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Review article

THE INTERACTION OF SIMPLE STATES IN COMPLEX ARCHITECTURAL RECTANGULAR SHAPES

Nuran Saliu[1*], Egzona Zendeli Vejseli[2], Kujtim Elezi[3], Andrea Maliqari[4]

[1, 2,3] Department of Architecture, Faculty of Applied Sciences, University of Tetova
[4] Faculty of Architecture and Urbanism, Polytechnic University of Tirana
**Corresponding Author: e-mail: nuran.saliu@unite.edu.mk*

Abstract

This research explores simple states of architectural shapes as a primary generator for the development of a technique for computational design. This paper gives an overview and examines in-depth the interaction and the logic between simple states, and their dominance based on daylit qualities they offer in articulated shapes of built forms. Simple states can exist as both dimensional and non-dimensional shapes, and their ability to keep intact the topological and dimensional qualities of architectural shapes can contribute to developing tools and methods for analysis and synthesis in architectural practice. An analysis of different case studies of different building types with an emphasis on hospital buildings is presented in this paper and their respective simple states are discussed.

Keywords: simple states, interaction, logic, dominance, computational design

1 Introduction

Of the three main discourses of architecture: form, function, and space, it is that of form that is one of the most difficult to bring into a classification analysis (Markus, 1987), and therefore, the most difficult to find rules and laws or computational methods that govern the form and can help create generative tools and computational methods to harness the capabilities of computers to aid in the initial design processes. In this matter, these computational strategies are based on identifying formal features of problem-solving (computationally efficient) and do not always require the use of a computer (Terzidis, 2006).

Several techniques have been created that try to automate certain design processes, including form, techniques, and methods which remain only in academic circles and are very difficult to use by the ordinary professional architect. The most famous, shape grammars present such an approach. Pioneered by Stiny and Gips in the early 1970s, shape grammars offer a rule-based approach that generates architectural designs through a set of predefined rules through transformations and relationships between parts and the whole. Samples of shape grammar applied in architecture include the Palladian Grammar developed by Stiny and Mitchell (1978), Flemming (1981) similarly develops parametric shape grammar to analyze the rules of architect Giuseppe Terragni's Casa Guiliani Frigerio; Koning and Eisenberg (1981) generate compositional forms and specify functional areas of Frank Lloyd Wright's scaled houses and of the first three-dimensional shape grammars applied in this period ; Buelinckx develops shape grammar for the generation of Christopher Wren's city churches; Terry Knight (1981) generates Japanese tea rooms; Downing and Flemming (1981) reveal house building rules and conventions of 1914-1926 in Buffalo, New York; Flemming (1987) also develops the Queen House grammar; Chiou and Krishnamurti develop traditional Taiwanese houses; Stiny and Mitchell (1980) generate mogul gardens; Çagdas (1996) reveals and clarifies the compositional rules of typical Turkish house floors developed during the last five centuries based on the typologies selected by the Turkish modernist Sedat Eldem; Colakoglu (2000) discovers compositional principles of Ottoman huyat houses in Sarajevo built between 18th and 20th centuries and through transformations of variables she generates prototype houses of the same style; Duarte (2001) generates concentrated houses based on Alvaro Siza’s compositions of houses in Malagueira etc., (Saliu, 2018).

Kalay (2004) points out that working with shape grammar in the synthesis of architectural shapes and forms depends more on good knowledge of shapes and the rules that form them rather than having computational capabilities. Otherwise, applying the rules arbitrarily leads to the generation of an infinite number of meaningless configurations of shapes and forms. (Kalay, 2004). Form generation in architecture is a complex process that involves the creation and exploration of various design options to develop the desired architectural form.

Other techniques and methods oriented towards form generation include cellular automata, parametricism, performance-driven generation of form, etc. The idea to contribute to the creation of computational techniques and methods to use the capacities of computers in the generation of architectural ideas has often been oriented more towards the creation of computer programs rather than the study and analysis of architectural forms and the finding of their compositional rules.

Generation as a design tool should be *redirected towards design explorations* and the development of alternatives and variants that consider only *selected aspects of design.* This would empower design creativity instead of only providing subjective answers to a simplistic problem (Kalay, 2004). Mitchell, Ligett, & Tan (1989) support the idea of stepwise refinement of a schematic idea into a complete and detailed design, similar to compositional rules developed in Beaux-Arts with the seminal work of Durand and his architectural design techniques which begins with highly schematic parts and progresses through series of refinement steps (Figure 1).

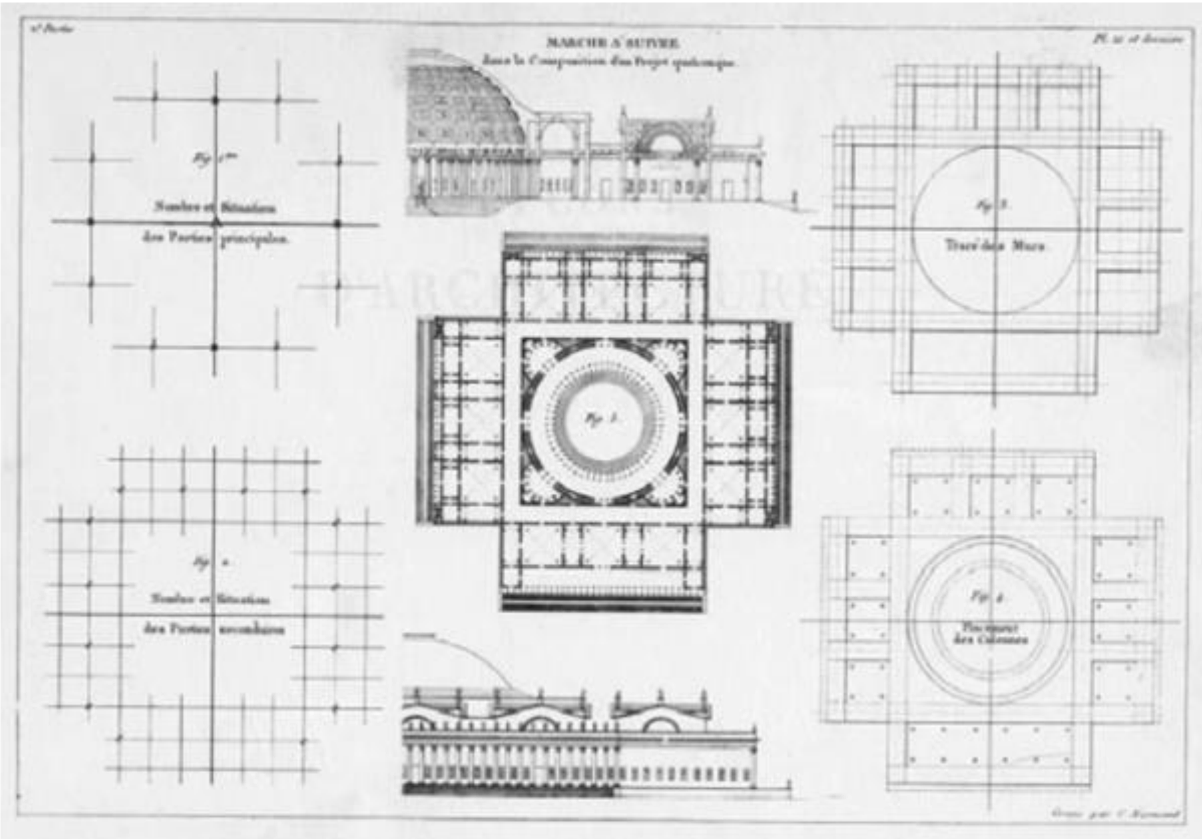
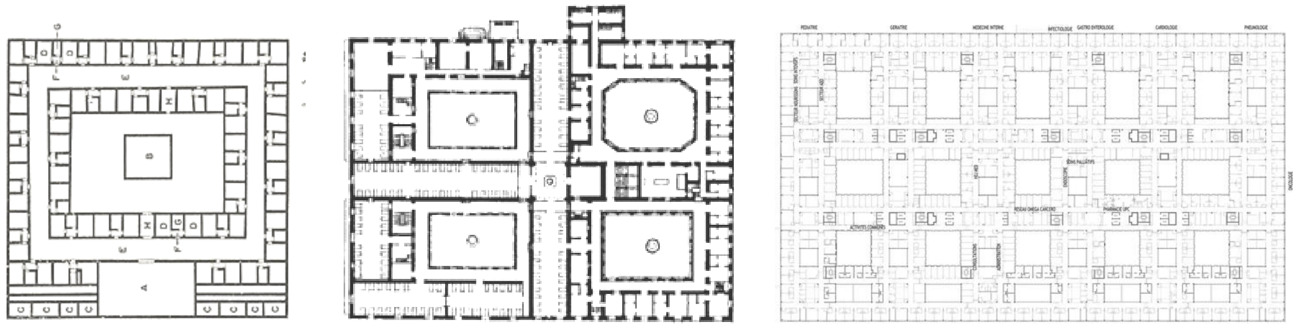


Figure 19. Durand's method for refinement of plan schemata (source: Klitsie, 2015)

In this paper, a new design exploration and a new grammar for complex rectangular shapes are presented based on simple states of shapes.

2 Simple states of shapes

The same types of buildings, according to Markus (1987), are usually governed by a set of rules drawn from the social practices formed in the building. This set of regulations will also regulate the aspects of other similar local construction. Figure 1 presents an even more complete overview of this definition. Three types of the same type of building - hospitals, with the same geometric shapes (with courtyards) expressing the same configurational characteristics in terms of spatial distribution and connectivity. Two main elements that always accompany buildings, are spaces, and the necessity to connect spaces (connectivity), despite the increase in the complexity of the hospitals due to the increase in the requirements for more spaces, they remain in the same configuration. Spaces that are distributed in the perimeter of the building and within the courtyard perimeter, are connected with corridors that follow the geometry of the shape of the building and courtyards.



(a) *(b)* *(c)*

Figure 20. Floorplans of courtyard hospitals evolved during history: a) roman valetudinarium in Vindonisa (1st century); b) Los Reyes Hospital (16th century) and c) Centre Hospitalieur in Marne La Ville (21st century) (source: Saliu, 2018)

Proven by this, the geometry of objects seems to be able to provide more than aesthetic information in architecture. For this, a deeper exploration into form, geometry, and the different configurations of forms to understand the connections that stand in terms of geometric primitives would give a better insight into the laws that exist at the center of the different configurations and then in the possibility of creating mathematical models that could help in the creation of computational techniques and that the same could be translated into computer models.

The initial shape of massing constitutes the primary form of any architectural idea and consists of multiple combined lines that form a closed planar shape. This shape determines the topological qualities of the form, perimeter, surface area, dimensions, and constituent simple shapes. Breaking down the shape even further would bring out its primitives. So each shape: a) consists of combined primary and simple shapes that are arranged accordingly; b) each of these simple shapes is characterized by a certain 'state' to other constituent simple shapes and c) the combination of these simple shapes determines the logical structure (logical construct) of each form and allows the possibility of bi-directional development during the design processes (descriptive-analytical-synthetic and vice versa). (Saliu, et al., 2020)

We have identified five unique 'simple states' (Figure 3) that constitute every possible complex rectangular shape. Since the aim of this study is articulated and complex shapes, i.e. shapes constructed of multiple simple contours, self-existing or isolated simple shapes will not be considered as 'simple states'.

The first state **(A)** represents a simple shape that is attached just to one side to another shape. This means that the other three sides of this shape are opened and day-lit (Figure 3-a). The second **(B)** and the third **(C)** states of simple shapes are free and opened by two sides and attached with other shapes by the other two sides accordingly - linearly attached for state **B** and in angle for state **C** (Figure 3-b-c). The fourth state represents a shape that is opened and day-lit only on one side while the other three sides are attached to other shapes. And, finally, the fifth state **(E)**, represents a simple shape that is attached by all sides with other simple shapes (Figure 3-d-e).

These 'states' are direct interpretations of shapes and forms and they convey logical information about the shape such as direction, connection, relations, and illumination. These qualities are both dimensional and non-dimensional so they can be preserved also as dimensional and non-dimensional structures. (Saliu et al., 2020)

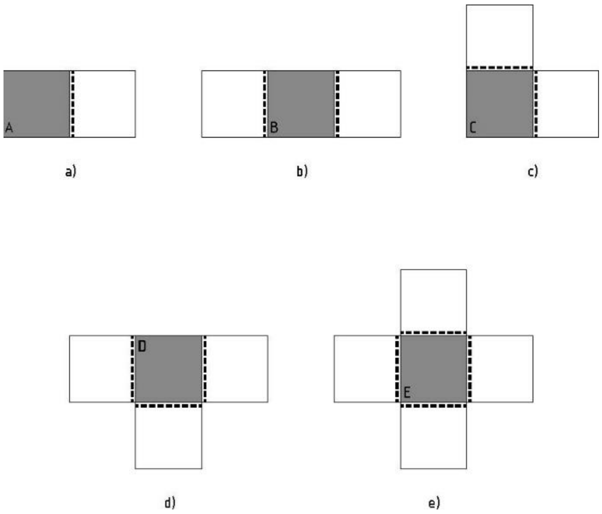


Figure 21. Five 'simple states' of shapes (source: Saliu, 2018)

3 Interaction and dominance of the simple states – a new meta grammar

Based on D'Arcy Thomson's logic, an architectural form can be viewed as the result of the interaction of external and interior forces. The environment is the fundamental parameter of the external factors that intervene in the form's manifestation. Adaptation to the given environment is employed as a major aspect (together with the official urban planning parameters of the site) to evolve the architectural form based on the abstract descriptions between the design parts during the design process.

Given this, the interaction between states will have to take into account both external and internal forces. The external forces in this situation would mean natural lighting in the interior spaces (daylit quality) while the internal forces in the simple states will be oriented towards the minimum requirement for connection between the states respectively between the internal spaces.

Let us assume a state (0) of simple forms (Figure 4. a). State (0) represents an isolated and self-existing object. Since the qualities of the object are intact, the object does not tend to impose itself on other objects since there is no definite connection with another object. Thus, the object is non-imposing and non-dominant.

In a second situation (Figure 4. b), let us assume two states (A) that tend to connect. The states present contours of objects with the same qualities in terms of their daylit qualities. Each of them will tend to impose the solution on the other.

In a concrete situation, we cannot encounter two states (A) since both would produce a single state (0), i.e. an isolated state. Similarly, in the case of combining three states or simple contours (A+B+A), the situation begins to be better understood. Since the two conditions (A) present the potential for more qualitative spaces in terms of lighting, they impose the solution in the simple state (B). Thus, they dominate over condition (B) (Figure 4. c). That is, state (A) is dominant over state (B).

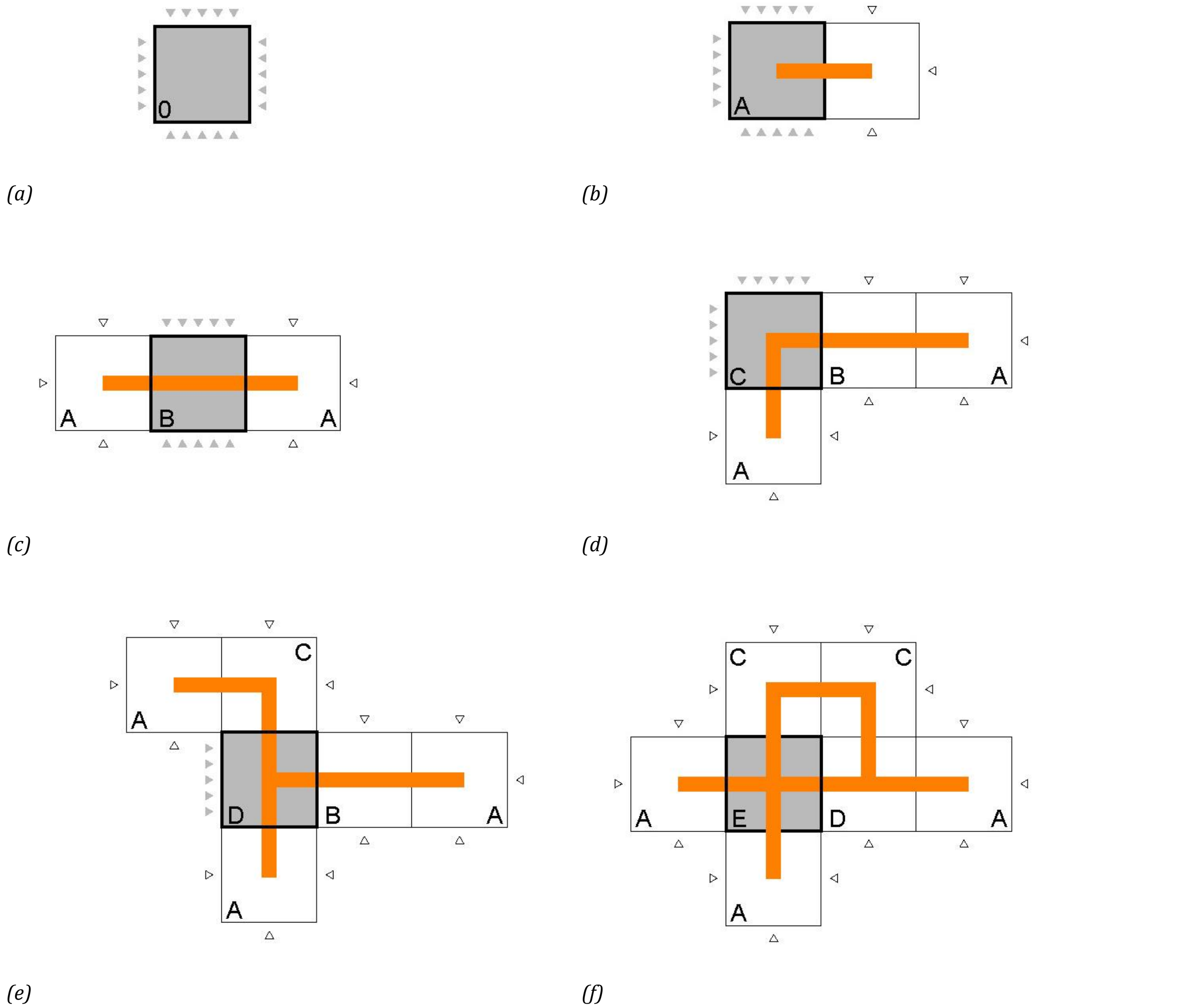


Figure 22. Interaction and dominance of simple states based on daylit qualities and minimum requirements for connection (source: Saliu, 2018)

In Figure 4.d we have the case of the combination of four states, two states (A), one state (B), and one state (C). Since the quality opportunities are smaller in state (C) compared to the other two states, state (C) is dominated by both state (A) and state (B). If we continue with the same logic of interaction of states for the following two situations, we can observe that in general, the dominance of states continues to follow the logic of qualities, so states with lower qualities are constantly dominated by states with higher qualities (Figure 4. a-f). On this basis, we create a complete overview of all possible states: A->B; B->C; C->D; D->E or A->B->C->D->E.

In observations made for multiple complex rectangular shapes of different types of buildings, it has been determined that, states A and B are the dominant states and are present in all possible configurations of rectangular shapes, together or separately. They act independently of one another and the flow of information is unidirectional towards simple stater C, D, and E.

Because of their ability to preserve logical and dimensional information, simple states can exist in both dimensional and non-dimensional states (Saliu, 2018). They can act as intermediates between the dimensional and non-dimensional worlds. In terms of computation, this will enable the establishment of two search spaces inside the overall design space. Non-dimensional search spaces can encode logical operators such as regulating lines, adjacency, and orientation, while dimensional search spaces can encode dimensional transformations and parameters. (Saliu et al., 2020). In this way, the refinement of the project will follow steps that will be interdependent between the two search spaces (Figure 5). In Figure 6, a sample of the system is presented in three hypothetical complex rectangular shapes for horizontal hospitals. Once the massing is presented to the algorithm (either by direct drawing or generated), the identification of simple states is done by the system as a logical operator, and non-dimensional simple states are constructed. This way, since the non-dimensional construct is fixed, we can code logical pieces of information within it. The next step in the process, finding the optimal surface area for the given hypothetical shapes was done with an evolutionary algorithm (in this case since the experiment was carried out in Grasshopper software in Rhino, Galapagos was used as a generic evolutionary algorithm). It used logical pieces of information (i.e. relations between simple states, and sectors of the hospital) from non-dimensional constructs to search for the optimal surface area of the shape in the new dimensional construct. In this way, the two design worlds within the software are generated and the following steps are done interdependently.

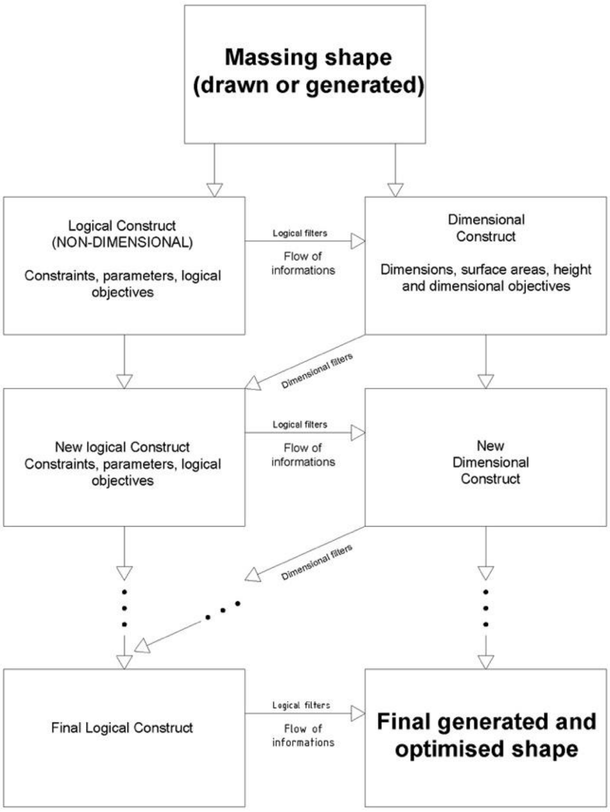


Figure 23. Diagram of interaction between non-dimensional search space and dimensional search space (source: Saliu 2018)

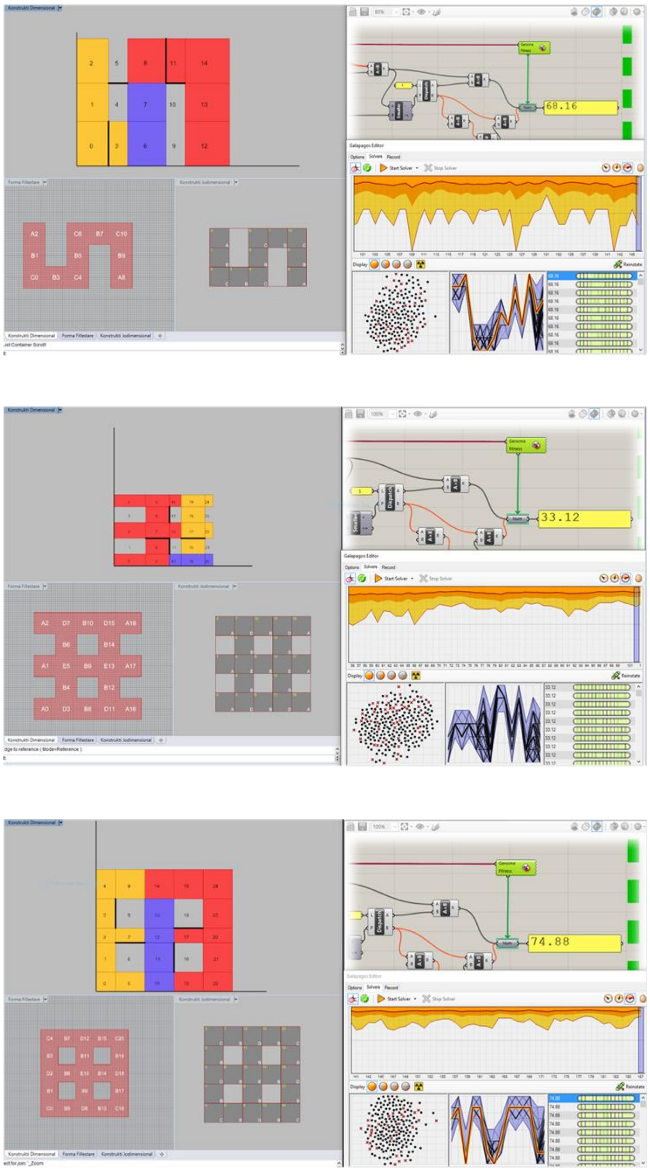
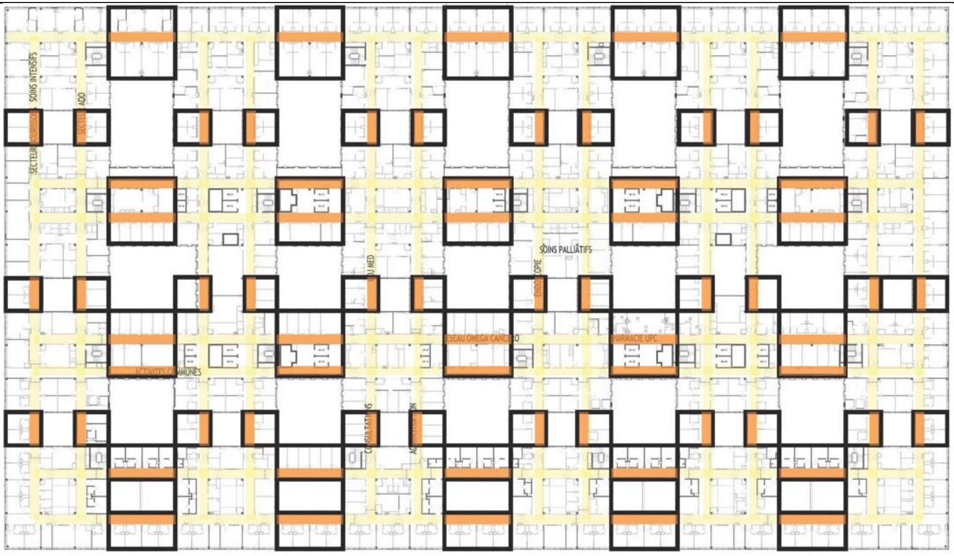


Figure 24. Optimization of a massing based on simple states for three hypothetical complex shapes of a horizontal hospital with three main sectors (source: authors)

4 Simple states in complex rectangular built architectural shapes

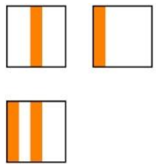
The dominance of simple states A and B can be observed in the following three types of buildings chosen for this paper as case studies: hospitals, schools, and offices. States A and B in each of the case studies are highlighted with bold black lines, meanwhile, the connectivity or interaction between dominant A and B states and the dominated C, D, and E states with orange and yellow highlighted lines respectively. The case studies presented are dimensional constructs and final products of simple states in real-built complex rectangular shapes (Figures 7, 8, and 9).

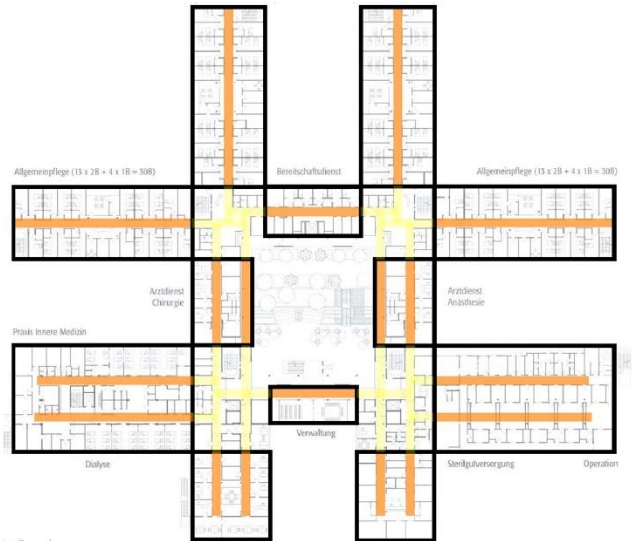


Centre hospitalier de Marne-la-Vallee (source: AMC – Le Monituer Architecture, March 2013)

Courtyard Hospital

Multiple dominant B simple states

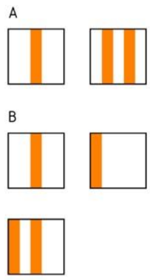


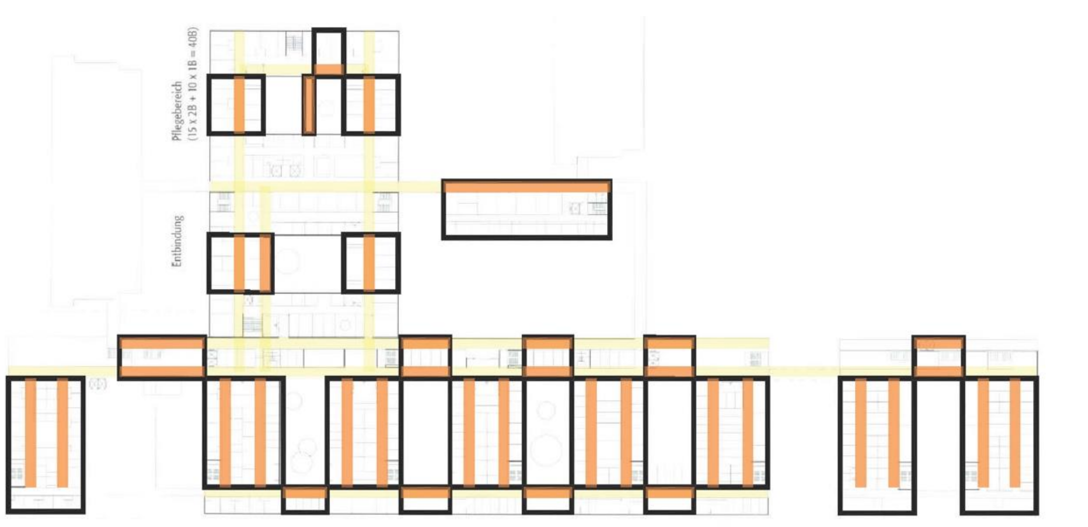


Helios Klinikum Gotha, Germany (source: Meuser & Schirmer, 2006)

Articulated Hospital

Dominant A and B states





Universitatsklinikum Halle-Krollowitz, Germany (source: Meuser & Schirmer, 2006)

L shaped with courtyards Hospital

Dominant A and B states

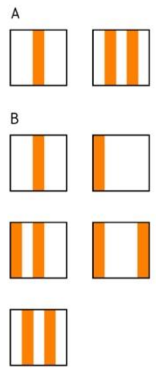


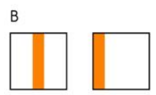
Figure 25. Dominant simple states A and B found in hospital buildings with complex rectangular shapes (source: Saliu, 2018)

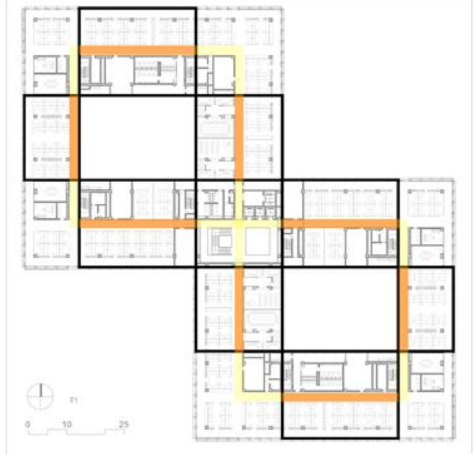
Elementary school in Lebbeke

(source: divisare.com)

Courtyard Hospital

Dominant B simple states

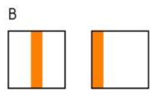


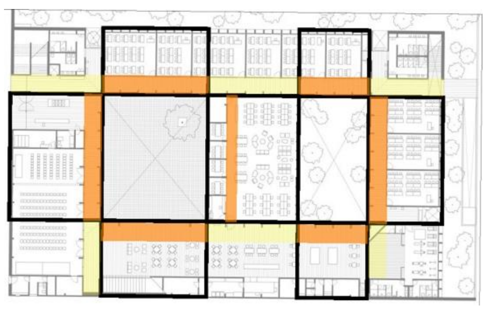


Huawei technological building (source: archdaily.com)

Courtyard Office building

Dominant B simple states



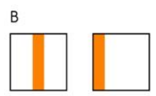


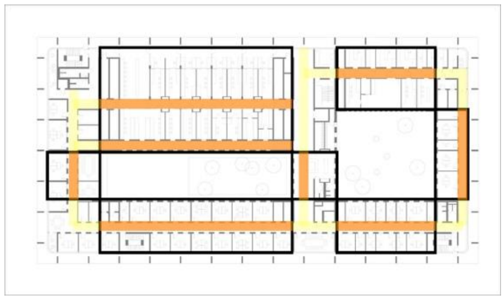
Escuela Bancaria Y Comercial in Aguascalientes

(source: divisare.com)

Articulated Hospital

Dominant B simple states





Geo and Environmental Centre (source: divisare.com)

Courtyard Office building

Dominant B simple states

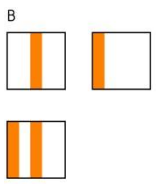


Figure 26. Dominant simple states A and B found in school buildings with complex rectangular shapes (source: authors)

Figure 27. Dominant simple states A and B found in office buildings with complex rectangular shapes (source: authors)

5 Interaction in non-dimensional simple states

According to Saliu et al. (2020), dimensional aspects are closely linked and imposed by the space requirements of a building program which designers try to solve in a later stage of the design process. Consequently, keeping relational aspects of shapes establishes a key factor in the initial steps of the process. We can proceed with the strategy from a non-dimensional world because all the logical and relational operators would be present without exception (Saliu, et al., 2020).

Following this, the necessity to maintain connections between simple states in a non-dimensional construct must be achieved within the logic of simplification and minimal requirements. To achieve this, non-dimensional states are placed in squares of 3X3 (, which fulfills the condition of creating daylit spaces and minimal connections between states. Additionally, finding all possible combinations of interaction between non-dimensional simple states was done subsequently, and a vocabulary of 'cuboids' was created (Figure 11 presents cuboids for simple states A and B). These quboides were encoded in the non-dimensional space and all possible combinations were obtained and encoded for all non-dimensional simple states. Thus, an interplay between the dimensional construct (Figure 6) and the non-dimensional construct (Figure 11) is conducted during the refinement process. The non-dimensional construct takes information from the dimensional construct - in the first steps, for example, it takes the transversal section of simple states A and B and their transversal measurements and automatically places cuboids in the non-dimensional construct (Figure 12) according to their dimensional interpretations (Figure 13). In this way, a top-down approach is conducted and the user can interplay with the proposed system in real-time if a solution is not satisfactory.

Dominant simple states *Dominated simple states*

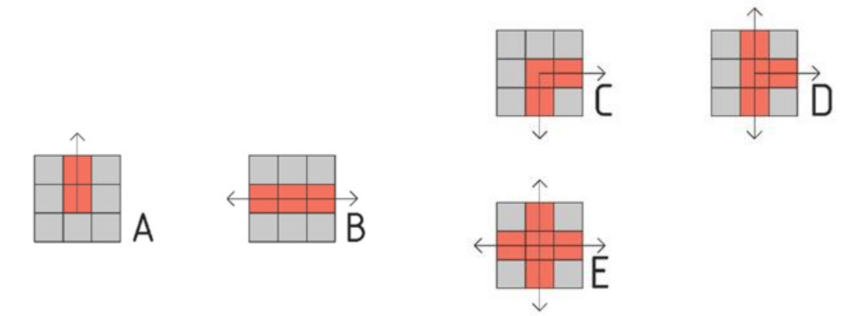


Figure 28. ***Non-dimensional simple states with their minimal interaction requirements.***

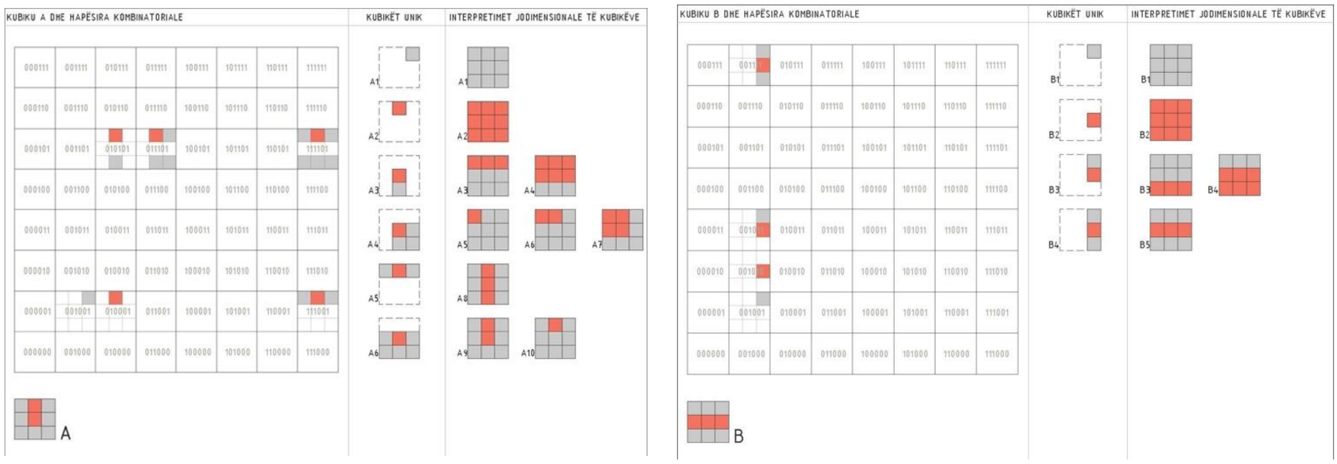


Figure 29. All possible combinations for connectivity of non-dimensional simple states A and B and their respective cuboids

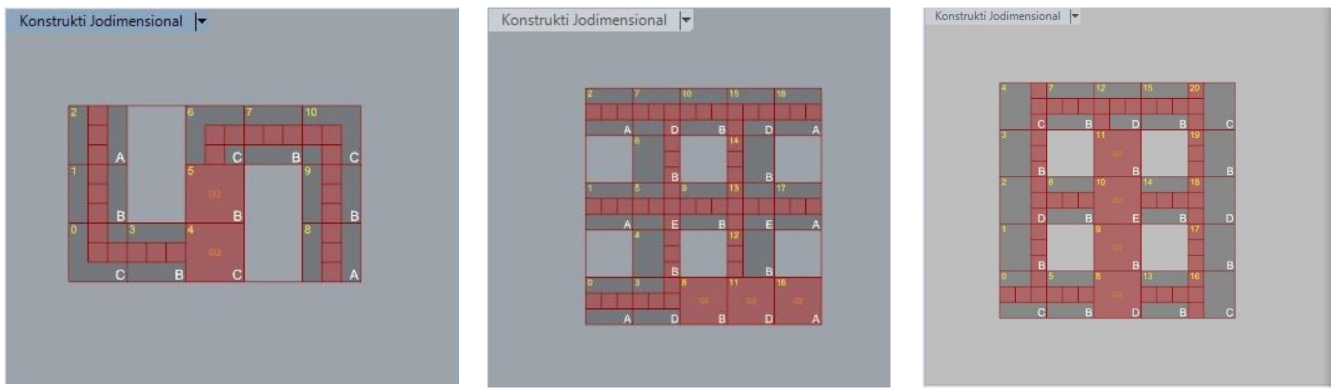


Figure 30. Generated interaction between non-dimensional simple states for three hypothetical shapes

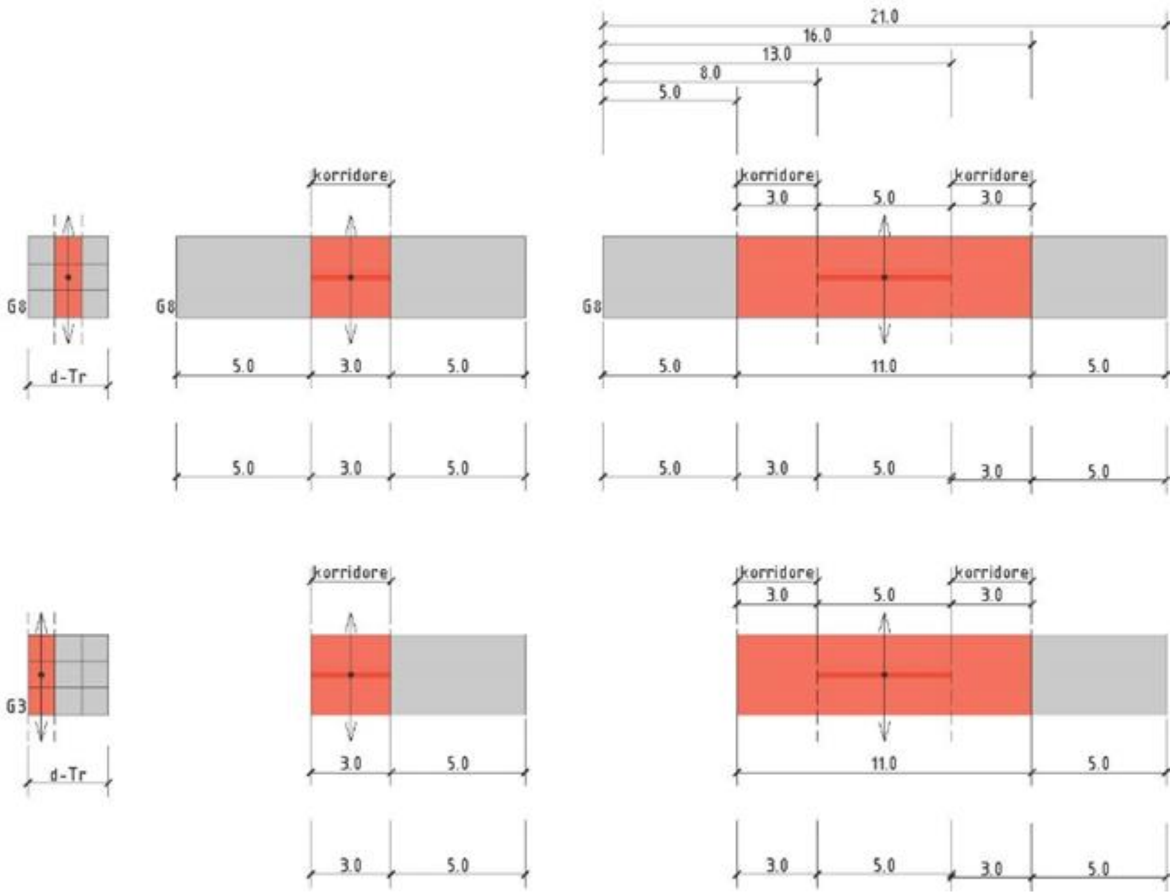


Figure 31. Dimensional interpretations of non-dimensional simple states for Hospital buildings (source: Saliu, 2018)

Conclusions

According to March (1974), "a designer with a well-understood and well-structured vocabulary of forms is more likely to find solutions coordinated with functional requirements than a designer who tries to let form follow function in a way that is supposed to be self-generative." Precisely, simple states offer a well-structured vocabulary. Their ability to act as dimensional and non-dimensional states offers a possibility of encoding declarative and procedural knowledge respectively. In each step during the refinement of the process, they exchange information between two search spaces thus enabling the user to interplay with the given solutions.

Simple states establish a new computational method that can be used in both the analysis and synthesis of architectural shapes. During this research, a total of twenty unique cuboids are identified for all simple states. Since the scope of this paper is limited only to the interaction of simple states, they are not presented here.

In conclusion, simple states can act as a reliable meta-grammar in solving complex rectangular shapes. They keep intact the topological, logical, and dimensional qualities of abstract forms They support a top-down approach, and their ability to be binary encoded could significantly reduce time in solution finding. This research confirms that ‘simple states’ that contain logical and dimensional information could derive other supplemental information during the refinement process. This information derived from analysis can be used later for the synthesis of architectural massing of the same building type. In this manner, each step of the process derives new supplemental information for the upcoming steps of the process.

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