INTERPRETATION OF IMPLICIT DESIGN KNOWLEDGE IN ARCHITECTURAL DRAWINGS INTO EXPLICIT KNOWLEDGE

SOO-HOON PARK
Hanbat National University, Daejeon, Korea.
soohoon@hanbat.ac.kr

Abstract. This paper concerns a methodology in applying architectural design knowledge to the interpretation of design concepts from architectural drawings. We formalize the design knowledge such that it plays a key role in the design interpretations that map between drawings and their design concepts. We consider this mapping, in general, as the link between design decision space and design performance space, where design variables in both spaces are examined and categorized from the drawings and concepts. Examinations on drawings are performed based on qualitative shape analysis schemes and we apply feature-based shape analysis techniques to encapsulate those design characteristics in decision space. Interpretations of design concepts through shape characteristics are based mostly on two types of symmetries, namely cyclic and dihedral groups. We use CommonLISP in analyzing shapes in design decision space and CLIPS expert system shell in illustrating simple reasoning based on those design knowledge. We select target drawings from some of Frank Lloyd Wright’s block housing plans. In this experiment we try to illustrate a valid methodology that explicitly handles some of the implicit design knowledge hidden in architectural drawings.

1. Introduction

In this paper we tried to interpret implicit design knowledge hidden in architectural drawings in terms of design variables on design behaviour as the mappings between design decision space and design performance space. We see this as the design interpretation model. As for the mappings between two types of design variable groups, we take qualitative representation formula of shapes in architectural drawings as in terms of design decision variables and the architectural design concepts such as geometrical symmetry as in terms of design performance variables. We adopted qualitative methods instead of the existing quantitative methods in representing shapes in drawings and applied feature based shape analysis methods. Considering the design concepts we examined the symmetry that forms one of the basic transformation concepts including the obvious operations of translation, rotation and reflection. We especially focused on cyclic and dihedral groups in symmetry
that are symbolized as \( C_n \) and \( D_n \) respectively. We defined formal design knowledge in terms of mapping relations between two groups of design variables in two different state spaces. We tried to formalize the knowledge using a rule-based system as explicit design knowledge because most design concepts are considered hidden in drawings as implicit design knowledge. We chose sample drawings mainly from Frank Lloyd Wright’s block housing plans and we added drawings on those building core parts to emphasize the point symmetry. The shape analysis of drawings are performed in a procedure that shapes are represented using a qualitative scheme, followed by the shape analysis procedure implemented in CommonLISP and knowledge representation and reasoning are illustrated using CLIPS expert system shell.

2. Methodology

2.1. QUALITATIVE SHAPE REPRESENTATION AND FEATURE-BASED SHAPE ANALYSIS

Qualitative shape representation scheme is a kind of compliment to the existing quantitative methods, in which a shape is represented by a series of symbols. The main difference is that the symbol represents not a single value but a range of values as a representative class. Shapes are qualitatively represented on singular nodes with qualitative codes (Q-codes) and featural characteristics of shapes are encapsulated by those Q-codes. Qualitative codes are formulated in terms of \( 'Q', \Rightarrow \{ \text{Character} \} \{ \text{symbol} \} \). ‘Character’ describes the shape characteristics of ‘inner angle’, ‘relative length of edges’, ‘curvature’ and ‘convexity’ measured at singular nodes and it is depicted by ‘A-’, ‘L-’, ‘C-’ and ‘K-’ codes respectively. ‘Symbol’ encodes the landmark and range values at singular nodes and it is represented, in general, with sign symbols with \{ -, 0, + \}. Thus the Q-code representation of shapes is considered the class representation method because one Q-code encapsulates the shape characteristics not by 1:1 but by 1:N ways. The representation and analysis are performed according to a procedure implemented in CommonLISP language such that firstly, shape representation formulas are formed as strings of Q-codes; secondly, shape features are extracted from the shape representation formulas by patter matching algorithm, thirdly, shape features are classified according to syntactic regularities into several shape feature categories; and finally, shape characteristics are analyzed with a sequence of processes and methods. We call this feature-based shape analysis method. Figure 1 illustrates the CommonLISP program extracting the shape feature patterns from the shapes in architectural drawings.

Those patterns are considered as ‘words’ that work as units encapsulating the specific geometric characteristics from the whole shape. The apparent syntactic regularities show several categorical patterns so that they are classified into shape
feature categories, namely alternation (A), iteration (I) and symmetry (S). They play a role as phrases where alternation shows repetition of words at irregular intervals, iteration showing repetition of words at no interval and symmetry showing palindrome type of word repetitions. In addition, a sentence is considered to be a complete and closed shape such that the hierarchy of ‘word-phrase-sentence’ works as an analogy with which shapes in architectural drawings are analyzed.

2.2. SYMMETRY CONCEPT FOR SHAPE REGULARITY

Architectural drawings are the most important communication media for design knowledge, that contain many geometric cognitive concepts of shapes architects have long manipulated. One of the conceptual tools that architects and designers adopted in analyzing and conceptualizing shapes is a transformation against the prototype shapes. The transformation mappings between the original and the transformed are established as the following six relationships in Table 1 (March and Steadman, 1971).

Amongst these relationships ‘symmetry’ concerns the geometrical relationships where isometry relation is maintained between the original and the transformed.

TABLE 1. Six relationships between the original and the transformed.

<table>
<thead>
<tr>
<th>Relationships</th>
<th>Geometric characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identity</td>
<td>All constraints including position, length, angle and ratio, parallelism, cross-ratio and neighbourliness conditions are preserved</td>
</tr>
<tr>
<td>Isometry</td>
<td>Position condition is relaxed</td>
</tr>
<tr>
<td>Similarity</td>
<td>Length condition is relaxed</td>
</tr>
<tr>
<td>Affinity</td>
<td>Angle and ratio condition is relaxed</td>
</tr>
<tr>
<td>Perspective</td>
<td>Parallelism condition is relaxed</td>
</tr>
<tr>
<td>Topology</td>
<td>Cross-ratio condition is relaxed</td>
</tr>
</tbody>
</table>
Symmetry, when it is examined in terms of translation, rotation and reflection as major operations, is considered mostly as in three-steps such as point-symmetry, line-symmetry and plane-symmetry, however, when it is examined in more detail it is grouped in the following four steps (March and Steadman, 1971, pp. 56–86).

- Cyclic group: $C_n$ group is the shape group showing symmetrical regularity for a point where the original rotates $2\pi/n$ for a centre point and the transformed shows the identical shapes with the original.
- Dihedral group: $D_n$ group is the shape group that shows the symmetrical identity for a point where the original is reflected by axes in $n$th time crossing a centre point and the transformed shows the identical image with the original. There are seven types in this dihedral group.
- Frieze group: $F_{m,n}$ group includes the symmetrical shape groups where translation in one direction is applied to $C_n$ and $D_n$ shape groups.
- Wallpaper group: $W_{m,n}$ shape groups include those symmetrical shape groups where translation in two or more directions are applied to $C_n$ and $D_n$ shape groups. There are seventeen types of such wallpaper groups.

This paper examines single shapes on architectural plans. We took the rotation and reflections in $C_n$ and $D_n$ except the planar translation in observing the target drawings. We tested if we could interpret some geometrical characteristics by the shape analysis of words and phrases in shape features for those qualitatively encoded shapes.

2.3. SAMPLE SHAPES TO ANALYZE

This paper examines Wright’s block housing plans in Figure 2. Nine typical floor plans and four of those core shapes are taken to be analyzed. Drawings include: (a) Quadruple block housing I 1903, (b) Quadruple block housing II 1903, (c) Larkin workers housing 1904, (d) St. Mark’s tower 1929, (e) St. Mark’s tower core part 1929, (f) Chicago towers 1930, (g) Chicago towers core part 1930, (h) Crystal heights 1939, (i) Crystal heights core part 1939, (j) Suntop houses 1940, (k) Pittsfield housing 1942, (l) Price tower 1952, (m) Price tower core part 1952 (Laseau and Tice:1992).

3. Analysis and interpretation

3.1. SHAPE ANALYSIS RESULTS

Every thirteen shapes in drawings follow the shape analysis method such that shapes are qualitatively represented, shape features are extracted as words and classified into shape feature categories as phrases and shape characteristics are analyzed.
Figure 3 illustrates the length-occurrence charts of words and phrases in alternation, iteration and symmetry shape feature categories. The axes of the charts are occurrences to lengths and one of the important findings is that the occurrence value converges to a certain number as the length of words increases. We could attach a certain meaning to this convergence value that it has something to do with point symmetry cases of \( C_n \) and \( D_n \). Figure 4 illustrates the examples of (a) and (b) where there are two axes of \( D_2 \) and \( 2\pi/4 \) of \( C_4 \) respectively.
3.2. INTERPRETATIONS OF SHAPES

Interpretation as one of the design activities is conceived as an activity in which designers observe a design description and extract design performances from it. Applying this to architectural drawings, we could generalize such that extracting the design meanings—the semantics—from the syntax of shapes in drawings. This is done by examining the shapes in drawings to find out the design decision variables and by mapping them to design performance variables as illustrated in Figure 5.

This type of mapping is applied in formulating the interpretive design knowledge so that concepts on shapes as implicit knowledge hidden in architectural drawings can be transformed into more explicit design knowledge to be manipulated. In order to do this, design decision variables in design decision space or in design description space should be established and design performance variables in design performance space should be defined as follows (Coyne et al., 1990).

\[ D = \{ d_1, d_2, d_3, \ldots, d_m \} \]
\[ P = \{ p_1, p_2, p_3, \ldots, p_n \} \]

From the mapping relations of these variable groups design knowledge is defined in the following mappings.

\[ K_i: \text{IF} <d> \text{ THEN } <p> \]
\[ K_g: \text{IF} <p> \text{ THEN } <d> \]
Interpretive and generative design knowledge is formally defined as $K_i$ and $K_g$. Moreover, any performance variables are classified either as expected performance variables or as actual performance variables. They include performance variables which the designer expects before the design description is formed and the designer discovers after the design description is established. The comparison of these two types of performance variables can therefore be formulated into design evaluation knowledge. In this paper we considered the design formula represented by Q-codes as a design description and the design performances as geometric concepts of shapes interpreted from the design descriptions. We examined these mappings as interpretive design knowledge.

3.2. INTERPRETATION OF SHAPES

The class hierarchy for the design decision variables and performance variables in CLIPS environment is shown in Figure 6. The plan as the super-class of two design variable classes is a sub-class of those classified for the projection types and there are distinctions between the drawings and documents. As illustrated in the previous figures, various mappings between design variables are defined as design knowledge.

![Class hierarchy for design variables.](image)

Figure 7 illustrates a procedure that decides the symmetry as an expected performance using a ‘symmetry-interpretation’ rule.
Table 2 shows the interpretation results of expected performances in the CLIPS environment and the comparison with the observations of the actual performances. Wa, Wi, Pi, Ws, Pe, and Pa describe words (W) and phrases (P) of Alternation, Iteration and Symmetry categories, expected performances (Pe) and actual performances (Pa) respectively. The results in Pe and Pa for the geometrical symmetry as the implicit design knowledge in architectural drawings are interpreted as follows.

<table>
<thead>
<tr>
<th></th>
<th>a</th>
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<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
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<th>h</th>
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<tbody>
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<td>Pₑ</td>
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<tr>
<td>Pₐ</td>
<td>D2</td>
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<td>C4</td>
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<td>C1</td>
<td>C1</td>
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</tbody>
</table>

- We produced the ‘expected symmetry’ as an expected performance in CLIPS environment using the iteration phrases and symmetry words. We however could only interpret the results in terms of cyclic groups of rotational point symmetry.
- Therefore, the reflective point symmetry of dihedral groups are described in terms of cyclic groups admitting that dihedral groups are inclusive to the cyclic groups.
C₁ describes a shape without any symmetrical characteristics.

In the case of shape d, the expected performance shows C4 with the convergence value ‘4’. However, the actual performance turns out to be C2 when you observe shape d. This is due to the Q-code granularity such that {-, 0, +} sign values are basically assigned to the landmark values of 0 and δ so that both acute and obtuse angle ranges are represented by an ‘a-’ code. The qualitative representation scheme depicts the transformation not in identity, isometry, nor similarity but in affinity level resulting C4 performance by the CLIPS interpretation. In order to correct this, we could improve the Q-code granularity from the landmark sets of [0, π] to [0, π/2, δ, 3π/2]. This would properly result in C2.

4. Discussion

In this paper, we examined the Frank Lloyd Wright’s block housing plans and applied qualitative shape representation and feature-based shape analysis methods. The shape representations are considered as design decisions that are mapped to design performances of geometrical symmetry. Implicit design knowledge in drawings is formulated as explicit rules in CLIPS expert system and simple reasoning has been tested. It is intended in this experiment that the representation and analysis technique are tested to be valid such that the understanding of shapes becomes possible using qualitative symbols. This would increase the utility of computing power in its design-related applications.

In this experiment, we focused on the fact that the convergence number of words and phrases has specific design meaning so that we related this in decision space to the design performances to formulate interpretive design knowledge. We tried to prove the correlations between the convergence number and the point symmetry of cyclic groups even though this does not efficiently reason about those of dihedral groups. When this methodology and results are applied to the search and exploration tasks of drawings, it would need no indexing information by reasoning the geometric characteristics and could possibly be applied in comparing the similarity of a group of drawings. It would also prove to be useful in extracting knowledge about design cognitive aspects related to graphic information.

Acknowledgements

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References