The *Yingzao fashi* in the information age[1]

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Introduction

In the study of Chinese architecture, the manual *Yingzao fashi* 營造法式 (Building standards) occupies a uniquely important position. Not only is it one of just two surviving traditional texts about building, but its rediscovery in 1919 was the catalyst for research that established Chinese architectural history as an academic field.[3]

The *Yingzao fashi* was compiled by Li Jie 李誡 (d. 1110), court architect of the Huizong emperor of the Song, and published in 1103. Li's stated goals were to reduce corruption and to introduce standards in architectural construction; his audience appeared to be both the officials who commissioned buildings and the builders who built them. The manual covers a range of topics, from foundations to painted ornament to the estimation of materials and labor. My interest here is wood-frame building design, also known as structural carpentry (*da muzuo* 大木作).

The pioneering scholar of the *Yingzao fashi* was Liang Sicheng 梁思成 (1901–72), who observed that it was a "grammar book of Chinese architecture." He contrasted it with the other surviving text on architecture, the *Gongcheng zuofa zeli* 工程做法則例 (Methods and models of construction), published in 1734, which

> sets out 27 different building types. It analyzes each building component one by one, mechanically listing its dimensions. The *Yingzao fashi,* on the other hand, in all cases gives formulas based on principles and proportions. It does not define each named component individually, but explains in detail its position and form (Liang 1984, 358).

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3 For an introduction to the *Yingzao fashi,* see Glahn (1984). Other useful studies are by Takeshima (1970), Glahn (1975), Xu and Guo (1984), and Guo (1999). The work most directly relevant to this article is by Liang (1983) and Chen (1993).

In other words, Li distinguished the permissible and the impermissible – which we will call *legal* and *illegal* – and he did this, not by enumerating legal designs, but by showing how to produce them.

A good example is the system for determining the roof section for a building of any given type and depth. Here it is worth remembering that, unlike in western buildings, the rafters (*chuan* 椽) are segmented and supported by the purlins (*tuan* 槫), which are the members parallel to the ridge of the roof. Thus, determining the roof section is a matter of determining the positions of the purlins.

The system is known as *juzhe* 舉折 and consists of two rules (see figure 1). The first is *ju* 舉, ‘raise,’ which determines the elevation of the ridge purlin (*ji tuan* 脊槫) above the outermost, or eaves, purlin (*liaoyan fang* 撩檐方). Connecting these two purlins gives a working roofline. The second rule is *zhe* 折, ‘lower,’ which fixes the position of each successive purlin. It does this by lowering the purlin below the working roofline. Connecting this new lowered purlin and the eaves purlin gives a new working roofline. This is repeated for each purlin, finally producing the segmentally curved roof section.

Thus Li provided a procedure for creating the correct section as required. This is what Liang meant by *grammatical*.[4] This grammatical procedure, *juzhe,* helps us demonstrate our understanding of roof sections in three ways.[5] First, it provides a means to create a new legal roof section. Second, it provides a means to determine whether a previously unknown roof section is legal: we simply test whether the procedure can create the section in question. Third, it explains what the legal roof sections have in common. It does all this simply and transparently which, as Li no doubt realized, could only help to reduce corruption and introduce standards.

But Li did not always maintain this perfect clarity. For example, what he wrote about the width and depth of bays (*jian* 間) is not enough for us either to determine legal bay sizes for a new building or, given a previously unknown building, to determine whether its bay sizes are legal. Chen Mingda (1993) examined this and other similar problems.

In fact, Li sometimes abandoned the grammatical approach altogether and resorted to lists. Take for example the sections of the *ting tang* 廳堂 building type (see figure 2), shown in chapter 31.[6] These are drawings of *ting tang* sections, most with a written description; this set of eighteen sections is known as a *corpus.*

If the corpus contains all the legal sections, then we can demonstrate our understanding in the first two of the three ways mentioned above. To create a legal section, we pick one from the list. To determine whether a newly discovered section is legal, we check whether it is on the list.

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4 Ledderose (2000) made a related point. He did not use the word *grammar,* but did emphasize the productivity of the approach.

5 For more on these three capabilities as criteria of understanding style, see Stiny and Mitchell (1978).

6 The two other building types are *dian tang* 殿堂 and “other” (*yu wu* 餘屋). They are distinguished both by their function (including the rank of their occupants) and by their structure (see Chen 1993).

But we fail at the third: the list does not explain why the legal sections are these eighteen and not others.

If, on the other hand, there are more than eighteen legal sections, then we fail on all three counts. We cannot with any assurance create a nineteenth legal section. We cannot evaluate a previously unknown section. And we do not understand why legal sections are legal and others are not.

How can we acquire and demonstrate an understanding of *ting tang* sections? And how can we do this in a way that is consistent with the approach that Liang found so noteworthy? I propose that the answer lies in the word that Liang used to describe the *Yingzao fashi: grammar.* In the decades since Liang was active, the theory of grammar has been formalized, generalized, applied to both natural languages and artificial languages (for computer programming, for example), and integrated with generative systems in other disciplines, such as mathematics (Post production systems) and biology (Lindenmayer systems for modeling plant growth).

For disciplines like architecture that use graphic and spatial representations, we have shape grammar. Here I demonstrate how to use shape grammar to investigate the problem of *ting tang* sections in a way that builds on Liang's grammatical observation and what it might imply for further study of the *Yingzao fashi* and Chinese wood-frame architecture.

Shape grammar

Shape grammar is a formal method for creating designs. To do so, we begin with an initial design, transform it repeatedly by applying design rules to it, and obtain a final design. What the final design is depends on how and in what sequence we apply the rules. The rules and the initial design make up a *grammar,* and the set of designs that can be created with a grammar is known as a *language* of designs, or a *style.*

To discuss shape grammar more precisely, we need some definitions. A *shape* is a drawing, such as a plan, section, or elevation. A *description* is a symbolic representation communicating some feature of the shape, such as the words *12 rooms* to indicate that a plan has twelve rooms. A *design* consists of one or more shapes and, optionally, one or more descriptions. In the case of the *ting tang* sections, we say that there is a corpus of eighteen designs, each consisting of a shape (i.e., the drawing) and, usually, a Chinese description (e.g., *sijia chuan wu, tongyan, yong er zhu* 四架椽屋通檐用二柱). For convenience, we can consider an English translation of the Chinese description (e.g., *4-rafter building, clear span, with 2 columns*) as a second description.

A grammar consists of an initial design and a number of design rules. Each *design rule* consists of one or more subrules, each corresponding to one shape or description. Each *shape subrule* consists of a left shape, a right shape, and a (right-pointing) arrow in the middle. Similarly, each *description subrule* consists of a left description, a right description, and a (left-pointing) arrow.

To apply a design rule to a design, apply each subrule to its corresponding shape or description. To apply a shape subrule to a shape, we compare the left shape to the current shape (which, when we are just beginning the process, is the initial shape). If there is a match, we subtract (that is, erase) the left shape from the current shape and add (draw in) the right shape. This yields a new current shape. Similarly, to apply a description subrule to a description, we compare, delete, and rewrite, creating a new description.

By applying design rules successively, we transform the initial design (both shapes and descriptions) step by step into a final design. There may be many such final designs; they make up the language. There are precise definitions for the terms we have used, but an intuitive understanding will suffice for our purpose.[7]

An example will help. Figure 3 shows a grammar that generates designs, each consisting of a pattern of squares and diamonds (i.e., the shape) and the numerals that indicate the numbers s of squares and d of diamonds in the pattern (the descriptions). The initial shape is a square with one dot; the initial descriptions are the numerals *1* and *0,* because there are one square and zero diamonds.

There are five design rules. The first shape subrule looks for a square with a dot, and replaces them with a square in the original position (seen by reference to the crosshairs) and, beside that, a new square and dot. In effect, this subrule adds a new square beside an existing square and moves the dot. The dot is simply an artifact that specifies where we can add the new square, but it will not be part of the final shape. It is known as a *label* and will be removed at the end of the process.

The description subrules, written as $s \rightarrow s + 1$ and $d \rightarrow d$, update the descriptions by replacing s with $s + 1$ and d with d. That is, d is left unchanged, so we could omit the subrule $d \rightarrow d$ for economy, but here we include it for clarity.

Design rule 2 adds a diamond beside an existing square and updates d. Design rule 3 adds a square beside an existing diamond and updates s. Design rule 4 adds a diamond beside an existing diamond and updates d.

Design rule 5 erases a dot and, strictly speaking, replaces it with nothing. It does not affect the design's distinctive features, namely the shape (squares and diamonds) and the two descriptions. It simply cleans up the design, just as we erase construction lines to complete a drawing.

We derive a design in the following way (see figure 4, fourth derivation). We begin with the initial design (square with dot, $s = 1$, $d = 0$) and apply rule 2; this adds a diamond, leaves s unchanged, and increments d to 1. This new transformation of the design is separated from the initial design by a double arrow and the number of the rule applied.

We continue by applying rule 3, which adds a square, increments s to 2, and leaves d unchanged. Then, we apply rules 2 and 3 again, adding a diamond and a square, and incrementing s to 3 and d to 2. At this point, we decide that we have finished setting those

7 For a formal discussion of the techniques used here, see Stiny (1980; 1981; 1990).

features that distinguish this design from others in the language; we call this the *distinctive* design. To complete the process, we apply rule 5, deleting the dot and creating the *final* design.

Now, just as *juzhe* defines a language of roof sections, so does our square grammar define a language of designs (see figure 5). And, like *juzhe,* the grammar helps us understand this language in the same three ways. It gives us a way to produce new legal designs: we apply the rules in different ways. It gives us a way to judge whether a previously unseen design is legal: we test whether we can create it with the grammar. And it explains what the legal designs have in common.

Ting tang sections

Now we are ready to return to the *ting tang* sections. Recall that a corpus of eighteen sections is shown, with no formulas, principles, or proportions; they are *listed.* We will write a grammar that creates these eighteen sections and their descriptions. But first we need to examine the descriptions. A typical description, with English translation, is this (see figure 2h):

> *Bajia chuan wu, qian hou rufu, yong si zhu*
> 八架椽屋前後乳伏用四柱
> 8-rafter building, 2-rafter beam in front and in back, with 4 columns

Each description has three parts:

1. The depth of the building, measured in (horizontally projected) rafters. Each section has a depth of 4, 6, 8, or 10 rafters.
2. The disposition of the structure, especially the beams. The lengths of beams are also given in rafters; hence, for example, *sanchuan fu* 三椽伏, *3-rafter beam.*[8] Each beam is supported by a column; thus to specify a beam is to imply a column.
3. The total number of columns.

Now if we compare the descriptions and the sections, we find an interesting discrepancy. The descriptions refer to features that we, nine centuries later, would probably overlook, and we notice features that the descriptions do not mention. For instance, where the descriptions refer to beams, we would speak of the spaces, or bays, below the beams. And where we would mention all the bays, the descriptions ignore central bays. This suggests which features were salient for Li Jie. We will incorporate these features into our grammar.

8 One- and two-rafter beams are named exceptionally; they are known respectively as *zhaqian* and *rufu.*

The grammar of *ting tang* sections

The grammar has four initial designs,[9] with depths of 4, 6, 8, and 10 rafters (see figure 6). Each design consists of a section *s* with one column in the front wall and one in the back wall; a Chinese description with 3 parts c_1, c_2, and c_3; and an English description with 3 parts e_1, e_2, and e_3.

The initial sections are diagrammatic versions of those in the *Yingzao fashi.* Each shows the floor line, the two columns, the purlins, and the vertical axis. In addition, there are a number of labels. On the left, the hollow triangle marks the front of the building. Below the floor line, the circles show where columns can be located, and the triangles show where to apply the rules, as we will see below. The initial descriptions have three parts, as explained above. Notice that the second part, dealing with the disposition of the structure, is blank (shown as ∅).

The rules work as follows. Rule 1 leaves the section unchanged, but adds *tong yan* 通檐, *clear span* to the description. Rule 2 instantiates a column in the center position, below the ridge purlin. It adds *fen xin* 分心, *centrally divided* to the description, and increases the column count by 1. Rules 3 through 8 each instantiate a beam and its supporting column in the front of the building; we call them *front-beam rules.* Rule 3 instantiates a 1-rafter beam and its supporting column, adds *qian zhaqian* 前劄牽, *1-rafter beam in front* to the description, and increases the column count by 1. The solid triangle moves to the position of the new column; if we apply a front-beam rule again, the new beam will begin here. Rules 4 through 8 act similarly for 2-, 3-, 4-, 5-, and 6-rafter beams. Rules 9 through 14 similarly instantiate beams in the back of the building; we call them *back-beam rules.*

The rules are subject to the following constraints.

- The front and back beam rules (rules 3 through 14) may be applied in pairs only: one front, one back. More than one pair may be applied if the building is deep enough.
- The rules must be applied in one of the following sequences:
  - The *tong yan* rule (rule 1) only.
  - The *fen xin* rule (rule 2) only.
  - First the *fen xin* rule, and then the beam rules.
  - The beam rules only.

Normally this type of control is encoded in labels. For clarity, however, we use English here.

As an example, we derive a new design, that is, one not among the corpus of eighteen (see figure 7). Its description is this:

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9 Strictly speaking, we are dealing with not one but four grammars, one for each building depth. However, each grammar consists of the same set of rules and differs only in its initial design, so it is convenient to speak about one grammar and one language. Even more strictly speaking, to have one grammar, we should have a single initial shape, such as a pair of orthogonal axes, and four rules, each transforming the initial shape into one of the four “initial” sections (see Li 2001).

Liujia chuan wu, fen xin, qian hou zhaqian, yong wu zhu
六架椽屋分心前後劄牽用五柱
6-rafter building, centrally divided, 1-rafter beam in front and in back, with 5 columns

We start with the 6-rafter initial design. We apply rule 2, which in the section instantiates a column in the central position. The rule leaves the first part of the description unchanged; to the second part, it adds *fen xin, centrally divided;* to the third part, it adds 1 to the column count.

We then apply rule 3, which in the section instantiates a 1-rafter beam in front, along with the column that supports the beam. The rule leaves the first part of the description unchanged; to the second part, it adds *qian zhaqian, 1-rafter beam in front;* in the third part, it adds 1 to the column count.

Finally we apply rule 7, which in the section instantiates a 1-rafter beam in back, along with its supporting column. The rule leaves the first part of the description unchanged; to the second part, it adds *hou zhaqian, 1-rafter beam in back;* in the third part, it adds 1 to the column count.

We have now created the distinctive design. The process for transforming the distinctive design into the final design is exactly like that for the square grammar. For any distinctive design, there is one final design, so we omit this part of the derivation.[10] This and four other new final designs, redrawn to look like those in the corpus in the *Yingzao fashi,* are shown in figure 8.

Clearly, with this grammar, we can do what we could not do before: we can create new designs, we can evaluate previously unknown designs, and we understand why the language contains these designs and not others.

Grammar, language, and hypothesis

Our section grammar defines a language of 121 designs (not shown). How do we know that these 121 designs are all and only the legal designs? In other words, how do we know that the grammar is correct? Actually, the grammar is a hypothesis; it is provisional. It is based on finite empirical evidence (the corpus) and makes predictions, namely that the 121 designs are legal, and that all others are illegal.

The next step is to test the predictions and revise the hypothesis as necessary. Scientists do this by inventing and conducting experiments. In other words, they devise questions and manipulate nature into answering. In linguistics, generative grammars produce sentences, which are then judged by native speakers.

In architecture, we would look for "native designers" to evaluate our designs. Take for example José Pinto Duarte's (2001) work on Alvaro Siza's houses in Malaguiera, Portugal. Siza, using a personal system, designed dozens of houses for a new town. Duarte wrote a grammar that generated those designs and more, and showed Siza some of the new designs. Siza's responses were more subtle than *legal* or *illegal.*[11]

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10 The rules for completing the design are given in Li (2001).
11 Paraphrased from an e-mail to me from Duarte, 15 August 2003.

- *No, it's not legal, but the difference is small.*
- *Yes, it's legal, but I wouldn't have done it, for idiosyncratic reasons.*
- *Yes, it's legal, and I might have designed it.*
- *Yes, it's legal, and I designed it.… What do you mean, I didn't design it?*

These findings help Duarte refine his hypothesis. The first, third, and fourth responses point out clearly where the grammar is and is not working. The second response, on the other hand, points out a discrepancy between what Siza permits and what he likes. Duarte now has to consider whether his grammar should take account of this distinction and, if so, how. For example, the grammar could generate both permissible and preferred designs without distinguishing them; it could generate both types, but distinguish them somehow; or it could generate only the preferred designs.

In our case with the *Yingzao fashi,* we are also making a hypothesis, but, since there is no native designer, we have to evaluate it ourselves. Consider five designs generated by our grammar (see figure 8). The first is not exactly like any in the corpus, but it is not obviously illegal either; it is probably legal. The second is in the corpus; it is legal by definition. The third is not very different from any in the corpus; probably legal. The fourth has no bays deeper than one rafter, making it difficult to use; almost definitely illegal. The fifth has a clear span, that is, a 6-rafter beam. The clear span is seen only in the 4-beam building, but the 6-rafter beam can be seen in an 8-rafter building in the corpus. Maybe legal, maybe not.

We can revise our grammar so that it does not create the illegal designs or others like them. For instance, if we think that the fourth design is illegal because there are 1-rafter beams in the inner bays, we could allow rules 3 and 9 to be applied only in the first round of beam rules. Then the 1-rafter beams would appear only in the front or back bays. In this way, we refine our hypothesis until it defines the language as best we understand it. The grammar expresses our hypothesis precisely, while still leaving us room for interpretation. This is as it should be.

Implications for teaching

This ability to formulate hypotheses about languages of designs – styles – has several implications, beginning with how to teach. It seems to me that students of the *Yingzao fashi* need to understand not only what Li Jie wrote, but also how to complete what to us in the twenty-first century is an incomplete picture. The usual analytical approach would be to present the interpretation of an expert, an interpretation which therefore is considered authoritative.

The approach I have presented, on the other hand, shows students clearly how such an interpretation is arrived at; indeed, it invites students to construct their own. They test the grammar and revise it as they see fit; they find information, interpret it, and defend their interpretations, all within a clearly defined framework. The lesson here is that style is not "out there"; it is a human construct. Style can be formalized, but it is not objective.

This approach to teaching can be enhanced by computer-based tools that support grammars. Such tools can automate the irrelevant parts of the process, such as those omitted in our examples (figures 4 and 7). This allows students to concentrate on the grammar and the language of designs that it defines.

I have been developing such a piece of software for the *ting tang* section grammar (Li 2002). Currently it allows students to create designs easily and transparently. They enjoy this and immediately want to be able to change the rules of the grammar. This is beyond the current capability of the software, but it is also a sign that the direction is promising.

Beyond building components

My explicitly grammatical approach can help create new knowledge as well. In trying to "translate" what Li Jie wrote – to create the same designs he had in mind – it becomes clear that he omitted information that we modern readers need. For example, he did not explain how to determine the grade of the building, its width in bays, its depth in rafters, or the spatial subdivision discussed above. These we may call *building-level parameters,* and we need them to describe a building completely.

It was these building-level parameters that Chen Mingda (1993) worked to clarify. Chen understood this implicitly; now we can state it explicitly. By saying precisely what Li Jie wrote, we can say – and investigate – more precisely what he did not write. What, for example, was the system for determining building-level parameters? We can characterize this in a grammar.

Beyond *ting tang* sections

At the level of the components, there is also much to be understood. In order to complete the designs explicitly, we have to specify each individual component: each column, each beam, each block. How does the form of each component vary with its context, and how are all the components assembled?

Here again, Li Jie told only part of the story. Despite all the detail he gave for forming the components of a bracket set, these were only prototypes, used in some but definitely not all cases. How to form these variants? No doubt this was the province of the builders – perhaps it was beyond Li Jie's own knowledge – but the builders must have had a method. Again, if we aspire to understand that method, we must be able, among other things, to create new (and correct) variants. Shape grammar deals directly with the shapes of objects, like building components, and so is well-suited for pursuing such a study.

Being precise about the shapes of components and buildings leads naturally to three-dimensional computer models. These are made by techniques like rapid prototyping and offer important advantages because they are "real": they have weight, they can be touched, assembled, and disassembled. Hypotheses can be tested physically.[12]

The section grammar discussed here is part of a larger grammar that creates plans, roof sections, elevations, and descriptions of *ting tang* (Li 2001). That larger grammar can be extended to include *dian tang* and "other" building types *(yu wu).* This would help us understand the relations among the three main building types.

Beyond the *Yingzao fashi*

As we know, the *Yingzao fashi* was a book of standards. Thus it is only reasonable to use it as a point of reference in examining extant buildings. However, we need a theoretical framework for examining these buildings, comparing them with the *Yingzao fashi,* and characterizing the relationships. Our computational approach offers just such a framework. It works like this.

Once we have a grammar that characterizes the language of designs defined by the *Yingzao fashi,* we have a formal reference point against which we can compare extant buildings. If an extant building can be created by the grammar as proposed, then it is a perfect example in the language of the *Yingzao fashi.* If, on the other hand, it can be created only after modifying the grammar, then the modifications characterize the difference between the building and the reference point.

If we do this for a number of extant buildings and compile all these differences, formally expressed, we can look for patterns, also formally expressed. We might look for patterns based on, say, the date or place of construction. Thus, we can understand stylistic evolution, as embodied in extant buildings, as grammatical evolution. This approach to stylistic change was first demonstrated by Knight (1994), for Greek pottery motifs.

This would help us in the three ways that we are by now familiar with. First, we could – given, say, a date, place, and function – create a legal building design. Second, if a previously unknown building is discovered, we could determine whether it is legal.

Now if our prediction is right – our design is discovered – or if a newly discovered building is judged legal – then our hypothesis is supported (though not proven, of course). If our prediction is wrong – a different building is discovered – or if we find an illegal building, then our hypothesis must be revised.

The third benefit, of course, is that we would have a unified explanation of what the text says and how that is related to extant buildings. The explanation is expressed by our grammatical hypothesis, which we can refine as relevant information comes to light, whether from fieldwork, archival study, or other types of research. Indeed, the explanation tells us where to look for information.

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12 For an example of rapid prototyping in historical study, see Sass's (2000) study of Palladio's villas. On virtual versus physical modeling in teaching the *Yingzao fashi,* see Li and Tsou (1995).

Beyond the Yuan

Liang (1984) has pointed out that in wood-frame architecture there is a significant stylistic divide at the beginning of the Ming. Thus pre-Ming buildings are associated with the *Yingzao fashi,* for example through the use of Li Jie's terminology. For the Ming and Qing, the *Gongcheng zuofa zeli* was also a standard. Thus we can use the strategy outlined above to look for patterns among extant buildings and their relations to the Qing text.

These two analyses – the pre-Ming and the Ming-Qing – can then be combined by comparing the grammars of the two texts. This could lead to a unified framework for understanding wood-frame architecture through extant buildings. If we include paintings, sculptures, and other indirect evidence, we can extend the time span even earlier.

Conclusion

These ideas about studying Chinese wood-frame architecture follow from the three significant features of shape grammars.

First, shape grammars are *transparent* or – more formally – *formal.* There are rules for reading and writing shape grammars, just as there are rules for reading and writing mathematical statements. This makes grammars – like math – off-putting to some, but it eliminates ambiguity. It becomes possible to make precise statements about buildings.

Second, shape grammars define languages, not by enumerating designs, but by showing how to create designs; they are *productive* or *generative.* Thus, we can demonstrate understanding of a language of designs in concrete ways.

Third, grammars are both *graphic* and *symbolic;* they use both the preferred medium of architects, namely drawings, and the more universal medium of symbols. Thus we can both think about buildings and represent them in the same media.

Liang emphasized these qualities implicitly. When he wrote that the *Yingzao fashi* consisted of "formulas based on principles and proportions" (Liang 1984, 358), he had his finger on the ideas of transparency and productivity. And when he produced the remarkable drawings in the *Yingzao fashi zhushi* (Liang 1983), he was following modern architectural conventions to make a graphic translation.

These three qualities are embraced by shape grammar, an analytical tool that derives from work – in mathematics, linguistics, artificial intelligence, computer programming – that has helped make ours the age of information. On the other hand, that Li Jie's work invites study with such sophisticated tools may suggest that the age of information actually began more than nine centuries ago.

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