

# A Multi-Windows Approach for Sketch-Based Conceptual Design System

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## Abstract

*Sketching plays a very important role in conceptual design. In this early stage of the design process, designers have developed some ways to help them to explore designs. Sketching is one of these methods. In this paper, a study of sketch nature was carried and a proposed sketch-based interface for modeling was designed. The sketch nature study investigated the cognitive activities in sketching process, analyzed sketches of design students and professional designers, and collected data about sketching process and sketch-based systems requirements from designers to develop sketching scenarios and determine sketch-based systems requirements. These requirements were used to design a proposed sketch-based system for conceptual design with a multi-windows approach. The proposed system aims to provide an easy way for designers to sketch freely and for ideas to flow easily by using a multi-windows approach for sketching, 3D generation and rendering.*

*Keywords: sketch, sketch-based system, conceptual design, design cognition.*

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## 1. Introduction

Designers used to express their ideas by drawing them on paper using a pen or a pencil. This way allows them a wide range of freedom in expression and helps ideas to flow better. With the development of computer hardware and CAD systems, designers tend to use these new technologies to implement the detailed design of products. But they still use paper and pencil to sketch out conceptual design ideas and explore design space freely. The reason for that is because CAD applications are not suitable for handling vague, ambiguous and inaccurate information (e.g. freehand sketches). Therefore, freehand sketching remains one of the most powerful and intuitive tools used at the conceptual design stage. Sketches, in contrast to CAD applications, can be quickly and easily created and modified.

Later, with the emergence of new hardware devices such as tablet compute, digital ink and stylus, a new interactive system comes into use. This system is sketch-based interfaces for modeling (SBIM). The goal of this system is to allow sketches –hasty freehand drawing- to be used in the modeling process from rough model creation through to fine detail construction. Over the last few years, various systems were presented such as Teddy [IMT99], SKETCH [ZHH96] and others. Most of these systems depended on 3D automatic construction based on the user's strokes. This approach pulls the user to think about details not the whole idea which can be developed. In Teddy, for example, the user draws 2D free-form strokes to specify the silhouette of an object, and then the system automatically construct a 3D model based on the strokes. In this case, the user finds

himself have to start editing the 3D model or delete it or start from the beginning. This criterion is not what the designer follows when he/she sketches. Designers draw more than one idea before they find the perfect one to further refine it. He/she may return to old ideas and start to develop it again. In order to integrate the advantages of direct geometric modeling from sketches and the flexibility of traditional pen-and-paper based design interaction into conceptual design, a sketch interface has to be developed to meet the designers' needs in terms of sketch nature and process.

In this paper, we propose a framework for sketch-based systems. This framework responds to the real requirements of designers in the conceptual design stage. It can be used in designing a sketch-based system for conceptual design. We first carried out a study of cognitive activities in the sketching process, sketches analyzing, and a questionnaire about sketching process and sketch-based systems requirements. As a result of these studies, a sketching scenario was developed. This sketch scenario shows that sketching process is divided into three stages: exploration, ideation, and sketch finishing. The designer can go backward and forward to the previous stage at any phase of sketching. From the data collected by the questionnaire, system requirements were determined. After that, the sketching scenario and the system requirements were used to design a proposed sketch-based system for conceptual design.

In the proposed system, a multi-windows approach is used, which means that 3D objects are constructed in a separate

window to be easier for the user to transform and edit it and without losing any unused 2D sketches. It depends on non-automatic 3D construction and put 3D construct process under the control of the user to avoid any confusion or unwanted results. The user starts to draw freely on a white sketchpad - works as a piece of paper- and this allows the user to think visually. To convert a sketch to a 3D, the user moves to an over sketching mode. In this mode, he over sketches what he/she wants to be converted in 3D but by using another color. This helps computer to know what exactly needs to be interpret into 3D. By pressing another icon, a 3D scene is created in a separate window and a 3D object is constructed. The 3D object can be edited or rendered in a non-photorealistic render. This multi-windows approach not only support s a user-centered idea exploration process but also a user-controlled 3D modeling scenario. We argue that the proposed system will be more intuitive and easier in use than other existing systems because we have developed its framework through comprehensive analysis of sketching process. It will give the chance to the designer to work exactly as happens in real without pushing him/her to sketch in 3D directly, but the designer can explore ideas freely.

## 2. Related Work

There are various studies that concerned the sketching process and described the cognitive activities of the designer while he/she sketches. Also, various sketch-based systems were presented to improve digitization of conceptual design stage. Rodgres et al. [RGM00] presented an investigation of the sketching activity depended on observation of eight participants. He explained the position of sketching in the design process and its flexibility as a method to expression about ideas. This flexibility was explained also by S. Lim et al. [LQP\*04] in a study about sketching behavior. Rodgres also determined five levels of complexity of sketches.

Tovey et al. [TP03] discussed the development of sketches throughout sketching process in the light of complexity levels of Rodgres [RGM00]. The authors analyzed these complexity levels throughout observation of professional automotive designers and could result a detailed description of sketches' features in every level.

In his work, Schon [SCH83] suggested that through sketching, designers construct a 'virtual world' where sketches are representation of their imagination. On that base, Kavakli et al. [KG01] analyzed results of design protocols of novice and expert designers. That helped in analysis of cognitive actions in the design process and difference in these cognitive actions between novice and expert designers.

Yan Jin and Pawat Chusilp [JC06] investigated the cognitive activities occurring in designer's thinking process throughout different design stages. In their research, they

focused on mental iteration in conceptual design. They tried to answer the question: How does the mental iteration behavior relate to different design situation?

As the development of CAD systems, Ben Jonson [JON05] explained that CAD systems are not suitable for sketching process because of the imprecise nature of sketches and the freedom that designers need to proceeds sketches. Therefore, several interfaces for sketching three-dimensional shapes have been developed, e.g. SKETCH [ZHH96]. SKETCH is a classical system that was designed by Zeleznik et al. It targets the exploration and communication of 3D geometric ideas. SKETCH is designed to bridge the gap between hand sketches and computer-based modeling programs, combining some of the features of pencil-and-paper sketching and some of the features of CAD systems to provide a lightweight, gesture-based interface to 'approximate' 3D polyhedral modeling.

Teddy [IMT99] is an interface for free-form modeling. There, a user first inputs a simple closed stroke and the system creates a shape matching this contour automatically. It depends on user's strokes. After that, the user can edit the 3D object through extrusion or cutting. But to draw another object, the user should start from the beginning.

Lipson et al. [LS02] proposed a new approach for reconstructing a 3D object from a single 2D freehand line drawing depicting it. It was shown how a 2D line drawing can be reverses-projected into 3D based on optimizing learned 2D-3D geometric correlations. These correlations are acquired from analyzing many 3D scenes and their corresponding 2D views.

Beom-Soo Oh and Chang-Hum Kim [OK01] presented a system for geometrical objects which depends on a progressive algorithm for reconstruction a 3D structure from a given 2D sketch drawing (edge-vertex graph without hidden line removal) according to the user's sketch order.

As the architecture was one of the fields that sketch-based systems were developed to serve, SMARTPAPER [SC04] offers a unified sketching environment that supports both direct and gestured sketching. It tries to give more freedom for the user by supporting casual sketching style, where several overlapping discontinuous strokes could be sketches. Also, it provides a feedback and editing system.

Dorsey et al. [DXS\*07] presented a system for conceptual architectural design. This system depended on free drawing on exiting canvas which can be oriented and rotated to form the 3D scene. The user first activates the canvas by selecting it, rotate it in the position he/she wants and then draw in 2D.

Bae et al. [BBS08] presented ILoveSketch for professional designers. Authors depended on a more judicious approach that focuses on the user instead of how to interpret 2D sketches to 3D models. This pushed them to identify design goals that a successful system must meet from both a fluid workflow and design throughout perspective. A year later, EverybodyLoveSketch [BBS09] was presented as a new version of ILoveSketch to serve a broad range of novice users. To do that, the system offers some new features as ticks, 2D axis widget, multi selection, and interactive grid. It depended on analysis of the basics of traditional perspective drawing and its use in professional practice. To better understand of how professionals work, authors analysed concept artist Scott Robertson's demo. We argue here that demos are not the suitable tool to get an accurate understand of how designers work because it typically prepared and don't reflect the whole fact.

To help designers in industrial design area, Kara et al. [KS07] proposed a pen-based system for 3D-object styling design. The system allows users to create 3D objects through direct sketching. In [KS06], Kara advocated the use of deformable wire frame models as a base to facilitate styling design. In that work, user's input strokes help manipulation exiting edges of wire frame model. In current work, he shares several similarities with the previous work, but introduces several techniques for 3D curves creation and modification.

Schmidt et al. [SKSK09] used analytical drawing as an approach to inferring 3D curves from perspective drawing. The system supports precise image-space construction of linear 3D scaffold. This system uses virtual vanishing points which help designers to draw accurately. Inferring 3D models is working by following strokes.

In his thesis [COO07], Matthew depended on the cognitive process of sketching, and summarized guide principles to design sketch-based systems. He also developed sketch-based systems requirements and used these requirements in building his system.

In addition to a good understanding of the cognitive process of sketching, we analyzed designers' sketches and asked PhD students in the design area to get a deep understanding of sketching process from different areas. Then we developed a sketching scenario and sketch-based systems requirements which are used in designing a framework for sketch-based systems. The framework depends on a multi-windows approach.

From previous works, studies that concerned with the structure of sketching process and cognitive activities of design process were used to explore sketching scenarios. It helped us to have a better understanding of the development of sketches through sketching process and how designers think through sketching. Also, it provided us with good information about elements of sketches and its

complexity levels. Other studies that related to sketch-based systems were used as inspiration sources to design the proposed framework for sketch-based systems through thinking in its contribution in light of sketch scenarios we have developed. In addition to that, they help in designing details of sketch-based system as 3D construction and editing system.

### 3 Sketching nature

Design sketches are different from 'drawing from the object' [ML05]. They are not drawing of something that already exists. They are a representation of something that is imagined in the mind of the designer. As Ferguson [FER92] mentioned in his book 'Engineering and the Mind's Eye', there are three kinds of sketches: the thinking sketch, the prescriptive sketch, and the talking sketch. The thinking sketch is used to focus and guide non-verbal thinking. The prescriptive sketch is used to direct a draftsman in making a finished drawing. The talking sketch is produced during exchanges between technical people in order to clarify complex and possibly confusion parts of the drawing. Here, we are interested in the first kind, the thinking sketch.

To understand the sketch nature, three methods were used: literature review of cognitive activities of the conceptual design, sketches analyzing, and a questionnaire.

#### 3.1 Conceptual design as a cognitive activity

Previous studies that related to cognitive activities of design process were reviewed. It helped in understanding how designers think through sketching. Both design researchers and cognitive scientists have developed various process models to study human creative behavior in design [JC06]. The models developed are often based on observations of design processes and analysis of design protocols. French [FRE85] presented a model of design process that describes cognitive activities of problem analysis and conceptual design. Maher et al. [MPB96] introduced a co-evolution model that describes creative design process as 'co-evolution' between problem space and design space.

Cross [CRO00] described a four-stage model of the design process, which is composed of exploration, generation, evaluation, and communication. Kruger [KC01] presented an expertise model of the product design process to study cognitive activities in design process. Benami [BEN02] described a model of conceptual design which explores interactions between cognitive activities, design entities, and design process. Also, Jansson et al. [JS91] proposed a theoretical model of the conceptual design process. This model describes the movement between configuration space and concept space.

In this context, we can understand sketching process as an embedded process in conceptual design process. It can be described as a link between design problem and design.

While designer explores the design space. Sketching process begins with exploration design-problem and design-space, and then designers start to generate ideas which are evaluated through sketching several times.

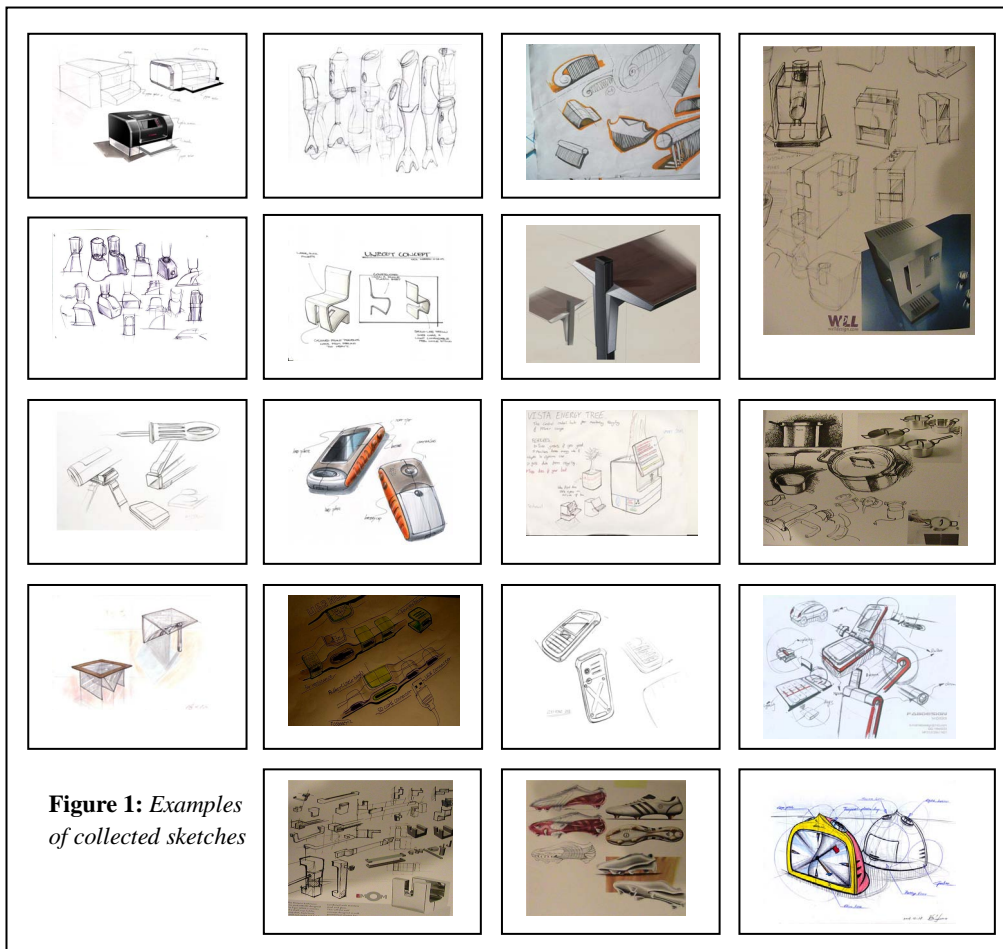
### 3.2 Sketches analysis

This sketches analysis has involved 70 sketches. 50 exercise sketches were collected from design students by using design forum website [PRO10] and 20 sketches of professional designers were collected from different companies (e.g. SMOOL Designstudio, WeLL Design, and Jan Hoekstra Industrial Design) by Koos Eissen and Roselien Steur in their book [ES09]. These 70 sketches are all thinking sketches and from different design domains. Sketching analysis was carried out based on the following five factors:

- The number of visual objects in each sketch
- 2D or 3D sketch
- Shading and colors
- Using of assistant lines to develop ideas
- Annotation

Results show that 66% of sketches contain more than one visual object in each- about 20% contain more than three visual objects. These visual objects vary from perspective view (3D sketch), side-view sketches, sections, annotation and/or incomplete drawing. Most sketches (over 90%) contain perspective view sketches and 40% of sketches contain perspective and side-view sketches together.

All professional designers and design students used assistant lines which converted to form lines in several sketches. All sketches have kind of shadings and 30% of sketches were colored to add a realistic appearance to sketches. About 20% of professional designers and design students used annotation to give more information about sketches. Figure 1 shows some of collected sketches.



**Figure 1:** Examples of collected sketches

### 3.3 Questionnaire study

We designed and distributed a questionnaire to identify the sketching habits and the requirements for developing sketch-based systems for conceptual design stage. The questionnaire was done by personal interview with 10 participants of design PhD students in Brunel University. Participants have a design background and they are between 25 and 35 years old, 5 males and 5 females. Questions were divided into two categories: sketching process and sketch-based systems requirements. In the first part of questionnaire, participants answered questions about sketching strategies, medium used, and elements of sketches. Questions in the second part were about their needs and preferences to be available in a sketch-based system for conceptual design stage. Research findings from the questionnaire study are as follows:

- All participants tend to draw many ideas before they get the perfect one and most of them draw more than one idea in one paper.
- They sometimes return back to old ideas to re-develop it to create new ideas.
- 8 of 10 participants use perspective sketches to express their ideas and some of them use 2D sketches to explore ideas firstly.
- About medium used, they use pen and paper basically but one of participants uses PC tablet beside pen and paper and in a later stage.
- 7 participants finish their sketches by adding shading and colors.
- For the sketch-based system requirements, 8 participants prefer non-automatic 3D construction. They think that drawing freely before converting to 3D will be better give them the chance to flow ideas without interruption.
- Most of participants (9 participants) prefer the 3D construction to be in a separate window to be easier for them to edit and transform. And they prefer using PC tablet and stylus because it is easier than a mouse due to its imitation to pen and paper medium.

### 4. Sketching scenario

According to the above results from analysing sketching as a cognitive process, sketches analysis and the questionnaire, a sketching scenario was developed. This sketching scenario is divided into three stages: exploration, ideation, and sketch finishing. Exploration is the stage where the designer explores design space and starts to express about ambiguous ideas that starts as a mental image. Designers try to convert these mental images to visual appearance to be understandable. This stage is ideation and as these mental images are not ordered, designers tend to draw several sketches before they reach to a final idea that can be developed. They use various kinds of drawing: perspective view, side-view, sections, and sometimes annotation. Then, they finish sketches by adding shading and colours. Designers can go back at any

stage to start a new idea or develop an old one. That is because the imaginary process is not ordered and affected by external factors. Figure 2 shows sketching scenario process.

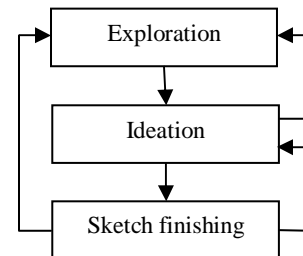


Figure 2: Sketching Scenario process

### 5. System requirements

According to results found from sketches analysis and the questionnaire, the requirements of a sketch-based system for conceptual design are determined as follow:

- Separate sketchpad for free sketching, shading, and adding annotation.
- Separate 3D scene window for 3D construction to allow easy transformation and editing.
- Non-automatic 3D construction with a complete user control in conversion process from 2D to 3D. This prevents system from producing unwanted 3D objects or moving to 3D mode in a wrong time before user completes his/her drawing.
- PC tablet and stylus to imitate the feeling of using pen and paper.

In addition to the above, there are two requirements which are inspired from previous works:

- Use of gesture editing to reduce selections of menus and icons which take a long time from users to learn and be familiar with them.
- Applying of Non-photorealistic rendering (NPR) to serve the interaction between designers and sketches effectively as Schumann [SSRL96] argued in his study.

### 6. System descriptions

The proposed system is a sketch-based interface which will work to improve conceptual design process. It is a multi-windows system which means that there are separated windows for sketching and generating 3D objects. The proposed system will present an interface which is located between WIMP system and SBIM system. The interface will be a blank space with just a bar on its top which can be positioned in any place of the interface (top, down, left or right). This bar will contain some menus and icons which are essential such as saving options, viewing, helping and switching work modes.



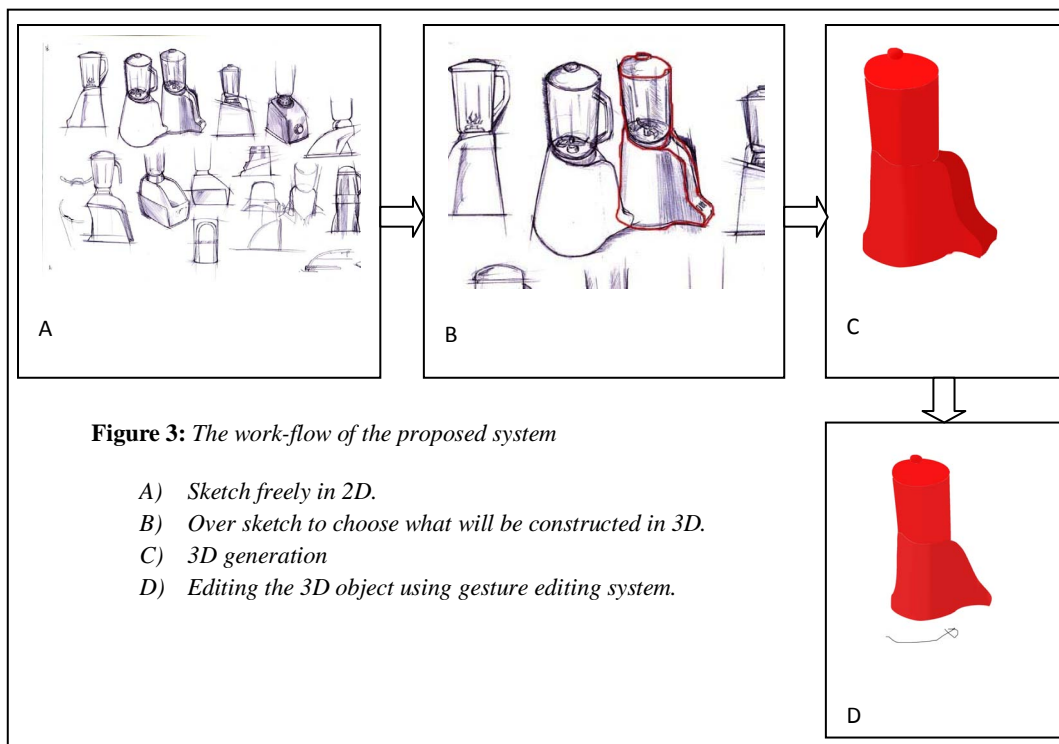
Its work-flow will start as a typical design with sketch drawing on an infinite (virtual) sketchpad under the sketching mode, corresponding to a designer as conceptualizing his design with pencil and paper. The system will not recognize sketches automatically. To convert 2D sketches to 3D objects, the user should over-sketch specific lines and curves that construct the chosen shape to be generated as a 3D object. A separate 3D scene will be created where a 3D object can be added and edited. The 3D scene allows the designer to transform the 3D object and edit it by a gesture-based editing system. The 3D objects generated by the system will be in an extension that can be exported to professional 3D CAD systems to further refinement and to speed up the design process at all. Figure 3 shows work-flow of the proposed system.

### 6.1 2D Sketching

An easy sketchpad will be manipulated as a piece of paper with input interaction designed to mimic the use of a pencil, e.g. PC tablet and stylus. This will provide the user

as close experience as drawing on a piece of paper with a pencil. Sketching mode will enable users to sketch out conceptual designs in 2D freely (Fig. 3A). It will allow fuzziness by permitting assistant lines, shadows, and annotation.

Before switching to 3D generation mode, where 3D objects will be generated in a separate 3D scene window, the user should over-sketch objects that he/she wants to be modelled in 3D. Usually, over-sketching is used to allow a user to carefully sketch over the offending region when a mistake is made during sketching. We will use it in the proposed system in a different way to allow a user to draw freely and explore design space, and in the same time to help computer to recognize what to model in 3D easily. The user moves firstly to the over-sketching mode by picking a colour icon from two coloured icons (refer to straight line and curve) to determine the shape and then over-sketch (Fig. 3B). To create the 3D model, the user presses the 3D generation icon to create the 3D model in the 3D scene.



### 6.2 3D Generation:

To generate a 3D object, a 3D scene window will be created separately. This separate window will help to avoid the interference between sketch contents and the 3D object. Also, it will provide a convenient environment for the user to edit the 3D object easily and give him/her the ability to re-create 3D objects from the same sketch. Figure 3C

shows simple mock-up of how the 3D objects will be generated in the proposed system.

Interpretation of a user's drawing as gesture may provide a quick and easy way to generate 3D content, but this method will not be suitable for certain types of drawing. We will use a reconstruction approach which is similar to that used

in [LS02] and [TML09]. In the over-sketching mode, the user must draw hidden lines of the sketch to be interpreted. This step is not a difficult step for a designer or a design student. And in this stage, user's strokes are collected and every stroke is split into smaller strokes. There may be intersection in the sketch plane, but these intersections will not be taken to represent intersections in the 3D scene.

In addition to that, we will use a system in over-sketching which make the user give extra-information about line type (straight or curve) through over-sketching process (two coloured icons as mentioned previous). This will help computer to select the best representation for the object throughout algorithms embedded in the system. Figure 4 shows the pipeline of the proposed system.

### 6.3 Editing

Editing is an important action that interacts with modeling to allow users to do some specific tasks such as selecting, copying, moving and rotation, Figure 3D shows also a simple mock-up for how editing process work. Using gesture editing system can mimic pencil and paper (when using stylus). It gives users familiar affordances because typical users will have intimate knowledge of the pencil-

and-paper medium. It also helps to reduce the amount of menus and icons selections which take a long time from users to be learnt.

To start editing, the user first switches to the editing mode to start manipulating the scene. In the proposed system we differentiate between two levels of editing. The first level will contain usual manipulation orders such as select, move, delete, and rotate. This level will be available in sketching and 3D generation modes and this is inspired basically from [FHKZ06]. The second level will contain orders that develop the 3D object as twist, bend, and extrude. This level will be available just in the 3D generation mode.

### 6.4 Rendering

Sketches are informal figures often created as a way of thinking about, or working through a problem [DAV07]. Also, designers apply techniques of 3D computer graphics to create images that communicate information for some purpose. Depending on specific purposes, photorealistic imaginary may or may not be preferred. Thus, a growing branch of computer graphics research focuses on techniques for producing non-photorealistic rendering (NPR) from 3D models [KMM\*02].

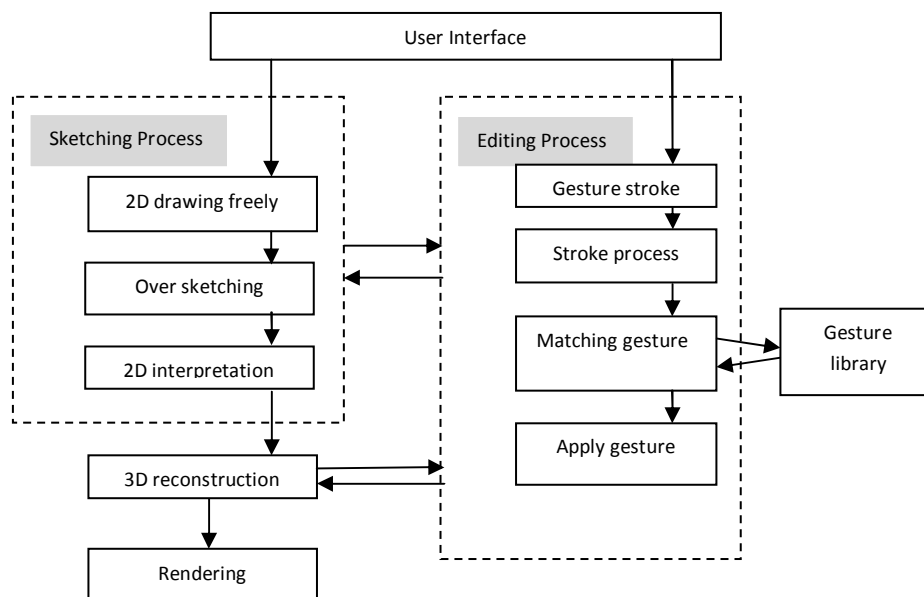


Figure 4: The pipeline of the proposed system

This direction of NPR is supported also by Mayer and Bederson [MB98]. They showed that the presentation of 3D model's appearance can have influences on sketch activities and cognitive processes of designers. Schumann *et al.* [SSRL96] argued that the using of sketchy appearance for conceptual design is more appropriate for discussions in the early design phases and between designers and costumers. Ku [KQWM08] has positively tested the integration of NPR rendering within a sketch-based modeling system. For these reasons, Rendering in the proposed system will be in a sketchy appearance to serve the interaction between designers and sketches effectively.

### 7. Conclusion and future work:

This study investigated sketching nature in the context of conceptual design process. We first studied cognitive activities of designers through sketching process, and then analyzed sketches of design students and professional designers, and conducted a questionnaire study about sketching process and requirements of sketch-based systems for conceptual design. From these studies, a sketching scenario was developed and sketch-based systems requirements were determined. Based on these requirements, a new multi-windows approach was advised to design a proposed sketch-based system for conceptual design. This new system aims to help designers to express their ideas freely and convert 2D drawing to 3D easily. This multi-windows approach not only supports a user-centered idea exploration process but also a user-controlled 3D modeling and editing scenario.

This paper reports research work in progress. Future work will realize the proposed system and make evaluation by designers.

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