20 16 CAADence

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Edited by Mihály Szoboszlai

2016

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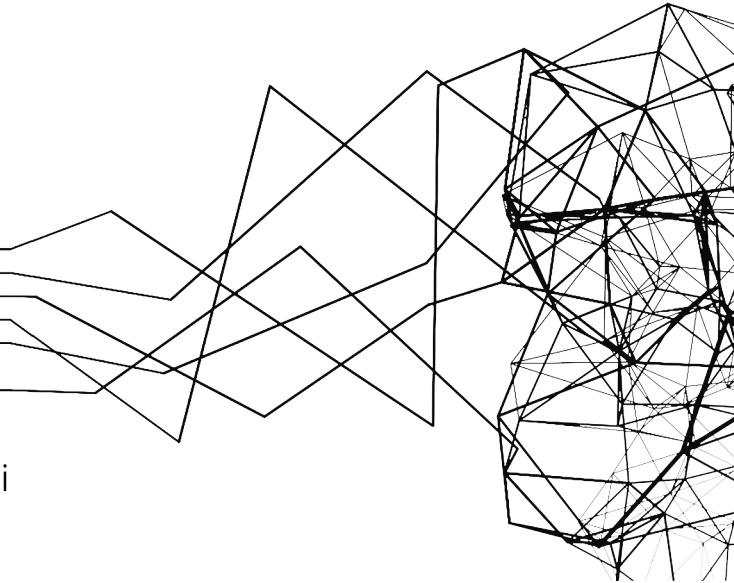
Theme

CAADence in Architecture
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The aim of these workshops and conference is to help transfer and spread newly appearing design technologies, educational methods and digital modelling supported by information technology in architecture. By organizing a workshop with a conference, we would like to close the distance between practice and theory.

Architects who keep up with the new design demanded by the building industry will remain at the forefront of the design process in our IT-based world. Being familiar with the tools available for simulations and early phase models will enable architects to lead the process. We can get "back to command".

Our slogan "Back to Command" contains another message. In the expanding world of IT applications, one must be able to change preliminary models readily by using different parameters and scripts. These approaches bring back the feeling of command-oriented systems, although with much greater effectiveness.

Why CAADence in architecture?

"The cadence is perhaps one of the most unusual elements of classical music, an indispensable addition to an orchestra-accompanied concerto that, though ubiquitous, can take a wide variety of forms. By definition, a cadence is a solo that precedes a closing formula, in which the soloist plays a series of personally selected or invented musical phrases, interspersed with previously played themes – in short, a free ground for virtuosic improvisation."

Nowadays sophisticated CAAD (Computer Aided Architectural Design) applications might operate in the hand of architects like instruments in the hand of musicians. We have used the word association cadence/caadence as a sort of word play to make this event even more memorable.

Mihály Szoboszlai
Chair of the Organizing Committee

Keynote speakers

REINHARD KÖNIG

Reinhard König studied architecture and urban planning. He completed his PhD thesis in 2009 at the University of Karlsruhe. Dr. König has worked as a research assistant and appointed Interim Professor of the Chair for Computer Science in Architecture at Bauhaus-University Weimar. He heads research projects on the complexity of urban systems and societies, the understanding of cities by means of agent based models and cellular automata as well as the development of evolutionary design methods. From 2013 Reinhard König works at the Chair of Information Architecture, ETH Zurich. In 2014 Dr. König was guest professor at the Technical University Munich. His current research interests are applicability of multi-criteria optimisation techniques for design problems and the development of computational analysis methods for spatial configurations. Results from these research activities are transferred into planning software of the company DecodingSpaces. From 2015 Dr. König heads the Junior-Professorship for Computational Architecture at Bauhaus-University Weimar, and acts as Co-PI at the Future Cities Lab in Singapore, where he focus on Cognitive Design Computing. Main research project: Planning Synthesis & Computational Planning Group see also the project description: Computational Planning Synthesis and his external research web site: Computational Planning Science

BRANKO KOLAREVIC

Branko Kolarevic is a Professor of Architecture at the University of Calgary Faculty of Environmental Design, where he also holds the Chair in Integrated Design and co-directs the Laboratory for Integrative Design (LID). He has taught architecture at several universities in North America and Asia and has lectured worldwide on the use of digital technologies in design and production. He has authored, edited or co-edited several books, including "Building Dynamics: Exploring Architecture of Change" (with Vera Parlac), "Manufacturing Material Effects" (with Kevin Klinger), "Performative Architecture" (with Ali Malkawi) and "Architecture in the Digital Age." He is a past president of the Association for Computer Aided Design in Architecture (ACADIA), past president of the Canadian Architectural Certification Board (CACB), and was recently elected future president of the Association of Collegiate Schools of Architecture (ACSA). He is a recipient of the ACADIA Award for Innovative Research in 2007 and ACADIA Society Award of Excellence in 2015. He holds doctoral and master's degrees in design from Harvard University and a diploma engineer in architecture degree from the University of Belgrade.

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3D Shape Grammar of Polyhedral Spires

László Strommer[1]

[1]Department of Architectural Representation
Budapest University of Technology & Economics, Hungary
e-mail: strommer@arch.bme.hu

Abstract: *Any random words can be put together – but in most cases they would not constitute a meaningful sentence. Similarly, any geometry can be used as the shape of a building or an architectural element, but in most cases tradition, aesthetics, and practice strongly restrict this theoretical freedom. The shapes of the spires of Western European medieval churches show a high variability – yet they use only a limited portion of the infinite set of potentially possible polyhedral or conical shapes. In this paper a generalized classification system of polyhedral spire shapes is presented as a kind of 3D shape grammar. This system can be used for describing the roof-shapes themselves – just like phonetic symbols can be used to represent the qualities of an oral language. At the same time the suggested notation system can hopefully provide unambiguous descriptions that can even be used in automated CAD modelling.*

INTRODUCTION

In architecture, a spire is a steeply pointed termination to a tower, which usually has an accentuated ideological and aesthetical significance.[1] In this paper the term will be used in a somewhat wider geometrical sense: not only for the most common pyramidal or conical shapes, but for any shape a roof of a tower can have.

In a previous article [1] I proposed a descriptive system which I thought to be appropriate for notating the 3D shapes of spires that are bounded by planar surfaces exclusively. In the past few years I have used this system in academic courses and I have found that it is suitable for educational purposes also: the simple descriptions can help the

students understand, and consequently reconstruct the 3D shapes of the more complex spire shapes. Actually, in some cases it happened the other way around: in order to achieve a satisfactory level of comprehension, sometimes we had to reconstruct the elements and the operations first, taking the description as a kind of "recipe", and using the modelling process itself as an explanation.

Yet, I have found then in certain cases this notation system is not specific enough – especially for describing compound shapes. All basic shapes that have the same notation are affine transformations of each other – however, even the same type of primitives can produce different compound shapes, if they have dissimilar steepness and/or relative size. Therefore, in order to accomplish a higher level of precision, the description system needs to be "upgraded".

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1 "In its mature Gothic development, the spire was an elongated, slender form that was a spectacular visual culmination of the building as well as a symbol of the heavenly aspirations of pious medieval men. Encyclopædia Britannica" • http://www.britannica.com/technology/spire

This article is intended to expand the previously proposed notation system in order to achieve a precision which ensures that every spire shape has a description sufficiently specific even to enable its – theoretical – reconstruction.

DEFINITIONS

The archetype of the medieval tower can be described as a building, or part of a greater building (mostly a church or castle), whose height is considerably bigger than the dimensions of its base – which is usually a square, a polygon or a circle, or, in rare cases, a rectangle or an ellipse. Figure 1 depicts a compound spire shape showing the names of its most important components that appear in this article.

1 Spire apex
2 Ridge
3 Valley
4 Gable ridge
5 Gable apex
6 Verge
7 Bottom plane of the spire
8 Gable (gable wall)
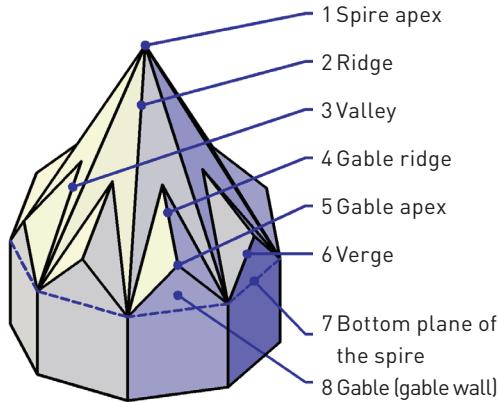
A *gable* is a vertical plane (a wall) whose existence is inevitable whenever the bottom edges of the sloping surfaces of the roof proper are not horizontal. A *verge* is the sloping outer edge of a gable, and the *gable apex* is the highest point of a verge. The *spire apex* is the point located over the centre of the base, typically the highest point of the whole shape. A *valley* is a concave break between adjacent surfaces, which therefore collects the water from them; while a *ridge* is a convex break, which consequently diverts, not collects water. Finally, a *gable ridge* is a ridge starting from the gable apex, usually, but not always connecting it with the spire apex.

BASIC SPIRE SHAPES

Figure 2 depicts a basic spire shape set: the "primitives" that either can be used in themselves, or as constructive elements of more complex shapes to cover a square base. Obviously, the same type of shapes can be used over polygons having different number of sides also.

The most obvious of all spire shapes over an n-sided base is a *regular n-gonal pyramid* (e.g. a_4 • St. Mark's Campanile, Venice, Italy).

If the midpoints of the edges of the base are moved upward, the triangular faces of the original pyramid break, and because of these new ridges (which connect the spire apex with the gable apexes), the shape becomes a *convex 2n-gonal base-truncated pyramid* (e.g. b_4 • Marienkirche, Lübeck, Germany). It is worth noting, that this shape is not necessarily regular ($b°$), since similar forms can
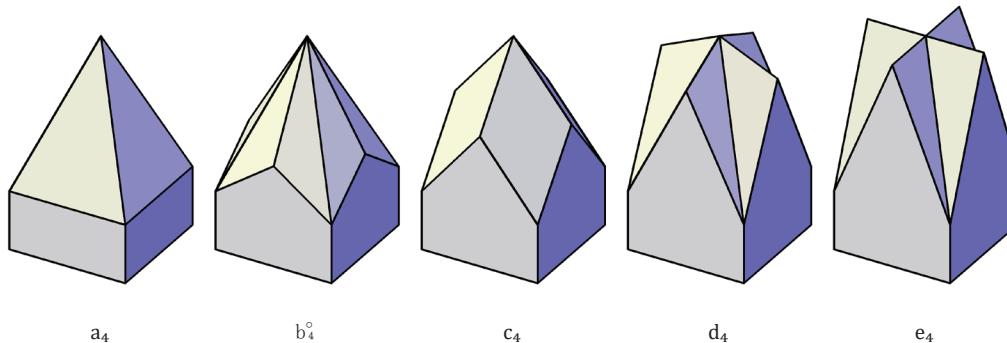
a_4 $\qquad$ $b_4°$ $\qquad$ c_4 $\qquad$ d_4 $\qquad$ e_4

$e_4 \cup c_4 \cup a_8$ $a_4 \cap c_4 \cup a_8$ $a_4 \cap c_4 \cup a_8$ $a_4 \cap c_4 \cup c_4$
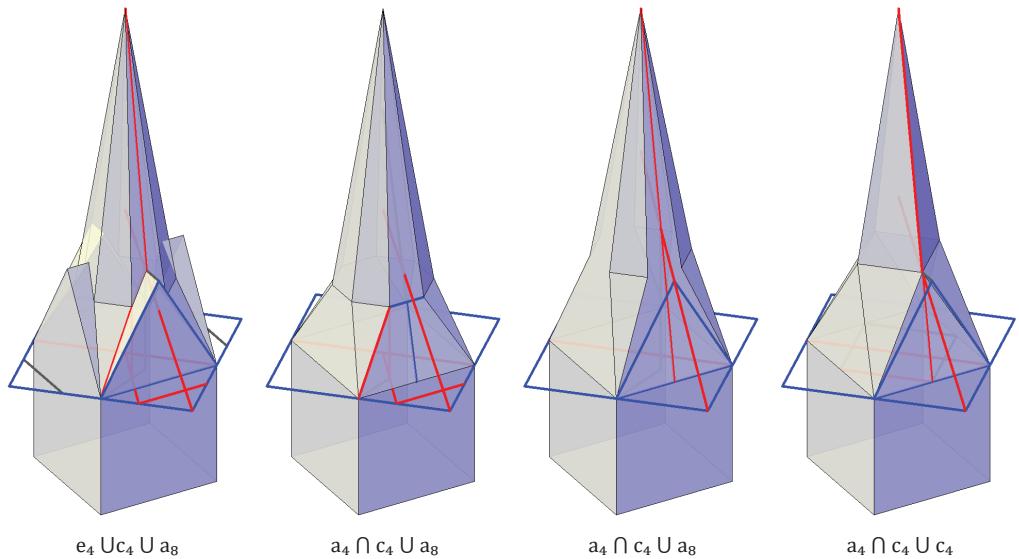
be constructed using a little bit higher (b^+) or lower (b^-) gable apex height also – but unless stated otherwise, we usually assume that the horizontal section of the spire is a regular 2n-gonal polygon. If the gable apexes are raised higher, the diagonal ridges "sink" into the roof planes, and the shape becomes a *rotated n-gonal base-truncated pyramid* – while the horizontal section of the spire (above the level of gable apexes) becomes a rotated convex n-gonal polygon (e.g. c_4 • St. Faith's Church, Sélestat, France).

If the gable apexes are raised even higher, the roof surface breaks again, and the diagonal edges reappear – but this time as valleys – and the shape becomes a *concave 2n-gonal base-truncated pyramid*. This shape is similar to the b_n type, since in this case the gable height can again be moved in a relatively wide interval: a decent lowering or raising the gable apexes does not change the basic attributes of the shape. We can find an equilibrium state, in which case the slopes of the verges and the diagonal valleys meeting in the corners are equal. Furthermore, when the number of the sides of the base polygon is more than four, an even more interesting shape can be used, which has a star-shaped horizontal section, since its every third face lie in a common plane. Hence,

assuming that the number of sides is even, this shape can be seen as the union of two isomorphic base-truncated pyramids (e.g. $d°_8$ • St. Aposteln, Cologne, Germany).

Finally, if the gable apexes reach the height of the spire apex, we get intersecting gable roofs – a not too impressive form, which seldom used in itself as a termination of tower (e.g. e_4 • St. Marienkirche, Wismar, Germany).[2]

COMPOUND SPIRE SHAPES

The more complex spire shapes can be generated from the basic spire shape set, using regular Boolean operations. Obviously, if we combine the same types of elements, but choose different relative heights for them, we end up with shapes that are not affine transformations of each other anymore.

A good example of the geometrical dissimilarity of similarly denoted shapes are the two $a_4 \cap c_4 \cup a_8$ shapes of Figure 3 – due to the different proportions of the same type of primitives, the horizontal edge on the front side might, or might not be present.

2 Theoretically, the gables can be even higher than the spire apex (f_4), but that would contradict the architectural purpose and the "message" of the spire.

The logical connections between the shapes of the figure is quite interesting.

The left shape has been constructed with three objectives in mind: the slope of the verge of the gable should be 60°, the angle of the horizontal projection of the valley between the e_4 and c_4 shapes should be 22.5°, and finally, the a_8 component should be placed so that its ridge would start from that same valley.[3]

The second shape is basically the same, only the gables have been "cut off" – resulting in a different frequently used spire shape, sometimes called *splayed-foot spire*[4] (e.g. Cathedral of Trier, Germany). The third shape uses the same type of elements as the second one, but since the slopes of its a_4 and a_8 components are equal, the aforementioned horizontal edge disappears (e.g. Patrixbourne, England). Finally, the fourth shape features the same a_4 and a similar c_4 element, but a different, c_4 termination (e.g. Cathedral of Trier, Germany also).

It is worth noting that in addition to the variety produced by the differences of steepness and relative height of the elements of compound shapes, the shapes often deliberately diverge from the "default" form. Probably the most important asset is the use of pinnacles – which actually use a similar geometrical shape set as the spires themselves, as it can be seen e.g. in Roriczer's booklet describing a construction method that ensures the "right" proportions of an e_4Ua_4 pinnacle shape [2].

SPIRE SHAPE NOTATION

I think the above notation system adequately fits the need of e.g. historical or artistic description – at the same time it could ensure some additional level of precision. Using these denotations one can easily say – and others can easily understand – something like: "*the* b_4 *type is one of the most frequent spire shapes in Austria*".

Yet, when one tries to be even more specific, some additional information would also be needed. For example, one might add, that "*in most cases the slope of the verge of the gable is* ≥60°". Fortu-

3 The height of the a_8 element has been chosen to be the same as the height of a b_4 spire having the same regular triangular gable (see Figure 5).
4 *http://www.lookingatbuildings.org.uk/glossary/glossary/S.html?&tx_contagged%5Bpointer%5D=7*

nately, this additional information can easily be integrated into the system without becoming "incompatible" with the simplified version used so far. I think it is important that even this upgraded system would preserve its human "readability" – yet, it should provide a description specific and unambiguous enough that even a program can interpret it, and it should be possible to create a 3D model using only the information provided by the description of the shape.

SPIRE PROPERTIES

If there was a CAD program capable of using the elements of the basic spire shape set as its regular "primitives", it would (or at least it should) have a panel containing similar information then the one that is depicted in Figure 4.

So far only the symbol of the shape type and the number of the sides of its base have been used in the description. In order to describe the spire shape more specifically, two more properties have to be specified. As the graph in Figure 4 indicates, one can choose one line (i.e. the two variables it connects) from the bottom two, and one from the top eight in order to specify the spire shape unambiguously. In case of the base polygon, the number of sides (N), and the radius of either the inscribed (Ri) or the circumscribed (Rc) circle is needed – the other can easily be calculated using the $Ri/Rc = cos(\pi/n)$ relationship – and it obviously sets the length of the side of the base polygon (S) also. In case of the spire shape itself, two of the following five variables have to be set: the type of the spire shape (T), the slopes of the verges of the gables (Λg), the slopes of the diagonal edges or planes of the spire (Λd), the height of the spire
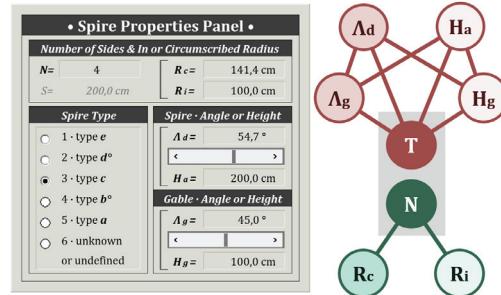
Figure 4:
The spire properties panel (implemented in Ms Excel VBA) and its logical graph

apex (Ha), and the height of the gable apex (Hg). Note however, that not all pairs can be used, since two pairs are mutually dependent: the slope of the gable sets the gable height ($Hg = tan(\Lambda g) \times S/2$), and the slope of the diagonal sets the spire apex height ($Ha = tan(\Lambda d) \times Rc$) – and vice versa.[5]

As it has already been mentioned, in case of the basic shapes the change of the slope of the roof would not produce a topologically different spire shape. However, the ratio of the height of the gables and the height of the spire apex is a unique characteristic, so their Q quotient is a distinctive feature.

In case of the a_n shape there are no gables, so Q_a is obviously 0, in case of the e_n shape the height of the gables is the same as the spire apex itself, so Q_e is evidently 1 – and the Q values of the other shapes fall between these extrema.

A b_n° spire is a base-truncated 2n-gonal pyramid whose diagonal ridges (starting from the spire apex) reach the base plane, while its gable ridges do not. Since both sets of ridges have equal

5 Notice also that an a_n spire does not have gables, so in that case neither Λg nor Hg can be used.

slopes, their height-difference is proportional to the length-difference of their horizontal projections, hence the radii of the circumscribed and inscribed circles of the base.

$$Q_b = 1 - \cos(\pi/n) \tag{1}$$

The c_n spire is also a base-truncated pyramid (this time an n-gonal one) whose base is circumscribed about the circumscribed circle of the original base.

$$Q_c = 1 - \cos^2(\pi/n) \tag{2}$$

The d_n° spire has the same gable height as $b_{n/2}^\circ$ spire would.

$$Q_d = 1 - \cos(2\pi/n) \tag{3}$$

Obviously, in order to use these basic shapes in conjunction with each other (for example to create a compound spire shape), it may be necessary to set the location of the elements relative to each other also.

Figure 5:
More spire shapes over square base

c_4 b_4 $a_4 \cap a_8$
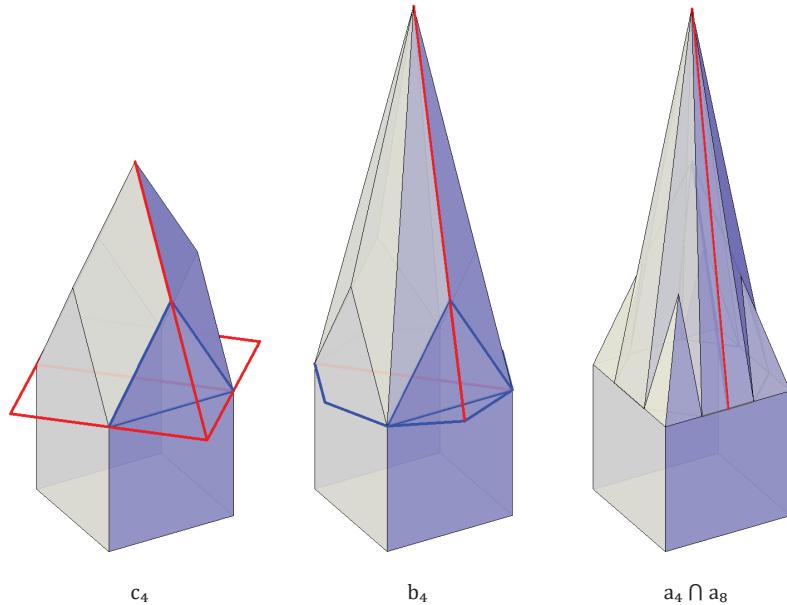
DISCUSSION

In my view, having an appropriate "vocabulary" is crucial in order to really understand, i.e. being able to "mentally reconstruct" the 3D shapes of the spires – otherwise one simply would not have the proper terms to draw even the most obvious conclusions. Unfortunately, the architectural definitions are sometimes not specific enough to be geometrically definite – and if they are, they might turn out to be self-contradictory.

"The Rhenish helm (...) is a pyramidal roof on towers of square plan. Each of the four sides of the roof is rhomboid in form, with the long diagonal running from the apex of roof to one of the corners of the supporting tower. Each side of the tower is topped with an even triangular gable from the peak of which runs a ridge to the apex of the roof."[6]

The citation is a meticulous description of the c_4 shape (see Figure 5) – the problem is that the only example that is given in the article – the Cathedral of Speyer – has b_4 spires on all four of its corner towers. On the other hand, the definition obviously cannot be applied to the c_8 shape that uses the very same logic, but has an octagonal base (e.g. St. Martin, Münster, Germany).

"In the attempt to coordinate (...) an octagonal spire with a square base, the broach spire was developed: sloping, triangular sections of masonry, or broaches, were added to the bottom of the four spire faces that did not coincide with the tower sides (...)."[7]

The $a_4 \cap a_8$ shape in Figure 5 is undisputedly a broach spire. Sometimes the $a_4 \cap c_4 \cup a_8$ splayed-foot spires of Figure 2 said to be a subtype of the broach spire too[8] despite their clearly different geometry, which would suggest that perhaps all spires without gables should belong to this category – but at the same time the above description definitely excludes the very similar $a_4 \cap c_4 \cup c_4$ shape of Figure 2 since it does not have an octagonal termination...

*

In my view, if one uses the same term for different shapes (and does not even have a specific name for others) then it is almost impossible to draw unambiguous conclusions. Therefore, I think that the notation system described in this article can be useful for designating the spire shapes much more precisely – just like phonetic symbols can be used to represent the qualities of an oral language.[9] At the same time this system can provide unambiguous descriptions that can even be used in automated modelling.

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6 Wikipedia • *https://en.wikipedia.org/wiki/Rhenish_helm*
7 Encyclopædia Britannica • *http://www.britannica.com/technology/spire*
8 "Splayed-foot: variation of the broach form (...) in which the four cardinal faces are splayed out near their bases, to cover the corners, while oblique (or intermediate) faces taper away to a point." *http://www.lookingatbuildings.org.uk/glossary/glossary/S.html?&tx_contagged%5Bpointer%5D=7*

9 Probably the only obvious restriction of the suggested notation system is that it presumes a high level of symmetry – but this presumption has seldom been rebutted, since architecture and aesthetics strongly favour symmetry against every incidental deviation. The most important exception to this rule is probably the twisted spire. (Wikipedia • *https://en.wikipedia.org/wiki/List_of_twisted_spires)*
10 *http://adtplus.arcanum.hu/hu/view/EPTUD_10/?pg=410&layout=s*

Acknowledgement

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