# Sketch Input of Engineering Solid Models

## 1. Introduction and Taxonomy

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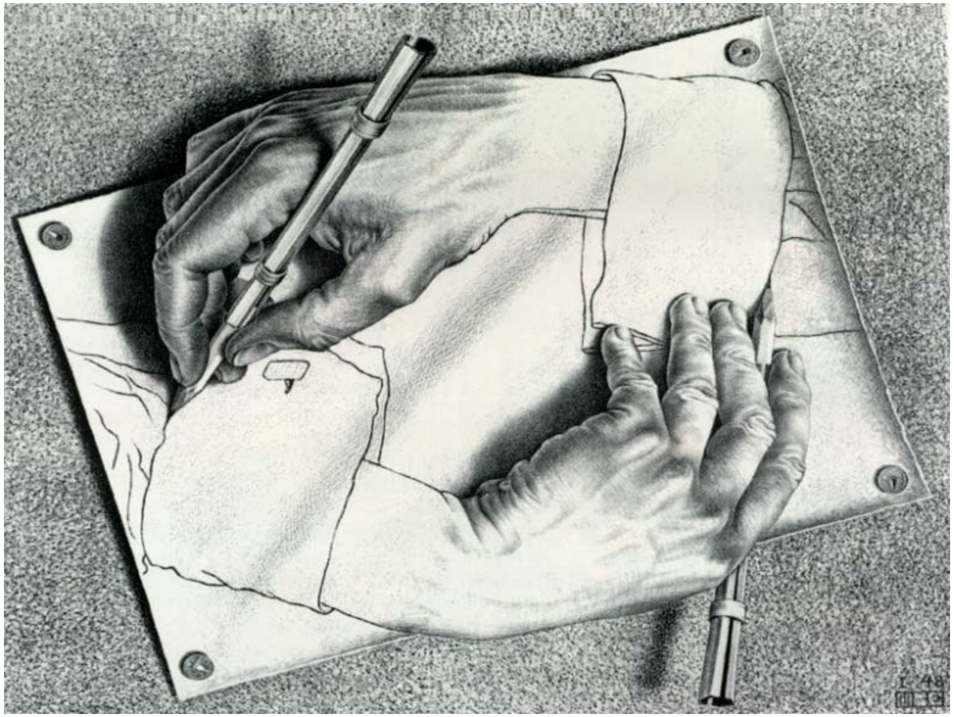
REGEO

# Introduction

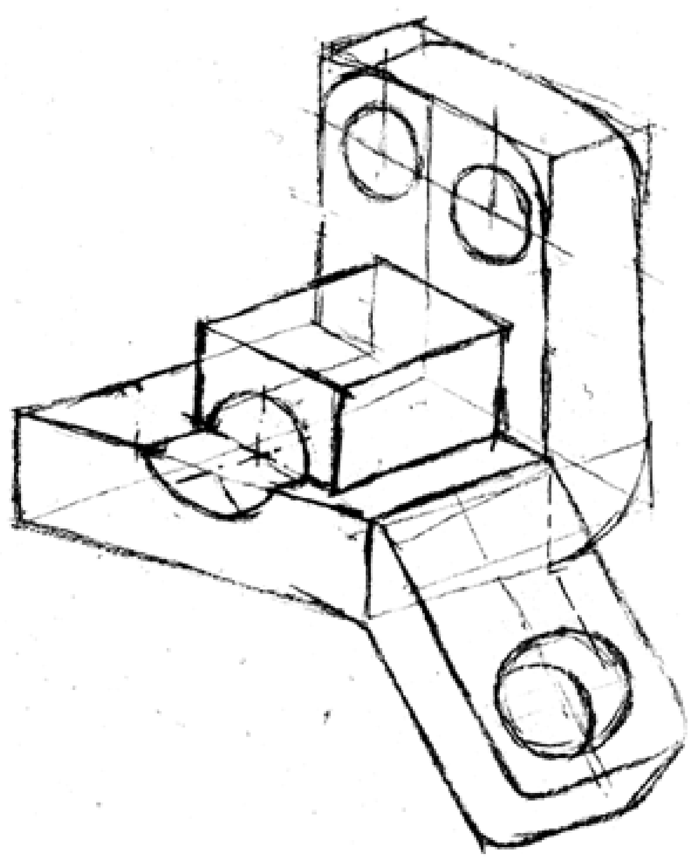
Sketches are drawings which are intended as preliminary explorations , not as finished works



M.C.Escher, http://www.mcescher.com

Sketches are an important kind of graphic

We are interested in sketches
as they assist product designers
during the creative stages of product design

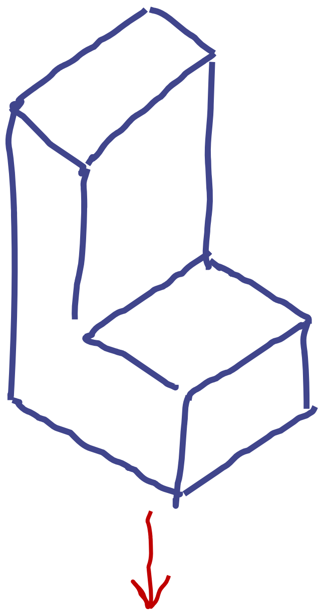


# Introduction

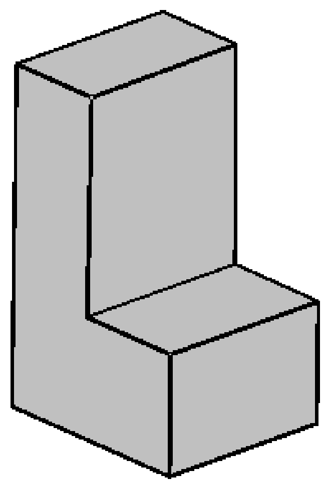


We know that people understand sketches!

If I draw this:



Most of you, if not all,
perceive this:



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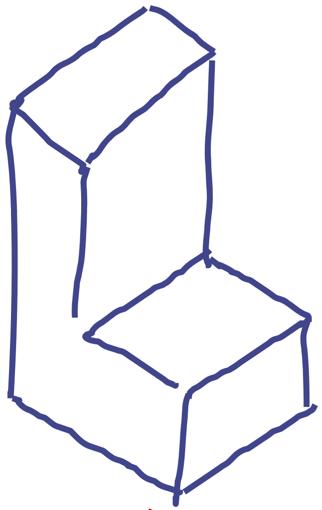

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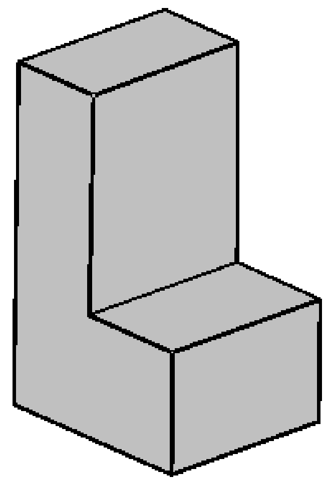
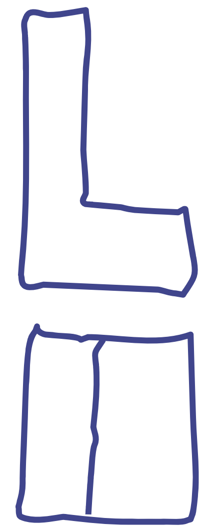


If I draw this:



Those of you who have *been trained*, perceive this:

Computers are **blind**
to engineering sketches!

**New computer tools** are required!

# Introduction



Computers are **blind**
to engineering sketches!

**New computer tools** are
required!

Computer-Aided Design (CAD) tools
cannot solve the problem!

...because CAD applications
are unable to work with:

- ✓ confused
- ✓ poorly structured
- ✓ incomplete ideas

# Why not CAD?



## CAD is a useful tool for **detailed** design:

DESIGN-BY-DRAWINGS
has been the major design approach
since the end of the 17th century

⇩

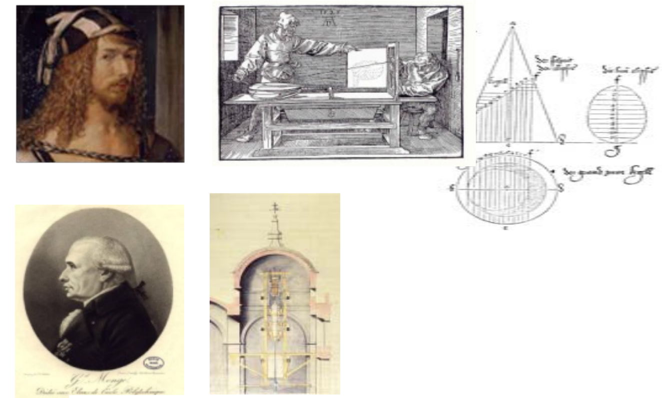
Later, it was assisted by the computer
(CAD 2D or CADD)

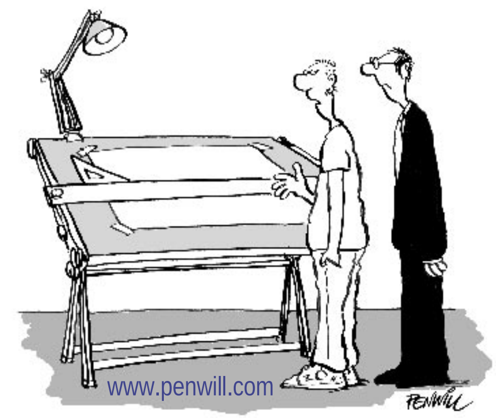
⇩

Finally, it is performed by the computer
(CAD 3D)

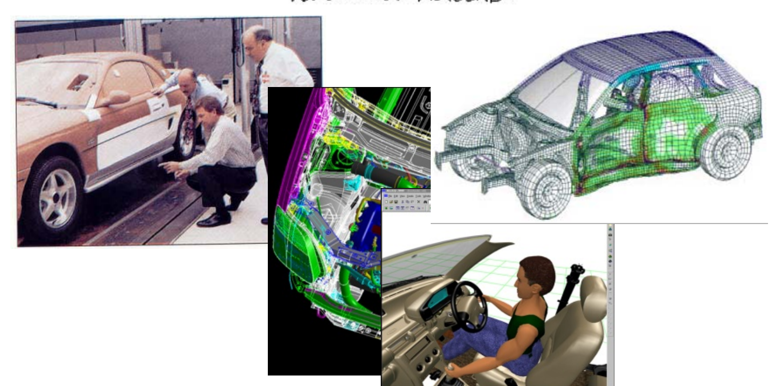
⇩

| Current paradigm is DESIGN BY "VIRTUAL" MODELS |
| --- |






"I HAVEN'T MUCH EXPERIENCE OF SUCH AN EARLY VERSION OF AUTOCAD"

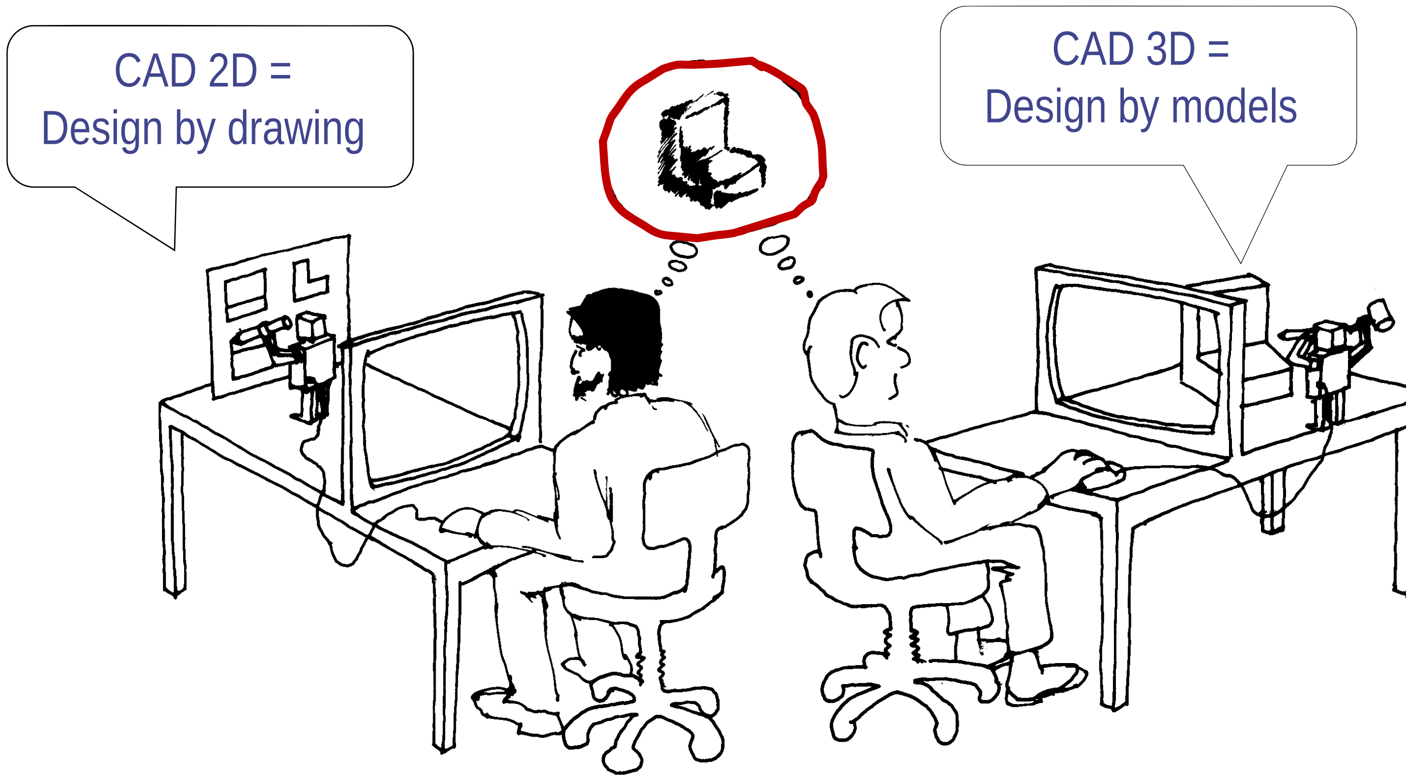


# Why not CAD?



But, neither CAD 2D nor CAD 3D is helpful for **conceptual** design...

...as both require a
**fully defined prior mental model**




The detailed geometry must be in their minds
before they start producing the drawing/model !

# Why not CAD?

The designer is asked to provide **actions** to be executed by the CAD application

well defined sequential tasks!


www.penwill.com

# Why not CAD?



The designer is asked to provide **actions** to be executed by the CAD application

well defined sequential tasks!


www.penwill.com

And this is not a good strategy while the designer is trying to fix **visions**

poorly-defined, non-sequential ideas!

The TOOL is conditioning the TASK!

# What else?



There is a lot of evidence that **engineering sketches** enhance creativity!

Ullman D., Wood S., Craig D. 1990, The Importance of Drawing in the Mechanical Design Process, Computers and Graphics 14(2):263-274

But
computers are **blind**
to engineering sketches!

New computer tools
are required!

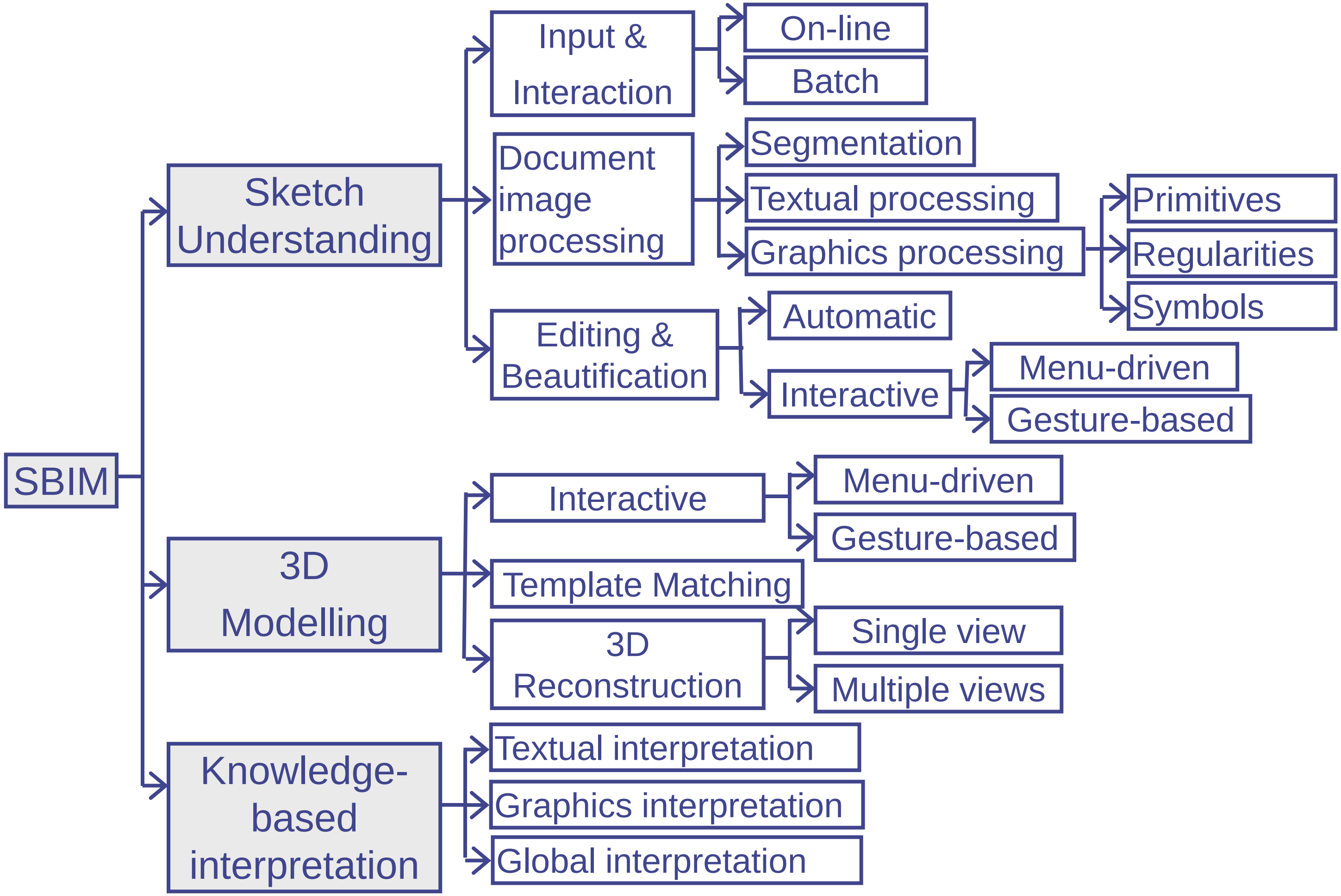
The scientific area aimed at solving this problem is known as:

**SBIM**

Sketch-Based Interfaces and Modelling

# SBIM

We consider SBIM to be divided into three main **spheres of work** and several different **sectors**:

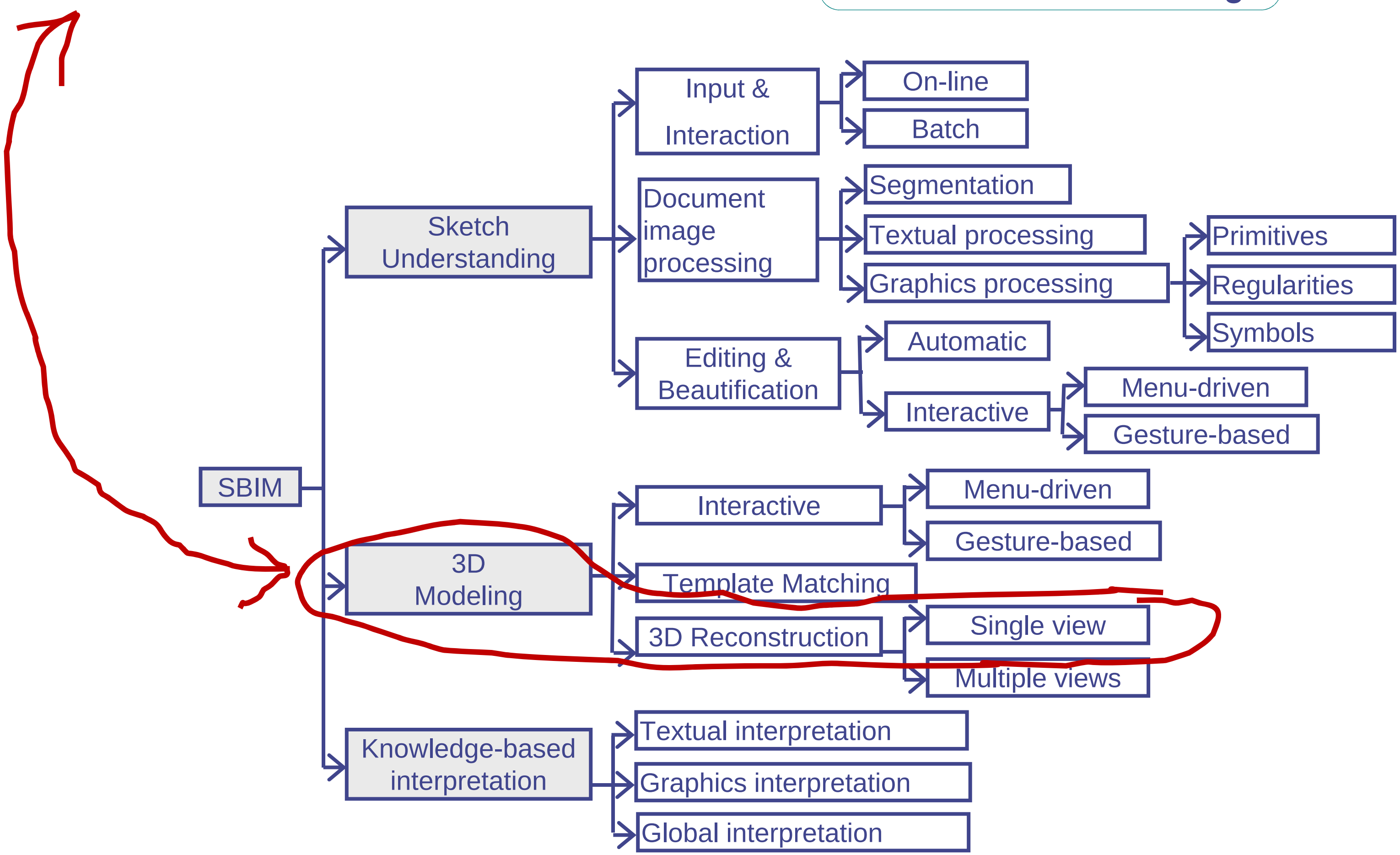



*(More details in Annex 1)*

We are currently interested in one particular sector:

Sketch Input of Engineering Solid Models

We name it as **Sketch-Based Modelling**

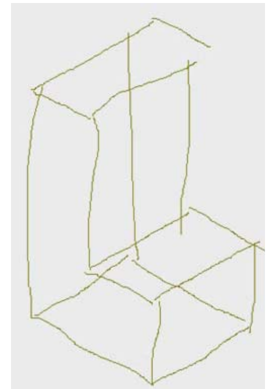


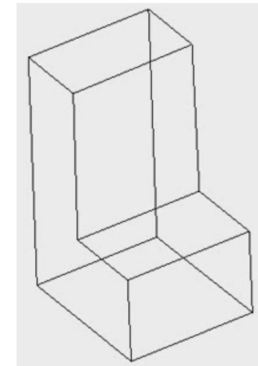
# SBM



SBM tools have been developed to some extent

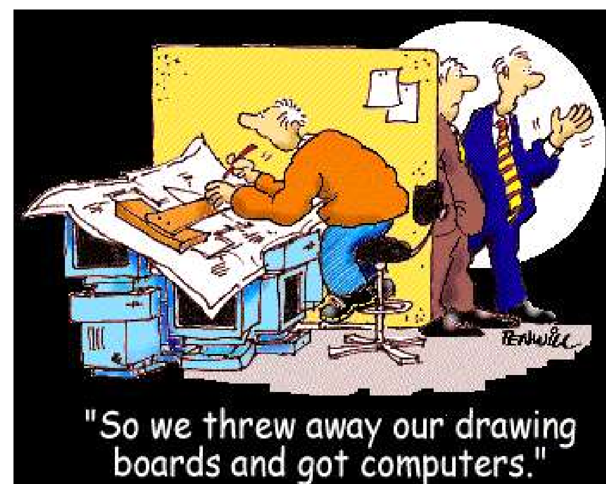
If I draw this … …my computer understands this





3D model obtained by REFER from the 2D sketch

But, DESIGNERS do not yet use Sketch-Based Modelling(SBM) tools !




www.penwill.com

# Background

What we now know as
**Sketch-Based Modelling**…

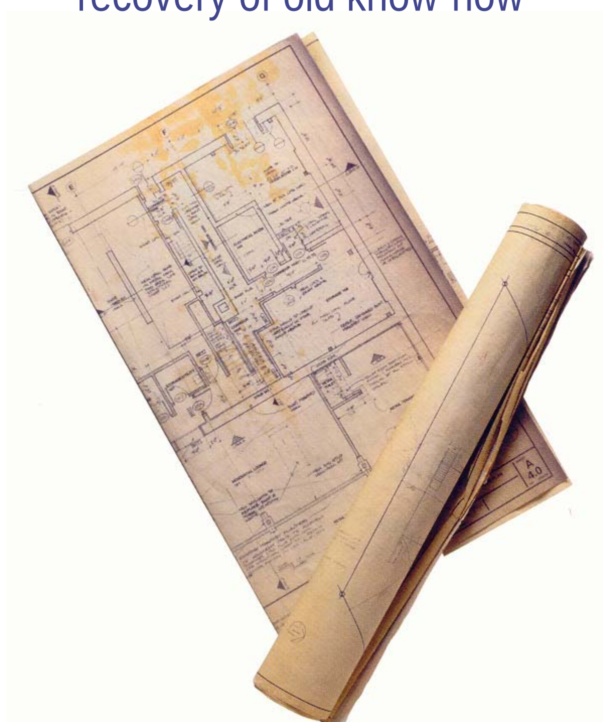
…comes from what was
formerly known as
**Geometrical Reconstruction**

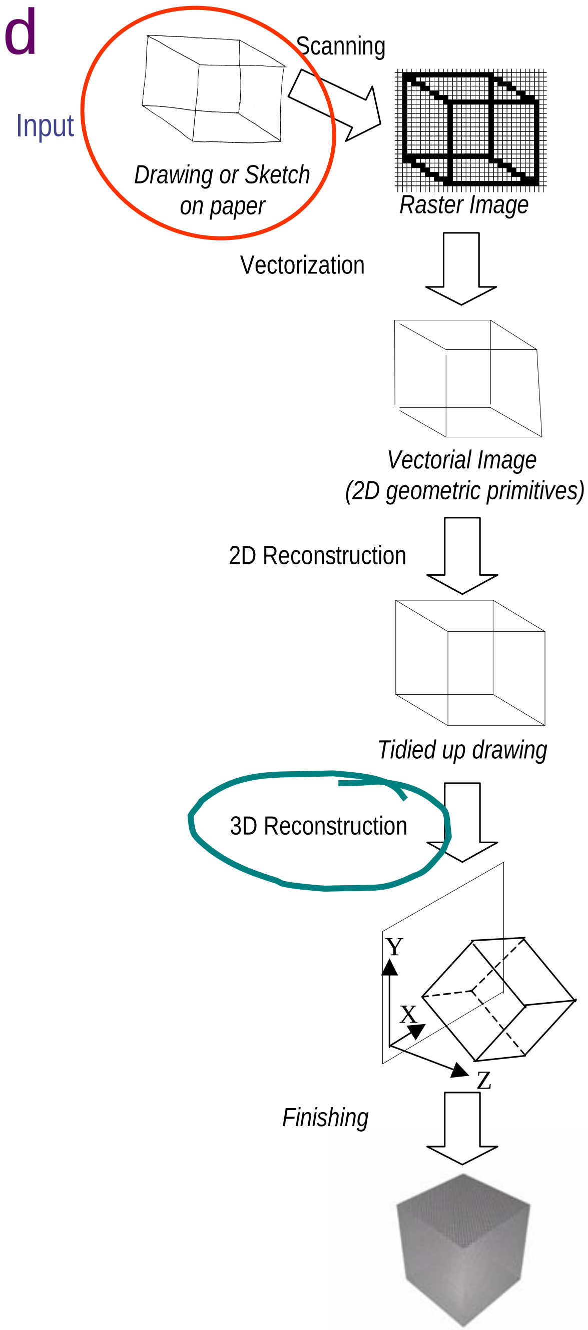
# Background



## The former goal of geometrical reconstruction was extracting information from old engineering blueprints

In other words, “archaeological” recovery of old know-how





# Background



But the task proved difficult…

...because the vectorisation stage is complex...


"SCANNING'S PRETTY FAST, BUT THEN CONVERTING EVERY LITTLE RASTER DOT INTO A VECTOR DOT TAKES FOREVER"

www.penwill.com

# Background

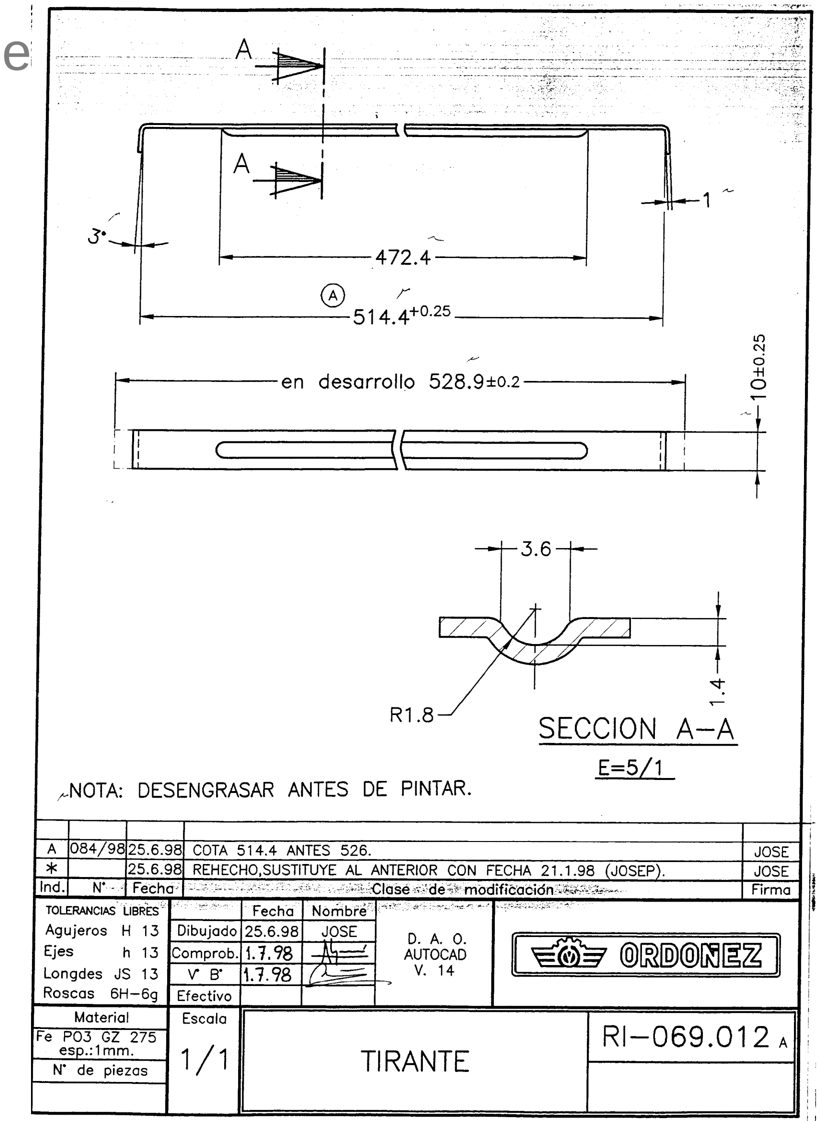
But the task proved difficult…

...because the vectorisation stage is complex...

…and because engineering drawings convey:

- ✗ 3D information represented through *complex* views
  - main orthographic views, particular views, cuts, etc.
- ✗ annotations
  - dimensions, tolerances, etc.

Dori D.; Tombre K. (1995) From engineering drawings to 3D CAD models: are we ready now? Computer-Aided Design 27, pp. 243-254



# Background



The short term problem
was solved trough brute force:


Translation services were offered!

Although this goal is still alive in architecture:

Xuetao Y., Wonka, P., Razdan, A. (2009) **Generating 3D Building Models from Architectural Drawings: A Survey** . IEEE Computer Graphics and Applications, 29 (1), 20-30

# Background

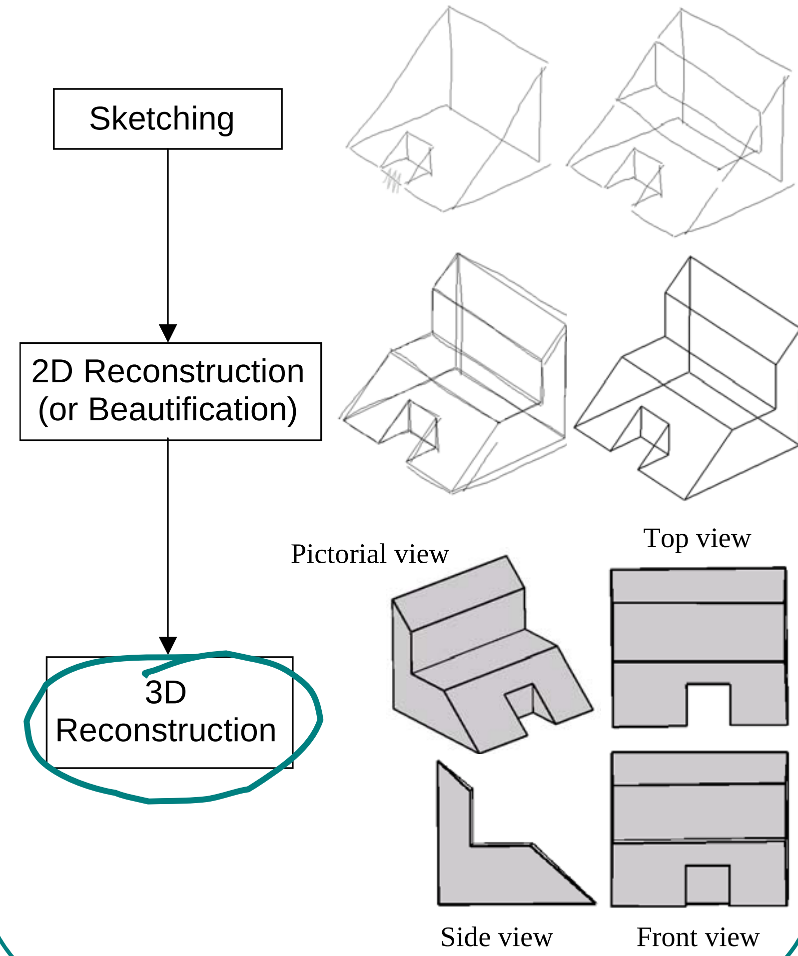


The main **goal** of the **reconstruction community** changed in the 1990s

Nowadays, most of the systems are oriented toward **conceptual design**

via **sketch-based modelling**

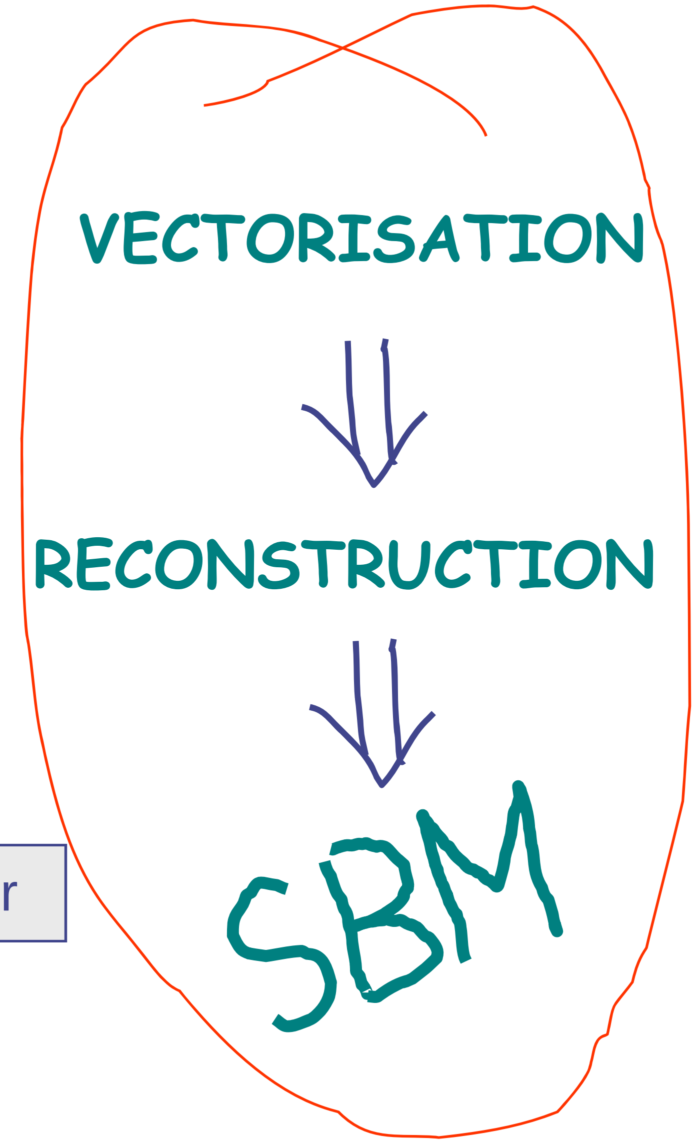
using sketches generated by the user as input data



# Background

The goal has changed over time:

- 2D + paper ⟹ 2D + computer
- 2D + paper ⟹ 3D + computer
- Conceptual design ⟹ 3D + computer



# Taxonomy



The current situation in **producing solid models from sketches** may be summarised as follows:

There is **no general approach** which solves all the SBM problems

*(More details in Annex 2)*

Some **critical features** produce different bottlenecks

**States of the art are different** for every critical feature

We propose a taxonomy of **critical features** !

# Taxonomy



The features we consider critical are:

1. Number of views
2. Types of surface
3. Variety of inputs
4. Design intent

(More details in Annex 3)

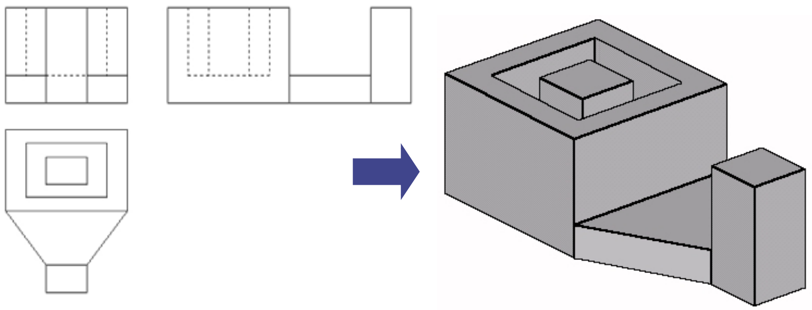
Company P., Piquer A., Contero M. and Naya F. (2005) A Survey on Geometrical Reconstruction as a Core Technology to Sketch-Based Modeling. Computers & Graphics. Vol. 29, No 6. pp. 892-904.

# Taxonomy

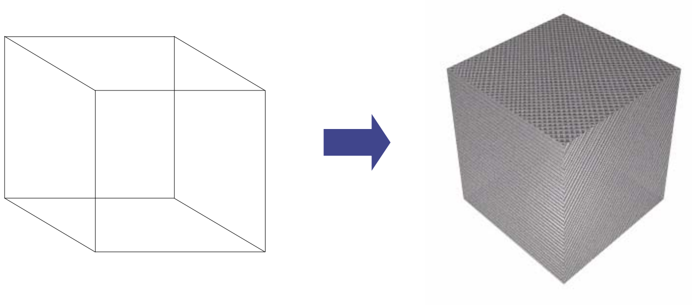


Two kinds of **VIEW** are distinguished for reconstruction approaches:

✓ multiple orthographic views



✓ single pictorial view



*(More details in Annex 4)*

# Taxonomy



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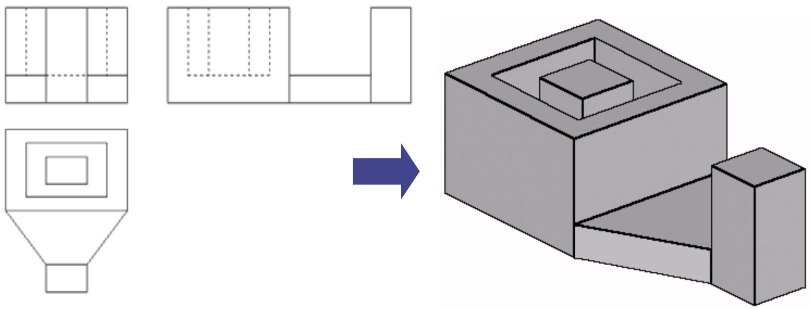
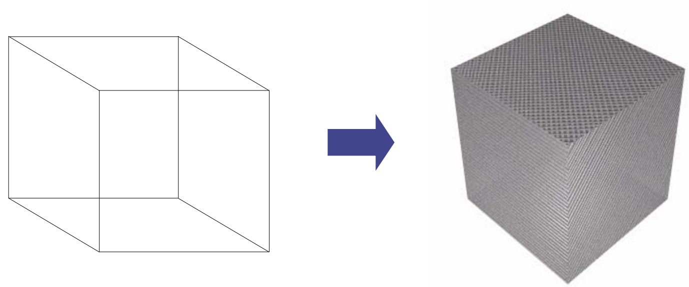


√ single pictorial view



More active in the beginning,
less active now

| Year | Authors |
|---|---|
| 1973 | Idesawa |
| 1976 | Lafue |
| 1981 | Wesley & Markowsky |
| 1982 | Haralick & Queeney |
| 1983 | Sakurai |
| | Aldefeld |
| 1984 | Preiss |
| | Aldefeld & Richter |
| 1986 | Gu et al |
| 1988 | Chen & Perng |
| 1989 | Gujar & Nagendra |
| 1992 | Chen et al |
| 1993 | Meeran & Pratt |
| 1994 | Yan et al |
| 1995 | Ah-Soon & Tombre |
| | Lysak et al |
| 1996 | You & Yang |
| 1997 | Masuda & Numao |
| | Shum et al |
| 1998 | Kuo |
| | Shin & Shin |
| | Tanaka et al |
| 1999 | Suh et al |
| | Sastry et al |
| 2001 | Liu et al. |
| | Shum et al. |
| 2002 | Geng et al. |
| 2003 | Soni & Gurumoorthy |
| 2004 | Zhang et al. |
| 2005 | Lee & Han |

*(More details in Annex 4)*

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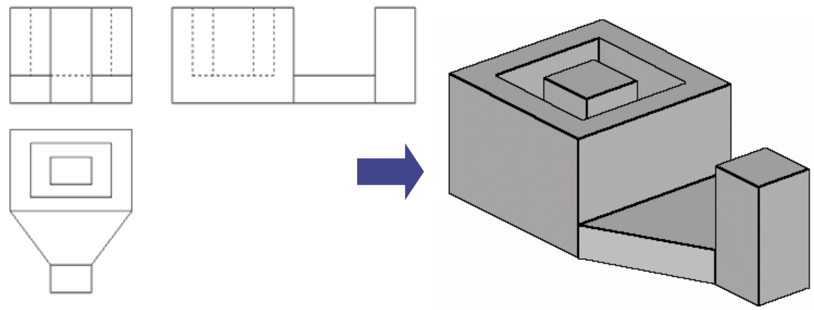
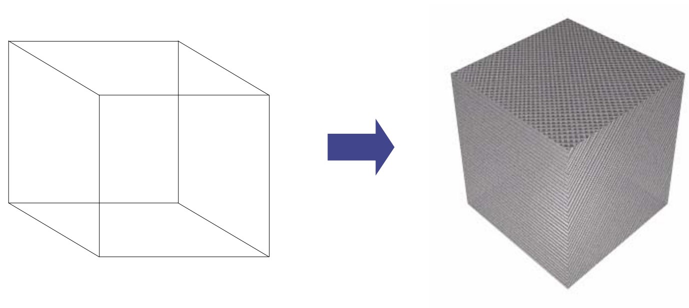


✓ single pictorial view



More active nowadays

| Year | Authors |
|---|---|
| 1963 | Roberts |
| 1968 | Guzman |
| 1971 | Huffman |
| | Clowes |
| 1973 | Mackworth |
| 1975 | Waltz |
| 1978 | Sugihara |
| 1980 | Kanade |
| 1982 | Sugihara |
| 1986 | Sugihara |
| 1987 | Malik |
| | Wei |
| 1989 | Wang and Grinstein |
| 1990 | Lamb and Bandopahay |
| 1991 | Marill |
| 1992 | Wang |
| | Leclerc and Fischler |
| 1993 | Wang and Grinstein |
| | Marti et al. |
| 1994 | Branco et al |
| | Shimshoni and Ponce |
| 1995 | Grimstead and Martin |
| 1996 | Grimstead and Martin |
| | Lipson and Shpitalni |
| | Parodi |
| | Brown and Wang |
| 1999 | Company et al |
| 2000 | Varley and Martin |
| 2001 | Varley and Martin |
| 2002 | Ros and Thomas |
| 2003 | Oh and Kim |
| | Varley et al |
| 2004 | Kang et al. |
| | Company et al |

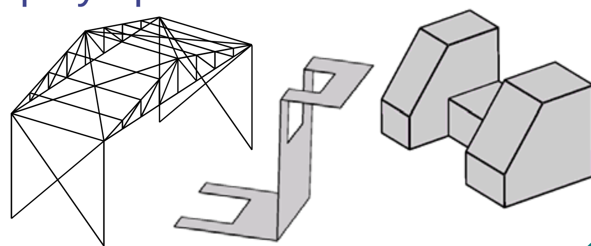
(More details in Annex 4)

# Taxonomy

Our classification distinguishes two kind of **SURFACE**:

- algorithms which only accept **flat** surfaces

They are generically known as polytopes



- algorithms which accept **curved** surfaces


*(More details in Annex 5)*

http://www-ui.is.s.u-tokyo.ac.jp/~takeo/teddy/teddy.html

Rivers, A., Durand, F., Igarashi, T. (2010) **3D modeling with silhouettes**. ACM Transactions on Graphics 29 (4), art. no. 109

Roth-Koch S. and Westkaemper E. (2010) **The implementation of a sketch-based virtual product development**. Prod. Eng. Res. Devel. 4:175–183

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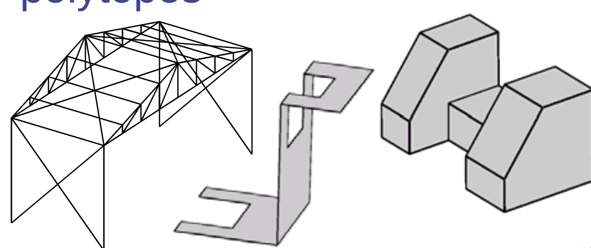

- √ algorithms which accept **curved** surfaces


*(More details in Annex 4)*

http://www-ui.is.s.u-tokyo.ac.jp/~takeo/teddy/teddy/teddy.html

Both have been studied, but planar surfaces are more developed

| Year | Authors | Surface: Planar | Surface: Curve |
|---|---|---|---|
| 1973 | Idesawa | * | |
| 1976 | Lafue | * | |
| 1981 | Wesley & Markowsky | * | |
| 1982 | Haralick & Queeney | * | |
| 1983 | Sakurai | * | * |
| | Aldefeld | * | * |
| 1984 | Preiss | * | * |
| | Aldefeld & Richter | * | * |
| 1986 | Gu et al | * | * |
| 1988 | Chen & Perng | * | |
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| 1997 | Masuda & Numao | * | * |
| | Shum et al | * | * |
| 1998 | Kuo | * | * |
| | Shin & Shin | * | * |
| | Tanaka et al | * | * |
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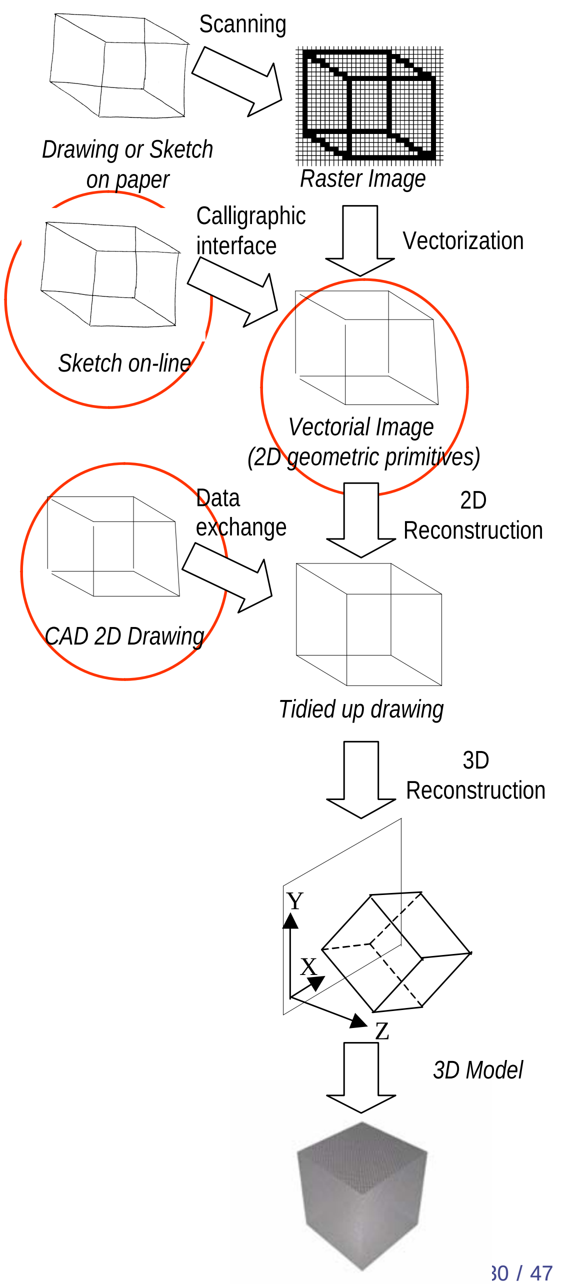
| | Sastry et al | * | |
| 2001 | Liu et al. | * | * |
| | Shum et al. | * | * |
| 2002 | Geng et al. | * | * |
| 2003 | Soni & Gurumoorthy | * | * |
| 2004 | Zhang et al. | * | * |
| 2005 | Lee & Han | * | * |

# Taxonomy



**INPUT** comprises:

1. perfect line drawings
2. line drawings containing some "geometrical" mistakes
3. freehand sketches



# Taxonomy

All three input types have been studied, but…

…perfect line-drawings were the most frequent in the beginning …

…now (in single view approaches) we are evolving towards hand-drawn line-drawings

| Year | Authors | Input: Perfect line-drawing | Input: Imperfect line-drawing | Input: Sketch |
|---|---|---|---|---|
| 1963 | Roberts | | * | |
| 1968 | Guzman | * | | |
| 1971 | Huffman | * | | |
| | Clowes | * | | |
| 1973 | Mackworth | * | | |
| 1975 | Waltz | | | |
| 1978 | Sugihara | * | | |
| 1980 | Kanade | * | | |
| 1982 | Sugihara | | * | |
| 1986 | Sugihara | | * | |
| 1987 | Malik | * | | |
| | Wei | | * | |
| 1989 | Wang and Grinstein | * | | |
| 1990 | Lamb and Bandopahay | | | * |
| 1991 | Marill | * | | |
| 1992 | Wang | | * | |
| | Leclerc and Fischler | * | | |
| 1993 | Wang and Grinstein | * | | |
| | Marti et al. | | * | |
| 1994 | Branco et al | | | * |
| | Shimshoni and Ponce | | * | |
| 1995 | Grimstead and Martin | | | * |
| 1996 | Grimstead and Martin | | | * |
| | Lipson and Shpitalni | | | * |
| | Parodi | * | | |
| | Brown and Wang | * | | |
| 1999 | Company et al | | * | |
| 2000 | Varley and Martin | | | * |
| 2001 | Varley and Martin | | | * |
| 2002 | Ros and Thomas | | * | |
| 2003 | Oh and Kim | | | * |
| | Varley et al | * | | |
| 2004 | Kang et al. | | | * |
| | Company et al | | | * |

# Taxonomy



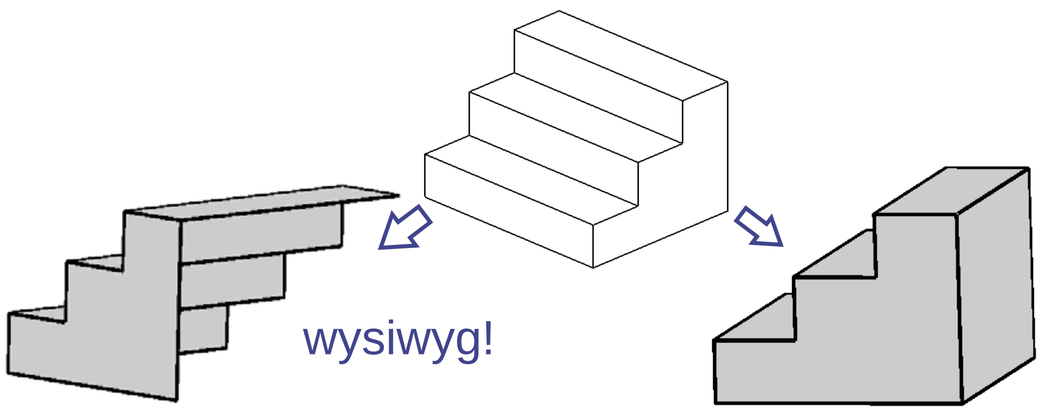
Use of **HIDDEN LINES** in the input drawing results in two different inputs:

**wireframes (transparent models)**

methods where the input includes all lines in the drawings

**natural (opaque models)**

methods which reconstruct from an input which only contains the visible edges




All lines must be drawn in the input, but generally there is no need to distinguish between visible and hidden lines

The system generally infers the rear part of the model after reconstructing the front part

# Taxonomy



## Natural drawings have been less studied than wireframes

The need to infer the rear of the object makes the reconstruction process more difficult

| Year | Authors | 2D hidden lines: Yes | 2D hidden lines: No |
|---|---|---|---|
| 1963 | Roberts | | * |
| 1968 | Guzman | | * |
| 1971 | Huffman | | * |
| | Clowes | | * |
| 1973 | Mackworth | | * |
| 1975 | Waltz | | |
| 1978 | Sugihara | * | |
| 1980 | Kanade | | * |
| 1982 | Sugihara | | * |
| 1986 | Sugihara | | * |
| 1987 | Malik | | * |
| | Wei | | * |
| 1989 | Wang and Grinstein | | * |
| 1990 | Lamb and Bandopahay | | * |
| 1991 | Marill | * | |
| 1992 | Wang | | * |
| | Leclerc and Fischler | * | |
| 1993 | Wang and Grinstein | | * |
| | Marti et al. | * | |
| 1994 | Branco et al | | * |
| | Shimshoni and Ponce | | * |
| 1995 | Grimstead and Martin | | * |
| 1996 | Grimstead and Martin | | * |
| | Lipson and Shpitalni | * | |
| | Parodi | | * |
| | Brown and Wang | | * |
| 1999 | Company et al | * | |
| 2000 | Varley and Martin | | * |
| 2001 | Varley and Martin | | * |
| 2002 | Ros and Thomas | | * |
| 2003 | Oh and Kim | * | |
| | Varley et al | | * |
| 2004 | Kang et al. | * | |
| | Company et al | * | |

# Taxonomy



**Design Intent** and CAD have been linked for many time

However, the definition of Design Intent is ambiguous

Back in 1989 Design Intent was associated with design constraints and the methods of manipulating design constraints during product design activities

Kimura F. And Suzuki H. (1989) **A CAD System for Efficient Product Design Based on Design Intent.** CIRP Annals - Manufacturing Technology , 38 (1), 149-152.

...it still continues to be for many people !

# Taxonomy



When CAD people use the word “design”, they usually mean “model”

http://www.dezignstuff.com/blog/?p=3612

Modelling is just representing the design in some way

Design intent equates to the phrase Design for Change

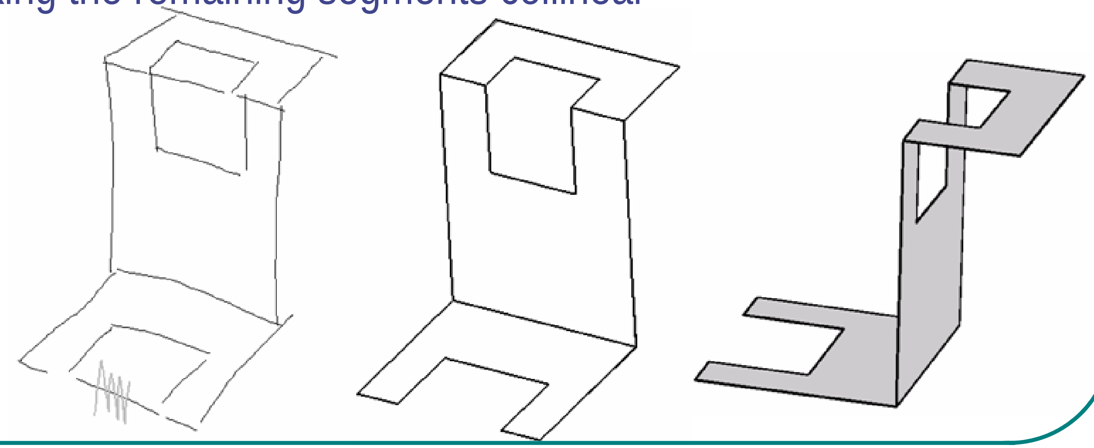
This implies that you are modelling a concept that can be flexible through changes

# Taxonomy



Something has been done in the SBM sector to cope with design intent understood as design-for-change

Sketching one single line and then removing the central segment implicitly conveys the design intent of making the remaining segments collinear



However, no practical approaches have yet considered the **explicit capture** of complex design intent from the input sketches!

# Taxonomy



We understand design intent as a mix of:

- ✓ Geometry ...as far as it is linked to the shape
- ✓ Psychology ...as far as it is not always explicit in the sketches
- ✓ Engineering ...as far as it is linked to the function

# Taxonomy



We understand design intent as a mix of:

- ✓ Geometry
- ✓ Psychology
- ✓ Engineering

When geometry dominates, design intent is mainly conveyed through geometrical features

which have already been studied as "**regularities**"


Lipson H, Shpitalni M. (1996) **Optimization-based reconstruction of a 3D object from a single freehand line drawing.** Computer-Aided Design , 28(8) 651-663

Yuan S., Tsui L.Y., Jie S. (2008). **Regularity selection for effective 3D objects reconstruction from a single line drawing.** Pattern Recognition Letters 29 (10), 1486-1495

Li M, Langbein F.C. and Martin R.R.(2010) **Detecting design intent in approximate CAD models using symmetry.** Computer-Aided Design 42 (3) 183-201

# Taxonomy

Introduction
Background
Taxonomy
Views
Surfaces
Inputs
Design intent
Summary/Next

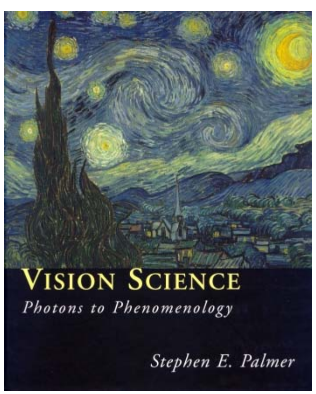
We understand design intent as a mix of:

- ✓ Geometry
- ✓ Psychology
- ✓ Engineering

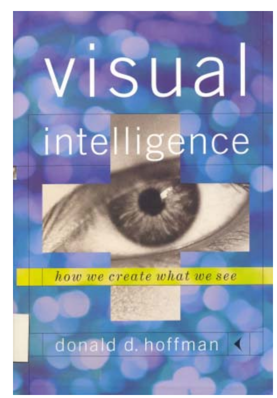
Information not explicitly included is perceived through "**perceptual cues**"

sometimes clues

Fundamentals of perceptual cues have been studied:




Palmer SE. Vision Science. Photons to Phenomenology. Cambridge, MA: The MIT Press, 1999




Hoffmann D. Visual Intelligence. How we create what we see. New York: WW Norton & Company, 2000

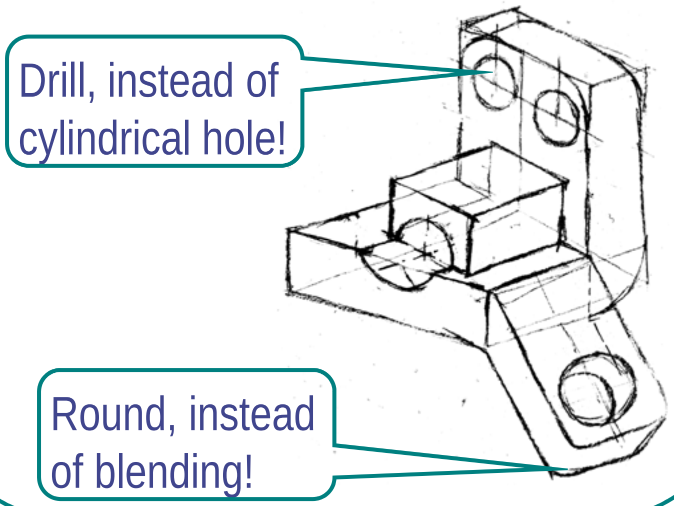
# Taxonomy



We understand design intent as a mix of:

- ✓ Geometry
- ✓ Psychology
- ✓ Engineering

When function dominates, design intent is mainly conveyed through "**engineering features**"



# Taxonomy



Consequently, we can define **Design Intent** as:

**The set of intentions**
in sketches
conveyed though **cues**,
which, when perceived,
reveal **regularities** or **features**
of the object

Just a few of them have already been studied

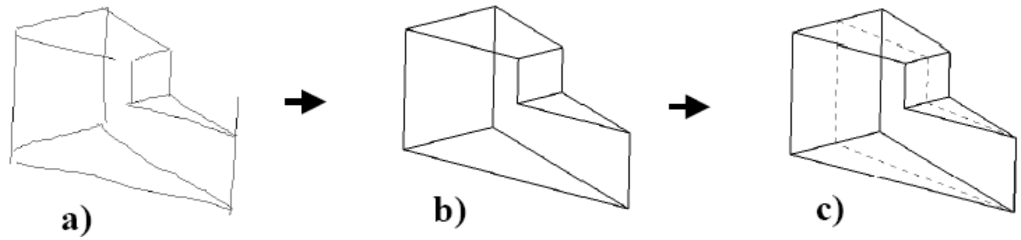
- √ Edge parallelism
- √ Face planarity
- √ ...

# Taxonomy

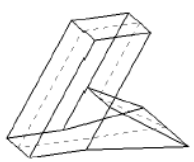
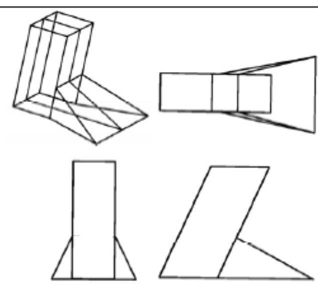
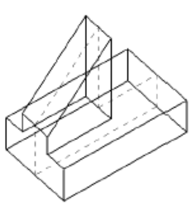
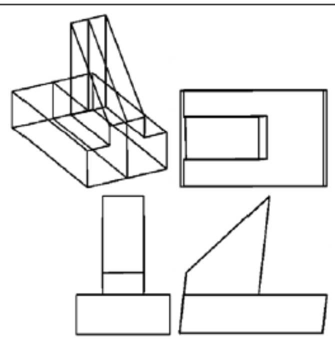


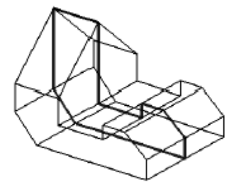
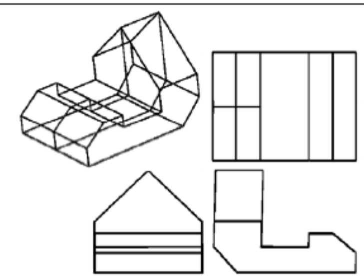
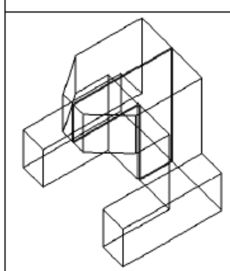
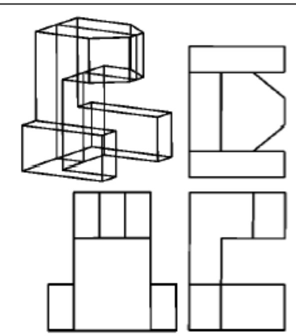
## Example:

Early detection of symmetry in a 2D line-drawing



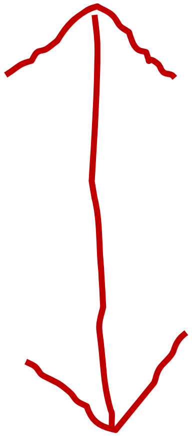

and improvement of the reconstruction process by making use of symmetry

| Line drawing | 3D model | Process |
|---|---|---|
|  19 edges<br>12 vertices |  | 9 faces<br>1 plane of symmetry<br>Inflation time: less than 1” |
|  24 edges<br>16 vertices |  | 10 faces<br>1 plane of symmetry<br>Inflation time: less than 1” |

| Line drawing | 3D model | Process |
|---|---|---|
|  33 edges<br>22 vertices |  | 13 faces<br>1 plane of symmetry<br>Inflation time 1” |
|  46 edges<br>30 vertices |  | 18 faces<br>1 plane of symmetry<br>Inflation time 2” |

# Summary

WIMP user interfaces
are not appropriate for
conceptual design stages



But SBM tools
are not yet used

www.penwill.com

# Summary



→ SBM tools look suitable, but need improvement

→ Roughly speaking, there are two categories of problem:

- ✓ Problems where a reasonably good solution exists
  - ...although some improvements are still required
- ✗ Open problems

→ Our taxonomy helps in finding critical features which must be studied further:

1. Number of views
2. Types of surface
3. Variety of inputs
4. Design intent

# Next presentations



In the **second** presentation we shall describe the **main stages** in an SBM process

We shall describe in detail the most important **algorithms** for required by an SBM process when the inputs are **wireframe drawings**:

1 Finding faces for polyhedral shapes

2 Inflating polyhedral shapes

3 Rounds and fillets

Starts ** time **

# Next presentations



In the **third** presentation we shall describe some **algorithms** required by an SBM process where the inputs are **natural drawings**:

1. Fleshing out frontal geometry
2. Deducing the back of the object

# Next presentations



In the **fourth** presentation we shall briefly introduce some **long term open problems** in the sector of SBM tools:

1. Making virtual paper and pencil more usable than actual paper and pencil
2. Interpreting annotated engineering sketches
3. Creating assemblies from sketches