an excellent chance to see the current methods, tools and practices. Participants from various domains of CSCW pointed out a wide area where annotations are used to support collaborative work, such as the automatic annotation of digital images in support of collaborative fieldwork [BG1], the medical domain, where the annotations are used to maintain and share the electronic health record [BB2], collaborative reading and writing [CC1], indexation of digital libraries [AA1], or engineering design [GD1] [MD1].

Many benefits of annotation usage in collaborative activities have been observed. A document annotated by one person supports the work of the others: annotations have a positive effect on the cognitive cost implied by the analysis of a document. Sharing indexation of documents trough annotations in a work group may reduce the information treatment work charge of each group member. Annotations support cognitive synchronization between the members in a workgroup. Besides, the consensus or disagreements between group members can be identified from the annotated parts of the document. In that sense, annotation supports decision-making processes.

In this paper, we will stress a particular role of semantic annotations as co-operative artefacts in engineering design. In co-operative design processes, where achieving a shared understanding between the participants from different domains is crucial, sharing the decisions and their rationale is as important as sharing the solution itself. In our case study, we will point out what we call an "information gap" between the asynchronous phase, when individual decisions are made, and the synchronous phase, when the solution is criticised, and collective thinking influences the decisions. Then, with a conceptual design scenario, we will show how semantic annotations can be used to reduce this "semantic gap".

2- Design co-operation and co-operation artefacts

Engineering design processes are becoming more and more complex. Since many years, successful design methodologies based on the decomposition of these processes into sub-process or tasks have been developed in order to deal with complex design situations. Companies have implemented design procedures in order to control the quality of the design process and eventually asses the quality of the product.

However, today's market environment requires more than complex procedures in order to asses the quality of the product. New organizations based on concurrent engineering principles involve co-operative work of an increasingly high number of stakeholders from different fields of expertise during the design process. The researchers now need to address the level of the "activity", i.e. the actual work carried
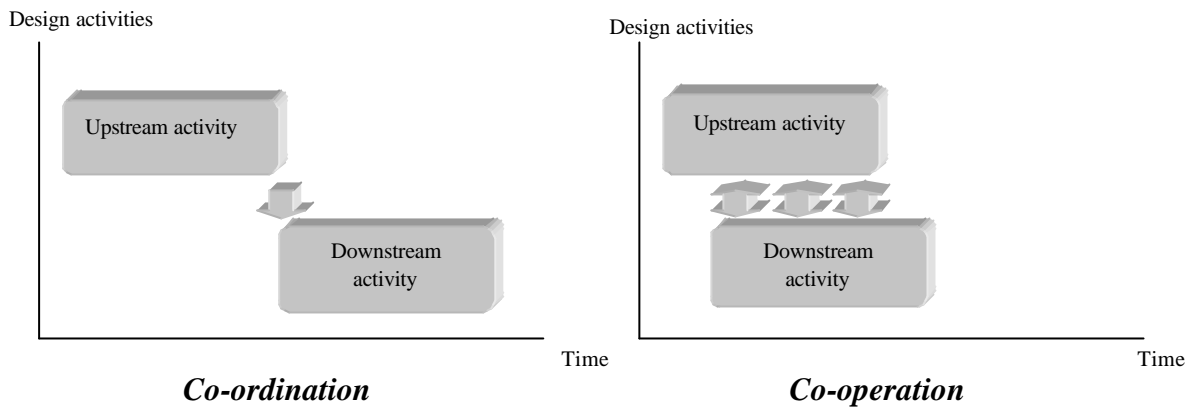
Co-ordination

Co-operation

Figure 1: co-ordination versus co-operation [BL1]

out by the participants in opposite to a task-based approach, where the unit of analysis is a definition of "what each participant is supposed to do". Having different understandings, representations and tools, the communication between the various stakeholders of a project and their integration into the design team is becoming vital. In this section, after making a description of co-operation, we will point out the importance of artefacts in co-operative design work.

2.1 - Design co-operation

In order to describe design co-operation, we will clarify the difference between co-operation and co-ordination. The Oxford English Dictionary defines co-ordination as 'the harmonious of effective working together of different parts', while co-operation is defined as 'the process of working together at the same end'. The main difference here is that the co-ordination requires a shared set of goals between different participants [BL1].

In the design context, co-ordination assures the sequential execution of activities. In that case, the participants of the upstream activity define an exhaustive description of the output to be provided to the downstream activity. Depending on the project phase and context, this may be a CAD model, a mock-up or a simulation model. In project management terms, this output is often called deliverable. Each activity is carried out in parallel, only the output is shared among the group.

On the other hand, in the co-operation case, activities are carried out concurrently (see figure 1). Unlike in the co-ordination case, participants do not only share the output of activities, but also immature descriptions of the product and design situations, in order to produce jointly the final output. Therefore, a shared understanding of the design situation and a common goal are required. In that case, previous work has shown that co-operation artefacts are of prime importance [BB1].

2.2 - Co-operation artefacts: intermediary objects and co-operating features

Among numerous works on co-operation artefacts, we will first mention Vinck's and Jeantet's works on the 'intermediary

object' concept [VJ1] [J1]. This generic approach covers all types of artefacts produced in the co-operation space, whether physical (plans, sketches, etc.) or virtual (CAD models, calculating results, etc). Two dimensions characterize intermediary objects: they are related to the action itself (i.e. the product), and they are means for co-ordinating designers' activity. Note that any representation of the product is a potential intermediary object and more generally, any artefact -when used in as basis for discussion-may become an "intermediary object".
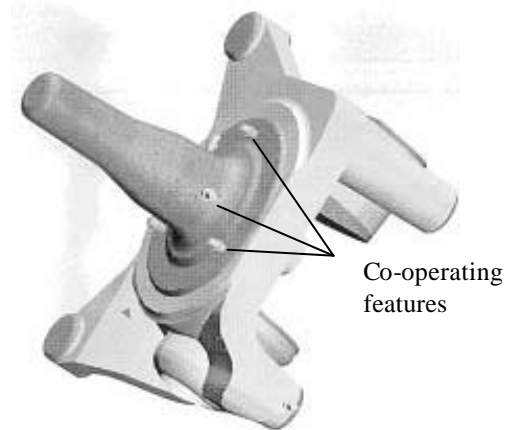

Co-operating features

Figure 2: co-operating features [BL1]

Our approach of design co-operation support is based on the concept of 'co-operating features' [BL1] [L1]. They are geometric symbol representations created during discussions between participants, and added to the CAD model (see figure 2). They are not representations of the product, but artefacts that materialize tacit design rules commonly used by participants. During discussions, these objects complement propositions of solutions made by one participant, and provide the other participants the opportunity to evaluate or react to the proposition. The importance of these objects as co-operating artefacts has been demonstrated in a cross-domain case study. Creating links between different domains, they have proved to achieve shared understanding between design and industrial experts.

3- Annotations in engineering design processes

Annotations have been used since many years in design teams as a mean to communicate. The use of digital media in design processes has radically changed the annotation processes [B1] which were traditionally paper based. From the different design situations that we observed, we concluded that the annotations were essentially used across two phases of design process: asynchronous phase, where the digital artefact is produced, and synchronous phase, where the artefact is collectively evaluated.

An asynchronous situation is defined as a situation where a designer produces a CAD model of an object, or more generally a situation where an individual activity is carried out. In that case, notes can be produced individually in order to establish a list of decisions, remarks, explanations, etc. making reference to a document (e.g. the CAD model). Annotated documents often remain private and can be used for several objectives, such as information indexation, or memorization of the current design situation, etc. Annotations are used in asynchronous situation to represent and capitalize information whose nature is not completely geometrical, such as a manufacturing process, or a type of material, etc.

The other engineering design situation when annotations are often used is a synchronous situation where a collective evaluation of the artefact is carried out. During this activity, intermediary documents are commented and annotated, mostly on a paper base. Today, these meetings are generally mediated by digital representations, and the actors who are more and more situated in distant places communicate through instant messaging and/or video conferencing tools. During these activities, annotations are used mainly as a way to reinforce the oral discourse. Annotations created here are poorly structured and cannot be reinterpreted apart from the context they are created. Therefore, the majority of annotations created through a design review cannot be reused during another one. All critics and argumentations are made in the design review, during the designer's presentation.

The objective of design reviews is not to develop solutions. It is a place where solutions are discussed, and points of view of the different involved actors (such as marketing, SAS, etc.) are expressed. Although these evaluations lead sometimes to alter the structure of the object, the object will not be modified during these activities. A minute is created during the meeting that records the main decisions and is supposed to help the designers during the asynchronous phase. We will see later how this solution leads to misunderstandings.

Those two situations are complementary and we will show in the following how this creates an "information gap" and how we propose to address this problem.

4- The use of annotations in an industrial vehicle design case

In this section, we will make a description of a co-operative design case, based on our field study in an industrial vehicle company. Our objective here is to track the information sharing between the asynchronous and synchronous phases of the process, in order to describe the information gap between these two phases. In the next section, we will show how annotations can constitute an effective solution to reduce this gap.

4.1- The design team

The cross-domain team we consider here is leaded by the architect. With his high technical level, he coordinates the design activities of an entire sub-system of the truck. He communicates with the designers during asynchronous phases of the project in order to assure geometrical
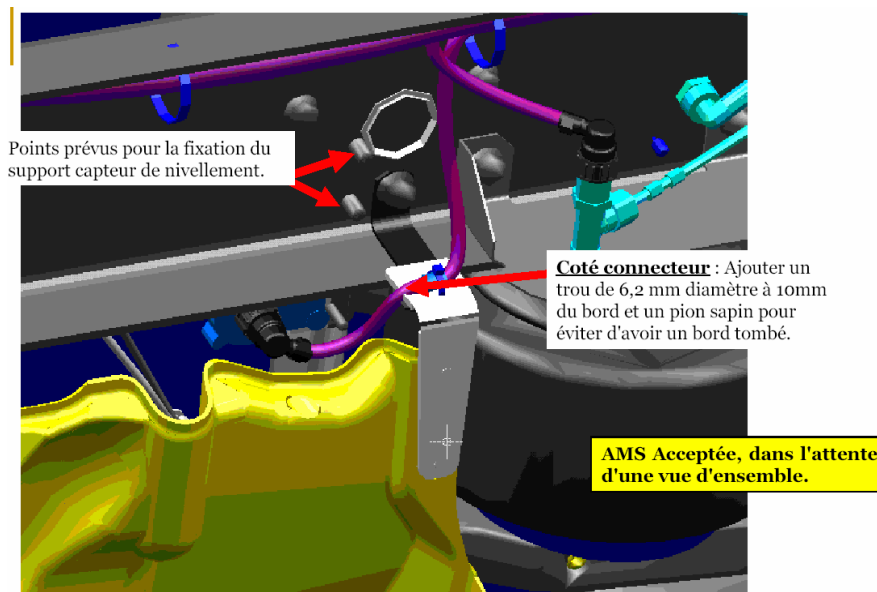

Figure 3: an annotated screenshot in a design minute

conformity and also coordinates the design reviews. He is responsible from the design solution. The actor called PMS (Project Management Support) works with the architect and is in charge of short-term operational management of the project. During the asynchronous phases, he manages and communicates information about the studies in progress (such as deadlines, types of vehicles impacted by each study, etc.). He is also in charge of the design minutes making during the design reviews. The "designers" are technical actors who develop solutions in CAD environment during the asynchronous phases. Another kind of actor, called "scenarist", supports the architect by collecting the up-to-date CAD representations of the technical solutions and update the shared CAD environment. Other actors, called "industrials" are specialists from different domains (manufacturing, SAS, etc.). They participate to the design reviews in order to evaluate the design solution with regard to their specific knowledge.

4.2 - Asynchronous phase

As we have seen earlier the asynchronous phase is the period when the designer develops a solution on a CAD model. This activity demands technical knowledge and precision. The important point for us here is the fact that the model is developed mainly according to the individual decisions of the designer, on the basis of his own knowledge of the context and decisions taken during the previous meeting.

Although this is an individual activity, the designer needs sometimes to collaborate with the other actors, especially with the technical actors (the architect, the scenarist, or another designer). Communication during these unplanned events is made in an unstructured way (face-to-face meetings, telephone calls or email exchanges). They are means to debate or unofficially validate a design solution proposition. Therefore, this is an event where important decisions can be made.

When the model is completed, the scenarist integrates this instance into the shared CAD environment. In other words, from that particular moment, the model (the solution) becomes accessible to the other actors, until the next design review.

4.3 - Synchronous phase: design reviews

The design reviews were originally dedicated to a control process (the procedure defines them as decision points only). However, the stakeholders took the opportunity of these regular meetings to debate on the solution, as there was no other formal design meetings dedicated to that activity in the general design process organisation. This implies that the creative input of a design review is not as secondary as it may seem. It is a place where key decisions and their rationale are made explicit [HM1]. In our case, as the participants do not have the opportunity to access information about the design decisions before, design reviews become the unique event when participants are able to exchange arguments about the design solution and make new propositions.

In a design review, first the designer presents the design solution that he produced. It is an oral presentation, when he explains all information that cannot be represented in the CAD model (decisions that he made, key points of the solution, etc). Then, the participants discuss the solution. That is the phase where domain-specific rules are made explicit, and key decisions are made.

The design minute is constructed simu ltaneously by the PMS within this discussion phase. When a decision is made or an action to take is decided, he takes a screenshot of the projected screen on his PC, and takes note of the decision or
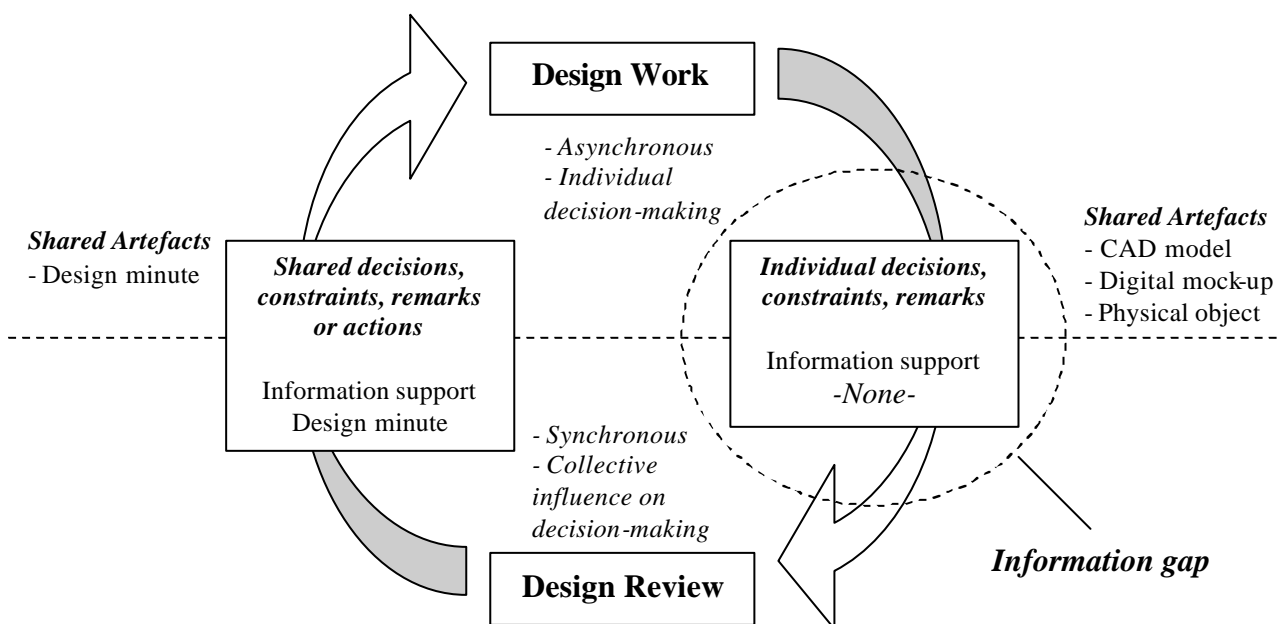

Figure 4: Information-sharing gap between the asynchronous and synchronous phases

the action by annotating it (see figure 3). The other actors cannot see the PMS's notes during the design review, in other words, they have not the opportunity to share and evaluate these annotations. Finally, the design minute is a pdf document composed of a series of annotated screenshots. The annotations are of textual nature, anchored to a point on the image by an arrow (see figure 3). After the review, this document is stocked on a shared database, and remains accessible to all participants.

In other words design reviews are the only moments where the designers, the architect, the PMS and the industrials meet together in order to collectively evaluate the current solution. The CAD model is used to visualise the solution, which is the only co-operation artefact shared during the design review. The minute is the only shared document after the design review and are composed of static annotated screenshots.

4.4 - Transmitting information between design phases and the *information gap.*

We have already stressed the importance of constraint elicitation to achieve shared understanding between cross-domain participants in co-operative processes, and the mediating structure in order to achieve it (see section 2).

In our case, the annotated CAD model screenshots (the design minute) are produced to achieve this objective (see figure 3). They are means to record the decisions during synchronous phase in a simple and more clear way than a text based minute, and to share them during the asynchronous phase. The design minutes are used by the designers as a memory in order to produce a new version of the CAD model, the design minute is then a means to transmit information from the synchronous phase to the asynchronous one as shown in figure 4.

On the other hand, we have noticed that there is no mediating structure during asynchronous phase that could allow the designers record rationale elements of decisions during the asynchronous phase (see figure 4, right side). The lack of that kind of mediating structure prevents this information to be structured and recorded, in a way that it can constitute a base for discussion between all design actors during the design reviews. In other words, this situation constitutes an information gap preventing to share (in the design review) all that happened during design work phase (see Figure 4).

In the next section, we will describe a conceptual design scenario, in order to show how an annotation system can help to reduce this gap by creating a shared environment where all actors have the possibility to elicit domain-specific constraints and engage discussions on design solution during the asynchronous phase.

5 - Semantic annotation in product design context: a brief definition

At this particular point of the paper, it is important to define more clearly the concept of semantic annotations in the engineering design context. In fact, there are quite a lot of definitions of the term annotation and they are not all convergent. We propose here a pragmatic definition based on our observations and experience of co-operative design processes.

Although the exact definition of an annotation is still controversial, it is possible to give a basic definition of the concept of semantic annotation by listing its properties and particularly by clearly distinguishing it from the concept of document.

Documents are graphical or textual representations, created to accomplish a task in a given context. Although there may be other documents that can be used complementary to the main document, any document can be interpreted independently from other documents. In our context a document is mostly a 3D CAD model or any extraction (VRML, etc.) of this model.

In contrast, annotations are attached to a document and can be interpreted only in the context of this document. Although they have this contextual relationship with the document, the goal behind their creation may differ from the goal of the entire document. Annotations are not all the time easy to detect especially when the documents are under construction.

The general properties of annotations in mechanical design context can be summarized as follows:
- An annotation have a different nature from the document on which it is attached to (representing non-geometrical information on a geometrical CAD object in our case),
- The document is the target the annotation refers to,
- The content of an annotation is the information the annotation convey,
- The anchor of an annotation is the point onto the document, where the annotation is attached,
- The sphere of influence of an annotation is defined by its personal or public status,
- Annotations lifetime is always shorter than the document lifetime.
- The originator and the user of an annotation may be different.

As we have seen, an annotation is only valid with the document on which it is attached to. The document constitutes therefore the context that makes it possible to understand the information that it conveyed by the annotation.

6 - Extending the use of semantic annotations for reducing the information gap between the asynchronous and synchronous phases

This section describes a co-operative design scenario, based on the use of annotation functionalities. According to our definition, the considered annotation system is a set of pre-defined geometrical objects, each of them embedding a particular knowledge (implicit meaning) and information (explicit content), such as a design rule or a domain-specific constraint may be elicited and visible for all the participants. In other words, they are co-operating artefacts, as described

in section 2. This tool has been described in a previous paper, for more information see [BD1].

6.1 – Basic annotation functionalities

Annotations are a natural way for expressing design constraints and they provide intermediary representations that may support communication between the designers [VJ1] [S1] [BL] [PS1]. Their function is to represent the various points of view, specific to each profession and each background, and to provide the members with the means to take part in and to support discussions concerning these differences in such a way that a shared understanding may be achieved.

The principle of the annotation structure is based on a three level information structure:

- The First level is composed by a geometric symbol placed onto the geometry and which form carries out a certain meaning. These symbols should be defined by the participants prior or during the project (see figure 5).
- The Second level is the information elicitation level. Attached to the symbol a plain text box can serve as a rational capture tool. The participants can edit and modify the content by adding their own remarks, propositions, etc. (see figure 5)
- Finally an indexing system allows the storage/retrieval of the annotations according to their status (i.e. Solution proposal, clarification, design/manufacturing constraint, etc.)

6.2 - Scenario : The design work

This annotation scenario is a projection of the observed practices described in section 3 into an expected situation. First we will consider the asynchronous part of the design process described figure 4, and detailed in section 4.2 i.e. the design work. The design work is mostly an individual work phase where the designer produces a technical solution in the form of a 3D CAD model (figure 6, left side). We have already mentioned a lack of information support at this level, this is the information gap we described earlier in this paper. In order to reduce this information gap we propose to introduce annotation functionalities as described in 6.1.
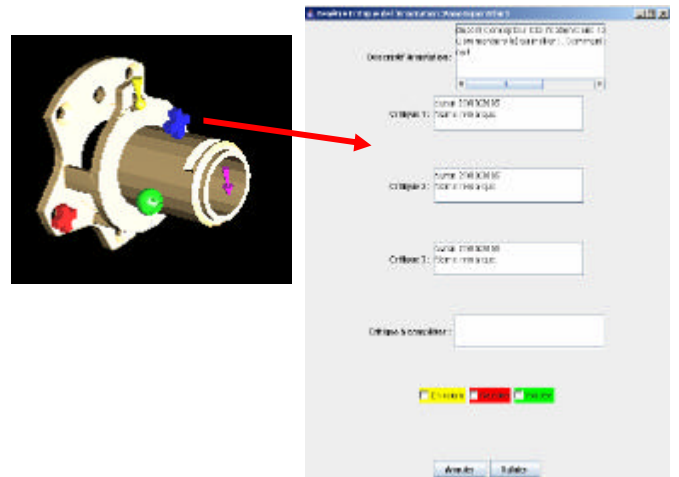

Figure 5: Graphical 3D annotations

6.3 Commenting on design decisions or/and specific parts

After creating this 3D object, the designer can elicit the main decisions that he made by taking notes and commenting on the geometry. At that particular moment, the 3D object contains a detailed brief of what and how the solution is produced (with its geometrical form, annotations and text).
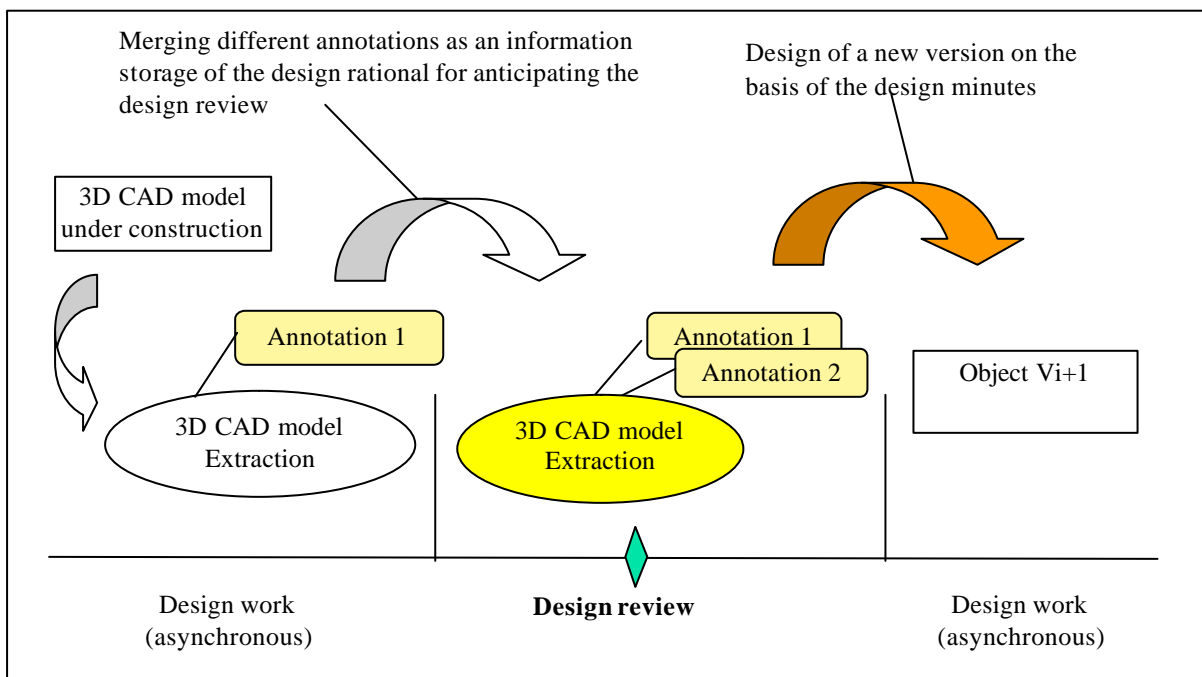

Figure 6: design scenario: information support for bridging the information gap in asynchronous design phases

This annotation may act as a pointer that help the designer to remind an important point he could have probably forget (figure 6 left).

6.4 Sharing in the design group

Then, in order to make it accessible to all other participants, he publishes this object on the technical data management system of the enterprise. The small size of the document makes possible his storage and access to all other participants via them personal PCs. The other participants now can see this object, comment and discuss the annotations, and put annotations themselves in order to elicit other constraints or rules.

This phase may lead to a first informal solution evaluation, prior to the design review. The other participants can then anticipate the design review and prepare comments or propositions. This may save time and effort during the design review.

6.5 Design review and design minute

The last phase, the design review is meditated by the 3D object as presented in the case study. The annotations that participants produced during the discussion phase and the textual discussions become additional information support for the discussions during the review. Participants can then use the annotations during the oral presentation of the solution as a memory of the important points (fig. 6 centre). When a decision is made, the annotation is validated, rejected, or enriched in order to synthesize the decision.

At the end of the design review, the 3D object (or the set of 3D objects) can be added to the design minute which then becomes a graphical design minute of the review. The designer will use this document, which contains all exchanged information, decisions and argumentations from his very first creation in the asynchronous phase until the end of the design minute, now as a reference document during his production of the next CAD model (fig. 6 right side).

Although we aimed to describe how annotations may contribute to solve the information gap situation, many other contributions of annotations have been pointed out during this description. We can summarise them as follows:
- Pre-defined annotations and the 3D model constitute a mediating structure that allows participants to communicate, to elicit domain-specific constraints and to negotiate solutions.
- They are means to record and share non-geometrical information in a structured way.
- They allow transmitting information between the asynchronous and synchronous phases, so they reduce information gap (as described in 4.4) between these phases.
- Pre-defined annotations are means to capture and structure design rationale during the asynchronous design phases.

7- Conclusion

In this paper we have focused on a particular problem that occurs in co-operative design processes. The question of information structuring within design groups is one of the actual topics of engineering design research. Our approach to this problem is based on an annotation scenario. Our scenario consists of annotating 3D objects with semantic annotations, and having a forum-based textual support associated.

The semantic annotation functionalities presented here differ from the actual functionalities provided by the PDM systems or by commercial design tools in that they are more than mere geometric pointer but they convey complex information and knowledge.

Therefore, from that particular point, our aim is to develop a technical structure in the form of an annotation server accessible through the web, which will allow the use of annotations in 3D documents. At the same time, we are working on the development of generic annotation symbols that could be used in an engineering design context.

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