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ANNOTATION IN DESIGN PROCESSES: CLASSIFICATION OF APPROACHES

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ABSTRACT
Collaboration among product designers, manufacturers and end users is a key factor for success in the design process. Effective concurrent design is determined by good communications. Design model reuse and design process reuse also have numerous contributions to shortening the design cycle, thus further strengthening competitive capabilities. In this paper, annotation is proposed as an inherent valuable in design to assist these essential factors. Based on an investigation of the state-of-the-art of annotation approaches in various disciplines, mainly focused on engineering design, annotations are classified into six major categories, in terms of the target audience, the annotation rendering system, the targeted media, the usage and functions of the annotation, the location of the annotation storage and the representation used for the annotation. Each category is further divided into sub-classes. A series of observations is presented in which the use of annotation in the design process was addressed. At the end of this paper, challenges in annotation technologies are presented and discussed.

Keywords: annotation, annotation technologies, classification, collaborative engineering design, design cycle

1 INTRODUCTION
To cope with global competition, collaboration among product designers, manufacturers and end users is a key factor during any stage of the design process in engineering industries. A generic design process consists of four main stages, i.e. clarification of the task, conceptual design, embodiment design and detail design [1]. The clarification stage is where the design specification is defined, through collecting requirements for and the constraints on the design. In the conceptual design stage, functions are established, and the initial solutions are proposed and developed. In the embodiment design stage, solutions gain a higher level of maturity, problems and weaknesses are solved. In the final, detailed stage, the design as a whole including all components is defined in full detail, in terms of the dimensions, tolerances, materials and so on. Within each of these stages and between them, reviews and evaluations are normally carried out iteratively until a satisfactory solution is reached. In these reviews and evaluations, communication plays an extremely important role for participants to collect information, share comments and authorize and approve designs [2].

In order to be more competitive and keep pace with the ever changing market, there is pressure to shorten the design cycle. For this reason, approaches such as concurrent engineering have been adopted to strengthen productivity at lower cost and shorten the product lead-time [3]. Again, the importance of better collaboration between participants in the design process through efficient communication is highlighted. The participants are not limited to the design teams, but also the manufacturers, post-sale service providers and customers both within the company and external to the company. Feedback from participants to optimise the current design and the next version/generation of the design and to maintain longer relationship between product provider and users is important, particularly within Product-Service-Systems (PSSs) [4]. For this reason, a geographically distributed working environment needs to be supported for any design stage.

In design practice, the communication data normally focuses on design details, e.g. the CAD (Computer-Aided Design)/CAM (Computer-Aided Manufacturing) model in mechanical engineering, Bill of Materials, geometric data and other models. In a complex design, the maintenance of the original design data and the communication data is vital to the efficiency of the collaboration. It determines how well the information can be searched, retrieved and interpreted. Due to the variety of roles in design teams, multiple viewpoints also need to be considered: the conceptual designer may focus on the initial concepts of a design; the embodiment and detail designers may be concerned with specific function and geometrical data represented as CAD models; a stress analyst may be concerned with loading cases and load points; a cost engineer will be interested in the volume of raw materials required, the tooling costs, and machining costs, while the packaging designer may not be concerned with the detailed design, but the envelope in which the design is defined. Maintaining more viewpoints but with less effort and understanding of all of the viewpoints is important throughout the design process [5, 6].

Another challenge to the current design process is design/information reuse. Efficient design reuse requires the interpretation of existing designs. This involves information indexing, searching, retrieving and interpreting. More widely, the process of selecting appropriate components from the candidate pool should be automated or semi-automated to improve efficiency.

To tackle these challenges it is proposed that the use of annotation techniques may assist collaboration/communication in the entire design processes, as well as benefiting the post-design in-service stage.

Annotation is defined as "a note by way of explanation or comment added to a text or diagram" [7]. In general, annotation is extra information inserted at a particular point in a document or other information object [8]. In a digital context, annotation involves adding a datum or reference point in a digital object and associating with it an annotation content, which can be a written note, a symbol, a drawing or a multimedia clip [9]. Some typical examples can be the highlighting of text on a paper, adding notes to written work, red-lining an image, labelling the surfaces of a 3D geometry object, and so on.

Annotation Technology (AT) enables the customizing of existing tools (e.g. CAD model) by allowing the addition of extra information by end users to satisfy their needs, and improving the efficiency of collaboration between participants, including designers, customers, manufacturers and suppliers though various types of representation. Annotations can also contribute to information management in terms of assisting with storing, retrieving and interpreting information, and some advanced ATs offering semantic features supported by ontologies further improve these capabilities [10-12] . These annotation approaches are explained in detail in the following sections.

In this paper, a classification of approaches to annotation, concentrating on but not limited to engineering design fields, illustrating how approaches are used at different stages in the design process, with case observations, is presented. The current state-of-the-art of ATs is then summarised. Based on the presented findings future challenges in the use of annotation in engineering design are described and research within ATs to overcome these is proposed.

2 CLASSIFICATION OF ANNOTATION APPROACHES

Generally, annotation contains two elements: the *annotation content* and the *annotation anchor* [13]. The annotation content is the data of the additional information that one wishes to add. including, but not limited to raw text, Extensible Markup Language (XML) [14], Resource Description Framework (RDF) [15], MPEG 7, the Multimedia Content Description Interface from the Moving Picture Experts Group [16]. XML is an extendable mark-up language, which allows users to define their own mark-up labels or "tags", and is designed for transporting and storing data, rather than displaying data [17]. RDF is a framework originally designed for describing Web resources including title, author, and ownership of a webpage and so on, written in XML. In fact, it can be used to describe anything with Web identifiers (URIs), by describing its properties and property values. For example, an RDF introduction webpage may have a property of "Author" with an property value of "Tim Bray"[18, 19]. MPEG 7 is a standard approach to the description of a wide range of multimedia content data, including video, audio, and 3D objects. The annotation anchor is the pointer referencing the address, datum or reference point at which the annotation is located.

In the past decades, many annotation techniques and systems have been proposed and developed in various domains. In this paper, annotations are classified into a number of categories according to six points of view, namely the targeted media, the audience, the rendering system, the usage and function, the representation and the storage location. These represent the annotation technologies, the purpose and the target of the annotations. Each category is further classified into subclasses, illustrated in Figure 1 and discussed further in the following sections.

2.1 Audience

In terms of audience, annotations can be classified into those directed at a *human audience* and those at a *computer audience* [20]. In the first category, annotations must be human readable, where the annotator can be any participant, either an individual or a team from any type of stakeholder who wish to share information with others. For example, an evaluation team may act as an annotator to add notes as feedback for a specific design team as the audience. In the case of a computer audience, the annotations are fed to one or more computer programs to manipulate the information, e.g. keyword searching through text files, information extraction and so on. In order to be computer readable, annotations must be strictly formalized by complying with a specific syntax or schema and well defined structures, so that they may be processed and comprehensible by computer programs [20].

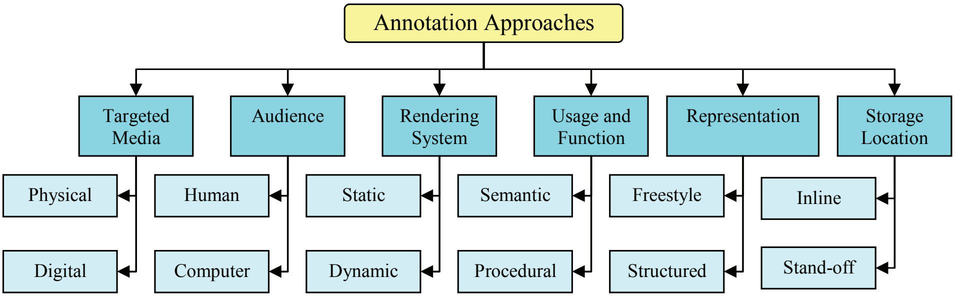

Figure 1. Overview of Classification of Annotation Approaches

2.2 Targeted Media

Annotations have been used for hundreds of years, from when monks made notes on the documents they were illustrating to digital annotations with computer programs in the present day. Annotations have been widely used on various target media. Two main classifications - physical and digital - for the target media for annotations, further subdivided as shown in Table 1, have been identified.

Table 1. Classifications of Annotation Target Media

Main Classes	Subclasses of Target Media
Physical Document	Paper text documents
	Physical 3D objects
Digital Document	Digital text documents
	Digital multimedia documents
	Digital 3D documents

As mentioned above, annotations are often made on paper documents in daily life, and are also made on digital text documents including common word processor and document distribution formats. As Internet bandwidth increases, multimedia documents including audio and video formats with annotations added are able to be communicated. However, 3D objects are differentiated from other types of media in both main classes, since representations of 3D objects are relatively complicated compared with the others. The 3D annotations can be applied to a geometric mock-up in physical form, or annotations to a CAD model in a digital form. Annotations on objects such as 3D maps of terrains, or genome representations, and many other three-dimensional objects are also used. The purposes of using the annotations are illustrated by case observations in later sections. 3D annotations are normally created in the embodiment and detailed design stages, while the others may assist design at any stage, such as using multimedia annotation for design demonstration, and text annotations for evaluation, approval, peer review, of documentation.

2.3 Rendering System

There are many different tools and systems to create and manipulate annotations, and these are hard to classify. However, according to Wang [13] who studied web-based annotation systems, annotation systems in the digital world can be classified into two main categories - proxy-based and browser-based - in terms of the way that annotations are rendered on a request. In the proxy based approach, annotation data are merged with the original document as a new webpage, and committed to a server. The Web pages combined with the annotations will be returned on request. In this approach, users are not able to alter the document, either in style or in content. In a browser-based approach, annotation data are saved separately, and leave the objects being annotated intact. An enhanced browser is able to retrieve the annotation data and the corresponding object, and render required information in a desired representation style according to the request. In more general terms, we extended this definition to any digital annotations as *Static* and *Dynamic* annotations. The Static approach implies that annotations are delivered as saved, and unchangeable; Dynamic refers to adaptable annotation content or/and representation style depending on the specific request.

2.4 Usage and Function

Marshall, Wang and Ovsiannikov and Arbib *et al*. [9, 13, 21] identified four general usages of annotations, namely (1) to assist creators to *remember* what they noted; (2) to assist creators and readers to do further *thinking*; (3) to help creators and readers to further *interpret*, such as translating to other language, or interpretation of another viewpoint; and (4) to contribute to information *sharing* between creators and readers.

Another classification based on the functional features of annotations at higher levels of abstraction is as the distinction between *semantic annotation* and *procedural annotation* [20], which is more practical and appropriate for application developers. Davies [20] also refers to semantic annotation as descriptive annotation, also defined as conceptual annotation by Theodoulis, Karanikas et al. [22]. Semantic annotation makes an entity more comprehensible within a certain context, for example aiding interpretation of a design model or within a domain through addition of extra information [23]. The extra information is normally organized by concepts or relationships, to make the annotated object more comprehensive explicitly. For instance, if "FLANGE" is used as a concept in mechanical engineering, it may be interpreted as an enlarged part of a shaft to which another shaft is coupled. Different interpretations can cause confusion. On the other hand, procedural annotations describe or control the procedures or processes of manipulating information and/or its constituents, or providing information to drive manipulation, in contrast to semantic annotations that normally describe the information entity and its constituents. Procedural annotations mainly contribute to reuse of design processes, which often requires semantically-rich information. This cooperation is illustrated through case observations in a later section.

Being rich in semantics, an ontology driven knowledge base becomes possible in some advanced annotation approaches. Semantic annotations based on a well-structured ontology can further assist automatic processing, such as indexing, information retrieval (IR), and natural language processing (NLP) thus further strengthening the procedural capability [24].

2.5 Representation and Storage Location

Annotations may also be classified as *freestyle* or *structured* according to their representation (the form). Freestyle implies that additional information is arbitrarily created and added to the target without a formal structure, such as random highlighting, underlining, red-lining or short notes and so on. Structured annotations are represented in a pre-defined schema, and managed in a structured way, e.g. indexing or categorizing the annotation data which are described in a formal language, such as XML or RDF [11, 24, 25]. Although freestyle annotation is less maintainable in comparison with structured annotation, it is still widely adopted as it is easy to create and handy for many general purposes. However, the structured annotation approach has enormous advantages, including more straightforward maintenance, semantic richness, self-explaining capability, and support for searching and self-annotation (i.e. annotation to other existing annotations) [13].

In terms of the approaches to save annotation metadata, annotations can be divided into two classes, *Inline* or *Stand-off*. In the case of the inline approach, also known as embedded annotation, annotations are embedded into the original objects, i.e. annotations with the target object are saved together. In contrast, annotations can be isolated from the object being annotated and stored as separate files in different locations. The annotation uses its anchor to reference back to the original objects. This is called stand-off annotation, also known as by-reference [20] or out-of-line [26].

Along with the increasing complexity and the size of the original design data, also the changing working environment, the stand-off approach presents some major advantages over the inline approach. Inline annotation is limited to the embedding of extra information inside the original object, thus cannot avoid some interferences between annotations (especially when XML is used), and also between annotations and the target object, but a stand-off approach enables the annotator to save the annotation separately, without interfering with any others. This feature solves the overlapping issue, which happens when two or more targeting objects share common portions [26]. Furthermore, stand-off annotation can easily mark up an object as a whole (e.g. metadata applied to a file), a view of the object (e.g. red-lining in CAD systems), or elements within the object (e.g. annotating a particular word or sentence of a text file, or a face, edge or vertex of a CAD file). Also stand-off annotation offers the possibility to annotate multiple parts within an object, or bi-directionally (e.g. to either retrieve targeting object or to find the annotation by its target), or even referencing to multiple objects (multi-directional) [9].

3 CASE OBSERVATIONS

In this section, we described a series of case observations of state-of-the-art annotation approaches, and identify them according to the classifications previously mentioned, and also their purposes and some potential usages in design processes are addressed. These case observations included many fields for the reason of general understanding of annotation uses, but mainly emphasised engineering applications.

3.1 Annotation in Specification Formulation

Generally, many current annotation approaches are used by designers to record design intent. One of the most common approaches can be the inline static annotation functions provided by widely used word processing tools (e.g. Microsoft® Office Word [27]), by which we can track changes, add comments, underline and highlight texts, and share with other participants. This is often used at the early design stage, when more detailed design concepts have not yet formed, and designers are still limited to raw information in text documents. Also it is often used in review and approval workflows. Similarly, Re:Mark [9] is another commenting tool working on Adobe® PDF documents, and the comments and markup functions in Adobe® Acrobat® 9 Pro [28] offers more features to assist collaboration through shared document reviews, including redlining images in a PDF file. When reading the annotations, these approaches fall in the scope of a human audience. However, a major advantage of the digital annotations is that they are searchable by computer. Thus they also suit a computer audience on a searching request. This applies to many other human audience digital annotation approaches.

In early design, standard word processing tools are often used by design process participants in the collaborative development of the design specification. Increasingly, specialist requirement management tools are also used for these activities [29], and in these tools annotation is usually an integral part of the capability. Another requirements management tool is called Cradle REQ [30], which is able to retrieve engineering project requirements automatically from word documents including the history records, with external user annotations processed by its built-in parser.

3.2 Annotation for Communication and Collaboration

Later in the design process, when a geometric design model becomes available, designers and any other participants are able to add or reference annotations to the actual design model for purposes of comments, analysis, review, evaluation and approval. Hisarciklilar and Boujut [31] addressed the important role semantic annotations can play in collaborative design processes. They addressed two situations of design activities. In an asynchronous situation, design activities are carried out by individual designers, where annotations can be made to record design intent, a list of decisions, remarks, explanations of a CAD model and so on. In a synchronous situation, design evaluation and reviews needs to be carried out through a real-time mechanism, such as holding a review meeting. In this case, annotations can be used to formalize the oral discourse, and ensure issues are recorded within a certain context, e.g. a comment can be referenced to a particular part of a 3D model. In the current state, geographically distributed working environments have been an obstacle for design collaboration. The most popular peer-to-peer communication mechanisms cause difficulties of maintenance where communication activities are carried out by individuals and may be not logged or managed centrally. Server based approaches are thus preferred.To satisfy these situations, Hisarciklilar and Boujut proposed a scenario that designers can share information for 3D CAD models through a forum-based interface powered by an annotation server [23].

Apart from the proposal of Hisarciklilar and Boujut, there are some closely related cases available, but most of them merely deal with text content on the Web. One of the Web-based cases is CritLink [32]. CritLink is used to add and view annotations on web pages. The anchoring mechanism is to use hypertext linking, in which a bi-directional linking technique is used to allow tracking of both annotation and the object. Another case is called Annotator [9]. Both of them use a static rendering mechanism, but, interestingly, Annotator displays annotations in a pseudo dynamic style. A key concept is that all communications between client and the Web goes through a proxy server. During annotating, an enhanced browser allows the end users to continually annotate a web page. When the user commits the changes, annotations are extracted from the annotated Web page by a proxy server, and saved into the annotation database with an extended URL (Uniform Resource Locator) while the original Web pages remain unchanged. This sets the user free from needing write permission on the pages. When the reader requests a web page, the proxy server simultaneously sends an HTTP request to the Web and to the annotation database. On the return of the web page, all annotations retrieved from the database will be merged with the web page, if any exist. And the browser allows the user to choose which annotation to expand for viewing through an index-card-style panel.

Another similar approach is called Annotea [33], proposed by Kahan and Koivunen. Annotation data is saved in one or more database servers with assigned URIs. On a request for a particular portion of a web page, e.g. text sentences or paragraphs, a plug-in enhanced browser will use a pop-up window to dynamically display the existing annotation for the readers by searching through all involved databases through a proxy server. Based on Annotea, another research group proposed a multimedia equivalent, Vannotea, with substantially more powerful features that applies to wider range of targeting media [34]. Vannotea provides a collaborative environment allowing participants to discuss, analyze and annotate not only text pages, but also multimedia documents including images, audio and video contents, and also 3D objects in a collaborative way, where annotation content includes participants' discussions, personal notes, anchored to either the whole multimedia file, or a portion of the object simultaneously, e.g. particular frames of a video or audio based on timestamps.

3.3 Annotation for the Collection of Specialist Viewpoints

In this section, we concentrate on the later stages of design processes where detailed design models are available. In current engineering design, CAD systems have been widely adopted for decades, and become an essential aid to any product design, especially in the field of mechanical engineering. How to efficiently edit a CAD design model and to reuse design parts are vital questions for industrial application.

Davies [20] proposed a hybrid annotation framework for both semantic and procedural annotations, which is able to annotate 3D CAD models for multiple viewpoints throughout the entire product lifecycle, including the manufacturing viewpoint, evaluation viewpoints and so on. This approach is to adding semantically rich information from various viewpoints to features (e.g. simple thru-holes, fixing holes, balance weights etc) of a 3D CAD model. For example, designers can add annotations with manufacture and stress analysis viewpoints to the CAD model. Having data exchanged to the manufacturer and analyst, a manufacturing engineer can determine a hole as a simple thru-hole feature from the annotation information and identify that it requires machining operations such as drilling. Information about these operations can also be added by annotation. At the same time, an analyst with a stress analysis viewpoint who has no interest in manufacturing information, but would find useful an indication that the hole is a fixing hole, which implies some boundary condition information for the analysis. Apart from the multiple viewpoint issue, this framework also supports procedural annotation, contributing to design process reuse. This is done by manipulating the annotations to control the operations. In the previous example, a CAD model designer may reverse the design process in order to remove the hole, or the manufacturer is able to define the appropriate manufacturing instructions to produce a prototype according to the knowledge of drilled thru-hole. The important contribution of this research work is the ability to collect multiple viewpoints for various types of participant in a collaborative working environment and the design process reuse.

MATRICS© (Managing Annotation for Training in an Immersive Collaborative System) [35, 36] is another semantic annotation approach to collect specialist viewpoints that aids digital virtual 3D mock up. MATRICS© facilitates collaborative design based on CADCAM design tools through the use of semantic annotations with a knowledge base. The annotation anchors are defined by 3D coordinates of the mock-up object, and annotation content represented in a structured form. The associated knowledge management system maintains three concepts (viewpoints) that annotations can be mapped into: the mechanical design concept including materials, scientific and technical domains; geometrical description of the mock-up; and the method related concept, namely, the methods in field expertise for engineering design. Queries are made on a selected concept, and the ontology-powered knowledge management system filters the annotation pool accordingly, and retrieves the best relevant results. Experimental work was carried out to test the effectiveness by comparing two groups of students: Group A answered a list of test questions with the assistance of MATRICS©, while Group B answered questions without it. The results showed that 69% of correct answers are achieved by Group A, against 27% made by Group B.

Another hybrid of semantic and procedural annotation is called Funnotation [11] aiding CAM design. Its core module is an ontology, which is based on a device-centred viewpoint and "role" concepts that represent the functions of a device. For instance, a tool having sharp toothed edge (class constraint for role) can play a "cutting" role (role concept) in a "manufacturing" relation (role context), and is called a "saw" (role holder). Annotations are obtained by processing semantic web documents, such as a description document of a machine or a summary report of a component. This complete semantic annotation model represented in RDF contains four elements: the function of a device; the way the function is achieved; the functional decomposition structure of the device; and alternative solutions to achieve the functions. When a database is filled with sufficient annotation entries, given a functional design specification, the system opens up the possibility of automatically searching for suitable parts that have the required functions and generating assembly processes to use the potential parts.

In comparison, instead of dealing with text documents, 3DAF (3D Annotation Framework) [37] is introduced as a semantic procedural annotation to assist design reuse by automatically manipulating 3D geometries. Annotation databases evolve through an annotation manager by adding, removing and updating semantic profiles of 3D scenes in various source formats, such as X3D and VRML (Virtual Reality Modelling Language). VRML is the predecessor of X3D, and was originally designed to describe 3D virtual worlds for Web resources with an interactive ability [38]. Users send semantic requests to the annotation repository through the query manager to retrieve the desired semantic information pointing to corresponding 3D fragments. A fragment integration component of the 3DAF system translates all fragments into a united format (X3D), and reassembles them into a new 3D model according to the geometric topology defined by the semantic request.

Other than directly manipulating 3D geometries through CADCAM tools, there are also some other usage cases of annotation. A stand-off 3D annotation approach used in architectural design called the Space Pen Java applet [39] has been developed. It is a web-based system, in which a 3D architectural design model represented in VRML is placed on a server, so that all participants can access simultaneously, and see the changes if any are submitted. Space Pen allows participants to walk through the 3D environment in a simulation mode, and participants can create freehand textual comments and drawing to the 3D model. If a gesture is made with the defined recognized command, the corresponding digital texts or drawings will be generated and saved externally onto the server, so that all others can view. Rather than dealing with digital virtual environment, ModelCraft [40] is also proposed to annotate physical geometries for engineering design, in which digital pen and Anoto paper technologies are used. Anoto paper [41] is ordinary paper but pre-printed with dot patterns that can be recognized by specifically designed digital pen. A digital 3D model created by a CAD system is printed out onto Anoto paper in an unfolded style. Freehand texts and drawings on the refolded model can be created and captured by the digital pen. All these captured annotations can be merged to the original digital 3D model, thus physical drawings are transferred back to the digital world.

3.4 Discussion

A matrix summary of existing annotation approaches, based on the classification given in this paper, is illustrated in Tables 2 and 3. Some cases are not covered in this paper due to the length constraints, but are provided here with references. In these two tables, ✓ indicates YES (approach matches onto the category), ✗ refers to NOT PRESENTED (the category is not included in the approach), KB refers to the presence of a knowledge base, facilitated with either an ontology or knowledge concepts, and N/S indicates that the author(s) did not specify. Through this research work, we found that annotation approaches and their applications have various purposes. In general, the more complex and advanced the annotation approach is, the more categories it may fall into. Most annotation approaches in these classifications are not mutually exclusive; in fact, many of them are hybrid systems.

Table 2. Case Observations Based on Audience, Repository and Target Media

Approach	Audience		Repository		Target Media
	Human	Computer	Inline	Stand-off	
Annotea [33]	✓	×	×	✓	Web
Vannotea [34]	✓	×	×	✓	Web, Multimedia & 3D
Annotator [9]	✓	×	×	✓	Web
CritLink [32]	✓	×	×	✓	Web
Davies, D. [20]	✓	✓	×	✓	3D
LIMMA [25]	✓	✓	×	✓	3D
MATRICS© [35, 36]	✓	✓	N/S	N/S	3D
Space Pen [39]	✓	×	×	✓	3D
3DSEAM [42]	✓	✓	×	✓	3D
3DAF [37]	✓	✓	×	✓	3D
Pittarello and Faveri [43]	×	✓	✓	✓	3D
XIRAF [44]	✓	×	×	✓	Raw data
DOSE [24]	✓	✓	×	✓	Web
Magpie [45]	✓	✓	×	✓	Web
MnM [10]	✓	✓	×	✓	Web
S-CREAM [12]	✓	✓	✓	✓	Web
KIM [23]	×	✓	×	✓	Web
Funnotation [11]	×	✓	×	✓	Web (CAM)
Li, Z., et al [46]	×	✓	✓	×	Web (CAM)
Shin, I., et al [47]	✓	×	×	✓	Web
Soo, V.-W., et al [48]	×	✓	×	✓	2D images

Table 3. Case Observations Based on Representation, Rendering System, Usage and Function

Approach	Representation		Rendering System		Usage and Function	
	Freestyle	Structured	Static	Dynamic	Semantic	Procedural
Annotea [33]	×	✓	×	✓	×	×
Vannotea [34]	×	✓	×	✓	×	×
Annotator [9]	✓	✓	✓	×	×	×
CritLink [32]	✓	✓	✓	×	×	×
Davies, D. [20]	×	✓	×	✓	✓	✓
LIMMA [25]	✓	✓	×	✓	✓	✓
MATRICS© [35, 36]	✓	×	×	✓	✓+KB	×
Space Pen [39]	✓	×	×	×	×	×
3DSEAM [42]	×	✓	×	✓	✓+KB	✓+KB
3DAF [37]	×	✓	×	✓	✓+KB	✓+KB
Pittarello, and Faveri [43]	×	✓	✓	×	✓+KB	×
XIRAF [44]	✓	×	×	×	×	×
DOSE [24]	×	✓	×	✓	✓+KB	×
Magpie [45]	✓	✓	×	✓	✓+KB	✓+KB
MnM [10]	×	✓	×	✓	✓+KB	✓+KB
S-CREAM [12]	×	✓	×	✓	✓+KB	✓+KB
KIM [23]	×	✓	×	✓	✓+KB	×
Funnotation [11]	×	✓	×	✓	✓+KB	✓+KB
Li, Z., et al [46]	×	✓	×	✓	✓+KB	×
Shin, I., et al [47]	✓	✓	×	✓	✓+KB	×
Soo, V.-W., et al [48]	×	✓	×	✓	✓+KB	×

4 CURRENT ISSUES IN ANNOTATION TECHNOLOGIES

In this section, some issues in current ATs are explored. Since the main constituents of an annotation are the anchor and the content, some issues are identified from these two aspects, and also a collaborative annotation system that supports a geographically distributed working environment is discussed.

4.1 Annotation Anchor

For the anchoring mechanisms, effectively identifying the target part of an object, and persistently maintaining the anchors are the current main issues. Anchoring in text documents is relatively more mature. For example, Alink developed a system called XIRAF (XML Information Retrieval Approach to Digital Forensics) [44] aiming at digital forensic investigation on raw data, where data are static and changes prohibited. Annotation anchors are applied by defining the region of the object with the start and end byte addresses of the raw data. In another approach, dealing with dynamic documents, Annotator applies the anchor by using the techniques of so called Atoms and Clumps [9]. An Atom is the smallest text unit (e.g. a word) or a freehand or square selection of a picture. A Clump is a series of Atoms that reference to the same annotation. On the other side, the annotation database logs a portion of the Atoms as a memorable sub-string together with the annotation. This sub-string will be used to re-locate the anchor when merging the retrieved annotations with a Web page to answer a request. Wang [13] also proposed advanced anchoring mechanisms to tackle the annotation persistence issue aiding text documents, including the meta-structure information match, the keyword match, and content semantics match.

The current issues concern more about how to anchor the 3D CAD models, which is vital in embodiment and detailed design stages. Bilasco *et al.* [42] introduced 3DSEAM (3D SEmantics Annotation Model) to index 3D scenes, in other words, to localize the 3D object, so that semantic information can be pointed to desired parts of 3D objects. Interestingly, an extended version of MPEG-7 is adapted to achieve this. MPEG-7 provides two types of localization: the structural and the spatial. The structural locator helps to select the content units structurally, and the spatial one helps to identify the targeting portion geometrically. For instance, the 3D object can be a virtual 3D scene illustrating a table or simply a stack of papers. Taking a table as an instance, the table can be structurally described by assembly of rectangular boxes in X3D indicating one table surface and four legs. In another case, if a stack of papers is represented as a single box on this table, in which the latest publications are at the top, and draft papers at the bottom, the latest publications can be identified by structurally selecting the box of the paper, and then geometrically referencing the top of the volume for the latest publication. Having localized the 3D object, annotation content can be referenced to the specifically identified elements. However, current annotation systems do not tackle the persistent anchoring issue (consistently updating anchors as the models change) yet for 3D object.

4.2 Annotation Content

In the annotation content aspect, the use, retrieval and interpretation of annotations raises some issues. Regarding to the use, whether or not annotation data can be recognized as application/platform independent is vital to collaboration among enterprises, and among design teams. Cheung, Yarrow, et al. [49] suggested that XML was the most recognized format according to their study, in which forty five Product Lifecycle Management (PLM) systems were examined, and thirty seven of them supported XML. Apart from the advantages mentioned already, a typical feature of XML is that it is naturally extendable, and is designed to define other description languages, rather than being a language itself. Furthermore, some other major standards tend to be compatible with XML, including STEP (Standard for Exchange Product Data) [50], RDF, and MPEG 7. STEP is an international industry standard for "computer-interpretable representation of product data, and its exchange" [51]. This enables the derived or compatible languages to inherit the merits from XML. Thus, the unification of representation offers greater collaboration and compatibility among organizations and tool systems in data exchanging or design cooperation. Although XML syntax and schema can be potentially used to describe general annotation content, widely accepted terms to define annotation content in various engineering disciplines does not exist yet, i.e. a well recognized way to represent anchors, to attach structured content. Therefore, a universal representation of annotations needs to be established, to solve the issue of application/platform independency.

Regarding retrieval and interpretation, how efficiently annotations can be retrieved and properly interpreted are the key issues. Ontologies are considered to effectively contribute to cluster domain knowledge, thus assisting searching and knowledge organisation. However, manually mapping semantic annotations against an ontology requires expertise, and automation of this process still largely depends on the capability of natural language processing.

4.3 Annotation System

A sound annotation system should address the issues stated in the last two sections, e.g. consistent and precise anchoring mechanism, and support data exchange internally and externally. Also, another challenge is sharing annotations in a distributed environment. This concerns issues including information security, annotations in concurrent collaboration, annotation data exchange.

Base on the idea of Hisarciklilar and Boujut [31], we propose a server-based platform supporting for 3D models, so that requirement documents, original design data (e.g. the geometry), annotations and so on can be managed centrally. In such a scenario, participants are able to make changes according to their access rights and shared by the others in real-time. In this system, semantics in annotations will be well structured, so that specialist viewpoints can be captured in a standardized way as knowledge. The knowledge base should be facilitated with ontologies in order to describe annotation targets explicitly within a certain context, to remove ambiguities. Furthermore, the system interface may be based on CAD systems, so that annotations can be applied to a CAD model at different granularity, e.g. annotating a 3D geometry as a whole, or annotating a face or feature of the geometry.

5 CONCLUSION

In this paper, having examined the role annotations play in engineering design processes, we observed over thirty existing annotation approaches and their applications. Case observations were concentrated on the annotation approaches for design processes, but not limited to the engineering domain, they also included cases in computer science, biochemistry and so on. Based on this research, we classified the application of annotations into six categories, and illustrated these with a selection of observed approaches, clustered into three aspects that aid engineering design processes. Finally, this work has also identified the gaps of current ATs, in terms of the anchoring mechanisms, the representation of the annotation content and the system interfaces. A collaborative working environment supporting annotations and an outline of a future work program have been proposed.

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