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Symmetrization of facade layouts

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ABSTRACT

We present an automatic approach for symmetrizing urban facade layouts. Our method can generate a symmetric layout through minimally modifying the original input layout. Based on the principles of symmetry in urban design, we formulate facade layout symmetrization as an optimization problem. Our method further enhances the regularity of the final layout by redistributing and aligning elements in the layout. We demonstrate that the proposed solution can effectively generate symmetric facade layouts.

1. Introduction

Symmetry refers to a sense of harmonious and beautiful proportion and balance [1]. It is ubiquitous in nature, science, and arts. In this work, we are interested in the symmetry exhibited in urban facade design.

In consideration of physical balance, aesthetic attractiveness, and construction costs, facade designs usually make extensive use of symmetry. These traits are presented in many kinds of architectures across different cultures and time periods (Fig. 1 shows two such examples). In computer graphics, symmetry has become a key ingredient for facade modeling [2–4], high level structural analysis [5], and manipulation [6]. However, when digitizing existing symmetric facades (e.g., extraction of facade layouts), errors are unavoidably introduced during the digitization process. Thus, it required to restore the symmetry faithfully to better represent the underlining layouts. By doing so, the visual quality of the facades' appearance could be improved, and the underlining description of the facades could also be greatly simplified. Other applications, such as changing an existing facade design (i.e., generating a new symmetric design from the original asymmetric design), generating facade variations from an existing layout, etc., could also benefit from symmetrization. In this paper, a layout of a facade refers to a two-dimensional arrangement of the facade's elements (e.g., windows, doors and ornaments).

Extracting and symmetrizing facade layouts is a challenging problem. Directly manipulating a facade image is difficult due to the lack of a reliable automatic, accurate, and robust facade segmentation tool. In our work, we are not interested in extracting layouts from facade images. Instead, we are more interested in the symmetrization problem itself. Therefore, we simplify the data acquisition process by using the labeled rectangles on the facade images as input to our system. These rectangles can be seen as the initial layouts of the facades. In literature, quite a few techniques have been proposed to address symmetry detection [7–9], and symmetrization [10] of geometric models. These works are based on the observation that sufficient samples can be easily obtained to recover the symmetry of the models. Unfortunately, existing approaches neither are applicable, nor can be extended for symmetrization of urban facade layouts due to the sparsity of facades' content. Symmetry is simple in terms of transformation types (e.g., reflectional, translational, rotational, helical, scale, and

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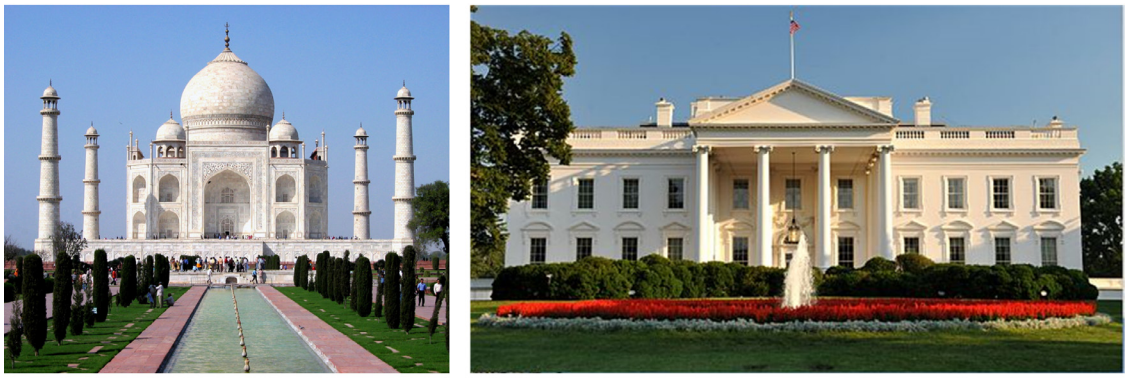

Fig. 1. Two examples of symmetric facade design. (a) Taj Mahal; (b) White House.

the combination of the above). However, the complexity of relationships between facade elements makes this problem non-trivial. To the best of our knowledge, there is no work addressing the problem of automatic symmetrization of digitized facade layouts.

We present a method for automatic symmetrization of irregular facade layouts. Since there is no closed-form solution for the symmetrization problem. We search for a symmetric layout by minimizing the designed objective function. Specifically, we employ the simulated annealing algorithm to get an approximate optimal solution. Then, we improve the visual appearance of the facade layout by redistribution and alignment operations in order to make the layout more regular. Our results demonstrate our algorithm is effective in symmetrizing facade layouts.

In summary, the main contributions of this paper are as follows:

- An intuitive approach for symmetric structure detection in facade layouts.
- A new optimization framework for facade layout symmetrization based on an effective objective function and several editing operators.
- A novel method to improve the regularity of the layout based on redistribution and alignment of facade elements.

2. Related work

We briefly review the most related approaches to our work. The reader is referred to a recent survey [11] for more details on urban modeling.

Facade modeling. Grammars are widely used in facade modeling, e.g., CGA shape grammars [12]. In specific cases, the grammars can be extracted from a facade image [13]. Structural analysis is another type of the facade layout modeling [2,5,14]. These approaches concentrate on the high-level semantic information. The split operation [15] and layering operation [5] are chosen to generate the hierarchical segmentation of the existing facade layout. During this procedure, some consensuses of the facade, such as the symmetry and regularity, are used to formulate the constraints to guide the segmentation and synthesis [2]. However, our work aims at generating new symmetric and regular facade layouts from the existing irregular inputs.

Layout design. Layout design can be formulated as an optimization problem with specific criteria. For example, furniture layout design is resolved by optimizing the cost function with the functional and visual constraints [16]. The prior knowledge of facade layout design can be specified as cost terms [16,17], or guided by the user's interaction [18]. The potential structural relations of the existing layout can also be inferred by the Bayesian network from the real-world data [19]. Bao et al. [18] divide the constraints into hard and soft ones. Ma et al. [20] use configuration spaces and a graph-decomposition based layout strategy to steer the solution toward feasible layouts. However, the layout constraints usually involves non-differentiable variables. Thus stochastic optimization is used to generate a pleasant layout. Jiang et al. [21] propose to detect constraints in the layout by an integer programming approach. The Metropolis criteria is preferred for its simplicity and effectiveness [19]. So we apply *Simulated Annealing* (SA) to our optimization problem.

Symmetry analysis. Symmetry and regularity of object layouts can make the shape captured by human more easily. Any symmetry in a design reduces the amount of information necessary to specify shapes, thus it minimizes the entropy of the object layout [22]. A compact representation of the Euclidean symmetry can be extracted by matching local shape signatures and clustering [7], while the symmetrization of the geometric objects can be achieved by an optimization process [10]. In our work, we only consider the reflectional symmetry of a set of boxes, which is a discrete optimization problem. In our scope, this is not involved in the previous works.

3. Overview

3.1. Definitions

Structural abstraction. Given a facade image **I**, we can abstract the elements $\{e_1,\ldots, e_n\}$ in the facade layout **L** by a