12 SHAPE LANGUAGE — HOW PEOPLE DESCRIBE SHAPES AND SHAPE OPERATIONS

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Many designers do not use CAD tools for shape ideation. They consider CAD systems not appropriate for the ideation phase. This research investigates how designers ideate shape, in particular which terms they use to exteriorize shape. The goal is to be able to propose digital tools that are useful for shape ideation. For the inventory of shape terms, an experiment was set up for two subjects. Both subjects receive a picture of a shape. Subject A receives also a picture of a derived shape. A explains the derived shape to B, who sketches it. The used shape terms are inventoried and categorized. The experiment was performed with two different groups of subjects. The research method is described in detail, the frequencies of the observed terms are presented and the differences between the groups are shown. The results are discussed and implications for digital shape ideation systems are mentioned.

Keywords: Shape ideation, Conceptual design, CAD, Language.

1. INTRODUCTION

In the ideation phase of design, the way a designer works differs from the later phases. This is not reflected in most CAD systems. In spite of many improvements in CAD systems over the last decades, many designers still prefer traditional ideation tools. For ideation, free hand sketching is considered much more appropriate than CAD.[1] The role of sketching has been studied by many researchers.[2–4] Requirements and prescriptions for conceptual design systems are listed[5] and systems are built that provide tools digital sketching and other tools for conceptual design.[6] Tools can help a designer to exteriorize ideas and reflect on them. Uttering ideas helps to think them over, and seeing back one's exteriorizations stimulates the visual perception. Both the externalization of ideas and the perception of the externalizations help to explore new possibilities.[7,8] They support the reflection in action, which Schon describes as essential for the design process.[9,10] A design can be made without tools, fully by imagination;[11,12] however, this is no common practice.

Ideas can be exteriorized by sketching, but physical modeling can also play an important role.[13] Simple, graspable prototypes can provide useful feedback.[14,15] In addition, verbal expressions play a role that is easily underestimated.[16,17]

We want to know in detail how an ideating designer works, in particular how he thinks about shape aspects and modification of shape. Because much research is done on sketching and not much on the verbal expression of shape, our research will focus on designers' verbal utterances. The goal of this research is to investigate in which shape aspects a designer thinks when he generates a shape. To discover a designer's mental image we only have the designers own exteriorization as a source. Brain studies can be done, however they show which parts of the brain are active, not the mental image.

2. METHOD

2.1. Bias and Feedback

Since exteriorization is a process that can be influenced in many ways, we should be aware of all kinds of possible errors and bias. The following errors can be thought of:

- The speaker's image of the shape is not clear, or inconsistent, or it changes.
- The speaker's exteriorized image deviates from his mental image (e.g. when the speaker is distracted by the environment or by parallel thoughts.)
- The speaker uses wrong words or grammar to articulate the shape.
- The speaker's utterances are incomplete or ambiguous and are misinterpreted.
- Inconsistencies in the speaker's description (e.g. the round edge of the triangle).
- Over specification, e.g. if the speaker releases a constraint, but does not communicate that. If the listener understands a constraint is dropped, he may choose the wrong one.
- The listener overhears a part of the utterances, or does not understand them.
- Wrong assignment of meaning caused by a difference in the frame of reference
- The listener makes drawing errors (e.g. lines that should meet in one point do not).

The above errors should be prevented if possible. However, there is a danger of over constraining the communication. For example, if ambiguity is not allowed, this affects the ideation process. Although ambiguity is not desired in many cases, in the process of ideation it is essential. Many ideas emerge from the possibility to re-interpret ambiguous representations. What should be prevented is misinterpretation, not ambiguity. Feedback is a means to correct misinterpretations while still allowing ambiguity. More generally, feedback can correct many errors without a priori constraining the input. All above mentioned errors can be brought to light by proper feedback. However, feedback does not mention the cause of the errors. If the speaker discovers from the sketch that it does not represent his mental image, the speaker and the listener together should find out what should be changed.

If feedback is used to decrease the number of errors, multiple subjects are required. Subject *A* should exteriorize his mental image; subject *B* should interpret the exteriorization and make a representation of the uttered shape. Because *B* has to make a presentation, it will be natural for *A* to exteriorize his shape image. This is an advantage compared to thinking aloud individuals, for whom staying aware of the need to express thoughts interferes with the assignment. If subjects freely design shapes, their results will be too different to be compared. To prevent this, we let them generate one known shape from another one.

2.2. Set up of the Experiment

Two subjects, *A* and *B*, take part in the experiment. *A* receives a booklet with ten pages. Each page contains two pictures of a shape, see Figure 1. The second shape is derived form the first one, or can be considered so. *B* receives a booklet with only the first shapes. *A* has to explain how the second shape can be made from the first one and *B* has to sketch the second shape based on *A*'s utterances and the picture of the first shape. *A* can use normal language, without restrictions. *A* can see the sketch and comment on it if necessary. *B* is allowed to ask questions if something is not clear. An experimenter checks if the sketch is sufficient. If not, he asks the subjects to improve the sketch. If subjects go on adding irrelevant details, the experimenter asks them to start with the next shape, until all shapes are sketched. Halfway the experiment the subjects change position. This is to prevent fatigue and to spread the different tasks over more subjects.

The experiment is performed 14 times, each time with a different pair of subjects. The subjects were first year bachelor students of design courses. Seven subject pairs were students of IPO (Industrial Product Development) of the Haagse Hogeschool and seven subject pairs were from IDE (Industrial Design Engineering) of the Delft University of Technology. All speech is recorded. After the experiment, the

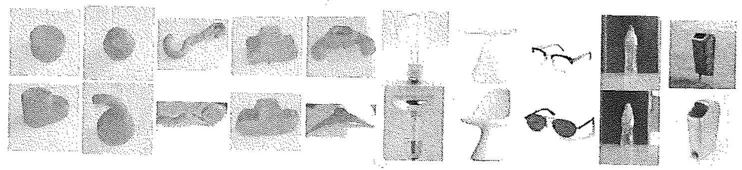

Figure 1. The ten shapes used for the experiment and the ten derived shapes below them.

Table 1. Shape term categories.

Category	Definition
Shape_instantiations	Terms to invoke an image of a complete shape (cube, car)
Shape_characteristics	Terms to express an individual shape aspect (spherical, hole)
Shape_operations	terms to express a shape modification (bend, cut)
Locations	terms to denote a particular location (top, front)
Dimensions	terms to specify a dimension (length, height)
Values	terms to indicate an amount (two, a bit)
Comparisons	references to other shapes or values (just as, more than)
Courses	terms to let a pencil move over paper (to the left, further, stop)
Confirmations	terms to tell the generated shape aspect is correct (yes, ok)
Negations	terms to tell that something must be changed (no, however)
Identifications	terms to identify a particular object or part (this, it)

recordings are written down and transcribed into shape terms. These terms are categorized and the term frequencies in each category are determined.

2.3. Categorization

Eleven term categories are distinguished, according to Ref. 18 see Table 1. Some categories can again be subdivided. For a better overview, subdivision will be postponed to the discussions of the details. *Shape_instantiations* can refer to geometry (*cube, sphere*), to a physical thing (*table, car*), or to an object with a similar shape (e.g. *pear* for a lamp bulb). The sub category names are *Geometrical_shape_instantiations, Thing_shape_instant-iations* and *Metaphor_shape_instantiations.*

Shape_characteristics may be expressed geometrically (*cylindrical*) or in more popular terms (*round*). Additionally, emotional utterances can be used that tell something about a shape characteristic (*dumb, modern*). Therefore, three sub categories can be distinguished: *Geometrical_shape_characteristics, Popular_shape_characteristics* and *Emotional_shape_characteristics.*

Shape_operations can be *Geometrical_shape_operations*, like *rotate* or *scale*, or *Boolean_shape_operations* (*add, subtract*). The remaining shape operations are called *Handicraft_shape_operations*, because most of them reflect an operation that can be done by hand, like *cut* and *press*.

Values can be crisp or fuzzy values. As crisp values we distinguish *Absolute_values* (*one, two*, etc.) and *Relative_values* (e.g. *twice as*). *Fuzzy_values* (like *a bit* and *more*) are no further divided, because it can often be argued whether they are absolute or relative.

To support proper assignment of terms to categories, the assignment procedure should be well described. The description should be able to tackle a number of problems, e.g.:

- Words may have multiple meanings
- Multiple words may denote the same
- People tend to repeat utterances, without supplying new information.
- Many utterances are not correct sentences
- One subject uses more words for the same shape aspect as another subject.

2.3.1. Words with Multiple Meanings

If a word occurs that has multiple meanings, the proper meaning will be derived from its context. The word may be replaced by a different synonym for each separate meaning. In this way, ambiguity is removed. This will be an advantage for the down stream analysis. Often, the same term that introduced a new shape is re-used as a reference, e.g. in the fragment "with two cones, but those cones are pretty long". The first occurrence of *cones* is a *Shape_instantiation*, the second one an *Identity*. Proper distinction may be difficult if the terms are far away from each other, or if a *Shape_instantiation* is implicit, e.g. when a subject mentions a characteristic of a shape, without first introducing that shape.

2.3.2. Multiple Words with the Same Meaning

If the same shape aspect is mentioned with different words, frequency analysis of terms may show misleading values. To prevent this, multiple words with the same meaning will be translated to one single term that characterizes the intended shape aspect.

2.3.3. Repeated Utterances

From earlier experiments it is known that people tend to go on speaking until the subject who has to represent the uttered shape has finished with the last utterance. The continuing speech contains many repetitions. To prevent misleading frequency numbers, mere repetitions are ignored. However, this should be carefully judged. Some repetitions aim to repeat a particular shape aspect. For example, a subject may describe a line as follows: "Start from the bottom and go up, further, further, further, stop." In this example, the word "further" can be considered functional all three times. A counter example is "and then round all edges, now round all edges". The second part of this sentence is a mere repetition, not a new instruction. It will not be included in the list of shape terms.

2.3.4. Incorrect Sentences

When transcribing speech of subjects, many fragments appear to be incomplete or incorrect sentences. Some sentences are not according to the rules of grammar and spelling, but can still be understood. We focus on shape terms and we neglect many words that are no relevant for the uttering of shape. Therefore, the mere fact that a sentence is not according to the rules is not a problem for our research, provided that the sentence can be understood. Other incomplete sentences, however, cannot be understood. Incomplete sentences occur rather frequently, e.g. "and then you must make this..." The sentence does not tell whether the current shape should be wider, or smaller, or whatsoever. Therefore, the meaningless part of this sentence will be neglected. In some cases this may be loss of data. It is possible that the listener could derive its meaning from its context, e.g. from a gesture or something else that can be heard from the recordings. In many other cases, however, the incomplete sentence just did not contribute to the communication of shape.

2.3.5. Different Amounts of Words for Describing the Same

Some subjects only mention a few words, and, amazingly in some cases, the other subject sketches exactly what was meant. Other subjects use ample descriptions for the same shape. We have to take this as it is. In some cases, this effect is decreased because only shape relevant words are transcribed. However, if one subject uses more shape related terms than another one, we just transcribe them.

2.3.6. Transcription

The transcription procedure contains the following steps:

- Writing down the spoken words
- Selecting the relevant words
- Translating the selected words into shape terms
- Lining up synonyms
- Assigning the terms to categories

- Calculating term frequencies
- Analyzing the data

2.3.7. Writing down the Spoken Words

The audio recordings are listened and all words are written down. Unclear fragments are listened again until it could be deciphered what was said. This procedure worked well for the majority of the utterances. A few fragments remained unclear. Some words could be determined from the context. The remaining words were neglected.

2.3.8. Selecting the Relevant Words

Words that indicate a shape aspect, directly or indirectly, are selected; other words are skipped; see Table 2. Care should be taken, because words that are irrelevant in most cases can be relevant in a particular context. This applies e.g. to the following words:

- *become, should, must*
- *of, such, with, at, another, again, that, it* and *come*

2.3.9. Translating the Selected Words into Shape Terms

Proper translation of words into shape terms requires both translation rules and a kind of dictionary. The rules are necessary to ensure that translation of all fragments is done in the same way and that similar shape descriptions are translated into the same shape terms. For this reason, all conjugations of verbs will be transcribed by their infinitive. With a term, in this paper, we denote an indication of a single shape aspect. A term is not necessarily the translation of a single word. Without its context, the meaning of a word may get lost. Table 3 shows the word *left* in four different contexts. In the three first cases, *left* is not transcribed individually, but in combination with the words that are necessary to indicate a single shape aspect. The examples in the table also demonstrate the neglecting of articles, the transcription of verb conjugations into their infinitive, and the lining up of synonyms, which will be explained below.

Table 2. Relevant word types.

Direct shape indicators	example	Indirect shape indicators	example	No shape indicators	example
Shape instantiations	circle	Values	more	Articles	a, the
Shape characteristics	straight	Comparisons	just as	Conjunctions	and, or, so, also
Shape operations	bend	Identifications	this	To be	It is...
Locations	on top	Confirmations	yes	To have	Here you have...
Courses	upward	Negations	however	Stopgaps	say, you know
Dimensions	wide			Fillers	even, really, just
				Introductions	What you see is...
				Uncertainties	I think..., may be
				Doubles	"No, not."

Table 3. Meaning of the word left in different contexts.

Context of the word	What the word denotes	Transcription of the word
as seen from the left	a viewpoint	seen_from_left
at the left end	a location	at_left
then go to the left	a direction	to_left
only the right half is left	a removal	remain

Table 4. Average number of terms used for one shape description.

Locations	6	Shape instantiations	4	Confirmations	2
Courses	5	Comparisons	4	Dimensions	2
Shape characteristics	5	Negations	3	Shape operations	1
Values	4	Identifications	3	Total	39

2.3.10. Lining up Synonyms

Synonyms that denote the same shape aspect will be transcribed into the same term. Each term should be unambiguous; the same term should not be used for multiple shape aspects. This requires that the shape terms are carefully chosen. To assure that the same words are translated to the same terms in all cases, a kind of dictionary was assembled.

2.3.11. Assigning the Terms to Categories

Next, the terms will be assigned to the categories mentioned in Section 2.3.

2.3.12. Calculating term Frequencies

When all terms are assigned to categories, frequencies will be counted. The frequency of terms in each category will be determined for IPO subjects, for IDE subjects and for all subjects. In addition, frequencies of individual terms will be determined

2.3.13. Analyzing the Data of Different Groups

The frequencies of all categories will be compared to see which categories are addressed most often. Additionally, frequencies of IPO subjects in each category will be compared to frequencies of IDE subjects in the same category, to see if both groups differ in the way they exteriorize shape.

3. RESULTS

The subjects' utterances contained 13.526 words and were transcribed into 5430 shape relevant terms, 2375 from IPO subjects and 3055 from IDE subjects. On average, 39 terms were used to describe a shape. Table 4 shows the average numbers per category.

Figure 2 shows the division of terms over the categories as percentages of the total number of terms. The most frequently addressed category is *Locations*. It contains 15% of all counted terms. More than 50% of these locations are terms that denote terms above, under, side or in. This includes terms that have similar meanings, e.g. top and over, lower and beneath, between and inside. Other categories that contain more than 10% of the terms are *Courses, Shape_characteristics, Values and Shape_instantiations*. The category *Courses* consists for 46% of terms that denote a direction, like *to_the_right, upward*, and *horizontal*; 28% are terms like *next, then* and *after_that*; and 26% are terms like *go, run* and *continue*. *Shape_characteristics* are nearly all *Popular* ones (11% vs. 0.5% *Emotional* and 0.3% *Geometrical*). About a quarter of them consists of the terms *straight, round,* and *shape*. *Values* are mainly expressed as *Fuzzy_values* (8.3% versus 2.1% for *Absolute_values* and 1.2% for *Relative_values*). *Fuzzy_values* consist for 40% of terms like *a_bit* and *some*, and for 12% of *sort_of*. *Negations* occur more often than *Confirmations* (8.6% vs. 5.2%). The three types of *Shape_instantiations* occur about equally often: about 4.0 % each. *Shape_operations* were mostly *Handicraft_operations*.

Figure 3 shows that there is a remarkable similarity in the use of terms by IPO subjects and IDE subjects. Differences occur in particular in the categories *Courses* and *Confirmations*. IDE subjects used 5.1% more *Courses*. They used the term *next* even 108 times! IDE subjects used 2.8% more *Confirmations*, while IPO subjects used 1.2% more *Negations*. They also used 1.9% more *Identifications*, 1.7% more *Shape_characteristics*, 1.5% more *Shape instantiations*, and 1.3% more *Dimensions*. In the remaining categories, no differences are larger than 1%. However, within the categories some differences occur. In the category *Fuzzy value*, IDE subjects used more often the terms *sort of, less* and

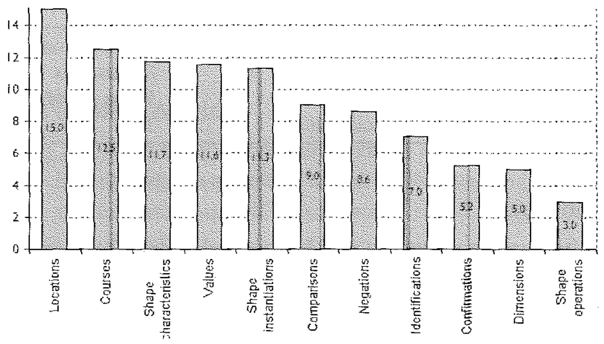

Figure 2. Division of terms over the categories (in % of the total number of terms).

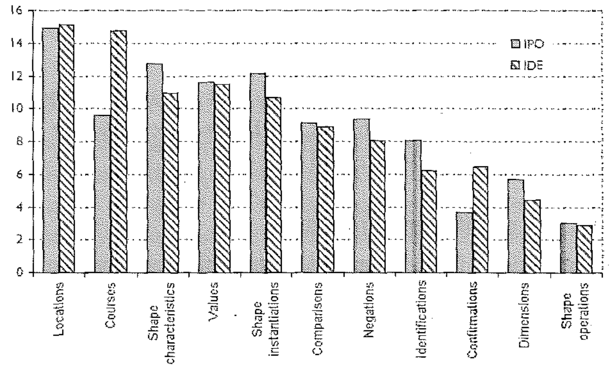

Figure 3. Division of terms over the different categories for both IPO subjects and IDE subjects (in % of the total number of terms used) .

about. In the category *Negation* IPO subjects used more frequently *not*, IDE subjects *no* and *however*. The latter shows a difference in approach: first an object is mentioned that globally has a similar shape, then the differences are expressed. In the category *Location*, IDE subjects used 24 times *there*, versus IPO subjects 7 times. As *Comparisons*, *like this* was used more often by IDE subjects. IPO subjects made relatively more use of the comparison term *just as*. IDE subjects used the term *line* twice as much as IPO subjects. As *Identity* terms, IDE subjects preferred *thing*, IPO subjects *that*. In the category *Handicraft operations,* IPO subjects mention more often the term *press*.

The number of terms used per subject ranged from 172...723. On average, IDE subjects used more terms. However, an IPO subject applied the most terms.

Individual subjects differed in the way they expressed the same shapes. We studied the deviations and analyzed the most outstanding ones. Eight cases were identified. In all of them, a subject used much more terms of a particular category than the other subjects did. Subject duo 3 appears three times in the list, and shape 10, the spectacles, also shows up three times. The other subjects were nrs. 2, 4, 11, 12 and 13, and the other shapes were nrs. 1, 4, 6 and 8. The deviations were in the categories *Thing_shape_instantiation* (2 times), *Identity* (2 times), *Popular_shape_characteristic*, *Course*, *Dimension* and *Handicraft_shape_operation*. In four of the cases, a shape aspect expressed by *A* was not well understood by *B*. Two cases contained many course descriptions in which *A* explained *B* the course the pen had to follow to generate the right curves. Three of the cases contained many details, small corrections and descriptions that were partly repetitions of earlier expressions. We conclude that a high number of terms in one particular category is an indicator of a problem in the shape communication.

From the above results can be derived that the below functions will be useful for a digital shape ideation system:

- Identification of locations. A location can be indicated by clicking a point on a surface. The system remembers the locations for use in a following operation.
- Sketching without defining a new plane, with the screen as a transparent sheet of paper. The sheet can be stuck to a surface, before, during or after the sketching. The result can be seen on the object, through the transparent sheet.
- Popular shape characteristics are known by the system, as well as how they can be applied and to which shape parts. Smart default values should prevent interference with other shape aspects.
- Shape instantiations of real world objects, such as table, leg, bulb and bin. Different levels of knowledge can be possible, varying from just a simple picture to multiple parameterized models.
- Dimension specification via a context menu, in which values can be controlled by a scroll bar and/or + and - buttons, like the zoom function in some CAD systems.
- Tracking of all identifications, including ill-defined ones, like *it* and *this part*.
- Recognition of handicraft operations
- On a negation, the system can react with showing shape handles for the parameters that were changed during the last operation, to provide easy adaption.

4. CONCLUSIONS

The use of shape terms for shape ideation is inventoried. The terms used by the subjects are categorized and used to identify useful functions for digital shape ideation systems. The following functions are proposed:

- Indication of locations that will be used in following operations
- Free hand sketching on a transparent sheet that can be stuck to a surface of an object
- Recognition of popular shape characteristics, handicraft operations and object shapes
- Dimensioning via a pop-up menu with a scroll bar
- Tracking algorithm to solve implicit identifications of parts
- Presenting relevant shape handles for easy tuning of shape aspects

Repetition of the experiments with different target groups is recommended for investigating the influences of education and experience on the use of shape terms.

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13 MODELING PROPERTIES FOR THE DESIGN OF BRANCHED SHEET METAL PRODUCTS

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This paper presents an approach to designing multi-chambered profile structures made by a new manufacturing process called linear flow splitting using an algorithm based approach. The basis for this procedure is a systematic view of product properties and the separation of its internal and external properties. The link between product properties must be derived by design knowledge such as physical models or guidelines. This specific knowledge enables one to decide which internal properties, as optimization parameters, need to be adjusted in order to meet desired external properties. This procedure leads to mathematical problems that are difficult to solve, presenting a challenge for research. This approach is demonstrated with an example of a development assignment seeking a topology of a profile structure consisting of several chambers.

Keywords: Algorithm-based design, Product properties, Optimization, Sheet metal.

1. INTRODUCTION

The product development process is shaped by the know-how and the intuition of the designer. Consistent computer aid is established in some elementary work procedures, but it is typically missing in the early phase of the product development process. The main focus of the new algorithm-based approach is to elaborate the customer- and market requirements for profile structures in such way, that mathematical optimization processes can follow. The difficulty is developing a product which exactly fulfills these requirements by the product's outward properties, called external. The vague customer statements must be prepared in such a way that they can be used as parameters in mathematical-algorithmic optimization procedures for the following topological and geometrical design of sheet metal profiles. New procedures for an algorithm-based product development are prepared in close co-operation between mathematicians and designers. The core element of the Collaborative Research Center 666 (CRC 666) (German: Sonderforschungsbereich 666, SFB 666) is made up of new forming processes called linear flow splitting and linear split bending. Linear flow splitting allows branched profiles to be formed using sheet metal in integral style without joining, laminating material or heating the semi-finished part. Since this forming technique is at an early stage of development, a way to integrate it into the product design process must be developed. Therefore, the goal of the CRC 666, which was founded in 2005, is to exemplify how branched sheet metal products can be designed and how a manufacturing process can be integrated into the design process.

1.1. Linear Flow Splitting

Integral sheet metal structures made by linear flow splitting show great potential for producing innovative and lightweight products. In nature, branched structures are used for numerous purposes,