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THE MANAGEMENT OF DIGITAL SKETCHES THROUGH PLM SOLUTIONS

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ABSTRACT
To manufacture successful products, companies are reliant on an efficient information and knowledge backbone. Within this context, this paper reports a preliminary investigation into the management and archival of early design information which typically manifests itself through a graphical format – sketches. Although a number of technologies enable the creation of digital sketches, this highly valuable company knowledge often remains paper-based and is then discarded once the final product solution is selected. Product Lifecycle Management (PLM) systems offer new perspectives for efficient management of information across the life of a product. Nevertheless, these new capabilities developed for engineering purposes have not been tailored to meet designers' needs. The authors therefore propose a preliminary classification of sketches in order to facilitate their management and storage in PLM systems. Integration scenarios are also suggested using current PLM capabilities and the observed limitations highlight the necessary requirements to stretch these information management systems towards a more complete solution for all stakeholders involved.

Keywords: sketching, design rationale, lean product development, Product Lifecycle Management, graphical communication.

1 INTRODUCTION

The development phase within the life of a product typically falls under the responsibility of three areas of expertise, namely design, engineering, and management. In this context, "Product development" can be defined as design, engineering, and manufacturing processes that begin with the definition of the market needs and end with the end of the production ramp-up (the point in time when the satisfactory manufacturability of the product is reached). In order to achieve success, a company must therefore tailor effective business processes and methodologies to facilitate and regulate multidisciplinary knowledge sharing and decision making inherent to the product development phase [1]. Although this approach seems obvious to most professionals, its implementation and practice are often major stumbling blocks for many product development teams.

Furthermore, in today's large companies, work is organized on a global scale using available resources from plants scattered across continents for the manufacture of a product constituted of parts designed in different locations [2]. In this context, a number of established strategies have been reported over the years to improve the efficiency of product development activities and the information and data sharing between partners, clients, and suppliers over the life of a product. Product Lifecycle Management (PLM) type solutions have been introduced on the market to support these industrial realities by integrating the various data management tools developed for the different stages of the life of a product in a single comprehensive package.

In the next section, the review of product development practices and tools highlight how these current trends stem from an engineering perspective, hence falling short in supporting earlier and latter stages in the life of a product. This paper then focuses on the need to integrate early conceptual design rationale and decisions embedded in sketching – the archetypal activity of design [3] – in product development information sources readily available to engineers through PLM systems. An analysis of sketching activities is therefore presented and a typology is proposed for the efficient reuse and archival of the wide variety of conceptual sketches that can be encountered essentially during the early stages of product development. Finally, the authors discuss possible scenarios of sketch management through current PLM solutions and outline requirements to improve these engineering platforms for this type of integration.

2 CURRENT TRENDS IN PRODUCT DEVELOPMENT PRACTICES AND TOOLS

As suggested in the introduction, modern industrial practices attempt to efficiently integrate the various stakeholders around the development of the new product. Closely related strategies such as Concurrent Engineering and Lean product development, briefly presented in the next paragraphs, advocate a product centered approach to this integration issue. Figure 1 depicts how current Digital Mock-Up technologies supported by a PLM platform can become the catalyst for the much needed integration of design, engineering and management activities during the product development phase. Indeed, as discussed in §2.3, current PLM solutions which manage the virtual product are in fact dedicated solely to engineering and project/business information and data, when they should also seek to manage information generated by designers.

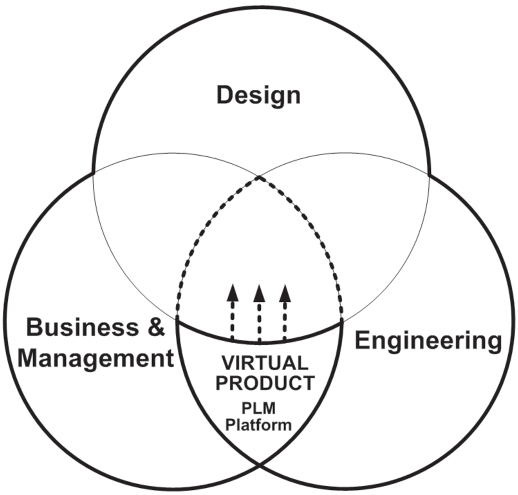

Figure 1.The necessity to stretch virtual product capabilities towards conceptual design

2.1 Concurrent Engineering and Integrated Product Teams

The comparative studies on the introduction of new products in Japan and in the West published in [4] and [5] have inspired the definition of the essential drivers for a successful management of the product development process: reduction of the “time to market”, improvement of the overall quality of product and processes, and reduction of product and process development costs [2]. To achieve these goals, companies seek effectiveness and efficiency where time, costs, and quality are the key factors [2], [6]. The strategy to address these competing aspirations is known as Concurrent Engineering (CE) or simultaneous engineering [7] as it was called in the early years of its definition.
In practice, CE targets strategic interactions between time, costs, and quality through a parallelization of processes and tasks, an integration of departments, persons, and tools, and a standardization of the product development process [2]. One of the central elements of CE is the project team, sometimes referred to as Integrated Product (or Process) Team (IPT). An IPT can be organized in different ways according to the work environment provided by the company. Various multidisciplinary team structures have been detailed in engineering research literature [6], [8]. Concurrent Engineering does not always imply a radical change in team structure; one of the results from the study carried out in [5] is that communication centered on the efficient use of preliminary information rather than complete information is paramount to good team integration. Furthermore, if the early stages of product development are taken into consideration, the experimental finding that 67% of paper-based information at this point in the process is sketch-based [9] makes sketches stand out as key communication artifacts between stakeholders.

2.2 Lean product development

"Lean" principles as defined in [1] provide strategic goals and an overall product development philosophy for companies to achieve success. Lean product development aims at creating profitable operational value streams through the generation of useable company knowledge. Although some studies [10] compare and oppose Lean thinking and CE thinking, the authors strongly believe, rather, that both approaches are complementary and they simply do not act at the same level or on the same instances within the product development process. As reported above, CE targets organizational aspects whereas lean principles outline a general work philosophy for product development teams. Lean thinking therefore focuses on eliminating knowledge waste in all its forms and creating value through learning. In this case, learning can take one of the three following meanings: integration learning (learning about customers, suppliers, partners and the physical environment where the product will be used), innovation learning, and feasibility learning [1]. In practice, lean product development principles and tools can be divided into three areas of focus:

- *People.* Here, team and individual roles and responsibilities are targeted. The role of Entrepreneur System Designer (ESD) is introduced. These "value stream leaders" have reduced administrative roles and are responsible for the engineering, aesthetic design, market and business success of the product. They spend the bulk of their time on creating new system knowledge for effective future value streams and are supported in their tasks by functional department managers. Functional managers head "teams of responsible experts" who demonstrate strong leadership and interpersonal management skills.
- *Processes.* Value creating, flow supporting management is all about cadence flow and pull. Lean concentrates on building *target events*. This is possible by defining a few target events where the knowledge or ignorance of the team is easy to see; pull planning by having all team members make their own plans for achieving those target events; cross checking the plans against each other, negotiating problems developer to developer; and rigorously enforcing target event timing and quality. Target dates must be hard lines.
- *Product.* Set-based design or Set-Based Concurrent Engineering (SBCE) advocates the generation of multiple concepts in order to develop better products. This effectively means that conceptual decisions are delayed in time (compared to a traditional point-based design approach) and that all the viable concepts are carried out right up to the prototyping phase [11].

Within the context of this research, SBCE is seen as a strategy where early design alternatives, usually embodied in different types of sketches, need to be archived in a systematic and structured way in order to create valuable company knowledge.

2.3 Product Lifecycle Management (PLM) solutions

As a consequence of the aforementioned lean principles for product development activities, the development of virtual prototyping and Digital Mock-Up (DMU) functionalities have contributed to the support and realization of SBCE with the aim of reducing physical prototyping costs and time-to-market. DMUs are typically managed by PLM platforms. Nevertheless, PLM aims to do more than supporting the virtual product and its visualization; it is about managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal [12]. The major focus of PLM is on the product development phases and the real challenge behind the current PLM solutions, as shown in Figure 2, is to provide the entire spectrum of stakeholders involved across a project with all the necessary and secured functional representations on the product and manufacturing processes through a single digital information model [13].

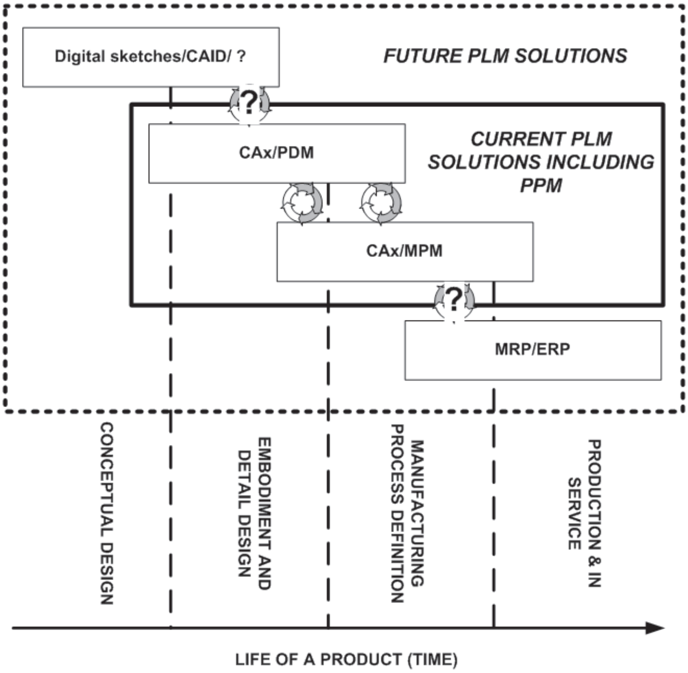

Figure 2. Technologies supported by current PLM platforms and future developments across the product lifecycle

This digital environment involves advanced computer aids dedicated to specific engineering tasks and sophisticated management technologies that support the product development process with information generated across the life of a product [14]. Figure 2 illustrates the existing and desired integration capabilities of PLM systems. Dedicated engineering and management software tools (CAx, project management software) have been gradually integrated through advanced information management systems that facilitate information flow between areas of expertise. These information management technologies can be clustered in three primary areas regardless of the commercial package at the user's disposal, namely:

- *Product and Portfolio Management (PPM)*. These functionalities enable the management of a company's product portfolio, which pilots the overall product development strategy at both a marketing and technical level. From a technical perspective this means managing the various technology platforms and the product development processes at a strategic business level.
- *Product Data Management (PDM)*. During the product definition phase (embodiment and detailed design stages), engineers use a number of computer aids (CAx) dedicated to specific engineering tasks, e.g. CAD, FEM. The information generated by these engineering design tools is therefore managed by an all encompassing PDM system. These systems enable a number of key functionalities through a secured data vault, such as the management and control of the engineering Bill of Materials (eBOM), the DMU of the product, configuration management, part maturity levels, engineering change management, etc. [14].
- *Manufacturing Process Management (MPM)*. Just like PDM systems, MPM systems manage the information generated by dedicated manufacturing tools, such as CAM or CAPP software and also connect to PDM systems to offer a complete process planning system. An MPM system even goes further by effectively managing a significant portion of the enterprise manufacturing know-how (standard process plans, internal manufacturing standards and compatibilities, etc.). The connection between the PDM and MPM systems is activated through the creation of a manufacturing Bill of Materials (mBOM), which enables the information to flow through links with the eBOM [14].

Figure 2 also highlights the shortcomings of current PLM solutions. As mentioned previously, they essentially focus on the management of engineering information and knowledge. The MPM module within PLM now offers viable perspective for companies to solution integration issues with Enterprise Resource Planning (ERP) systems, by transforming the incomplete product data from PDM into stable manufacturing information [14]. The ERP/PLM integration remains a custom fix with limited functionalities and is therefore the topic of ongoing research. At the other end of the spectrum, there appears to be no advances towards the management of conceptual design information and its integration within a PLM strategy. Even though designers have at their disposal advanced computer technologies, such as Computer Aided Industrial Design (CAID) software and haptic technologies [15], the digital management of the information they generate remains absent in the literature.

3 GRAPHICAL COMMUNICATION BETWEEN DESIGNERS AND ENGINEERS

Even within a same field of knowledge, such as engineering, experts are confronted with major communication barriers related to their specific domain of activity that hinder the continuous and value-added flow of information required to fulfill a product design brief. These often lead to misunderstandings which generate unnecessary rework and modifications to the product under development. When looking at the information transfer among multiple knowledge fields such as design and engineering, significantly greater communication barriers can be observed, often due to differences in work processes, vocabulary, professional goals, etc. Designers for instance use various types of sketches and representation techniques to express an ambiance or convey emotion and meaning of a concept. Often these sketches are intentionally ambiguous yet suggestive enough, to trigger initial responses of clients and potential users. These sketches are rather intended as a visionary guideline for the later design development process and are rarely sufficient enough for the product development process. Other modes of representations such as orthographic views or section views need to be produced for this purpose of information transfer between design and engineering. Nonetheless, the authors believe that focusing on specific intrinsic commonalities that exist between the way designers and engineers express concepts and ideas can help develop appropriate tools and methodologies to reduce the communication breakdown. This section therefore presents first the context in which designers and engineers interact, i.e. the early stages of the product development phase. Then, a brief review of the sketching activity is proposed as it is believed to generate federative artifacts around which designers and engineers can communicate and share an understanding of the product under development. Finally, a tentative classification scheme for sketching is proposed as a stepping stone for the efficient management and archival of sketches.

3.1 The early stages of the product development process

When developing a complex product, an advanced design team is formed in the early stages of the process and usually tackles the following aspects of product design: understanding market and user needs, outlining product requirements and specifications, generating product concepts and proposing a suitable planning of the project. During these activities, designers play a key role; they contribute to the project by analyzing existing products and their use, observe design trends, identify new design opportunities, establish design criteria (functional, ergonomic, aesthetic) and most importantly help visualize the overall design intent including alternative design solutions [16].

An example of design activities which take place during the conceptual phase of product development has been reported in [16] presenting a case study in the automotive industry; these can be summarized in terms of generic milestones, as follows:

1. Issue of brief and product specification
2. Review of competition and influences
3. Informal discussion and selection of concept sketches
4. Management review of concept sketches
5. Tape drawing presentation (some companies)
6. Scale model presentation (some companies)
7. Presentation of full size clay models
8. Final representations
9. Approval of 3D models

At each one of these milestones, a team of experts from each domain, such as engineering, design and marketing are gathered to review the developing concepts. During these particular events, the advanced design team communicates all ideas through visual representations such as sketches, mood boards, study mock-ups, clay models, etc. Following the lean principles for product development activities presented previously in section 2, it is clear that successful companies must address a number of issues right from the start of a new product development project, namely:

- Provide adequate support for the SBCE approach to product development, meaning the support of multiple concepts and their representations until late in the product definition process;
- Archive all the early design decisions and related representations for company knowledge.

3.2 Communicating concepts through sketching

Sketches are used by both designers and engineers to communicate ideas and concepts with self or others [17]. Sketching therefore plays a fundamental role in design communication, especially during the early stages of the product development process as mentioned previously. A number of studies have highlighted interesting properties related to sketches in design. Although sketches are ambiguous and imprecise, they seem to contain the minimal necessary information to convey an idea [3] and the quantity of sketches has been found to have a direct impact on the quality of the final product [18]. It is also important to stress that sketches are often complemented with words to facilitate communication with others. Not only they have proven to assure better comprehension of ideas, they also document critical information that accompanies an idea. Unfortunately, most of the earlier exploratory drawings are often discarded and all early thoughts and ideas disappear without leaving a trace [19].

It seems critical to change such counterproductive practices because they deprive companies from critical knowledge, which is typically generated during a learning process. By investigating the spectrum of possible sketch types encountered during a development process, a preliminary sketch taxonomy can be established as a fundamental stepping stone towards their management and archival. Although the literature in the field of sketching in design essentially focuses on its role and relationship to the human thinking process, the authors were capable of distilling a number of classification criteria used in the reviewed literature, i.e. [3], [16-23]. These criteria can be summarized as follows:

- *Complexity Level* [19], [20]. A complexity scale from 1 to 5 is suggested to order sketches along the scale, accounting for the following attributes: color, annotation, shading, pencil thickness, and level of rendering.
- *Purpose* [3], [19], [21]. The "purpose" criterion was found to be understood in different ways. It can relate to the intention of the sketcher, i.e. for reflective, communication or presentation purposes [3], [19]. It can also relate to the design stage for which it was produced, illustrating a design intent, product features, functioning principles or its contextual use [21], [23].
- *View type* [3], [22]. In sketching, specific view angles can be inferred in both 2D and 3D representations (top, bottom, isometric, etc.) [3]. Also in engineering and design sketching, a number of technical terms are used to identify specific types of freehand drawings, which are composed following pre-established rules (perspective, exploded, orthographic, etc.) [22], [23].

This brief study of criteria used to qualify sketches needs to be further explored and adapted for the purpose of this research, i.e. the management of sketches with computerized information systems. The next paragraph further develops this approach and presents a preliminary classification scheme for sketches.

3.3 A tentative proposal of a classification scheme for sketches

While the role of sketching in design has been the subject of much research, less work has investigated the different types of sketches and a comprehensive classification or typology does not appear to exist. This may be because even a cursory inspection of the typical designer's notebook reveals that sketches may be classified in a large number of different ways, such as chronological order, level of detail, drawing medium, whether it represents something concrete or abstract etc.

A pragmatic understanding of which of these perspectives are likely to be most useful in a product development context is a necessary first step in exploring options for the effective integration of sketches with existing information management solutions such as PLM. To that end, a tentative proposal for a classification of sketches is outlined.

The initial typology, derived from the literature discussed above, then went through two further iterations by using it to classify sketches, first from a relatively simple 1st year design project at Ecole

Polytechnique Montreal (Canada), and then using a wider variety of sketches from the notebooks of more experienced engineers and designers from both Ecole Polytechnique Montreal and the University of Bath (UK). These notebooks were from projects that encompassed the entire design process and thus were a more accurate reflection of the range of sketches that designers and engineers create. The sketches ranged from very quick conceptual 'ideas', through to relatively detailed 3D representations of parts and assemblies and even the artifact in its environment. The example sketches in Figure 3, below show the variety encountered.

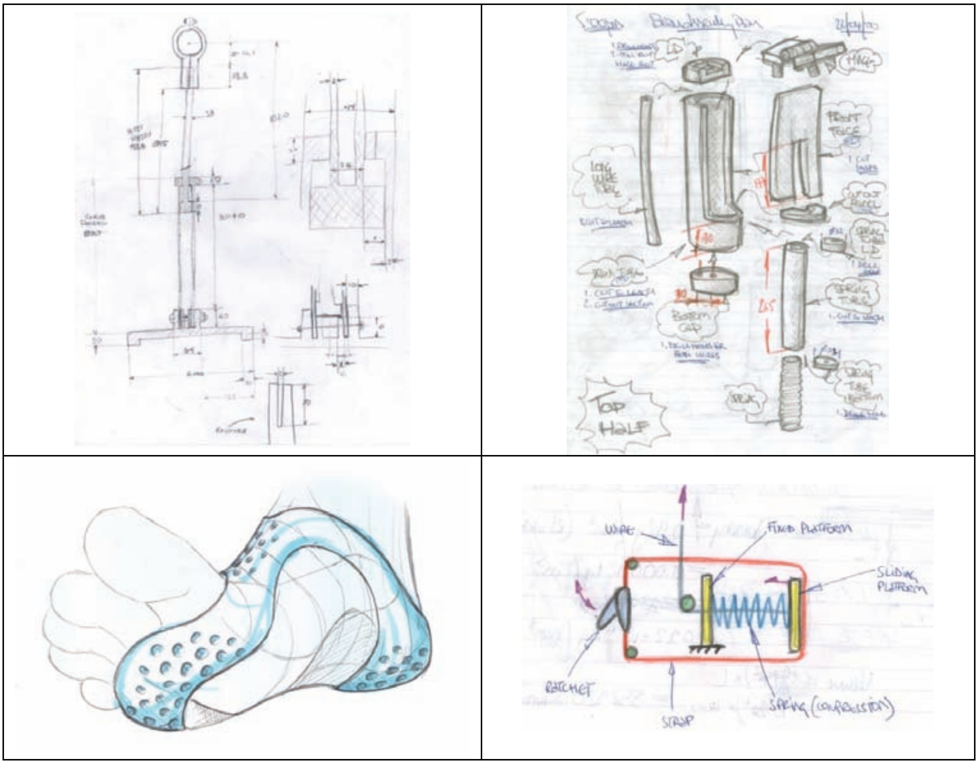

Figure 3. Examples of sketches from student project notebooks

Both sources of sketching data were used to verify, reflect upon and refine three aspects of the classification:

1. The *Completeness* of the classification – can all the sketches be described by each category?
2. Whether the classification terms applied to different sketches provided sufficient *discrimination* – for example, if the typology were to be used to classify sketches for subsequent retrieval, would an appropriate balance between precision and recall be obtained?
3. Criteria *relevance* from a product development perspective? For example, assembly drawings are specific to engineering design, but would be irrelevant in an architectural design context.

These three criteria were used to refine the terms and extensive modifications were made to arrive at the final typology, detailed in Table 1. The proposed classification scheme integrates some of the criteria derived from the literature, but also suggests number of others that the authors perceive as essential for an effective computerized management.

Table 1. The final iteration of the preliminary classification scheme for sketches

Primary Criteria	Attributes	Comments or examples
Descriptors	Textual	Title of sketch, annotations
	Graphical	Symbols or personalized signs
Chronology	Date	The date at which the sketch was produced
	Numbering	Sketches may be numbered in sequence
	Graphical	Arrows may show order of sketching
Complexity	Color	Monochrome or color
	Annotation	Presence of notes, dimensions, etc.
	Shading	Lighting/shading effects
	Pencil thickness	Variable pencil thickness
	Level of rendering	How realistic is the sketch?
Design stage	Conceptual	Usually sketches produced by designers
	Detailed design	Engineering design sketches
	Manufacturing	Design for manufacturing sketches
Subject	Detail	A “zoom-in” on a specific detail of the part/product
	Part	A sketch of a part in the product assembly
	Sub- assembly	A sketch of a group of parts
	Assembly/Product	An overview of the product
View type	2D	Front, side, top, back views, etc.
	3D	Exploded, isometric, etc.
Purpose	Reflection	Used to focus and guide non-verbal thinking
	Communication	To communicate ideas informally to others
	Presentation	To formally submit a concept to colleagues, superiors or clients

Whilst it does not claim to encompass every possible way that sketches may be classified, it has – together with use scenarios – played a useful role as a framework to reflect on the merits of possible ways sketches could be integrated with existing PLM solutions, which is now discussed in detail in section 4, below.

4 INTEGRATING SKETCHES IN PLM SOLUTIONS

Despite the importance of sketches as a source of knowledge and design rationale for product development teams, business and engineering processes have not even taken into account their possible integration and management as a value-added stream of information. This section details an exploratory study into sketch management using existing PLM systems. The next paragraph will briefly summarize a variety of technologies that enable the creation of digital sketches. A digital format is indeed the first necessary step for the management of any kind of information using computer systems. Once a digital sketch is obtained, its management through an information system must support a number of user scenarios as reported in §4.2. Finally, this section will conclude by exploring a possible approach to structure digital sketch data to enable its use and archive with an existing PLM system.

4.1 Technologies to support digital sketching

It is not the intent of this paper to propose an exhaustive review of sketching technologies. Many research projects and resulting software prototypes have aimed to replace completely the pen and paper, effectively trying to imitate the move towards CAD that happened in engineering in the early 1980s. Some of these software, type CAID, are indeed used by designers [15] but only for a specific purpose; the presentation of concepts, as defined previously in Table 1. The technology available is becoming increasingly sophisticated but many designers still prefer to use pen and paper for a number of reasons such as portability, easy spatial rearrangement, spontaneity, responsiveness of the medium, etc. More importantly, computer solutions have been found to hinder creativity because of the heavily structured approach imposed by the software program [24]. These simply do not support the imprecise and ambiguous nature of the sketching activity so important in the creative process that early design stages require.

Currently, there seems to be no design information support technologies that place an emphasis on the management of the sketches and early product development knowledge. Most research efforts have been focused on linking sketching to CAD, with aims to generate 3D models directly from a design expressed through sketches [16]. More importantly the authors believe that although these technologies might be useful in certain circumstances, designers and engineers have different viewpoints on the product and should therefore be supported by different tools rather than an all encompassing system. It is also believed that new hardware technologies such as Tablet PCs, Digital Pens, Pen Tablets are close to offering a viable alternative to pen and paper. The digitization of sketches is not the focus of the research presented in this paper; the sketches used for the validation of the classification scheme presented in §3.3 for example were either scanned from student logbooks or directly produced on a Tablet PC with a freehand drawing software such as Autodesk Sketchbook Pro.
The real issues related to the goal of this research have more to do with technical aspects of how the sketches are stored, e.g.:

- *Formatting.* Proprietary formats? This is an important issue and the example of CAD model formats and the trouble they cause for information exchange is of a similar nature. The archival life of formats is also an issue.
- *Imbedded information.* Are only the lines of a sketch stored, or more information needs to be imbedded? Annotations? Voice descriptions?

The next sections therefore propose a preliminary exploration into possible scenarios to manage sketches through PLM systems, and their digitization has been assumed possible with the use of the technologies mentioned above.

4.2 Usage scenarios for the management of sketches through existing PLM solutions

The first step towards the management of sketches through existing PLM solutions was to define the user context in which the integration methodology should be applied. Table 2 lists 5 usage scenarios that need to be supported by the PLM system.

Table 2. The five essential usage scenarios for the management of early design data

Usage / Purpose	**Description of the scenario**
New product	No data exists in the system. A product structure must therefore be created so that the sketches can be associated and organized within this structure.
Information search	The designer will typically look for existing solutions to avoid unnecessary rework or simply for inspiration. Proper tagging of the sketch data will greatly facilitate queries made through the system.
Modification	In case of failure or negative feedback from the latter product development stages, designers need to modify sketches without losing the design rationale. Also change impacts must be managed, so that modifications on parts and sub-assemblies are properly integrated with the rest of the product
Adaptation	Parts and sub-assemblies can be adapted to meet new functional requirements. Minor modifications are sometimes required, but in this case the designer must be able to check that the adapted design fulfils the new function.
Reuse	Existing parts and sub-assemblies are integrated to a new product, but fulfill the same function. Here the interface management is essential to guarantee the realization of the product's main function.

As illustrated previously in Figure 1, the management of early design information would need to be closely integrated to the PDM module which deals with information further downstream in the process. As a preliminary approach, current PDM systems should be tested to verify if they provide a sufficient platform for the management of sketches in the product development process. They offer a range of collaborative functionalities that are necessary for the support of the aforementioned 5 scenarios, namely:

- A secured database with access control, reservation mechanisms, document management, data validation processes, information maturity control, etc.
- Product configuration management with change tracking, versioning, and product option management.
- Visualization of the product DMU.

The first two functionalities are valid for any kind of computer file, so these would be applicable to digital sketch files, but the DMU visualization dimension relies on built-in connectivities that exist between PDM and CAD software and would therefore not be applicable for sketch management. The next paragraph looks more specifically at possible ways to structure sketching information in an existing PLM system.

4.3 Possible structures to manage sketches

A standard method of structuring information within PLM systems is by means of association with a product structure, a hierarchical breakdown of a product into its constituent sub-assemblies and parts. Within PDM, MPM and ERP systems, information can be directly linked to a component to which it refers. However, for identical products, the structure can differ according to needs of the stakeholder, as shown in figure 4. For example, a component which a design engineer views as a single part may be considered to be an assembly by the manufacturing department due to the necessary fabrication method. Another example is when in-service personnel must replace a standard part which has been discontinued or is unavailable. This part will be replaced with another, approved substitute. In the case of design, manufacturing and in-service activities, the product structures can be referred to as 'as designed', 'as planned', and 'as maintained' respectively. It should be noted that figure 4 is a simplified view of a product tree, which has been arranged to show the links in a more or less linear fashion. In reality, the correspondences between the complementary structures can be much more complex.

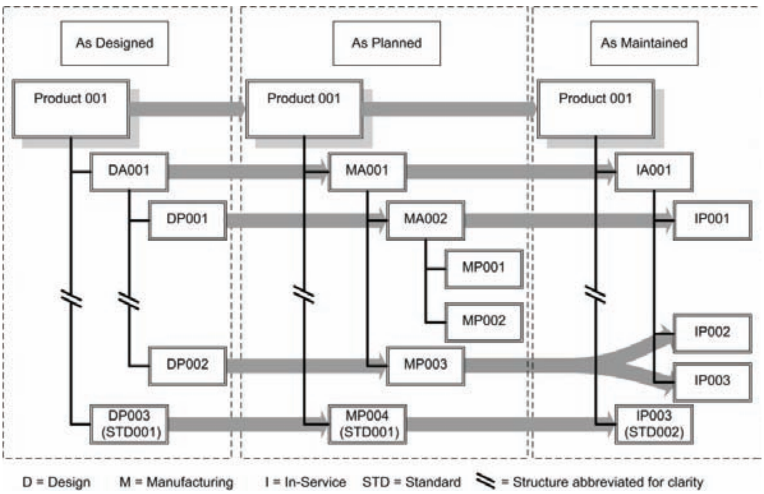

Figure 4. Illustration of complementary information structures in PLM systems

Based on what has been reported so far in this paper concerning the nature of sketching and the context of the conceptual design phase, two main criteria should guide the establishment of a methodology to efficiently organize digital sketches, namely the *importance of managing design alternatives*, and the necessity for designers to keep sight of *the environment in which the product will be used* [3]. These two fundamental criteria will be decisive in the choice of the research and development path to follow; will the PDM be sufficient to answer these requirements or will the development of an entirely new information management system within a PLM framework be required?

5 CONCLUSION AND FUTURE WORK

The work reported in this paper is essentially of an exploratory nature. Nevertheless, a number of research issues have been outlined concerning the management of early design information. The authors have therefore decided to concentrate their efforts along three axes of research:

- *The classification of sketches*. More validation is required; sketches from both student engineers and student designers will be collected and used in a validation process.
- *The definition of a "sBOM"*, i.e. the "sketching Bill Of Materials". An observation of designers' practices concerning personal information management would provide a more robust insight on

how the product is perceived. The authors feel that a functional decomposition of the product might be the way forward. Also the sBOM must specifically support multiple design alternatives and find a way to integrate data concerning the environment in which the product will be used.

- *The evaluation of PDM as a sufficient platform to manage conceptual design information*. One of the essential features of a PDM system is the visualization of the DMU of the product. This will not work for digital sketches, but maybe a new dedicated information management solution needs to be developed in order to provide designers with a conceptual DMU.

The continuing research on the topic will involve researchers from both engineering and design fields, and new approaches will be tested with multidisciplinary design project teams working at Ecole Polytechnique Montreal and the School of Industrial Design at the University of Montreal [25].

Finally, although this research primarily focuses on bridging the design-engineering communication gap through information management tools and methodologies, it is important to note that new educational programs as the one reported in [26] are also key to success. Indeed, providing both design and engineering students with common fundamentals in graphical communication is paramount for an enhanced collaboration of these disciplines within product development practices.

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