Morphology systems for databases on buildings with curved façades

Karel Vollers
Delft University of Technology, Faculty of Architecture, k.j.vollers@tudelft.nl

Buildings are emerging with an increasing degree of geometrical variation. As yet no scheme categorises data on the basis of non-orthogonal geometries applied. The author proposes an easily accessible morphological scheme which for example, enables data to be retrieved on sustainable performance of glass types as related to the distinctive building shapes. The scheme focuses on high-rises; in a later version buildings with less prominent vertical character will be included. The shaping of most non-orthogonal buildings is related to developments in modeling software. The morphological scheme is based on software manipulations to describe shaping, not on mathematical formulae. As software develops, new ways of form generating and new shapes emerge. In consequence the shaping scheme gradually will be updated. The scheme can be made accessible both in printed version by illustrations, as in digitised form, for example by keywords. The scheme is illustrated by examples of overall shaping. Trends in the applications of types of curved glass are briefly discussed.

Keywords: morphology, façade, glass, geometry, non-orthogonal, curved

1. Non-orthogonal high-rises

High-rises mostly are shaped like boxes and as curved volumes. But, especially in high-rises, curved volumes offer economical and sustainability advantages. A very efficient floor/façade ratio is attained by bulging the volumes and rounding the contours. This implies less building material, maintenance and energy consumption. Also as to windage, curving a high-rise volume often is profitable. Windage of a 90º twisted building, for example, is 40% less than of a cube-shaped building of the same floor area. It implies a lighter superstructure.

The high investments in iconic projects push industrial innovation to meet the new shaping and the quality demands to guarantee extra-long building life-spans. The growing market of non-standard curved products, stimulates application of increasingly stronger curvatures. Iconic articulated buildings in the mid-rise range of 60-100 m are now filling the gap between slightly curved high-rises and strongly curved low-rises.

2. Morphological scheme for high-rises

Integration of digital technologies into the various stages of building development is resulting in a variety of high-rise volumes with curving façades. Their geometrical complexity is increasing rapidly, and by implication the complexity of materialising. An easily accessible database that distinguishes according to overall shaping, will be useful when optimising build-up and performance of high-rises with curved façades. The author found no morphological system matching the geometrical variety. Without a system that names the various building shapes, no database can be made that allows retracing data connected to building shapes.

Mathematical descriptions that qualify façade surfaces as being anti-clastic/synclastic, single- or double-curved, do not describe overall building shapes. Mathematical definitions of curved surfaces like hyperboloids, conoids, etc., aside of being too difficult for most building participants to understand, do not reflect the variations in building volumes.

A topology classification system designed by architects is described in Phylogenesis [1]. It schematises surfaces - not building shapes. The scheme requires too much study to be generally used in the building industry.

In his book Skyscrapers-Skycities [2], Charles Jencks classifies by form and expression. A grouping by metaphorical equation (in skypricker, skyscraper or skycity) is elaborated with ambiguous and subjective names. He also lists the topics Morphology, Articulation of surface, Style, Activity, Technology, Motivation. Only the Morphology section deals with geometric descriptions. It subdivides into Central, Longitudinal and Compound buildings.

The section Longitudinal, classifies high-rises as a slab, stepped-, curved-, shaped-, amorpheus- or complex slab. It covers high-rise shapes in general, but does not determine variations in buildings with curved façades. Similarly Central or Compound volumes do not classify volumes with curved surfaces.

Up-to-date high-rise project information is available on the website www.Skyscrapercity.com, at this moment the main website forum. Its database classifies according to geographical location, height, usage, etc. Not to geometrical shape.

The morphological scheme proposed by the author deals with the overall shaping of volumes with curved façades. Compound buildings, i.e. those consisting of segments of different geometry types, are briefly discussed.

3. Modeling software and high-rise shaping

High-rise shaping is largely related to the modeling tools that architects have available. Simple modeling procedures enable intuitive shaping of complex geometry designs. Little mathematical insight is required, but the consequences for structure, usable floor-space, etc. are considerable. Designers are assisted by software in handling such data. Some focus on parametric modeling of the overall volume, others on morphogenetic structures, textures, etc. The relative ease by which one can design, allows rapid shape development and quick generation of digital data on components. The parameters can be manipulated numerically, and by adjusting points on the screen operated by mouse-clicks.

In the first generation non-orthogonal building shapes, volumes were mostly geometrically described by manipulating straight lines or flat surfaces using the commands Copy, Move and Rotate [3]. The process to describe non-orthogonal volumes involved handling large quantities of data.

In the second generation non-orthogonal building volumes, solid modeling software was applied. In such software, shapes are described by relations between their composing elements. Scripting and parametric modeling procedures greatly eased drawing procedures and processing of data. Control of freely curved surfaces built of, for example, Nurb curves is maintained by manipulating only a small number of points. In solid modelling software, volumes can be transformed by commands like Shear, Twist, Scale, Unite or Merge.

The third generation non-orthogonal high-rises reflect the use of the before mentioned tools, but a sequence of their use is hard to distinguish. By scripted procedures, new shapes are generated with increased complexity in geometrical build-up. Such designs as yet often appear monolithic, with freely curved surfaces, textured by patterns of holes, ripples, etc. The complexity of their materialising, is anticipated by second generation building geometries that each were transformed with only a few tools.

In the first generation of the morphological scheme, some façade geometries were grouped by the chronological availability of a small selection of tools and software. Additionally, the popularity of parabolic hyperboloids and conoids for façade surfaces, had lead to incorporate into the scheme volume names that related to the use of such surfaces. Similarly, in the scheme, names for twisted volumes were related to superstructure features. To avoid ambiguity, the CAD-tool 3.0 morphological scheme, as the scheme is named by author, only distinguishes volume geometries by the tools used [4].

4. Information exchange by grafics

The scheme is based on the observation that most high-rise geometries are primitive shapes, transformed by a limited number of manipulations. Most people can easily mentally visualise subsequent transformations. Computer commands thus replaced mathematical formulae to indicate the form build-up. Manipulations may be depicted by icons and these may be supplemented with numerical information. Such representation resembles the way software parameters are depicted on computer screens.

In their search for new images and added expressions in the shaping, architects increase the geometrical complexity. For example, some years ago most twisted towers were generated by scaling a cube into proportion, and then twisting the volume. Now the box additionally gets scaled and/or is rotated in varying degrees along their heigth. Whereas the axis of rotation initially was centred in the floorplan, now it may well be chosen aside of the building volume and even be curved. Also the volumes to be transformed, often are more complex than the initial boxes. On the one hand, architects have gained experience in modelling and increase the complexity by applying more elaborate transforming tools. On the other hand, esthetics and building economy limit the number of parameters used - generally to less than 4 tools. Following closely behind the architects, the general public gets used to buildings of greater geometrical complexity. The abilities to understand by which tools a volume was generated, is growing.

5. Nomenclature

To function optimally, the proposed scheme methodology and type names must find general acceptance. Hereto the scheme's names originate in widely used geometric descriptions of volumes (sphere, cylinder, cone) and in transforming commands (extrude, rotate, twist). Many command names resemble those in the tutorial book Architectural Geometry [5] and in modelling software of Generative Components and Rhino.

With software evolving, for a similar command a different name may come into use. This changing of names is confusing, but sometimes is necessary to connect to new insights into form generation or to use of other or updated software. As shaping diversifies with new tools, more typologies emerge and new names will enter the scheme.

Shapes can be generated in various ways, and by use of a variety of commands. Such parallel options imply that a volume can be classified by various transforming commands. A sphere, for example, may be selected directly as a primitive shape, be made by rotating a half circle around an axis or be generated by scaling in a modeling script a circular plan as it is moved upward. By listing these commands in an order of importance, more unity in use of names is achieved. When a choice between listed commands is possible, then the preferred adjective for a primitive, is the first from left. As other shaping procedures may come into use, other adjectives or a changed sequence, may become more fitting.

When parameter values vary, for example the degree of twisting and scaling, or when a large series of transformations is applied, then the overall image often loses optical inner consistency. When the sequence of manipulations is not obvious, or when the form does not fit in a category, then the volume is classified as a *Free shape*. (Names allotted by author are written in Italics).

Special categories discriminating by function, composition or formal characteristic, supplement the scheme of overall shaping. These relate, for example, to wind energy or bio-climatic aspects. Specific features may also lead to adding descriptive adjectives to a shape name, such as *Arched* or *Perforated.*

6. Example of generating a high-rise volume

The 396 m high Oktha Gazprom tower (Figure 1abc) is a *Compound of sliding tapered twisters* (the name will be explained later). The generating process of the building volume is exemplary for the use of modelling software. The overall volume does not twist, only the volume segments outside the cylindrical core do.

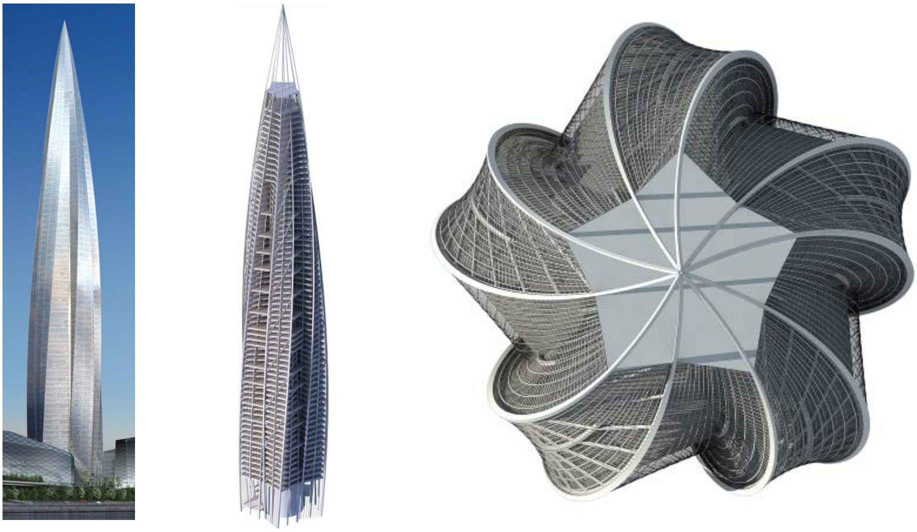


Fig. 1abc: Okhta Gazprom tower, under construction in St. Petersburg, Russia (by RMJM); superstructure sideview; topview.

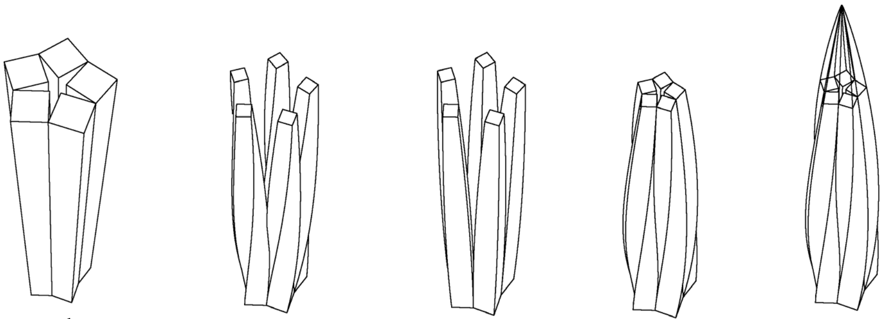


Fig. 1abc: Okhta Gazprom tower, under construction in St. Petersburg, Russia (by RMJM); superstructure sideview; topview; genrating process.

The volume can, for example, be generated in by positioning 5 cubes on the ground floor as a five-pointed star (Figure 1d). Then scaling the cubes upwards, tapering and twisting each volume around its individual central vertical axis. Next each axis is bent sideways while keeping the floors horizontal (‘shearing’) to make the volume’s tops touch. The model can also be scripted. Then for example the squares are drawn as ground floor plan. Similar curved trajectories for the floorplans to follow are described, or constructed on the screen. The floorplans subsequently are scripted to get smaller and rotate while moving upward along the trajectories. The top was added later in the above sequence, to outline the geometry of the first drawings more clearly. It should have been shown from the beginning, as integral part with the lower volumes.

Most articulated high-rises are variations of primitive shapes. The scheme (Figure 2) is based on the transforming of such shapes. Primitive shapes and transforming commands in the scheme are limited to those that are most used, to obtain a concise overview.

The *Main Categories* have 2 groups of volumes: Primitives and *Generated Primitives*. The Primitives only have limited variations in shape, because of the geometry of their origins. The Generated Primitives, like *Extruder, Revolver, Merger, Skinner,* add variation to the primitive shapes. They were generated by applying deforming commands with related names.

A Sphere, Cylinder and Cone can be made by rotating a generating line around an axis. They are so often used that they are listed as separate primitives. As the standard is to scale the primitive Cube into the right proportions before further transforming, the name *box* is used for this allready scaled shape. The same applies to pyramid, cylinder and cone. Less common primitives, like truncated cones (i.e. cones of which the top has been cut of), are left out. Such a primitive is classified by adding an adjective to the Sub-Category name, like *Bent truncated cone*.

Transformers, are the commands (shear, bend, scale, etc.) that can be applied to transform the shapes in the Main Categories.

Building volumes are named according to their shape in the Main categories, with the transforming command as adjective, for example a *Scaled twister*. When after transforming, a primitive maintains its shape characteristics, then it is classified under that primitive's name. If not, then it is stored in the Sub-Category with the transformer adjective.

Buildings sharing a specific feature are grouped in the Special Categories. *Repeaters* for example, have identical façades, of *Turners* at least 1 floor can rotate.

7. Elaboration of the scheme

Transforming commands can also lend their names to groups of volumes onto which a specific command was applied. Such groups are named *Transformers*. For example, the transformer group *Twisters* contains twisted boxes, twisted mergers, etc.

Some volume types are relatively easy to materialise and therefore more often applied. They are grouped in sub-categories. As an example, Extruders in the scheme by definition are extruded vertically, without rotation. Their floors are repeated. Sheared boxes and Sheared cylinders have a similar repetition of floors. They can be regarded as Sheared extruders but their naming includes specific geometric origins. *Anglers* and *Sliders* are *Sheared extruder* sub-categories, including those originating as boxes or cylinders. Anglers have an inclined straight axis along which the floors are sheared, the axi of Sliders are curved.

The adjective *Basic* to a Transformer is used when it is a fundamental type of transforming, with fixed parameters. A *Basic twister* has identical floors, them being repeated upward with a constant rotation around a vertical axis. Also its façades repeat

on all floor levels. The basic twister is an early twisted volume design. In later twisters, the parameters of floorplan contours, axis shape, axis inclination and/or rotation vary.
Hyperboloids are classified as a Revolver Sub-Category. They have a straight generating line that revolves around a rotation axis. The lines neither lie parallel nor intersect. Tordos and Conoids are classified as Line Controller Sub-Categories. They are created by moving contours, while ensuring that one or more of the transformed surfaces is a ruled surface (i.e. a surface built of straight lines that don't lie parallel or intersect).

8. Glass market

The use of parametric modeling software, stimulates application of non-standard elements. They approximate orthogonal flat products in price. The use of non-standard elements is visible in many non-rectangular high-rises; repetition of elements is losing importance now freely curved shapes can be materialised rationally. In consequence, twisted geometries with repetition of elements are applied not so much for economic gain as for semiotic connotation. As yet, most high-rise facades are built of flat panes. Their size repetition decreases. On the other end of the scale, increasingly small buildings with non-standard panes, of great geometrical complexity are applied. Whereas materialising large scale building facades only deviates little from traditional industrial processing, materialising small scale buildings often implies much manual labour and experimental production methods. The materialising of the two scales of building by technology transfer integrates rapidly.

9. Evaluation

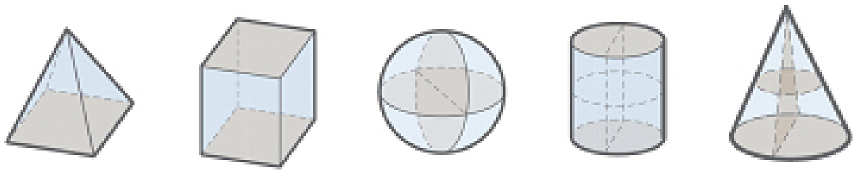
Designers, clients and general public alike, are getting used to more complex geometries and their understanding of geometrical build-up grows. Use of transforming commands for building names, requires basic knowledge of modelling procedures. One need not be able to work with the software tools, only need mentally visualise the transforming principles: move, bend, twist, rotate, copy, mirror and know some primitive shapes, like box, cylinder, cone. However, as modelling software developes, numerous specific commands are created, and applied. The more tools are used, the harder people understand the geometrical build-up. This limits the general application and acceptance of the morphological scheme.

A durable database that classifyies articulated high-rises, will ease retrieval of information. Such a scheme should be kept up-to-date, for example by links to the skyscrapercity.com and emporis.com websites. A keyword system is to enable data retrieval on specific functioning, finishing or shaping variety. Linking various ways of the volume generation in a keyword based database, optimises the shape retracing.

[9]. The modelling tools related keywords may be entered into an information retrieval system, based on syntactic key words. This allows retrieval, understanding and operationalising scientific texts and images in urban, architectural and related technical design. [7]

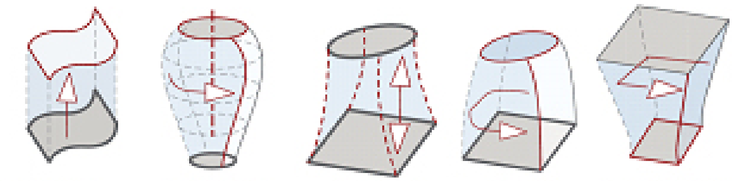
Main Categories:

PRIMITIVES



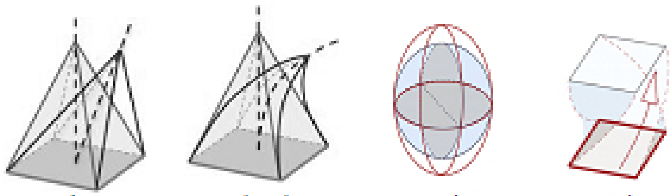
pyramid box sphere cylinder cone

|------------------**GENERATED PRIMITIVES**----------------------|



extruder revolver merger skinner line sweeper

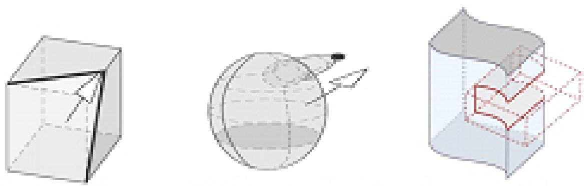
Main Transforming Commands:



shear bend scale twist

as **Sub-Categories** above icons are a:

sheared pyramid bent pyramid scaled sphere twisted box



line control field control Boolean operation

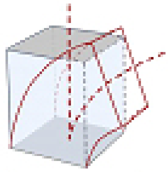
as **Sub-Categories** above icons are a:

line controlled box field controlled sphere Boolean extruder

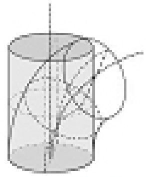
Examples of Sub-Categories and Special Categories:

REVOLVER Sub-Category **BENDER Sub-Category** **SWEEPER Sub-Category**

Hyperboloid
(straight generator)

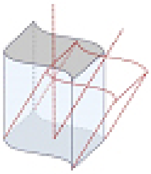


Tube (constant section
perpendicular to axis)

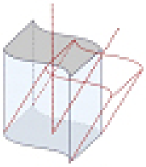


Pipe (constant circular section
(perpendicular to axis)

SHEARD EXTRUDER Sub-Categories



Angler
(straight inclined axis)

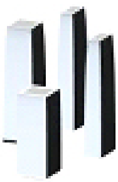


Slider
(curved axis)

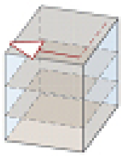
Special Categories

Fig. 2

Compound volumes



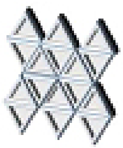
Cluster



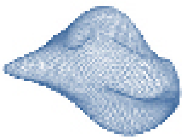
Turners

Slicers

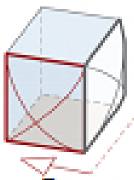
Façade patterns



Structural patterns



Freeform volumes



Repeaters

Like the Blob Inventory Project (BLIP), data can be made accessable by a web-based environment that formalises knowledge which resulted from digital design/engineering/production processes. It establishes a grammar of influences between formal, structural and production related aspects of the free-form development process. Conceptualised as a semantic network of keywords by formulating various context independent factors (features), the application allows extensive cross-referencing and interactive searches. A search starting with the structural typology feature provides information on production technologies and form development processes associated with specific typology. Designers may use this application by starting from a specific feature of their architectural form to get information to see the structural and production related consequences of their form and may visualise alternative applications in precedent projects. Similarly, a search starting with the structural typology feature will provide information on production technologies and form development processes associated with this specific typology. [8]

Projective geometry, making use of algorithms for the reconstruction of 3D objects from several images of that object, may be applicable to trace similar building geometries on a global level.

10. Conclusion

Non-orthogonal buildings with curved façades can be morphologically organised in accordance with the computer manipulations used to draw them. When applying the above proposed names, data on comparable projects can be retraced.

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