Chapter 6 Epilogue and future research

Chapter 6 provides a summary of the work, an assessment of its strengths and limitations and suggests future work.

6.1. **Introduction**

> *'Many things, both new and old, my dear Cube brings into view; so my Cube much pleases me, because through it so much I see. It is a little world.' Froebel cited by* (Downs 1978)

A major motivation for this work is the systematic exploration of the simplest of means present in a design inquiry. Many other tangential discourses were informed by this precise look and grew in several directions to acquire a life of their own. An example is the suggestion that languages of architecture are often informed and constructed by, with the same formalisms that can be used to describe, interpret and evaluate them. For example, Richard Meier's work has been presented here as a hyper-refinement of the modernist imagery that has been inspired not by machines but by other architecture that was inspired by machines and especially Le Corbusier; similarly, the group formalism that can describe Meier's architecture could constitute a hyper-refined construction that relies on specific representations and mappings that foreground internal complex relationships of the structure itself, i.e. the symmetry subgroups and super-groups of any given spatial configuration. This analogy far as it goes has its limitations too, and the same exist for many other implicit theses herein. Here in this last section we try to foreground a series of other extensions and domains that this research points to. These extensions generally fall into two categories; a) on the improvement of the system itself; and b) on the interpretative capabilities it affords for the construction and evaluation of critical languages of design.

6.2. **Model**

The model described in this research uses well-known constructs from group theory along with specific constructs of architectural notation including abstraction, projection, weighting, and layering to construct representations that are then computed in the system. Four major avenues for future research are readily available and all of them have to do with the types of representations fed into the system and the transformations under which the rules apply in the system. All these directions are briefly described below.

6.2.1. Dimensionality

Currently, all plans of a design are analyzed in terms of corresponding group structures and all are represented in partial order lattices using axonometric orthographic projections. A major new direction for the model would be to tackle three-dimensionality both in the representations used as in the group structures that provide the partial order lattices. Two alternative schemes are readily envisioned; one would still use the planar representations of the current model but would require a parallel computation of at least three planes to simulate the *XYZ* Cartesian space. In this case, all drawings computed are two-dimensional as are the groups that describe them, but their combinations produce the three-dimensional analysis. An alternative mode would use directly three-dimensional representations and three dimensional groups. In this case, the corresponding group that would describe the symmetry, say, of the Smith House, would be the $C_2C_2C_2$, a three-dimensional prismatic group consisting of the Klein group C_2C_2 of order 4 augmented by a cyclic group C_2 of order 2.The degree that an analysis can be carried directly in three-dimensional space is really an open question as the complexity of the structure of these groups is growing exponentially with the rising order of the groups. Still, the argument is valid because most of the group structures dealing with the design are relatively of low order. A table of three-dimensional structures that capture the symmetry of three dimensional shapes that have a singular axis of rotation n and for order n <12 is given in Figure 6-1 (Economou and Grasl 2007).

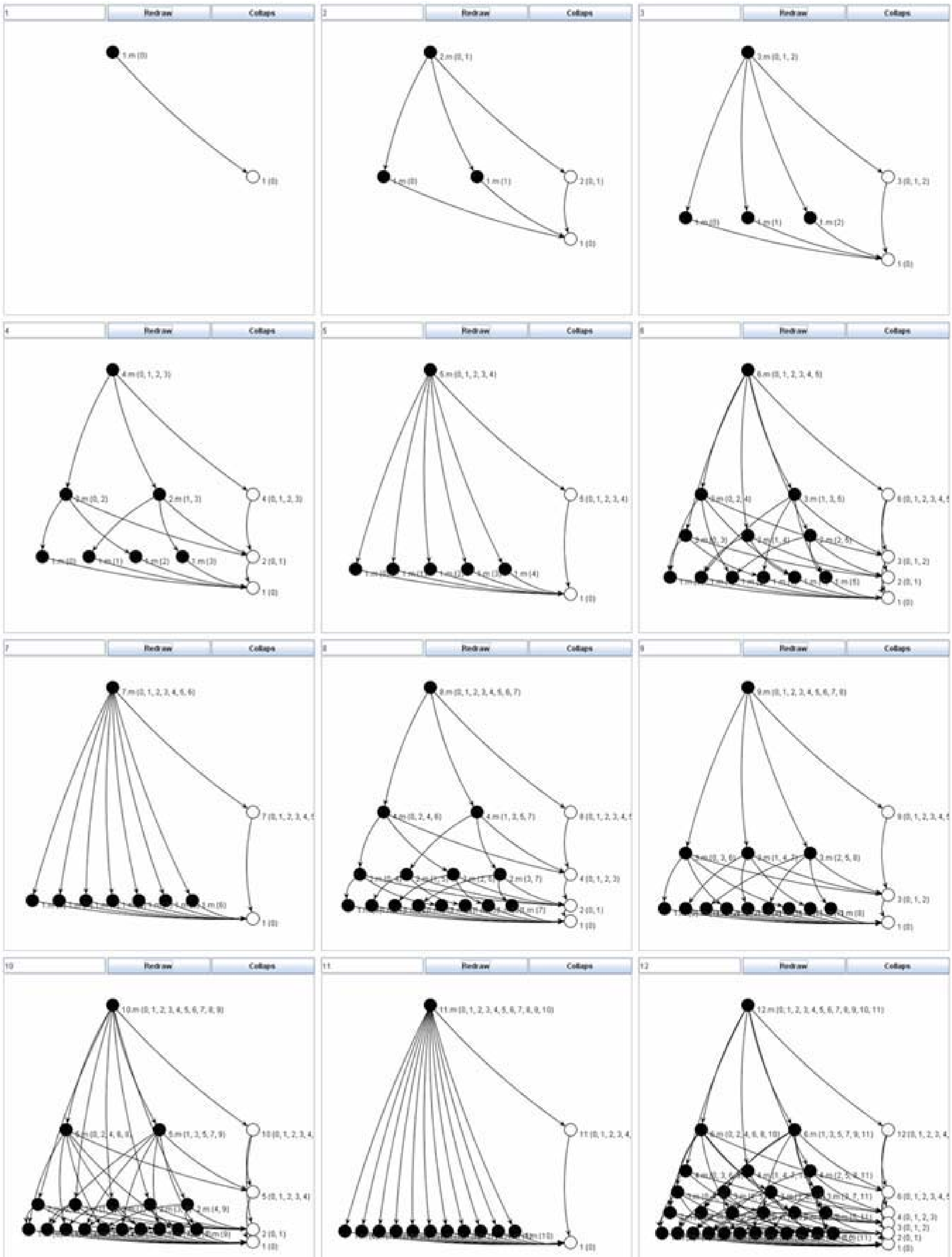

Figure 6-1: Graph representation of the subgroup structures of the dihedral groups *Dn* for *n*<12

6.2.2. *Topology*

The existing model is used primarily on rectangular compositions that are conditioned by straight lines and right angles. The enlargement of the model to include designs defined in affine, linear or topological words is straightforward. The rules that map an initial complex design to a simpler rectangular one can be straightforward for a good amount of cases. In these design worlds the nested hierarchies can be modeled after corresponding hierarchies of transformations. For example in a Euclidean system – the current one of the model – any rectangle can be mapped back to a square; this was anyhow the underlying theme for the application of Polya's theorem of enumeration for all wall structures based on a 3 × 3 grid. More complex design worlds are readily available. For example any parallelogram can be mapped back to a square in an affine design world; any trapezoid of quadrilateral can be mapped to a square in a linear design world and any disk of topological genus-1 (no holes) can be mapped back to a square in a topology or rubber sheet design world. In all these cases, it is straightforward to design mappings between grids by similarity, linearity and topology transformations in conformal mappings and attain more sophisticated regulating lines to support the design systems. A nice illustration showing the same mappings between equivalent systems is given in Figure 6-2 and Figure 6-3.

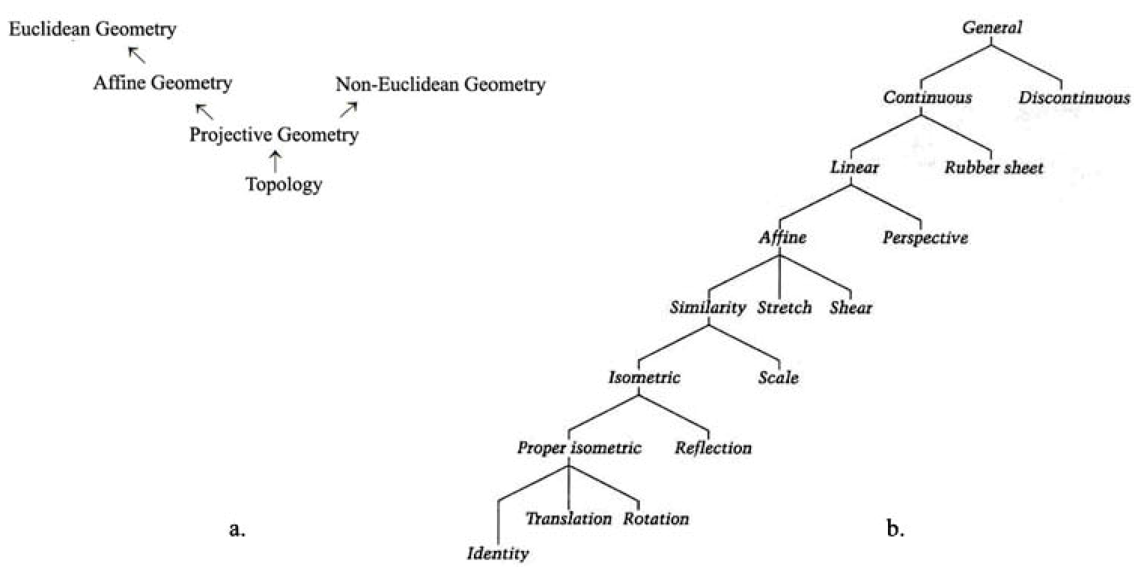

Figure 6-2: Grid mappings by linear and topology transformations - a) Klein (1921); b) Mitchell (1990)

Figure 6-3: Grid mappings by linear and topological transformations - Klee in Spiller (1961)

6.2.3. Shape grammars

The bias of the model described in this work is overtly analytic: given an architecture work the model produces a partition according to a set of symmetry considerations. The exact opposite is a somewhat different problem but even more challenging and rewarding. Given a set of symmetry considerations – perhaps observed in one or more architecture works, the model should produce alternative architectural works that exemplify the given requirements. Sets of shapes and spatial relationships could be carefully selected too to establish degrees of conceptual and aesthetic clarity and vicinity with the original. In these latter cases the reworking of this material can provide a rich palette to visit not only the composition of the house itself but to contemplate on the possible configurations that are not used in this specific case but can be used in other cases. If we were to use the example worked out in this work we should claim to then to design configurations that could be done either by Meier himself or any other of the NY architects. The range of these applications is indeed unlimited and may even help connect various aspects of group theory and provide new material to shape grammar discourse (Stiny 2006), (Knight 1994). Figure 6-4 shows a partial order lattice exemplifying the group $C_2C_2C_2$, using sets of shapes and spatial relationships broadly conceived as extracted from the NY5 language (Economou 2001).

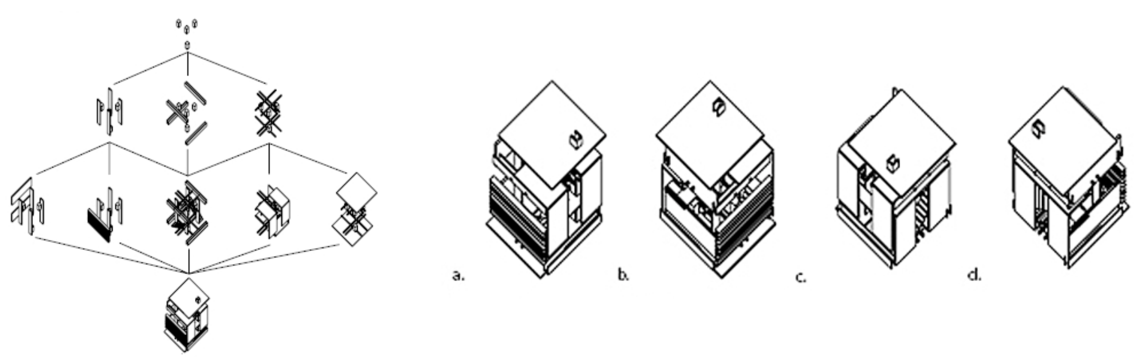

Figure 6-4: A partial order lattice of a design modeled on the C2C2C2 structure

6.2.4. *Automation*

The existing model used computer projections of a three-dimensional model to specify all the parts for the computations. All symmetry parts and projections were manually extracted and arranged in spreadsheets for viewing. An extension of this application for an automatic extraction of these drawings is highly desirable. The extraction of the symmetry part is not a formidably computational problem, albeit not a trivial one. Figure 6-5 shows a flow chart for the determination of the symmetry group of a two dimensional figure. Corresponding flow charts fro three dimensional shapes are readily available too. What is harder is the identification of the parts that need to be examined for a symmetry decomposition (Rose 1981).

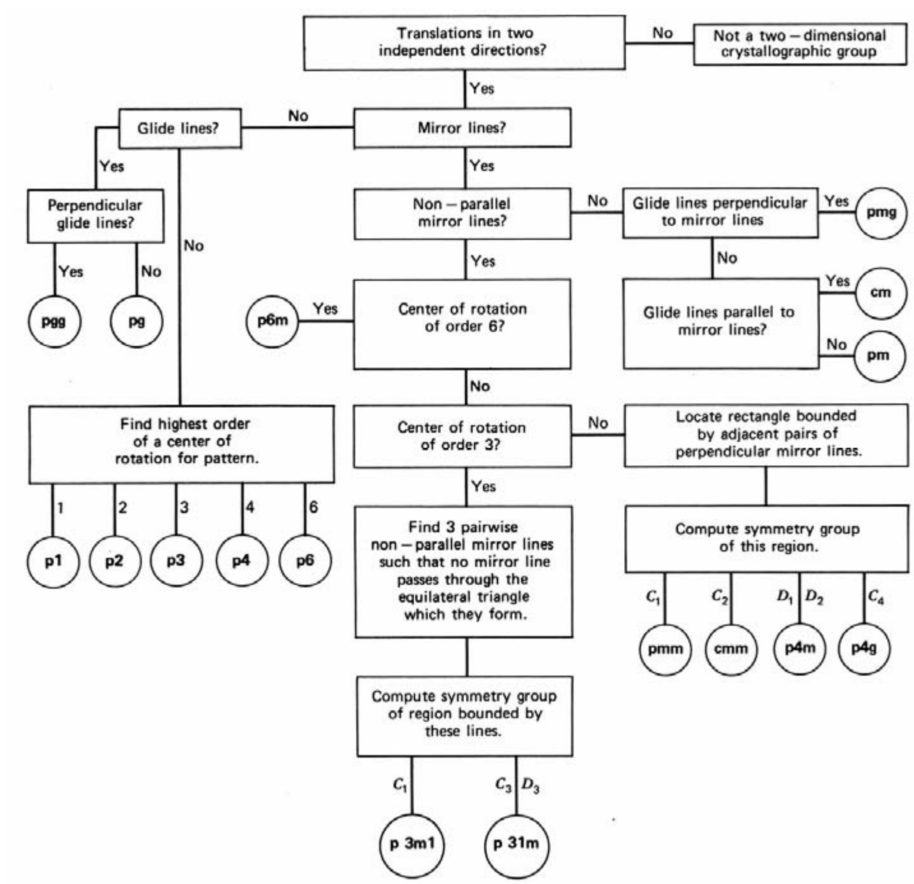

Figure 6-5: An algorithm for identifying the seventeen symmetry groups of the plane

6.3. **Interpretation**

The model aspires in complete computations that provide all the corresponding parts that are extracted from a given system taken into account the symmetry properties of the underlying configuration. The degree to which the computations support existing discourses about the interpretation of a design work or point to new ones is still a problem to be investigated. Some directions pointing to these directions are given below.

6.3.1. Emergence

The term ‘conceptual emergence’ signifies emergence based upon the exploitation of conceptual knowledge. The fit between visual images stored in the designer's associate memory and the way the designer maps these images into a formal-configurational schema is here defined as conceptual emergence. Images can contribute to the emergence of generic patterns, or schemas. With these assumptions contradicting the idea of unanticipated emergence, it is proposed that domain knowledge guides emergence and that all emergence is, to some extent, guided.

In perception one sees objects that are physically present. In imagery one can 'see' objects that are not currently being viewed. ‘Transformational emergence’ is the externalization of retrieved images and the activation of transformational operations as a class of design knowledge. Transformation is the ability to modify patterns in images. Objects can be shifted and rotated and alter imaged patterns. Transformations are important in design generation. In order to be able to ‘think’ with a visual image it is necessary to identify its generic qualities: the 'know-how' to transform.

The domain content of visual images, or visual prototypes, constitutes a significant class of visual knowledge of the designer. The guiding role of these visual prototypes may be said to introduce a dimension of 'anticipation' in the process of emergence. The designer may not know exactly what he or she is looking for, but it is still possible to select a language for transformations. To this extent, emergence is guided and anticipated. It is the re-cognition of images as visual prototypes which enables emergence. We refer to this kind of guidance function in emergence as 'anticipated emergence' (Suwa, Gero et al. 1999). Any theory of creative discovery through emergence must be made to accommodate the idea of ‘anticipated discovery’.

The visual exploitation of shape ambiguity is an integral part of thinking with images. Designers do not know what exact shape will emerge but they do know how to manipulate shape ambiguity and transform images in order to obtain a desired form since they know in advance the spatial effects of the qualities of subgroups. When designers employ a certain class of images, they canalize emergence. They do not know exactly what form they will see, but they anticipate, and are ready to perceive, a new form. Thus the application of certain symmetrical principles can guide the emergence of the form.

The modeling of emergence demonstrates how cognitive emergence operates and how high-level cognitive schemas contribute to our ability as designers to generate new forms through the manipulation of shapes and images. The specific case study illustrated here is the 'the Smith House'. The following figures illustrate an example of the exploration of the configurative pattern.

6.3.2. Complexity

A major idea pursued in this work is that the typical notion that complexity can be understood as opposite to symmetry can be understood in entirely different light as an aggregate of simple symmetry constructs or layers. In order to develop such a theory of complexity, a theory of symmetry is necessary to support such claims. One may acknowledge that up to now in the classical tradition, the effects of geometry have been limited to the use of grids, proportions to bind relationships into signifying systems. As suggested by the square-grid composition, what this work proposes is to expand the use of geometry to group theory of transformations in order to map it to any architectural composition no matter how difficult the difficult whole and conflicting geometric systems have to be. It happens that March and Steadman have renewed the interest toward this approach more than three decades ago with their book, Geometry of the environment (1971).

An object has symmetry if there are spatial transformations that allow the object to move, and yet end up occupying the initial space. Group theory of symmetry lets us know how many sub-symmetries of an object can be exploited in design. That is to say a whole design may have no overall symmetry; such a globally asymmetrical composition is always replete with local symmetries or sub-symmetries. Form suggests reference to both internal structure and external outline, and the principle of symmetry brings unity to the whole. Today's design is mainly based on transformations of some visual prototype. The study of Meier's architecture is just one striking example; it teaches the designer that equipped with the powerful tools of computational symmetry, he or she can generate enough configurations to interpret, to generate, and to manipulate form, how complex it may be.

This internal structure of objects is twofold: the one face that is invariant, the other one that is ever-changing. Symmetry plays a key role in tracing the metamorphosis of form through space and through time. Lattice theory provides the means to partially order decompositions of shape, with shape rule application. Symmetry is also a helper for a conscious organization of space, from the symmetry group point of view one can enumerate all arrangements and choose the best one. A sequential analysis of the three floor plans of the Smith house will reveal how various sub-symmetries of the dihedral D_2 are systematically superimposed. As a whole, each floor plan - *xy* plane - does possess the full symmetry of the rectangle; even some sub-shapes conform to some subsymmetries. By extracting sub-shapes, which maximize the representation of some particular subsymmetries of the rectangle, one can construct various diagrams to illustrate the overlay of symmetries involved in the floor at each level. Thus, the final design displays an abundance of symmetries within the parts while negating the strict symmetry of the whole, and can equally assemble the lattice by type (V - S - H) to get the whole. Sub-Symmetries may be like maps; if some insights are difficult to decoding by using the map of architecture itself: orthographic projection [plan - section - elevation], the partial order lattice may be a cue, a device, an instrument for unlocking architecture from its own representation.

6.4. **Discussion**

A brief overview of the work has been given and some of its limitations and promises were briefly discussed. An array of future projects based on the work presented so far was briefly mentioned as well including advances so much in the model itself as in the wider epistemological directions it points to and belongs in. Future work in the design of the model includes exploration on a) the dimensionality of the representations and the symmetry groups that are taken into account, b) the topology of the underlying grid and the regulating lines of the designs that are analyzed in this model; c) the affinity with a shape grammar formalism and particularly the design of new languages of designs that are based on the findings of the model; and d) an automation of the whole process to give automated reports with the parts of the model that exhibit specific symmetries. Other future work seeks a more profound look on the findings of the model and a critical assessment of the ways these findings support or not existing discourses, help construct new discourses, and genuinely contribute to issues pertaining to complexity and emergence in formal composition in architectural design.

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