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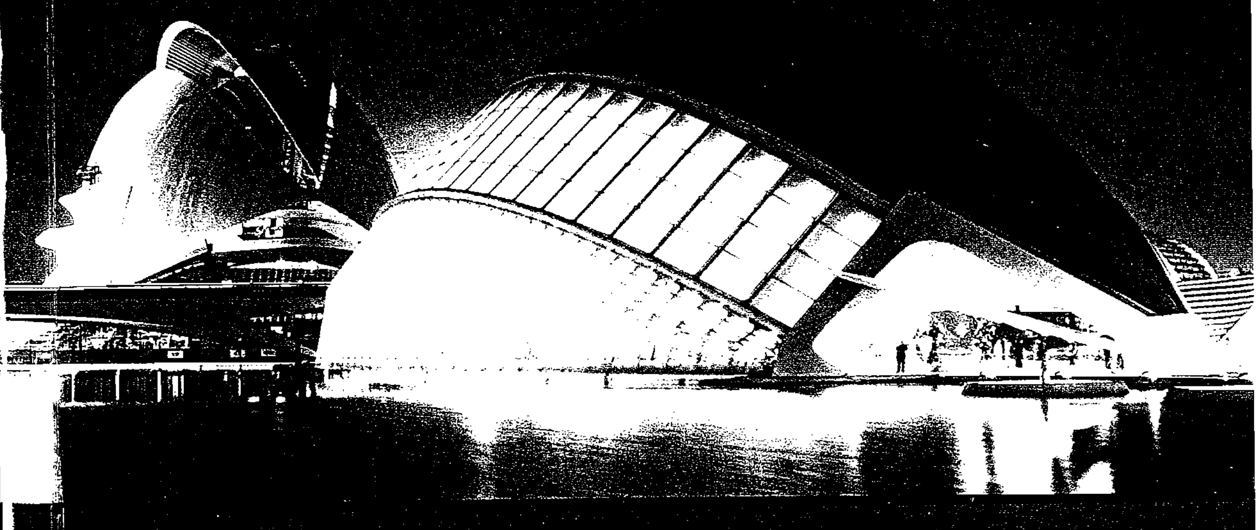

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COMPUTER-AIDED SKETCHING IN ENGINEERING SCHOOLS

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In this paper we analyze the current role of sketching in engineering design, and its importance as a learning outcome in engineering courses. Then we examine the current disconnection between sketching and CAD tools in the new product development (NPD) process, concluding that recent advances in the field of sketch-based interfaces and modelling (SBIM) promise better integration of those separated worlds.

Sketching is certainly a powerful tool that greatly enhances design creativity and helps designers during the fixation of new products [1], but as a result of using computer-aided drafting in both engineering education and professional practice, hand-sketching skills have been overlooked [2].

A recent survey conducted by the ASEE's Engineering Design Graphics Division includes the ability to sketch engineering objects in the freehand mode as the second main engineering student's outcome [3]. This means that engineering teaching community considers sketching to be a capital outcome for current and future engineers. Hence, sketching must regain its capital role in engineering schools, but digital sketching must replace paper-and-pencil sketching, and it must become a "natural" process does not disturb the user. It seems feasible now, since the reasons for its absence come only from the facts that appropriate hardware was not available until the recent advent of tablet PCs, and that currently available academic applications [4] are not yet prepared for broad, commercial use.

Moreover, the majority of handbooks and textbooks oriented towards assisting CAD users do not exploit the limited advantages that current CAD applications can offer during conceptual design. Such books introduce the reader to a world of actions (drawing) instead of a world of ideas (designing). In short, they are oriented towards obtaining maximum computer efficiency, instead of being designer-efficiency oriented.

In this context, commercially available CAD tools with some "pseudo-sketching" capabilities are far from being an alternative to satisfy sketching needs as they are clearly oriented towards detailed and not conceptual design [5], forcing designers precisely in the wrong direction. This process is better than the simplest and obsolete computer-aided drawing of predefined geometrical figures which was allowed by the first generation CADD tools. However, it is far from being genuine sketching; where incomplete and ill-defined geometries actually germinate from the designer's mind's eye. Current CAD applications are not suitable tools to integrate both conceptual design (where sketches dominate) and detailed design (where 3D modelling is the nucleus).

True computer-aided sketching (CAS) tools, oriented towards engineering design, are required. SBIM is an emerging research field, and seems to be able to create the computer tools required to shift to a new paradigm where sketches should be used as input to create digital engineering models in a true computer-aided ideation environment. In this paper, we analyze the main characteristics that a successful and fully integrated CAS tool must include.

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Abstract

In this paper we analyze the current role of sketching in engineering design, and its importance as a learning outcome in engineering courses. Then we examine the current disconnection between sketching and CAD tools in the new product development (NPD) process, concluding that recent advances in the field of sketch-based interfaces and modelling (SBIM) promise better integration of those separated worlds.

Sketching is certainly a powerful tool that greatly enhances design creativity and helps designers during the fixation of new products, but as a result of using computer-aided drafting in both engineering education and professional practice, hand-sketching skills have been overlooked.

A recent survey conducted by the ASEE's Engineering Design Graphics Division includes the ability to sketch engineering objects in the freehand mode as the second main engineering student's outcome. This means that engineering teaching community considers sketching to be a capital outcome for current and future engineers. Hence, sketching must regain its capital role in engineering schools, but digital sketching must replace paper-and-pencil sketching, and it must become a "natural" process that does not disturb the user. It seems feasible now, since the reasons for its absence come only from the facts that appropriate hardware was not available until the recent advent of tablet PCs, and that currently available academic applications are not yet prepared for broad, commercial use.

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True computer-aided sketching (CAS) tools, oriented towards engineering design, are required. SBIM is an emerging research field, and seems to be able to create the computer tools required to shift to a new paradigm where sketches should be used as input to create digital engineering models in a true computer-aided ideation environment. In this paper, we analyze the main characteristics that a successful and fully integrated CAS tool must include for its application to engineering teaching.

Keywords

Sketching, engineering design, engineering teaching, CAD, CAS, calligraphic interfaces.

1. INTRODUCTION

Perhaps sketching is not an art, as it has been suggested by Kivett [1] Jonson [2] and others, but it is certainly a powerful tool that greatly enhances design creativity! For this reason, sketch must be an important learning outcome in engineering courses. In this context, a recent survey conducted by the Engineering Design Graphics Division of American Society for Engineering Education (ASEE) includes the ability to sketch engineering objects in the freehand mode as the second main engineering students' outcome [3]. The same happens to occur in the American Society of Mechanical Engineers (ASME) [4]. In spite of this, as a result of using computer-aided drafting in both engineering education and professional practice, hand-sketching skills have been overlooked ([5], [2], [4]) in the recent past. The problems is clearly apparent in product design, or even in civil engineering, as new engineers often have inadequate experience in making sketches by hand in order to effectively communicate information graphically. Besides, while many studies ([6],[7]) guarantee sketching as an important conceptual design tool, some engineers when faced with conceptual design still rely more on verbal and numerical synthesis tools than on graphical ones [8] since the scope of graphical tools is supposed to be limited to detailed design and manufacturing specification. To sum up, the advent of CAD did endanger the paper-and-pencil sketching activity; teaching included.
Besides, the sketch-based conceptual design continues to be unplugged to the rest of the design process. After a final sketch has been obtained and the conceptual design is over, the designer must create the CAD model from scratch. Then, this model will indeed serve as a primary view for all the subsequent phases of the processes (detailed design, CAE, CAM, etc.). Hence, only the sketching stage remains aside! Therefore, the paradoxical situation is that freehand sketching is still carried out in conventional paper-and-pencil. This is simply due to the lack of true commercial and academic computer-aided sketching (CAS) tools.
In order to improve the above situation, different research lines have been explored during last decades. Sketch-based interfaces and modelling (SBIM) is an emerging research field, and seems to be able to create the computer tools required to shift to a new paradigm where sketches should be used as input to create digital engineering models in a true computer-aided ideation environment. The absence of such tools in the design process cannot be argued as being "natural". This is not due to sketching being an "art" in the sense of it being incompatible with computers or other sorts of tools that are supposed to constrain creativity. It has been demonstrated that the use of CAS tools is at least as helpful as the conventional paper and pencil for training novice engineering students [9]. The reasons for this absence come only from the facts that appropriate hardware was not available until the recent advent of tablet PCs, and that currently available academic applications are not yet prepared for broad, commercial use.
In this paper we present a brief review of the above-summarized situation, and we then analyze the main characteristics that a successful and fully integrated CAS tool must include.

2. THE ROLE OF SKETCHING IN ENGINEERING DESIGN AND TEACHING

Engineering design is extensively documented to be a complex and not well understood ideation process where new industrial products are synthesized, involving the creative and analytical processes used to satisfy a need or solve a problem. To do this, it is interesting to note that it is necessary to communicate the mentally conceived ideas to others in a form that is easily understood. For that reason, sketches, drawings, computer models, and presentation graphics are all linked to the design and production processes. Typically, the design process consists of several stages (Fig. 1).

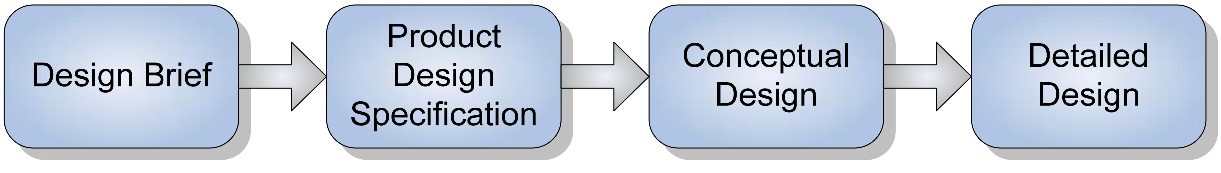

Fig. 1. Stages of design process

The design brief is typically a statement of intent. Although it states the problem, it does not generate enough information to start designing. Product design specification is possibly the most important stage of the design process. It is important to gain a true understanding of the actual problem before trying to produce "solutions". The designer should constantly refer back to this document to ensure designs are appropriate. Using the product design specification as the basis, the designer attempts to produce an outline of a solution. A conceptual design is usually an outline of key components and their arrangement with the details of the design left for a later stage. This phase of design is sometimes called ideation (ideation is a structured approach to thinking for the purpose of solving a problem). In the detailed design stage of the design process, the chosen conceptual design is developed in detailed with all the dimensions and specifications necessary to provide a complete definition of the product.

Typically, sketches are the first step to presenting a conceptual or visual idea; they are usually done very quickly, are roughly sketched and do not include details. For example, after the need has been defined in the design brief stage and after the specifications have been analyzed in the product design specification stage, designers capture their ideas by sketching them on paper in conceptual design stage. Also, sketches are used to facilitate explanation of technical points or simply to point out features that are not yet worked out. In this case, annotation helps identify key points so that their ideas can be communicated with other members of the company. Such sketches record fleeting images in the mind and communicate initial ideas to others. Sketches are also used in the detailed design stage and they are modifications of the basic ideas, but with greater detail.

Therefore, sketches play varied roles in the design process. According to the classification by Fergurson [10], it is possible to distinguish among thinking sketches used to focus and guide non verbal thinking, talking sketches employed to support discussion on the design between designers and engineers while clarifying complex and possibly confusing parts of a drawing and prescriptive sketches applied to give instructions to the draftsman who is in charge of making the finished drawing.

To sum up, sketching is the natural communication technique widely used by designers and engineers and is a useful and a powerful tool that helps designers during the fixation of new products ([6],[7]), because greatly enhances design creativity. For that reason, the "paper and pencil" approach is the basic support and is better suited for expressing the designer creative ideas at the early stages of product design process in a fast way. In the words of Jonson [2], "it is commonly held that the strength of the freehand sketches lies in its economy of means (low cost), immediacy (single tool interface) and ease of low level correction and revision (scribbling over, erasing or a new sheet of paper)".

Sketch also is an important learning outcome in engineering courses. The Accreditation Board for Engineering and Technology (ABET) recommends a list of eleven student outcomes, one of which, criterion 3(g), states that students must possess an "ability to communicate effectively". This communication need is assumed to encompass written, oral, and graphical forms, according to the interpretation of many engineering programs [3]. In this context, Ronald E. Barr describes the survey that was conducted to attain consensus on student outcomes for engineering graphical communication, by the ASEE's Engineering Design Graphics Division [11]. We can highlight that the "ability to create 3-D solid computer models" and the "ability to sketch engineering objects in the freehand mode" were rated to be the first and second graphical communication outcomes. The same happens in ASME [4]. Hence, we can conclude that the engineering teaching community considers sketching to be a capital outcome for current and future engineers.

3. SKETCHING AND CURRENT CAD SYSTEMS

The question is how sketching is supported by current CAD systems? Current commercial CAD systems are not specially, tailored to support sketch-based design. In this context, the problem is that this sketch-based design continues to be unplugged to the rest of the design process, and after the conceptual design is over and a final sketch has been obtained, the designer must create the CAD model from scratch.

Therefore, in spite of recent advances in Computer Aided Design and large strides made by commercial CAD applications in terms of descriptive power, flexibility and functionality, current CAD tools are not well suited to the initial design stages of product development, because many techniques and idioms characteristic of hand-made drawings cannot be used directly in CAD systems and it is still difficult to capture the drawing language used in conceptual design, where designers prefer pencil and paper over computer-based tools. Available Graphical User Interfaces (GUI) for CAD applications are still by and large constrained by the WIMP (Windows, Icons, Menus and Pointing) paradigm, which severely hinders both ease of learning and ease of use. In this case, users are forced to learn a very

different methodology involving the use of menus combined with certain keyboard commands or mouse actions. Present-day interfaces require designers to leap a large conceptual gap from their image of a desired object to the geometric model that formally expresses its shape. To sum up, there is a disconnection between sketching and CAD tools in the new product development process.
The usual alibi to put sketching aside as an old toy is that CAD applications can do a better job, therefore sketching is old fashioned. What is more, some CAD vendors argue their applications to encompass sketching scenarios. Legally speaking, this may be more or less true; such CAD applications do include input modules (named “sketchers”) which allow the user to input under-constrained line-drawings, which are later converted into final line-drawings by either adding or modifying the desired geometrical constraints. In fact, such under-constrained line-drawings are not real sketches because their topology and approximate geometry must be determined in advance: the designer must draw lines, arcs and other basic two-dimensional primitives, and then connect them with the help of a “snapper” that automatically, or with some guidance from the user, detects the basic geometrical relations (connectivity, parallelism, perpendicularity, tangency, concentricity…). As long as this process is done in an interactive environment with the great help of icons and contextual menus, and with less care to final geometry than that required by the old CAD, brochures describe it as “sketching”. However, a line drawing is created, and not a true sketch. What is named “sketch” at those brochures is:

1. Doing “tentative” line-drawing, by means of “classical” CAD geometrical primitives until the desired shape is obtained.
2. Sequentially adding geometrical constraints until the final geometry is achieved.

Of course, this process is better than the simplest and obsolete computer-aided drawing of predefined geometrical figures which was allowed by the first generation CAD tools! However, it is far from being genuine sketching; where incomplete and ill-defined geometries actually germinate from the designer’s mind’s eye.
The first step of this “pseudo-sketching” strategy differs from real sketching because the final geometry must be in the designer’s mind’s eye before he or she begins to draw the first line. So, creativity must take place before drawing begins.
The second step differs even more clearly from a truly enhancing creativity tool because of its sequential nature. The resulting geometry is obviously dependent on the constraints. But the final shape depends as well on the sequence in which those constraints are introduced.
Hence, we can conclude that “Pseudo-sketches” done during a modelling session belong to a different outcome, namely the ability to create three-dimensional solid computer models. Thus, commercially available CAD tools with some “pseudo-sketching” capabilities are far from being an alternative to satisfy sketching needs as they are clearly oriented towards detailed and not conceptual design [12], forcing designers precisely in the wrong direction. As Jonson presumed [2], “the computer encourages the user to go straight into the finished work without the critical and creative thought period”.
Moreover, the majority of handbooks and textbooks oriented towards assisting CAD users do not exploit the limited advantages that current CAD applications can offer during conceptual design. Although some remarkable textbooks (supposedly representative of the most successful contemporary syllabuses) are oriented towards putting computers at the service of designers’ creativity, a lot of them still try to put designers at the service of computers. In other words, such books do not teach designers the best way to use computers to help them to do what they want to do; instead they force them to alter their natural workflow (were ideas dominate) in order to fit the “proper” way, i.e. the one compelled by computers. Such books introduce the reader to a world of actions (drawing) instead of a world of ideas (designing). In short, they are oriented towards obtaining maximum computer efficiency, instead of being designer-efficiency oriented. In the worst cases, a lot of teaching the old computer-aided design and drafting applications (CADD), and even some “anti-CAD” teaching, still survives! In the best cases, parametric drawing is being taught as the “real” and definite conceptual design tool.
To sum up, current commercial CAD applications are not suitable tools to integrate both conceptual design (where sketches dominate) and detailed design (where three-dimensional modelling is the nucleus). Thus, true computer-aided sketching tools, oriented towards engineering design, are required.

4. DIGITAL SKETCHING REQUIREMENTS

While the old fashioned design-by-drawing methodology is being substituted by the design-by-digital-prototypes, the need for effective sketch-based geometric modellers in the environment of design can be traced back to the last decade [13], [14], [15], [16].

Sketches have been present in computer aided design systems since their beginnings in the 1960's. Sutherland's Sketchpad [17] was the first program that allowed the user to create graphical images directly on the computer screen by means of a light pen as data input device. Johson's Sketchpad III [18] added three-dimensional modelling to Sutherland's system. Taggart, Negroponte [19] and Herot developed at the beginning of the 1970's the HUNCH system, composed by a set of FORTRAN programs which were designed to process freehand sketches drawn with a data tablet or light pen. This system was able to provide automatic latching of line endpoints, and detecting corners analyzing changes in stroke direction. Also, a first attempt to interpret sketches as representations of three-dimensional objects was done, as noted by Herot in [20]. However, there are several key aspects to provide an effective digital sketching environment.

Thus, in this section we are concerned about the requirements those digital sketches must accomplish, because the paradigm of digital sketching is still to be fixed. For example, a majority of authors agree that CAS should achieve some key aspects that are not currently accomplished, e.g. it should be a transparent process because creativity decreases as soon as it becomes perceptible to the user, i.e. since it does not become a tool, rather an objective in itself.

According to Ullman [13], the conceptual engineering-oriented CAD tools should have "friendly and intelligent tools to assist in the creation of functional product models; to allow a fast and easy introduction of design intents and serve to check the completeness of design". Besides, in accordance with Ullman the first requisite for such engineering design oriented CAD tools should be two-dimensional sketching capability, to allow a fast and easy exploration of new ideas and serve as a short-term memory. In other words, sketch-based modelling systems must facilitate the speedy creation of detailed three-dimensional designs, usually from elementary two-dimensional sketches, and to improve support for the flexible generation of alternative design ideas at the early stages of design [21], where non-formalized and non-structured ideation processes could flow freely and final three-dimensional shapes would be automatically derived from such ideation processes.

In our opinion, two are the key aspects to provide an effective digital sketching environment: usability and functionality are the two main requirements that sketchers must accomplish.

Thus, an important key aspect is related to the usability. According to IEEE (Institute of Electrical and Electronics Engineers), we understand usability as the ease with which a user can learn to operate, prepare inputs for, and interpret the outputs of a system or component. As long as one main CAS purpose is becoming as usable for the designer as paper and pencil, a critical element to guarantee a successful implementation of the user interface is to keep user interaction as paper-like as possible (user-friendly, transparent…). Hence it must be as least intrusive as possible to allow the user to concentrate on the creative task.

The other important key aspect is related to the functionality provided by the sketching application. The objective is to offer an "augmented paper" to the user. The aim is to offer the same functionality that real paper does, and, at the same time, take advantage of the "extra" functions provided by the software application. Besides, the sketching application must do this while guaranteeing at least the same freedom offered by real paper while the user sketches. Basic CAS functionality that provides some improvement over the characteristics of real paper is:

- Easy storage and transfer.
- Limitless drawing space (zooming and other virtual-paper navigation tools convert the limited screen surface into a limitless paper).
- Edit capabilities (erasing, copying, resizing and other transforming operations help to convert the virtual-pen into a most effective tool than the conventional pen).

Only with this "standard" functionality a CAS system already offers an interesting alternative to sketching on real paper. For instance, the digital representation allows the sketches to be incorporated in a product lifecycle management system (PLM) in the same way that the rest of documents generated during the product development process.

Besides, an advanced CAS system should provide more functionality than paper or a whiteboard, trying to provide an added value to sketching on a digital environment. This extra functionality has been directed to improve the graphic quality of the sketch by means of beautification functionality, providing as output an improved two-dimensional representation, or it has been oriented to automatically transform the two-dimensional sketch into a three-dimensional model. Intelligent support for automatically recognizing the sketch is the way to integrate sketching into standard design

applications; hence this is the advanced functionality final goal. This advanced functionality justifies the importance of automatic creation of models from sketches.
Finally, designing a true interactive sketch based modelling system required the proper hardware devices. During the early 90's Microsoft intended to promote "Windows for Pen Computers", an operative system built over standard Windows with a set of extensions to support a user interface based on the interaction with a stylus and a LCD tablet. It was a commercial failure because of the small processing power of those "pen computers". Nowadays, the launch of the Tablet-PC at the end of 2002 has renewed the interest in sketch based applications.
In short, a CAS application must be usable to the effect that it must be, at least, as user-friendly and transparent as paper and pencil, and this is not the current situation, because current computer tools are less usable than paper-and-pencil sketches and do not posses significantly improved functionality [22]. Basic or “standard” functionality must provide an environment equivalent to paper-and-pencil. Besides, it must be more functional than paper and pencil in the sense that, apart from accomplishing the purpose of quickly exploring different designing alternatives, it must help the designer to turn the final idea into input for the following designing phase.

5. SKETCH-BASED INTERFACES AND MODELLING

As has been mentioned before, Graphical User Interfaces (GUI) of most CAD applications present little evolution from the WIMP (Window, Icon, Menu, Pointing device) paradigm and are not enough flexible to support sketching activities. In this context, during last decades some research has focused on developing applications that aim at designing person-machine interactive systems as an alternative to the systems available today [20], providing some of the drawing facilities afforded by conventional pen and paper. The current generation of powerful computer processors and affordable input/output devices, can justify the feasibility of the new systems and open new opportunities to experiment with interactive user interfaces. At present many personal digital assistants (PDAs), Tablet-PCs and Ultra Mobile PC (UMPCs) use new user interfaces based on this type of interaction (Fig. 2).

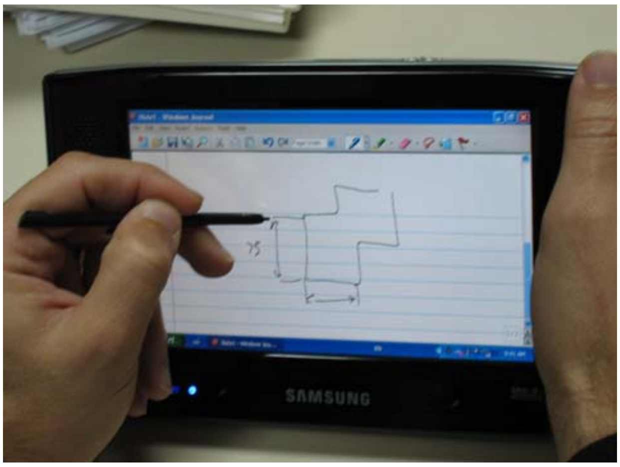

Fig. 2. User input on a Ultra Mobile PC

In this context, during last decades different research lines have been explored to improve the human-computer interface in CAD systems. Sketch-based interfaces and modelling (SBIM) is an emerging research field and seems to be able to create the computer tools required to shift to a new paradigm where sketches should be used as input to create digital engineering models in a true computer-aided ideation environment. In this environment, non-formalized and non-structured ideation processes could flow freely, and final three-dimensional shapes would be automatically derived from such ideation processes. However, the current objectives inside the SBIM community are still very diverse (see Computers & Graphics special issue 29(6)); they range from increasing sketching capabilities of current three-dimensional CAD applications, to car stylists or three-dimensional cartoon makers. This is a consequence of both the youngness of this research field and the diversity of problems it is intended to solve: from software GUI design to mechanical parts design and from three-dimensional geometrical models to graph drawing.

Hence, a more particular subfield is considered in this paper, namely sketch-based ideation or sketch-based conceptual design. Recent advances in this field of sketch-based ideation promise better integration of those separated worlds (sketching and CAD tools). Work on SBIM has looked at a paradigm shift to change the way geometric modelling applications are built, in order to focus on user-centric systems, rather than systems that are organized around the details of geometry representation. In this context, sketch based ideation applications aim at providing an intelligent and interactive modelling support to visual thinking in the initial design stages of product development.

Within this research area, the machine interpretation and reconstruction of sketches has attracted a lot of attention. A number of different authors and groups using different techniques have contributed to this field. Besides, the judgment of designers about computer support for sketches in the design of industrial products has been a field of interest for some time and is still very active at present (see, for instance [23], and [24]).

For the purpose of create these new true interactive sketching systems, several recognition techniques have been developed, in order to fit sketches into beautified sketches, or in order to interpret sketches as symbols, as geometric shapes or as command gestures. There are also approaches aimed at transforming the two-dimensional sketch into a three-dimensional model.

Some of this work stems from early attempts of shape interpretation in Computer Vision. While most of the activity in this area in the past has been focused in off-line algorithms, the growing focus on sketches and modelling has brought forth a new emphasis on approaches geared towards interactive applications. These new sketch-based interactive applications use a digitizing tablet and a pen, an approach termed calligraphic interfaces (see Computers & Graphics vol. 24, special issue "Calligraphic Interfaces: towards a new generation of interactive systems"). These rely on interactive input of drawings as vector information (pen-strokes) and gestures, possibly coupled with other interaction modalities. In these interfaces the artificial dialogue constraints imposed by the previous generation of UIs are removed and designers can work with the computer much the same as they would with more traditional media, to capture rough shapes and ideas. This new generation of calligraphic applications uses gestures and pen-input as commands [25], [26], [27]. The development of these new graphical systems opens new perspectives to the creation of tools oriented to satisfying the needs of the designer in conceptual design stage. This is in contrast to the current generation of systems, which seem to take the approach of billing themselves as APIs to geometry kernels, which do make a poor job of hiding the internal details of the underlying representations.

Within this research area it is possible to distinguish two main approaches to transform the two-dimensional thinking sketches used in the conceptual design stage of industrial products into three-dimensional models in sketch-based modelling. One method relies on gesture alphabets as commands for generating objects from sketches. The second approach, derived from computer vision, uses algorithms to reconstruct geometric objects from sketches that depict their two dimensional projection.

In gestural-based modelling systems, modelling operations encoded by gestures are used to transform two-dimensional sketched sections into a three-dimensional object. Gestural systems provide predefined gesture alphabets that encode some geometric modelling operations; basically these systems substitute the selection of icons and menus by graphic gestures. An example of these sketch based modelling systems is SKETCH [28]. This system is a classical reference due to its gesture-based interface to approximate three-dimensional polyhedral models. SKETCH uses a gestural mode of input in which all operations were available directly in a three-dimensional scene through a three-button mouse. The user sketched the salient features of any of a variety of three-dimensional primitives and, following some simple placement rules, the corresponding three-dimensional primitive was instantiated in the three-dimensional scene. Its main contribution was to provide a gestural interface for many of the operations of the system. SKETCH is basically aimed at architectural forms, in which the geometric model is entered by a sequence of gestures according to a set of conventions, regarding the order in which points and lines are entered as well as their spatial relations. For example a primitive of the type Block is defined by three segments starting from the same point. Positive volumes are built in the same direction as the outer normal of an adjacent surface whereas negative volumes are drawn opposite from outer normal.

In reconstruction-based modelling systems, a sketched single view projection is interpreted and a plausible three-dimensional model is generated. Current state of the art of geometrical-reconstruction approach to this subfield was described in [29]. An example of reconstruction sketch-based modelling system is CIGRO [30]. The CIGRO (Caligrapphic Interfaces & Geometric ReconstructiOn) application is an interactive system, where the three-dimensional model is constructed while the user draws the sketch (Fig. 3). The application combines a calligraphic interface with geometric reconstruction algorithms. CIGRO uses an online reconstruction engine, capable to propose a real three-dimensional model from the freehand sketched two-dimensional representation, providing automatic beautification and a true integrated two-dimensional sketching (planar) and three-dimensional view visualization (spatial) sketch work environment. The application operates with polyhedral models using an approximate axonometric projection sketch as input. The advantage in reducing the models than can be created to polyhedrons is that it is possible to apply straightforward reverse-projection techniques to directly generate a three-dimensional model in real time, without having to resort to expensive optimization techniques. This way allows the user to see the current three-dimensional model as he/she completes the sketch. Besides, compared to sketching on real paper, CIGRO provides some extra functionality, i.e. the user can change the point of view to orient the three-dimensional model to a more advantageous position, and then continue sketching. Spareness and simplicity are the main characteristics of this system. Everything is made as easy as possible for a natural user experience, trying to provide an experience close to real paper and pencil usage.

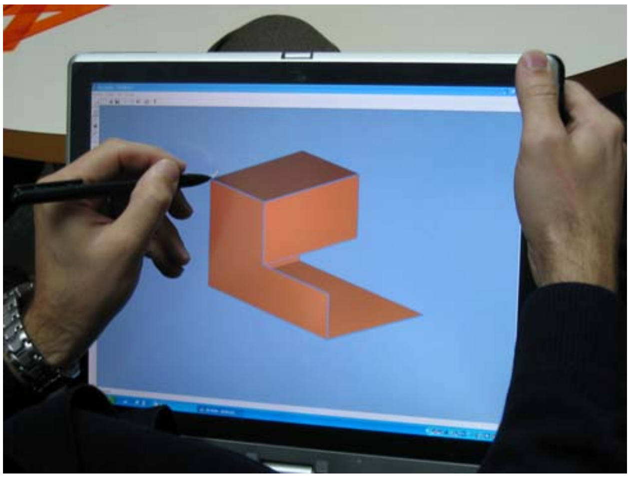

Fig. 3. User stroke input on a Tablet-Pc (CIGRO)

With respect to talking sketches, some recent developments from the computer support collaborative work (CSCW) scientific community are aimed at both collaborative creation and the sharing of two-dimensional sketches. But nothing has been done in the field of its automatic interpretation and conversion into three-dimensional digital models. Finally, no work was found in the literature aimed at studying the transformation of prescriptive sketches into three-dimensional computer models.
To sum up, in contrast to conventional drawing applications, the stylus can also be used to enter continuous-mode sketches and freehand strokes. Thus, there is a growing research interest in using freehand drawings and sketches as a way to create and edit three-dimensional geometric models.

6. CONCLUSIONS

The role of sketching as a creativity tool has been revisited. Besides, it has been argued that sketching must regain its capital role in engineering schools, but digital sketching must replace paper-and-pencil sketching, and it must become a “natural” process that does not disturb the user. It seems feasible now, since the reasons for its absence come only from the facts that appropriate hardware was not available until the recent advent of tablet PCs.
The wrongness of the approach to sketching interfaces induced by “pseudo-sketchers” embedded in current CAD applications has been argued. Then the main features that true computer-aided sketching (CAS) tools must possess (i.e. usability and functionality) have been analyzed. It has been argued that simplicity is the key to keep user interaction as paper-like as possible. Finally, it has been also stated that CAS is not a single problem, but at least three, because of the distinction between thinking sketches, prescriptive sketches, and talking sketches. Hence, we have explained the different approaches to improve functionality through the automatic conversion of sketches into three-

dimensional models. These new sketch-based conceptual design systems seem to show that is feasible to replace the traditional sketch and paper by CAS tools running on Tablet PCs or PDAs, providing a greater level of functionality than real paper. Thus, sketching approach is a viable option and sketching applications are clearly more usable than WIMP interaction.

To sum up, engineering teaching community mustn't play down the importance of sketching and they must consider sketching to be a fundamental outcome for future engineers. Moreover, another important aspect is that the new computer-aided sketching tools can be used by engineering students insofar as these tools will be available for use.

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