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Contents

Research for Cultural DNA in Design

John S. Gero

Abstract This position paper commences with a brief overview of where the cultural DNA may lie in the enterprise of designing. It puts forward the concept that cultural DNA is not a unitary concept and needs to be treated multi-dimensionally deriving from multiple sources. The paper outlines research that supports cultural DNA research in design.

1 Introduction

The term “Cultural DNA” has come to mean any mechanism that transfers culture from one generation to the next. Culture here is taken in its broadest meaning, ranging from social implicit knowledge to explicit technical knowledge with many shades of knowledge in between. Cultural DNA implies both a means of representing culture and a mechanism that transfers culture from one generation to the next. The notion of generation here does not necessarily imply human generations, rather it is meant to signify that culture is transferable.

Designing, the process of generating proposed changes in our physical, virtual and mental worlds motivated by a set of initial requirements, is one domain where cultural DNA can be studied more formally. Designing involves the value systems of a heterogeneous set of players in its enterprise and it is those values systems that form the basis of a culture.

This position paper commences with a brief overview of where the cultural DNA may lie in the overall enterprise of designing. It proposes seven potential loci. This is followed by a brief overview of what has been studied by researchers in these areas that may point to engaging cultural DNA. The methods used to study design culture are listed. This is followed by examples of research that captures cultural DNA. The final part outlines a number of future directions for design cultural DNA research and posits a set of research questions for each of the directions.

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2 Where Can the Cultural DNA Be in Design?

Where can the cultural DNA be in design? Although this is an obvious question it is surprisingly difficult to answer. There are seven hypotheses that are candidate answers to this question:

- in the design;
- in the observer/user of the design;
- in the design process that produced the design;
- in the designer;
- in the interaction between the user and the design;
- in the effect the design has on the individuals and the society in which they sit; and
- in the interaction amongst all of the above.

Given that are multiple hypotheses about where the design cultural DNA might be implies that cultural DNA in design is not a unitary concept and needs to be treated multi-dimensionally. In the remainder of this paper will use the term "cultural DNA" as a shorthand for "cultural DNA in design".

2.1 Cultural DNA Is in the Design

The design itself would appear to be the most obvious place to locate cultural DNA since it is the design that is most commonly experienced by a user or observer. Designs are consumed and their representations, even when not reified, are transferred and viewed. However, since this requires a consumer or an observer, it may be that it is insufficient to claim that the cultural DNA only resides in the design. However, representations can readily be transmitted from one generation to another.

2.2 Cultural DNA Is in the Observer/User of the Design

If the cultural DNA does not simply lie in the design itself it may be that it is an interpretation of a design by the assessor. The assessor may be a consumer of the design or an observer. They generally do not specify the criteria they use in their assessment. This turns cultural DNA from an inherent property of the design to a property of the assessor of the design. The consequence of this is that different assessors would assess the cultural DNA of a design differently.

2.3 Cultural DNA Is in the Design Process that Produced the Design

Since designing is a process it can be suggested that the cultural DNA is in the process that produces a design. This has the attraction that processes can be readily studied.

2.4 Cultural DNA Is in the Designer

Most designers are recognized as having a regularity and consistency in the designs they produce. It may be that is the unique characteristics of those designers that gives them this consistency. It may be the characteristics of the designer that embody the cultural DNA.

2.5 Cultural DNA Is in the Interaction Between the User and the Design

It may be that cultural DNA is an affordance (in the Gibsonian sense) between the user and the design and as a consequence is the result of an interaction between the user and the design. This means that the cultural DNA is in neither the design nor the user but is a consequence of the interaction of the user with the design. That interaction could take many forms. It could be a derivation by the user of the behavior of the design. It could be an ascription by the user to the design. It could be a mixture of both of these.

2.6 Cultural DNA Is in the Effect the Design Has on Consumers and the Society in Which Designs Sit

It may be that cultural DNA is an effect that a design has on the individuals and the society in which it sits. This implies that cultural DNA is in the changes in the values of individuals and of society.

2.7 Cultural DNA Is in the Interaction of All the Above

It may be that cultural DNA lies in the interactions between users, assessors and the design within a society. The consequence of this is that cultural DNA becomes a situated, constructive act. Situated means that the social interactions of individuals depend on their view of the world at that time and this guides their interactions. Constructive means that any assessment is not simply a recall of past assessments but is generated based on the past and the current situation to meet expectations that come from the situation.

3 What About Cultural DNA in Design Has Been Researched?

All seven of these hypotheses for the location of cultural DNA in design have been examined at various levels of intensity and detail.

3.1 Studying Cultural DNA in the Designs

The study of cultural DNA in designs assumes that cultural DNA resides in the transferable representations of the designs, i.e., the representations embody the cultural DNA. All CAD systems are built on representations of objects. These representations include geometry and topology and increasingly material properties and occasionally behavioral and functional properties, that together make up the cultural DNA Thus, we can observe design style and schools of design from the designs themselves.

An example of such an approach to the generating the representation of designs can be seen in the genetic engineering of the genes of an object. Genes, in natural evolution, are the building blocks of the representation of an organism. They need to be transformed into the elements of the organism. In design they are building blocks of the representation of a design that need to be transformed into the components of a design.

Genetic engineering applied in design captures gene structures that are causally linked to structures in the design [10]. An example of this is given in Fig. 1 where (a) is a set of four floor plans of Frank Lloyd Wright buildings and (b) shows a set of genes genetically engineered from those plans that capture the cultural DNA of those Frank Lloyd Wright floor plans. Figure 2 is an example of a genetically engineered Frank Lloyd Wright house based on transferring the cultural DNA of such houses to a new instance. Similar ideas are embodied in the induction of shape grammars from examples, where the shape transition rules capture the embodied cultural DNA in the initial representations [12].

The representations of the genetically engineered genes in Fig. 1 become the cultural DNA for these objects. While the “design” in Fig. 2 is a demonstration of the use of this cultural DNA in the next generation.

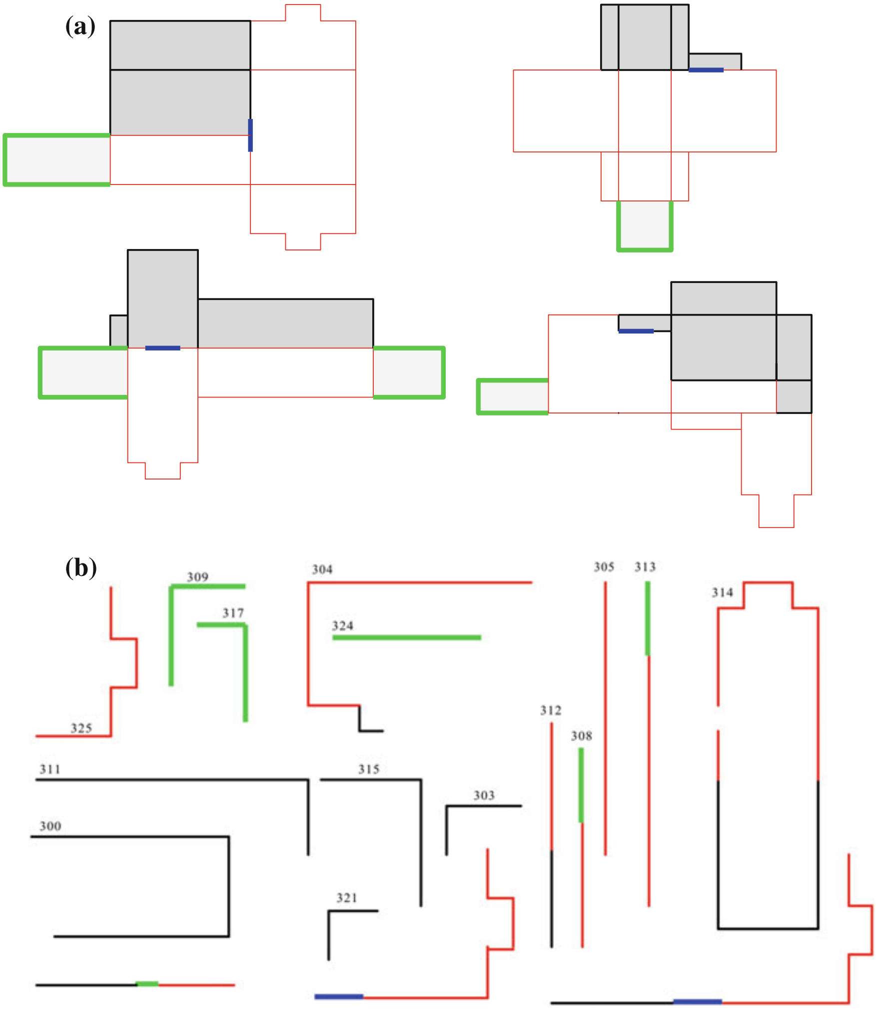

Fig. 1 **a** Four Frank Lloyd Wright prairie house floor plans, **b** 18 genes that represent the cultural DNA embodied in those floor plans (after [10])

3.2 *Studying Cultural DNA in Observer/User of the Designs*

As indicated in Sect. 2.2 all designs must have an observer/user to bring them into human cognition through perception. This implies that the cultural DNA is an interpretation by an observer of the design. Interpretation is a rich cognitive activity that depends on the past experience of the observer and the observer's expectations, which are a function of the observer's current situation [5]. Take the case where the past experience covers both Frank Lloyd Wright floor plans and of Andrea Palladio villa

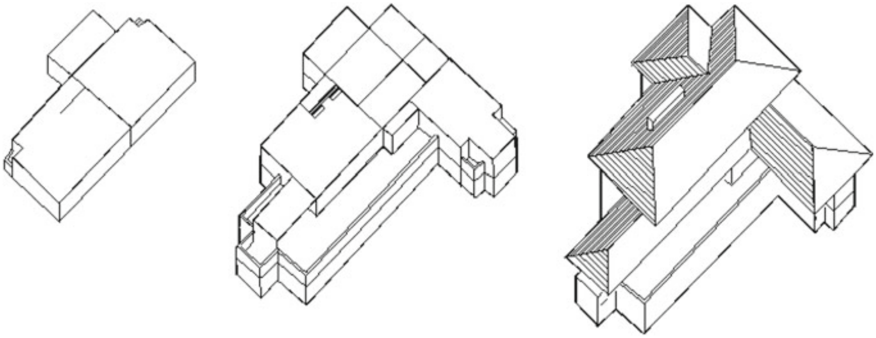

Fig. 2 A genetically engineered Frank Lloyd Wright prairie house based on the cultural DNA, in Fig. 1b, of a set of existing Frank Lloyd Wright houses (after [10])

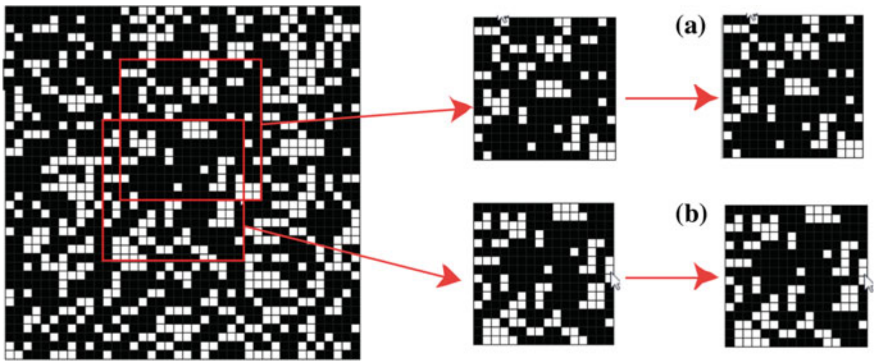

Fig. 3 The same source data on the left produces different results for different expectations. **a** Expecting a Frank Lloyd Wright floor plan, and **b** expecting a Palladio floor plan [4]

plans. If we present the observer with some source data to be interpreted it depends on what the observer is expecting as to what features they see in the same source data, Figs. 3 and 4.

3.3 Studying Cultural DNA in the Design Process that Produced the Designs

All designs are a result of a set of processes. Design processes can be learned and represented so that they can be executed later. Just as genetic engineering applied in design captures gene structures that are causally linked to structures in the design, so it can be applied in design processes to capture regulatory gene structures that are the processes that are causally linked to the structures in designs. This captures the

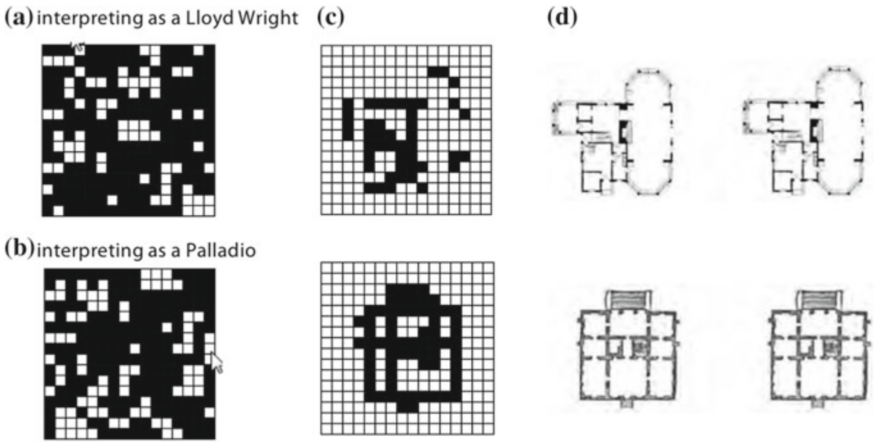

Fig. 4 The two interpreted features are compared to the original representations that were part of the training set from: **a** a Frank Lloyd Wright floor plan, and **b** an Andrea Palladio villa plan. The images labeled **c** are representations of the concepts within the system that have been interpreted based on expectations. The images labeled **d** are the original representations used in the training set [4]

Fig. 5 Example of Chinese façade exhibiting a particular style [1]

cultural DNA of design processes in the form of the processes that generate a design style.

Take the example of a particular Chinese architectural style exemplified in Fig. 5. There are multiple facets of this style that need to be captured such as "eave is above column", "repeated eaves" and "pyramidal eave is above eave". Then a process is needed to arrange these style elements into a uniform style.

We can use the same genetic engineering concepts as earlier to capture the design processes that produce the style. We can commence with the elements of the designs and evolve genes to capture the processes that operate on them to produce the style, Fig. 6.

3.4 Studying Cultural DNA in the Designer

In order to gain access to the designer's cognition we can use protocol analysis and produce models from the results of the analysis. Protocol studies of design cognition involve having designers verbalize as they design and converting their verbalization

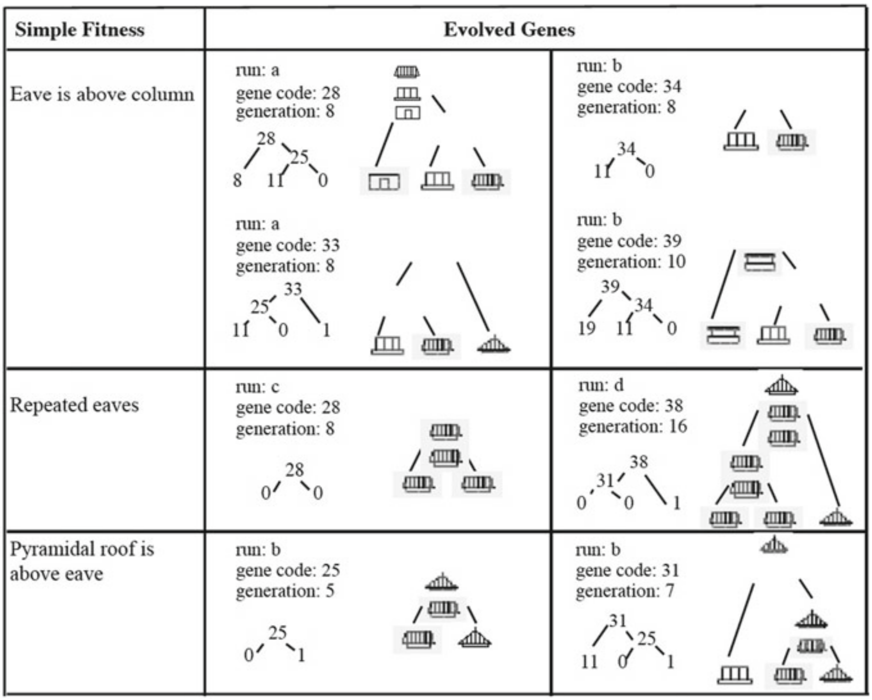

Fig. 6 Examples of the evolution of genes that capture style elements [1]

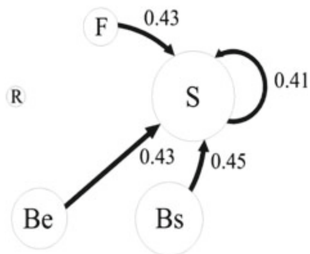

Fig. 7 A designer's pattern that contains implicit knowledge [14]

into semantic symbols. These symbols can then be analyzed in multiple ways to build models of f the designer designing. Exemplary results are patterns of cognitive behavior while designing. A design pattern of a designer is captured in the transitions between different cognitive variables indicated by high probability of moving from one to another. The high probability implies a level of invariance, which can be considered the designer's cultural DNA. A designer's pattern connecting function, structure, expected behavior and behavior from structure, derived empirically, is presented in Fig. 7.

How implicit knowledge represented by such a pattern can be transferred from one generation to the next is currently unclear.

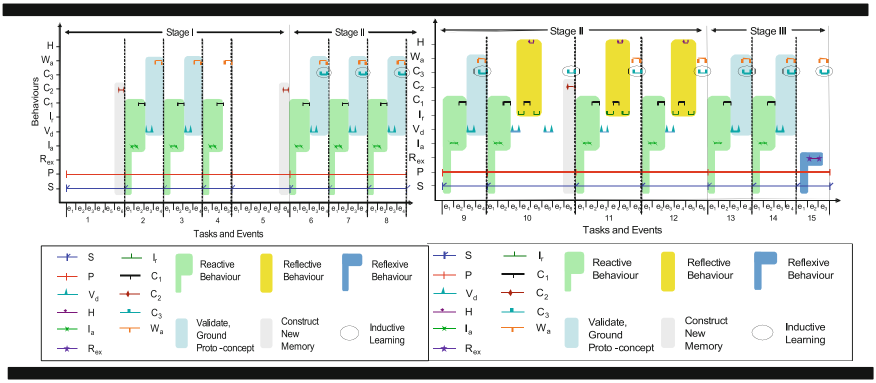

Fig. 8 A constructive memory system where an initial interaction results in a proto-concept (shown in grey). That concept is used if possible in future interactions (shown in green). If the use is successful it adds to the grounding of that concept. If no concept can be found that is useful a new concept is constructed (shown in yellow). If a concept is sufficiently grounded it becomes a habituated concept (shown in blue) and becomes a pattern that requires no reasoning only matching for it to be used [8]

3.5 Studying Cultural DNA in the Interaction Between the User and the Design

There have been many studies of the affordances the users find in their interactions with designs (e.g., [9]) and there is considerable research on using affordances in design (e.g., [2, 6]), but there is very little research on learning and representing affordances in a transferable way that is required for it to be cultural DNA. Affordance can be considered as a habituation or grounding of patterns that connect function with structure.

Research on constructive memory [8] is one direction that has the capacity to learn habituation, which makes it a candidate for learning and representing affordances [7]. An example of a constructive memory system that learns through interactions with its environment is presented in Fig. 8. This is a constructive memory system learning concepts that are reinforced through use resulting in habituation of the grounded concepts so that no more learning is needed to apply them.

3.6 Studying Cultural DNA in the Effect the Design Has on Consumers and the Society in Which They Sit

From a cognitive perspective any interaction between the design and consumers potentially results in a change in the values consumers use to assess designs. In addition to direct interaction with designs consumers interact indirectly with designs

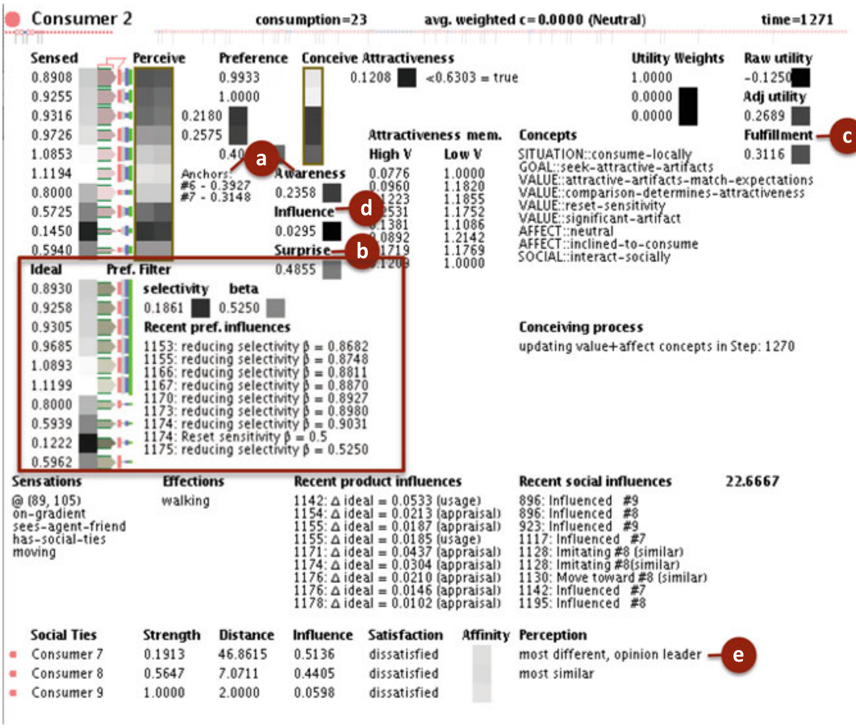

Fig. 9 A screen shot of the values inside an agent showing **a** perception connecting with awareness, **b** the surprise metric, **c** the fulfillment metric; **d** the influence metric, and **e** social influence metric, within the sensation-perception-conception-situation cognitive framework. The values that the agent uses for its ideal product, shown inside the red rectangle, change as a consequence of its interactions [3]

through the social media of the society in which they sit. Agent-based models of interactions including social interactions have the capacity to model and capture this behavior, Fig. 9 [3, 13].

The cultural DNA is represented in the value systems of the individuals and is based on their experience. However, it is affected by the social influences of others. In this view cultural DNA is distributed between the designers and consumers and is influenced by their social interactions.

3.7 Studying Cultural DNA in Design in the Interaction Amongst All of the Above

This last notion of cultural DNA subsumes the notions of cultural DNA being in the representation, of the cultural DNA in the process, of cultural DNA being in the assessor, of cultural DNA being in the designer, of cultural DNA being in the interaction between the user and the design and of cultural DNA being in the society within which the design exists. This holistic view has not been researched in any formal way.

4 Conclusions

Cultural DNA may not be a unitary concept: any mechanism that transfers culture from one generation to the next. However, it appears to have many facets. In this paper we have identified seven facets of where the cultural DNA might reside:

- in the design;
- in the observer/user of the design;
- in the design process that produced the design;
- in the designer;
- in the interaction between the user and the design;
- in the effect the design has on the individuals and the society in which they sit; and
- in the interaction amongst all of the above.

These and potentially other facets indicate that cultural DNA in design is a rich concept that plays a role in the way in which individuals, groups within a society and societies interact with their artefacts and with each other.

Cultural DNA remains a relatively under-researched area, as a consequence there are numerous research questions to be raised and answered to develop an understanding of it and its role. The results of such research will lead not only to an understanding of cultural DNA in design but will generate the foundations for the development of tools to support cultural DNA in design and to provide society with more formal means to transfer knowledge between its members. In doing so it raises counter-balancing issues: formalization of acquired knowledge facilitates its transfer that increase cultural coherence while at the same time increases the likelihood of it limiting the acquisition of other knowledge that is in opposition to the initial formalization of that knowledge. This is a form of “dynamic conservatism” which is the way that established institutions normally respond in the face of change in order to stay the same [11]. For cultural DNA to remain a useful concept it must embody means for its adaptation to changing social values.

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Directly Interactive Design Gallery Systems: Interaction Terms and Concepts

Arefin Mohiuddin, Narges Ashtari and Robert Woodbury

Abstract A human-computer interface interposes objects between a person and the underlying representation with which the person interacts. Previously, we introduced two interaction objects, alternatives and their collections in an interactive design gallery. We revisit the terms, refining their definitions, and introduce the explicit notion of a "view" to accommodate multiple references to the same alternative or collection in an interface. We outline fundamental interactions over alternative and collection views. Finally, we outline a special type of collection called the *Parallel Coordinate View*.

Keywords Design exploration · Design alternatives · Computational models Computer-aided design · Design tools

1 Introduction

In computational design, the case for design alternatives is established, and need not be repeated here. What is not widely understood is the need for a complete and effective suite of direct interactions with design alternatives. Instead, the literature largely reports techniques and systems for presenting to a user the results of some automated generative process. Yet, as Bradner et al. [1] point out, "Professionals reported that the computed optimum was often used as the starting point for design exploration, not the end product." We aim to remedy this situation by devising and evaluating a suite of direct interactions with design alternatives. We meet these aims through the iterative design and evaluation of prototype systems that represent multiple alternatives. For both intellectual and practical reasons, we build these prototypes on

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top of existing commercial parametric modeling systems. First, parametric systems are mature and increasingly used in practice–they are the best type of system for gaining research participants and external impact. Second, parametric systems yield a particularly simple and useful abstraction for representing alternatives [2], allowing clean separation of modelers from what we call design galleries for supporting alternatives. We have devised a general, flexible system architecture that enables us to rapidly prototype new interaction concepts.

2 Alternative Views

We revisit the definition of an alternative provided in [2] reproduced nearly verbatim (correcting only the capitalization of variables) herein.

1. An *alternative* is a selection and abstraction of nodes from a parametric model such that the nodes of the alternative each correspond to a property of a model node.
2. An alternative may contain both graph-independent and graph-dependent properties of the model it abstracts. The graph-independent properties enable alternatives to be edited; the graph-dependent properties enable performance to be assessed by evaluations tools, which are commonly available within a parametric modeler.
3. The operation *apply* assigns values from an alternative f to a model m. Specifically, it assigns the property values from the f only to properties that, in m, are graph-independent.

This led to overloading of the term "alternative" as a *logical alternative* (a subset of model nodes) and its interface counterpart, the *interface alternative* (a logical alternative plus a parametric model). It introduced two problems. First, it is verbose and its terms are not memorable. Second, it failed to separate underlying symbolic models from human-computer interfaces to them. Here we resolve the first problem by introducing the term "aspect" to replace "alternative," and using "alternative" to describe the former "interface alternative." The second problem we address through the term "view." In Model-View-Controller (MVC) frameworks, a common software architecture pattern for graphical user interfaces [3], a *view* is a representation of underlying information, and multiple views of the same information are possible. This is also consistent with information visualization principles where multiple visual representations of data should be available to support users with different tasks and requirements [4, 5]. Our definition thus becomes the following.

1. A *model aspect* (or just *aspect*) is a selection and abstraction of nodes from a parametric model such that the nodes of the aspect each correspond to a property of a model node.
2. An aspect may contain both graph-independent and graph-dependent properties of the model it abstracts. The graph-independent properties enable aspects to

be edited; the graph-dependent properties enable performance to be assessed by evaluations tools, which are commonly available within a parametric modeler.

3. The operation *apply* assigns values from an aspect p to a model m to produce an alternative a. Specifically, it assigns the property values from p only to properties that, in m, are graph-independent.

Using this new definition, since an *alternative* is a representation of the underlying aspect and parametric model, we adopt the term *alternative view*, and introduce it as a more nuanced concept.

In the Design Gallery implementation, an aspect and a model are stored in the alternative data structure, and an *alternative view* visually represents the alternative and is the primary interface object with which users interact. There may exist, as alternative views, multiple references to an alternative across the Design Gallery, and each may or may not be a different visual representation or *view*.

$$p = \text{aspect}$$
$$m = \text{parametric model}$$

$$\text{An } alternative = {}_{j}a = <p, m>,$$

where j indexes alternatives, i.e., in a gallery G (galleries contain alternatives), ${}_{j}a \in G$ is the jth alternative contained in G.

We introduce the concept *view*, denotes by v, and specialize is to alternatives.

$$alternative\ view = {}_{j}v_{i}^{a},$$

where, a denotes *alternative*, that it is of type *alternative,* as contrasted with an interface view of type *collection*.

j indexes alternatives, i.e., in a gallery G, j refers to the jth alternative.

i is a *view index*. If, in a gallery G, multiple alternative views ${}_{j}v_{i}^{a}$ of ${}_{j}a$ were to exist, i denotes the ith alternative view of the jth alternative contained in the gallery. To elucidate, in the Design Gallery [6], ${}_{j}a$ exists as views ${}_{j}v_{0}^{a}$ glyph with thumbnail image, ${}_{j}v_{1}^{a}$ larger thumbnail image, and ${}_{j}v_{2}^{a}$ thumbnail and text, and would be denoted as ${}_{j}v_{1}^{a}$, ${}_{j}v_{2}^{a}$, *and* ${}_{j}v_{3}^{a}$ respectively.

Note that these view kinds (thumbnail, large thumbnail, and thumbnail and text) are not exhaustive, and as our research progresses, we propose and design novel kinds of alternative views.

The model defaults to the one from which the alternative was initially abstracted, but is not restricted to it. Therefore, alternatives can be created by tuples selected from collections P of aspects and M of parametric models. This is consistent with the notions described in [6], i.e., an aspect can be applied to any model, even if the model changes. Such applications produce effects to the extent that node names correspond across models. *Fault tolerance* in the modeler prevents system crashes, and *partiality* allows aspects to be applied to models in which node mappings are either (or both) incomplete or extraneous.

This notation also gives rise to a novel way of generating alternatives within the Design Gallery. Sheikholeslami [7] describes the *Cartesian product* of values stored in an alternative or in a subjective node, whereas [8] extends this to products of parametric models. The Cartesian product $A = P \times M,$ where P is a collection of aspects, and M a collection of parametric models, is a collection A of all possible applications of $p \in P$ to $m \in M.$

3 Collection Views

Many desired operations act over multiple objects [6], that is *collections* of alternative views. A collection is

$$C = \left\{ v^a \right\}.$$

Collections are mutually non-exclusive and collectively exhaustive. Mutual non-exclusion means that views to the same alternative can exist across multiple collections, that is, collections C and D can each contain a ${}_j v_i^a$ with the same j value. Collective exhaustion means that every alternative has an alternative view in some collection. We guarantee collective exhaustion by providing a *universal collection* containing one view of each alternative in a gallery. Collections are sets with respect to the alternatives underlying a gallery, that is, a collection can contain at most one alternative view of a given alternative. A *collection* is denoted as

$$C = \left\{ {}_0 v_i^a,\ {}_1 v_j^a, \ldots,\ {}_n v_k^a \right\},\ \text{where}$$
$$\{0, \ldots, n\}\ \text{indexes alternatives, and}$$

i, j, k index their respective alternative views across all collections in the gallery.

This means that alternative views of a single alternative may exist in multiple collections as a similar or dissimilar representation or *view*, but no collection contains more than one reference to the same ${}_j a$ even if the *view* is different. Effectively, in ${}_j v_i^a$, i indexes across all alternative views of j present in the gallery.

Interacting with *collections* of *alternative views* necessitates that there be different representations of these *collections*, again in line with information visualization research [4, 5]. An example may be visualizing relations between elements of collections. Thus, we introduce the term *collection views*. A collection view *i*s a visual representation of a collection C, and collection views form the primary interface objects by which users interact with collections. Following the convention set previously, we denote a collection view as

$${}_j v_i^c,$$

where

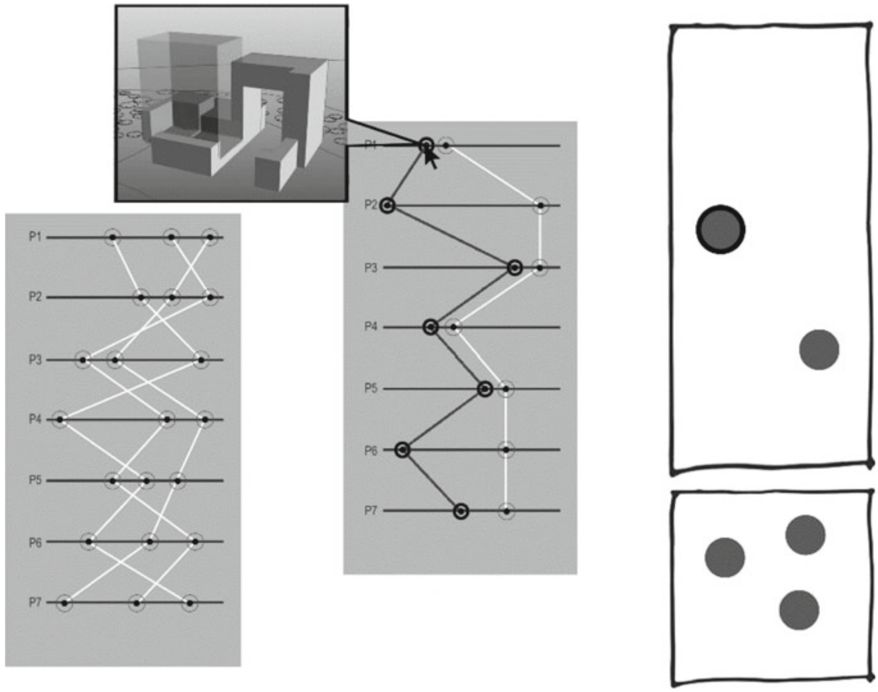

Fig. 1 (left) Parallel coordinate view controller (left) showing alternatives and handles, details on demand show 3D view, and (right) brushes corresponding general alternative view as a glyph in a general collection

j indexes collections, i.e., in a gallery G, j refers to the jth collection.

i is a *view index*. If, in a gallery G, multiple collections ${}_jC$ were to exist, i denotes the ith collection view of the jth collection contained in the gallery.

c indexes collection view types, an extensible set of visualization types provided by the gallery. Currently, the gallery defines three collection view types:

$c = \mathsf{c.general}$. The general or default view of a collection, where *alternative views* appear clustered in a user-directed layout (Fig. 1 right),

$c = \mathsf{c.parallel}$. A *parallel coordinate controller* view (Fig. 1 left), and

$c = \mathsf{c.pareto}$. Multiple Pareto graphs in which properties of an alternative may be plotted against each other (Fig. 2).

These would be denoted as

$$v_1^{\mathsf{c.general}}, v_2^{\mathsf{c.pareto}}, v_3^{\mathsf{c.parallel}}$$

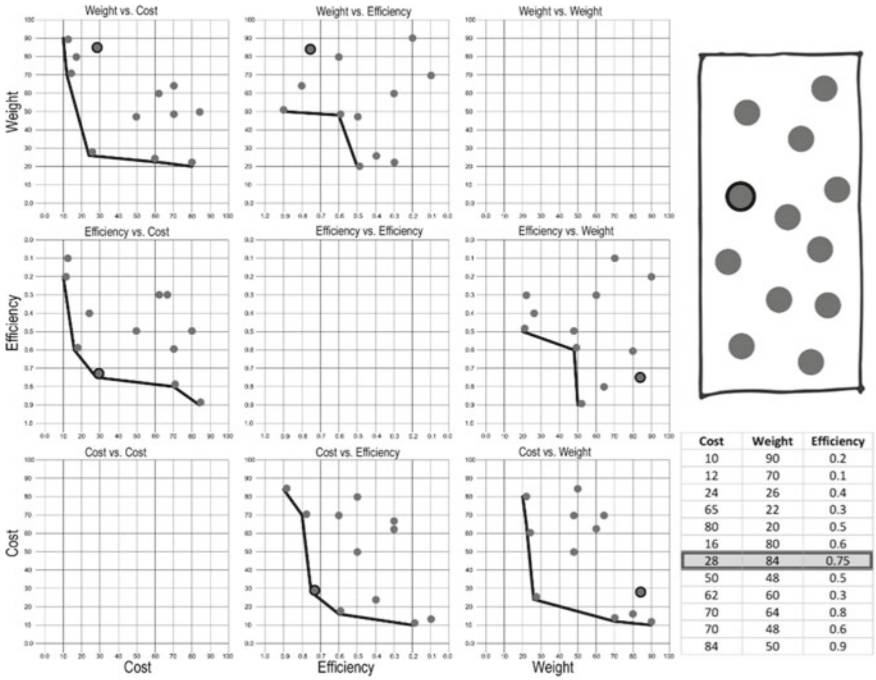

Fig. 2 A collection view as multiple pareto views showing representative performance criteria evaluated against each other. One ${}_j v^a$ is highlighted across all views

4 Interactions

The fundamental interaction with interface objects is selection. The two primary interface object types v^a and v^c give rise to two distinct selection sets s^a and s^c. Users should be able to select discretely or continuously, multiple v^a and/or v^c preceding any operations that may follow. Selecting an object adds it to its type's *selection set*. A selection set is also a collection (though this is not strictly true for s^c), except that it is ephemeral in nature. We describe here a core set of interactions upon which more detailed interactions depend.

The primary acts of interaction using a mouse pointer in the gallery are "click" and "drag". A modifier, which may be one or more key-presses, different mouse buttons, click sequences, or any combination thereof, is applied to specialize these. Tables 1, 2 and 3 show primary interactions on the two principal types of target objects, the modifier used, and the result. For modifiers, we indicate both an integer identifying the modifier and our current design decision binding a particular action to the modifier. The following interactions we explicitly define hold true for $v_1^{\text{c.general}}$; while being theoretically valid for $v_2^{\text{c.pareto}}$ and $v_3^{\text{c.parallel}}$, they have case specific implications that are a work in progress.

Table 1 Interaction on null objects with modifiers and results. At the time of writing, we bind modifier 1 to SHIFT, modifier 2 to the ALT key and modifier 3 to CTRL

Target object	Interaction	Modifier	Result
Null	Click	Null	Null
Null	Click	1	*Clears* s^c, the collection selection set
Null	Drag	Null	Adds to the selection set s^c all v^c within the boundary of the selection rectangle. This implies that selection is cumulative
Null	Drag	1	*Subtracts* all v^c within the boundary of the selection rectangle from s^c. Deselection is also cumulative
Any	Double-click	Null	Creates a v^c of a new collection C from s^c. if s^c is empty, create a new empty collection. This effectively merges all collections in s^c. No effect on selected v^c. The original s^c persists, but now includes the new v^c
Null	Click	1 & 2	*Clears* s^a, the alternative selection set
Null	Drag	2	Adds to the selection set s^a all v^a within the boundary of the selection rectangle. This implies that selection is cumulative
Null	Drag	1 & 2	*Subtracts* all v^a within the boundary of the selection rectangle from s^a. Deselection is also cumulative
Any	Double-click	2	Creates a new $_ja$ and corresponding $_jv^c_0$ for each v^a in s^a. No effect on selected v^a. The original s^a persists

Table 2 Interactions on alternative views v^a with modifiers and results

Target object	Interaction	Modifier	Result
v^a	Click	Null	*Adds* clicked v^a to s^a (Fig. 3)
v^a	Click	1	*Subtracts* target from s^a
v^a	Click	1 & 2	*Clears* s^a, and *adds* the clicked v^a to s^a
v^a or s^a	Drag from *source to target* v^c	Null	*Adds* a new v^a to the collection C of target v^c. Does not remove the target v^a from source v^c. Clear s^a and add the new v^a to s^a (Fig. 4)
v^a or s^a	Drag within v^c	Null	Changes screen position of v^a in v^c if the type of v^c so allows, otherwise NULL
v^a or s^a	Drag from *source to target* v^c	1	*Adds* the v^a to the collection C of target v^c. Removes it from source v^c. Clear s^a and add the new v^a to s^a (Fig. 5)
v^a or s^a	Drag within v^c	1	Null

Table 3 Interactions on collection views v^c with modifiers and results. For brevity and clarity, we omit cases where a source v^c and target v^c refer to the same C

Target object	Interaction	Modifier	Result
v^c	Click	Null	*Adds* clicked v^c to s^c (Fig. 6)
v^c	Click	1	*Clears* s^c, and *adds* the clicked v^c to s^c
v^c or s^c	Drag	Null	Changes screen position of v^c in gallery (Fig. 7)
v^c or s^c	Drag	2	*Add* all v^a from the collection C of source v^c to that of target v^c. The display of v^a in v^c depends on the type of v^c. No effect on selected v^c (Fig. 8)
v^c or s^c	Drag	3	Makes a new v^c of the collection at the end-of-drag screen location

The selection convention found in most interfaces is exactly the reverse, i.e., unmodified clicks select single objects, and deletes existing selection sets. Since our tasks almost always involve working with multiples, we eschew this convention in favor of its reverse. This is less error-prone, as large selection sets can be lost by unintentional clicks, thus frustrating users. Accidental deselection is harder, because actions required are more deliberate. Explanatory tool-tips or introductory screens during adaptation will improve the learnability of this new convention.

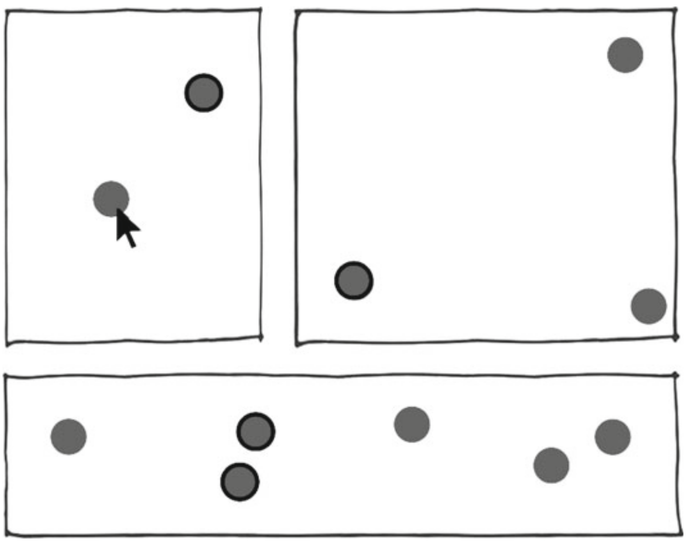

Fig. 3 With a Null Modifier, the clicked v^a will be added to s^a

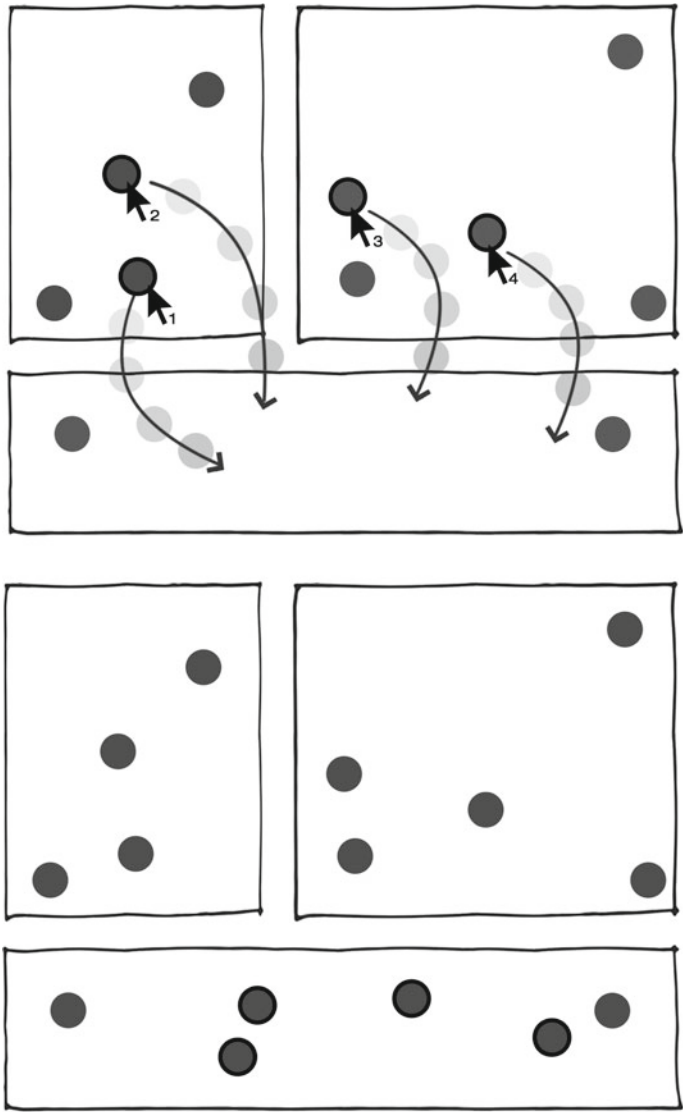

Fig. 4 With a Null Modifier, dragging from source ${}_iv^c$ to target ${}_jv^c$ (top) adds v^a to target ${}_jv^c$ (bottom) without deleting from source ${}_iv^c$

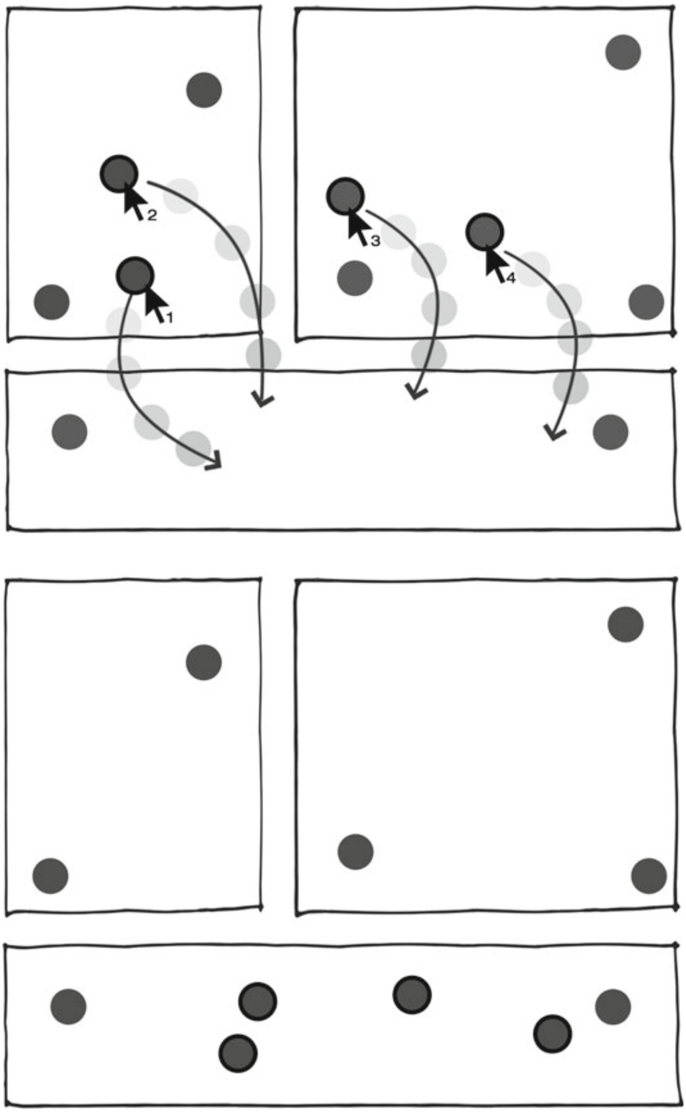

Fig. 5 With Modifier 1, dragging from source to target v^c (top) adds v^a to the target collection and removes the dragged v^a from the source collection (bottom)

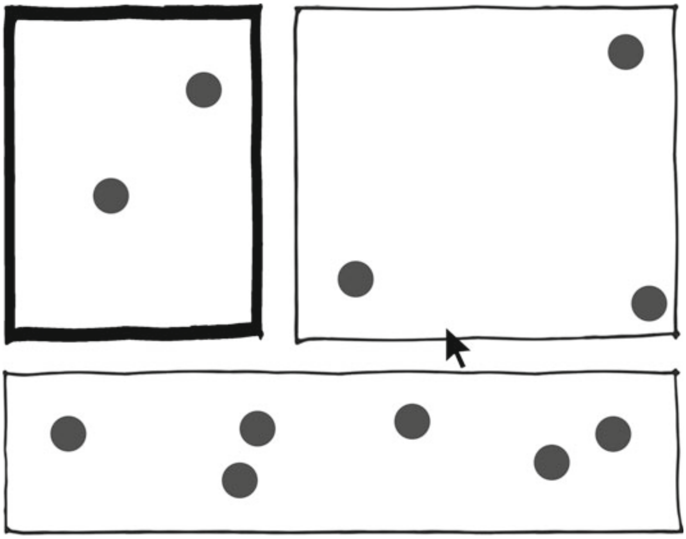

Fig. 6 With a Null Modifier, clicking on a v^c adds it to the s^c

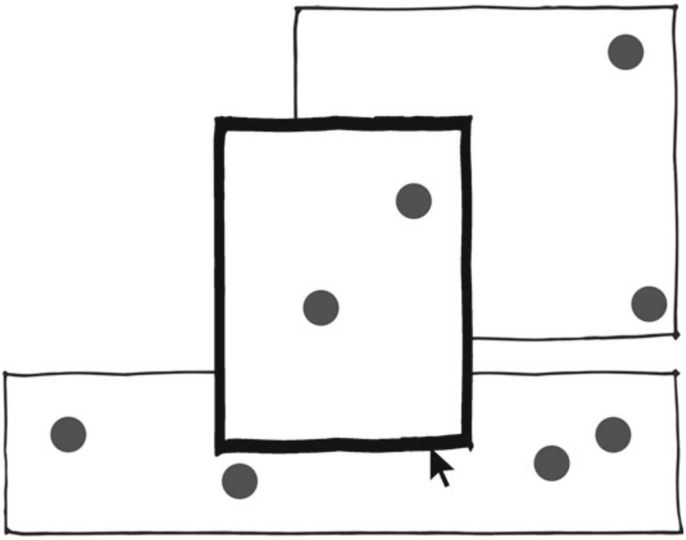

Fig. 7 With a Null Modifier, dragging a v^c on another v^c superposes the selected v^c without affecting the v^c located underneath

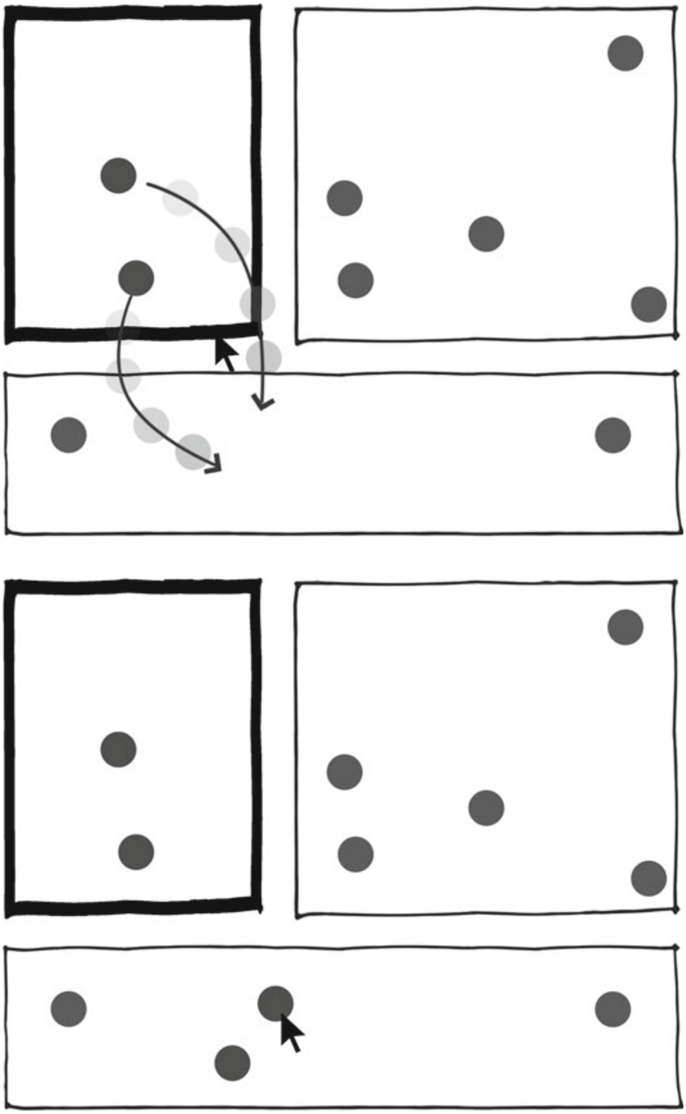

Fig. 8 Dragging a v^c with Modifier 2 (top) on another v^c adds the v^a from the dragged collection to the target collection. The display of v^a is based on the type of the destination collection (bottom)

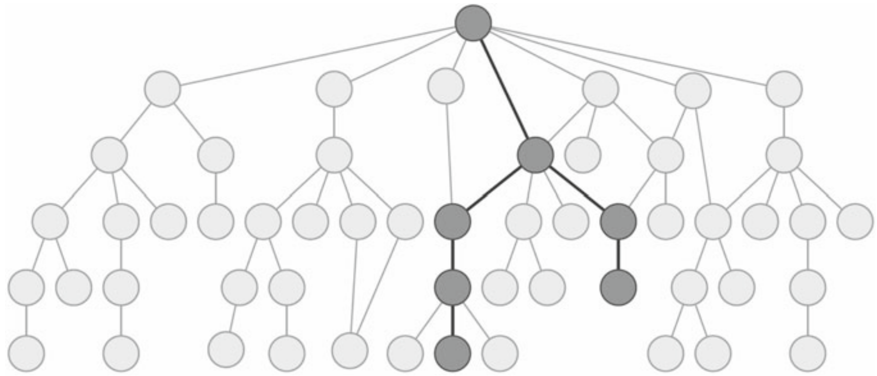

Fig. 9 Brushed paths depict the explicit design space that a designer passes to reach a solution. Unbrushed paths depict other possible paths not taken, i.e., implicit design space. Note that the implicit paths would not be represented in any interface as to do so would make them explicit in some sense. Image credit Sheikholeslami [7]

5 Introducing the Parallel Coordinate View-Controller

5.1 Motivation

Woodbury et al. [9] propose the idea of combining designers' past decisions in new arrangements, by which designers may be able to discover new meaningful alternatives. They coin the term *design hysteresis* to describe operators that perform such recombination. They call the set of states already visited the *explicit* design space, and the set all possible states the *implicit* design space. They introduce the concept of *hysterical space* (after *hysteresis,* the lagged entry of an effect into a system) to describe the result of operations that use states in the explicit space to access those in the implicit space.

Sheikholeslami [7] describes a specific case of such an operator, the *Cartesian product* of graph independent properties of an invariant parametric model, and coins the term *hysterical state* to describe states derived out of this recombination and, after Woodbury and Burrow, calls the set of such states the *hysterical space* (Fig. 9). In this context, the explicit design space is the set of states visited by the designer, and the implicit design space is the set of states achievable by exhausting all parameter values, which in the case of continuous parameters, is indenumerably infinite. The hysterical space is the Cartesian product of all parameter settings recorded by the designer.

To interact with the hysterical space, Sheikholeslami proposes the *Dialer* (Fig. 10), comprising concentric rings, where each ring represents one parameter and the divisions on the ring correspond to the recorded values of that parameter. The outermost ring contains the Cartesian product of recorded parameters. Each ring has a slider with an adjustable size that selects the values on the rings. By moving and resizing

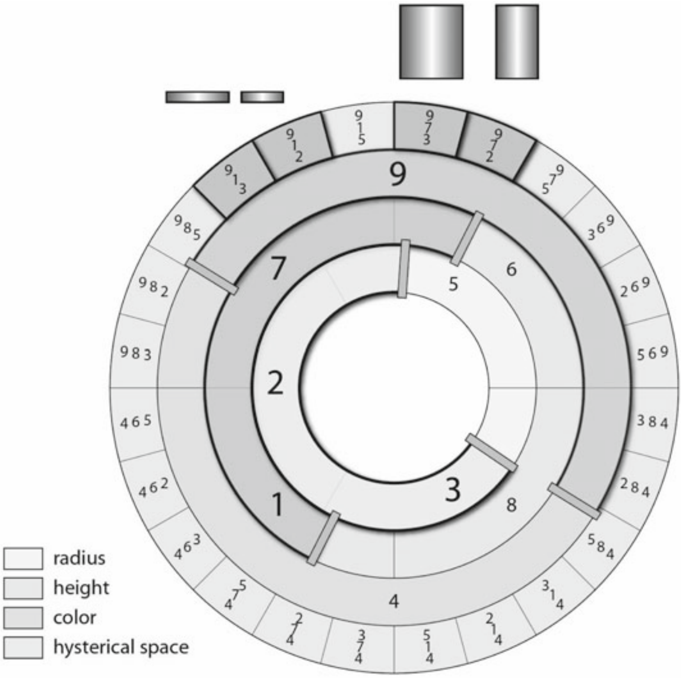

Fig. 10 A Dialer for a simple parametric model of a cylinder with radius, height, and color as input. The outer ring represents hysterical space, the Cartesian product of recorded inputs. Image credit Sheikholeslami [7]

the sliders, one can select the desired values for highlighting the corresponding items in the outermost ring (hysterical space). The shortcomings of this interface are that it is not scalable, as the number of divisions increases with the number of recorded variations; and the number of concentric rings increases with parameters. The hysterical space also increases exponentially, thus making the Dialer unreadable.

We use the Cartesian product in the Design Gallery as the expand operator. Interactions in the gallery closely follow the interaction model described by Sheikholeslami. Graph-independent node properties of every aspect in the gallery correspond to the recorded parameters in the explicit design space. In our Grasshopper™ implementation, users may choose to create a "pool" by recording states, or pick individual parameter values from alternatives in the gallery as candidates for the Cartesian product. In both cases, the exhaustive Cartesian product is calculated in the modeler, and a dialer (Fig. 11) lets users browse through members of the product in rapid serial visual presentation. In our study [2], we found that participants extensively used the expand operator to rapidly generate variations and scan through them using the dialer before selecting alternatives of value. This strategy was dominant across all users, and participants verbally confirmed preference for this form of interaction. However, participants used only a few "seed" alternatives to generate relatively fewer varia-

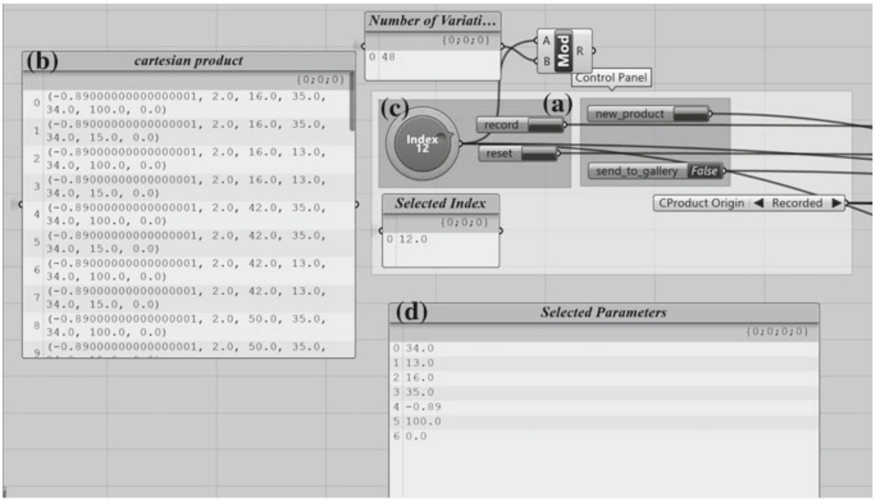

Fig. 11 Cartesian product dialer in Grasshopper™ implementation of design gallery **a** record button to record parameters **b** Cartesian product or hysterical space as vectors **c** dialer, and **d** parameters of member at selected index

tions–foresight tells us that, as the Cartesian product expands exponentially, linear scan through results by rapid serial visual presentation will become a less meaningful way of interacting with alternatives.

This brings to us the design challenge of visualizing, interacting with, and navigating large hysterical spaces (e.g., as generated by a Cartesian product), in the specific case described by Sheikholeslami, as well as the larger problem of design space exploration. Hysterical space is multi-dimensional data in nature, and we turn to *parallel coordinates*, a widely used and effective way of visualizing multi-dimensional data [10]. A vast body of literature exists on efficient and enhanced use of parallel coordinates for data visualization and exploratory data analysis, as well as widespread use of it in academia and industry.

5.2 Design Overview

The choice of using parallel coordinates follows nearly directly from parametric modeling interfaces. Extant parametric modeling tools use horizontal sliders as the most common interface for varying input parameters. It is not uncommon to find complex graphs with numerous slider nodes aligned horizontally. In information visualization, parallel coordinates are typically vertically oriented, where the up direction signifies an increasing value and vice versa. In our Parallel coordinate view-controller (henceforth abbreviated as PCVC), we change this to a horizontal alignment to match sliders, maintaining familiarity in the design discipline.

A PCVC is a special case of a v^c. Graph independent and dependent nodes from all $m \in M \in C$ form each axis in the PCVC. The property values of the $p \in P \in C$ in the v^c are plotted on the axes, marked by a circular "handle". In the case of ordinal properties, they increase from left to right, and default bounds are set by minima and maxima found by querying the property. In the case of nominal properties, discrete points are formed whose order may be changed. A v^a is therefore represented by a line running through the handles. Selecting a line selects the v^a, and selecting a handle selects the individual property value for that v^a only. Selecting an axis selects every value for all v^a that intersect that axis. Multiple lines may be selected independent of multiple handles across axes. Handles may overlap, and on selection attempts, a pick parade is proposed. Handle selection sets up an *create* or *edit* operation described later.

The ordering of the axes themselves is arbitrary, or in the order they were encountered from when the aspect was created, however, it is typical in implementations of parallel coordinates to allow re-ordering. This is necessary because parallel coordinates transform the search of multivariate relations in the dataset to a pattern recognition problem, and such rearrangements help in gaining insights [10]. However, independent and dependent nodes remain in separate groups for clarity.

Selection of two or more lines and computing the Cartesian product will yield all the possible lines through handles of those lines. As new alternatives are added to the v^c, the axes are automatically populated. There are many methods of maintaining and enhancing the readability of dense parallel coordinates in the literature that may be applied when the view is densely populated. Brushing and filtering are some common operations. Therefore, the PCVC avoids at least some of the scalability issues that plague Sheikholeslami's *Dialer*. A parallel coordinate view may be brought up by toggling any v^c, or it may be viewed side-by-side in combination with other view types of v^c. As an example of a $v^{\text{c.general}}$ interaction valid in $v^{\text{c.parallel}}$, dragging lines (${}_jv^a$ or s^a) from $v^{\text{c.parallel}}$ to any target v^c will add ${}_jv^a$ or s^a in the default view. Dragging within $v^{\text{c.parallel}}$ results in a null operation.

5.3 Generative Use

We propose that, in addition to visualizing values, each axis also behave as an input interface, hence the suffix "controller". Moving a handle will effect changes in the corresponding graph independent properties in the aspect *p*. As a consequence, a new alternative *a'* will be computed by *applying* this modified aspect *p'* to *m*. Multiple handles can be changed, and this will create multiple new *a'* in parallel (Fig. 12). If the choice is not to retain the original *p*, then this operation will be an *edit.* Drawing a line through the graph independent axes by dragging the mouse will create a *p* (Fig. 12) by creating values at the intersection points of the line and axes, while the user has the freedom to choose the associated *m* for the <*p*, *m*> tuple to create a new *a.* Thus, the model may vary, unlike Sheikholeslami's proposal. This new *a* appears in the controller's v^c. We propose that moving handles for graph dependent

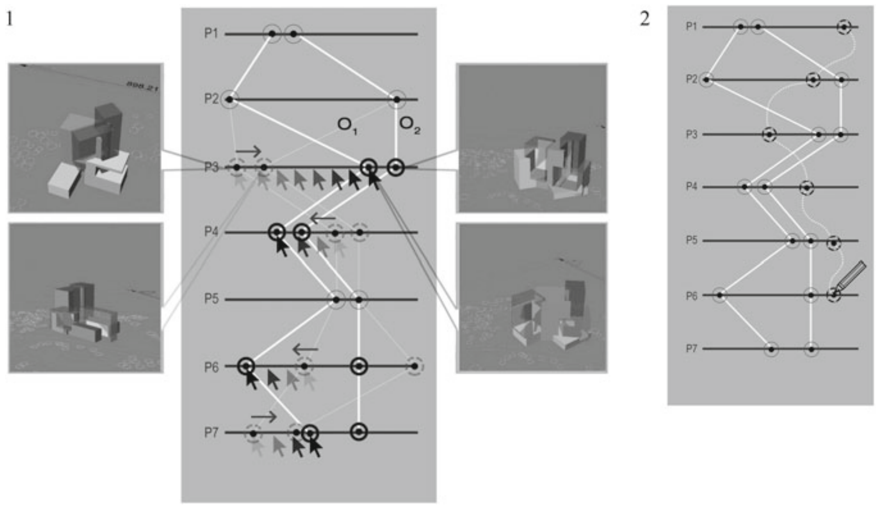

Fig. 12 (1) Dragging handles computes new alternatives. (2) Drawing a line through the axes creates a new aspect

properties trigger multiple goal-seeking operations that result in new alternatives meeting the new performance criteria. Currently, we have implemented parallel generation/editing of new alternatives using graph independent properties. We employ a server-client architecture. A request from the gallery sends the new *a* = <*p*, *m*> to a remote server running an instance of the same modeler, which applies *p* to *m* to create a new *a*. Sufficient computing power will allow continuous and real-time update of the 3D view.

5.4 Summary

The PCVC is our current focus of work. It is evident from the short overview that there are numerous possibilities for rich interactions to be designed and evaluated. We are possibly the first to propose that a visualization tool be also used as a generative tool. Information visualization principles go hand in hand with creativity support guidelines. A large literature in each area poses problems that need to be addressed and solutions that can be applied. However, as with the Design Gallery system, our immediate goal is to describe the most fundamental interactions.

6 Future Work

There exists a finite set of available interaction controls (e.g., CTRL, ESC, ALT, right- and left-mouse click). Despite finiteness it is evident that a sufficiently rich set of interactions arise, and devising a coherent and consistent encoding commands using these controls is a major design challenge. For example, Modifier 1 and Modifier 2 in the above may both be mapped to CTRL. This is our current work and the subject of a future paper.

The gallery system is also designed for high-resolution large displays [6]. This too adds to the design challenge on every interaction aspect, for example, selecting distant objects in the gallery. It also raises the question whether the traditional mouse and keyboard is adequate for such a challenge [11, 12] given the easy availability of advanced pointing devices and touch-enabled displays. This too is the subject of our future research.

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Underlying Principles and Emerging Designs: Design Exercises Based on Magic Squares

Jin-Ho Park

Abstract This article discusses how a simple and efficient design principle may be used to create a large collection of hybrid designs. Applying such principle in creating assembled arrays of designs can generate visually elusive final designs. This paper has three tasks. First, it examines the influence of the fundamental principle on the creation of new designs. Some notions and approaches of designers and architects are also reviewed. Second, this paper examines the basic properties of magic squares and employs its principles in the analysis and synthesis of designs. Third, this paper applies the principles of magic squares in creating new designs. Some examples of designs are also presented in this paper.

Keywords Magic sqaure · Principle · Grid · Geometric pattern · Parametric design

1 Introduction

One may encounter various designs or patterns in any cultural artifact, especially artwork. Some designs seem to come out randomly, by chance, or as a capricious act of the designer's will. These designs are very personal to the extent that they have been criticized for being arbitrary, ad hoc, or eccentric although nothing is wrong with such designs. By contrast, the sophisticated look of these designs have been praised by others. Given their complexity, the composition of such designs is difficult to analyze at first glance. However, these designs may be explained in a rational and methodical manner.

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Some designers have developed their own styles and come up with designs that may be consistent or similar with their other projects. To achieve consistency in their designs, designers must develop their own design principles or rules. Styles with different designs may share the same design principles [1]. By following their own design principles or methods, designers have the power to invent new designs. Applying certain principles can guide these designers in creating new designs. Accordingly, some designers keep in mind the notion of consistency when creating subtle designs. These designers may also be challenged in creating completely new styles for each of their project.

By modifying their principles through their creative talent, some designers can efficiently generate a multitude of design variations. They must also leave some room for subjectivity according to their creative desires and tastes. Designers may even break the stylistic conventions on purpose to achieve a certain effect, to improve their focus, or to highlight a specific reason. For example, by mastering the symmetry fundamentals, designers can easily break the symmetry and create asymmetrical designs [2]. One does not have to follow particular principles or rules; a mere appreciation of the fundamental principles in arts and architecture will be extremely useful in developing unique design styles or comprehending other styles.

This paper discusses the influence of fundamental principles on the creation of new designs. Aside from reviewing the notions and approaches employed by designers and architects, this study also examines the basic properties of magic squares and employs its principles in the analysis and synthesis of designs. This study also applies the same principles in creating new designs, which will be presented in this paper.

2 Notion of Underlying Principes

The fundamental principles of designs imply the ways that designers array the motifs of design in their artwork. These principles also help designers understand the spatial forms of their designs from the initial planning to the design stages. On the one hand, these principles compose the basic framework for understanding complex designs. On the other hand, these principles offer inventive insights into the creation of innovative designs.

The significance of the fundamental principles in creating new designs must not be overemphasized. In his article, The Metamorphosis of Plants, Johann Wolfgang von Goethe proposed the notion of metamorphosis and pursued *urform*, an ideal form, that underlies all plant and animal forms [3]. This article also lays the foundation for the subsequent developments in arts and architecture. Goethe also coined the term, morphology, to delineate the study of natural forms.

Many researchers, including Ernst Haeckel, D'Archy Thompson, and Wilson Bentley, have tried to find the underlying principles in natural objects. Their approaches have greatly influenced the search for pure geometric forms and the underlying principles of spatial compositions in architecture with stripped-out ornamental elements. Such tendencies are most apparent in the works of Étien-

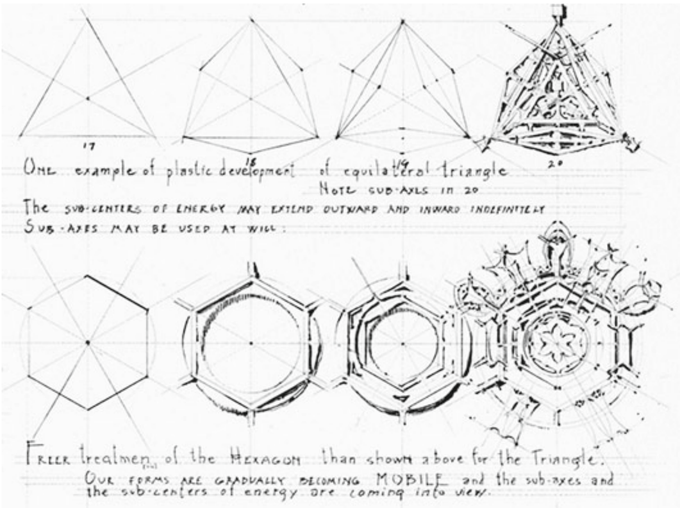


Fig. 1 Sullivan's generating process where simple polygons and their axes are used as underlying principles of final organic designs (from Louis H. Sullivan: A System of Architectural Ornament)

ne–Louis Boullée, Claude–Nicolas Ledoux, and Jean–Nicolas–Louis Durand in France as well as those of Friedrich Gilly and Karl Friedrich Schinkel in Germany. Gottfried Semper also used the term, "tectonics," to describe his theoretical perspective toward the fundamental principles of forms in nature and in art. He wrote, "Tectonics is an art that takes nature as a model—not nature's concrete phenomena but the uniformity [Gesetzlichkeit] and the rules by which she exists and creates" [4]. He emphasized that appreciating the fundamental principles would help one generate various creative works through modification and transformation.

Unlike others, Louis Sullivan demonstrated how these principles could be elaborated and developed for the creation of new organic designs. On the first page of his book, A System of Architectural Ornament, Sullivan wrote, "Remember the Seed-Germ" [5]. He defined the notion of seed-germ as the universal beginning or fundamental principle from which a plant will grow. In other words, the seed-germ is a concept of biological growth where several complex designs are elaborated through organic or geometric means. In A System of Architectural Element, Sullivan demonstrated how designs evolved and transformed from principles. Several creative and idiosyncratic designs can be developed by grasping the fundamental principles at work. In fact, these principles have been transformed into integral parts of designs (Fig. 1).

The most striking notion in architecture that emerged during the 20th century appears in the discussion of Louis I. Kahn regarding form and design. According to Kahn, form is an abstract notion, while design is an interpretation of the form. Moreover, the former has to do with eternal essence, while the latter relates to elaboration and manifestation [6].

Albeit their slight differences, abstract artists and architects have attempted to find the underlying rules or essential forces of forms. De Stijl architect Theo van Doesburg described how he simplified a cow into an abstract painting in Study for Composition (1917–18) and how he designed the stained glass window, Grote Pastorale (1922), where human figures were simplified into basic geometric components by arranging and juxtaposing rectangular and triangular elements with primary colors [7].

Pablo Picasso adopted the similar process. In 1945, Picasso introduced a novel abstraction approach in his drawings of a bull in lithograph [8]. He demonstrated how realistic objects could be transformed into abstract ones through a series of sketches. During this process, Picasso aimed to present the essential elements or presence of a bull through a successive analysis of its form. By reducing and simplifying its anatomy, Picasso sketched a few lines that represented the essential parts of forms. While van Doesburg simplified the cow with planes and colors, Picasso outlined the bull with lines. This whole process aims to find and express the absolute essence of the bull in a concise and abstract manner.

Several theoretical and practical perspectives have emerged to highlight the significance of the fundamental principles in the creation of new designs. Some of these perspectives search for the notion of design principles, while others encode such principles as guiding laws of their designs. When equipped with the necessary knowledge, designers have a higher degree of freedom to break the existing rules or set their own rules. Instead of following an array of seemingly arbitrary rules, designers may be better off by creating their own styles. This tradition continues to shape much contemporary scholarship of architecture like Christoper Alexander's pattern language, Lionel March's fundamentals of architectonics, and George Stiny's shape grammar [9–11].

The following sections present analytic and constructive approaches that adopt the underlying principles of designs. These approaches are complimentary in the sense that the analytic approach seeks to reduce a substantial whole into parts and components to clarify how the parts are arrayed and to infer the principles and rules that comprise the whole, while the constructive approach seeks to achieve the opposite. Partial motifs are combined into a coherent whole according to certain principles and rules [12]. Some design examples are presented as proof of applications. Both of these approaches have also been applied in analyzing the designs.

3 Magic Square: An Underlying Principle of Spatial Designs

Although different computational tools may be applied in the analysis and synthesis of designs, we use the fundamental principles of magic squares as an example. Despite being a relatively modern trend, magic squares have been used by designers and architects to devise design solutions. The principles of magic squares have fascinated mathematicians for many years. This technique is believed to have originated from China before spreading across the world [13]. The principles of magic squares

Fig. 2 The order of 3, 4, and 5 magic squares

4	9	2
3	5	7
8	1	6

15

16	2	3	13
5	11	10	8
9	7	6	12
4	14	15	1

34

11	24	7	20	3
4	12	25	8	16
17	5	13	21	9
10	18	1	14	22
23	6	19	2	15

65

have various applications relating to divination, alchemy, cosmology, and astrology. Some scholars have used the magic square to create a pattern for the layout of royal cities in China. The application of this technique can also be found in Melancholia I by Albrecht Dürer [14] and in *Sagrada Familia* by Antoni Gaudi.

Mathematicians have developed variations of magic squares, such as alphamagic squares, panmagic squares, antimagic squares, Franklin squares, and Latin squares. This paper limits its focus on an elementary property of the mathematical structure of magic squares. A magic square is an arrangement of consecutive natural numbers. The sums of the numbers in each row, column, or diagonal of an $n \times n$ matrix are the same. Given that a magic square follows an $n \times n$ format, its size is described by the order of n. Accordingly, a 3×3 magic square is described as the order of three magic squares. The sum of each row, column, and diagonal of a basic magic square is calculated as $[n(n^2 + 1)]/2$, while the middle number of an odd order magic square is calculated as $(n^2 + 1)/2$. Accordingly, a 3×3 magic square contains every number from 1 to 9, thereby having a sum of 15 and a middle number of 5. When $n = 4$, 5, and 6, the sum becomes 34, 65, and 111, respectively.

Several methodical accounts for constructing odd and even order magic squares have been presented in the literature. Figure 2 shows a sample order of 3, 4, and 5 magic squares (Fig. 2).

Given that magic squares are presented as a square grid, the symmetry group of the square is used to transform the arrangement of magic squares. The symmetry group of the square comprises eight distinguishable operations, namely, four reflections and four quarter-turns. Accordingly, any magic square can produce eight distinct squares through rotation and reflection.

Claude Bragdon and Richard Paul Lohse discussed the active usage of magic squares in arts and architecture. Influenced by the organic architecture of Louis Sullivan and Frank Lloyd Wright, the architect Bragdon actively applied magic squares to create geometric patterns for artwork and to provide “a source of formal beauty.” He argued, “There is nothing strained or illogical in this, for beauty is ever the fine flower of order and necessity, and in magic squares order and necessity predominantly rule” [15]. Bragdon followed a relatively simple logic when creating the patterns in his designs; starting from a number, he connects the centers of squares in a numerical sequence. The line paths, which he called “magic paths,” connect the consecutive numbers in each square to form a pattern. By tracing the numbers in their consecutive order, Bragdon creates a beautiful motif for an ornament. He also

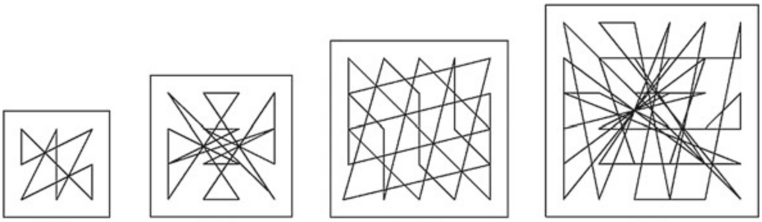


Fig. 3 Bragdon's system of connecting the centers of magic squares in a numerical sequence in the case of order 3, 4, 5, and 6 magic squares (drawn by the author)

proposed other novel uses of magic squares for generating characteristic designs [16] (Fig. 3).

Bragdon elaborated and enumerated a large spectrum of patterns following his own logic. He also created several patterns for architectural applications, such as ornamental panels, brickwork, gate patterns, and ceiling designs [17]. Despite following a simple process, the final designs of Bragon are very intriguing in the sense that their underlying principles cannot be identified at a quick glance. Above all, these designs may not be immediately apparent to the viewer. However, upon close analysis, one can find that these designs are highly superimposed, intricately planned, or based on reason.

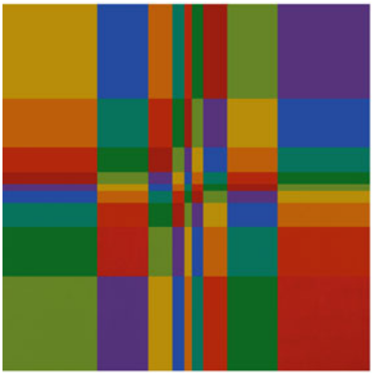
Unlike the use of linear paths with magic squares in the work of Bragdon, Lohse created several gridiron paintings with colors. Many viewers have focused on the symmetries, proportions, and color sequences of these paintings, while others have focused on their underlying systems. Upon closer observation, one can study how Lohse composed the grids and permuted colors on the canvas.

Figure 4 illustrates how the spatial layouts of each painting of Lohse are designed. Most paintings of Lohse are based on a grid structure that comprises proportional or gradually incremented subdivisions that form the basis of a systematic approach for constructing a layout. Lohse systematized the groups of colors by arranging them in a rotational progressive sequence. These colors are arranged in such a way that only one color occupies a grid unit by means of sequential principles. The sizes of grids and colors progressively and proportionally increase or decrease clockwise or counterclockwise. The geometric design of the grid and the succession of colors form the principles that determine the expression of colors and forms of the entire painting.

The choice of colors follows a clear pattern; Lohse based his choices and arrangements of colors not on intuitive or impromptu but on certain principles. Therefore, the color and form in his paintings are closely bound to strict design principles. For example, in his famous painting, 'Nine Vertical Systematic Color Sequences with Horizontally and Vertically Increasing Density', Lohse followed a particular sequence of color choices and positions (Fig. 5).

Based on the underlying modular grid of a square, each of the nine colors in the painting is distinctively used for each row and column, that is, the same color does not appear twice in the same row and column. This method has introduced a unique type

Fig. 4 Lohse's three paintings where proportions and symmetries are used as instrumental devices for the spatial compositions (redrawn by the author)



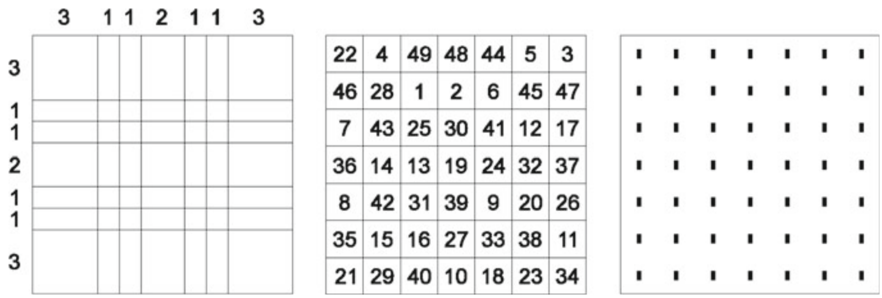
a	b	c	d	e	f	g	h	i
c	d	e	f	g	h	i	a	b
e	f	g	h	i	a	b	c	d
g	h	i	a	b	c	d	e	f
i	a	b	c	d	e	f	g	h
b	c	d	e	f	g	h	i	a
d	e	f	g	h	i	a	b	c
f	g	h	i	a	b	c	d	e
h	i	a	b	c	d	e	f	g

Fig. 5 Lohse's paintings nine vertical systematic color sequences with horizontally and vertically increasing density, and a latin square (redrawn by the author)

of magic square that was called a "Latin square" by Leonhard Euler. In this square, each number or alphabet can only be used once to fill an $n \times n$ grid. Each row, column, and diagonal uses each number or alphabet. Lohse repetitively applied a similar methodical approach in many of his paintings. His methodical approaches have been well illustrated in the working sketches and drawings presented in his book [18].

4 Parametric Designs

Parametric design is a rule-based approach that deals the algorithmic and geometric properties of a design with constraints and rules. Therefore, the strategic transformation of components is applied to explain the design of complex compositions. This approach allows for an unusual control over the designs in such a way that the aesthetic qualities of the final design is described as complex yet structurally organized.



22	4	49	48	44	5	3
46	28	1	2	6	45	47
7	43	25	30	41	12	17
36	14	13	19	24	32	37
8	42	31	39	9	20	26
35	15	16	27	33	38	11
21	29	40	10	18	23	34

Fig. 6 Left: A polyrhythmic grid. Middle: A 7 × 7 magic square. Right: A simple motif is arranged without any transformation in the grid

This section provides examples of constructive designs where motifs can be arranged, transformed, and superimposed according to the underlying principles and rules. Some methodical approaches are applied and manipulated as generative methods for creating new designs. Through these approaches, the development of various designs requires only a few abstracting steps and several sequences.

We use a rhythmic grid instead of other conventional regular grids. Lionel March categorized a series of grids with "three linear elements A, B, C, which had distinct integer dimensions with a < b < c [19]. The grids were designed to accept permutations of these elements." In this exercise, we use the permutation of the 3, 4 and 5 linear elements that produce a polyrhythmic grid, 3 + 1 + 1 + 2 + 1 + 1 + 3. Given that the grid has seven intervals, a 7 × 7 magic square is used as an arraying tool to array a motif. Afterward, each motif is placed on the center, corner, or side of each square grid. During this process, one must keep in mind that the type of accuracy and regularity that connects each number in sequence is an important aspect of the spatial composition of the designs [20].

We begin by placing the simplest possible motif on a grid to explain the increasing complexity that is captured in the parametric designs. The ordered structure of the whole design is revealed. Following Bragdon, we place the motif on the center of the grids in a numerical sequence. By applying the principle without any transformation in the square grid, the resulting configurations design becomes too apparent (Fig. 6).

Several other parametric rules can be applied in this process. For example, we apply symmetry operations, particularly rotations, where transformations and displacements of motifs are performed such that a motif can be simply displaced in a certain position within the grid according to the symmetric operations [21]. Instead of placing a motif on the center of the grid, a motif can be displaced on each corner of the grid according to the symmetric operations. Therefore, a motif can be rotated and placed while moving according to the sequence of numbers. Assume that we follow a set of rules where we place a motif on a corner of a point of a departure grid [22, 23]. Afterward, we move the motif clockwise before placing it on the next corner of the next grid according to the sequence of numbers while being rotated

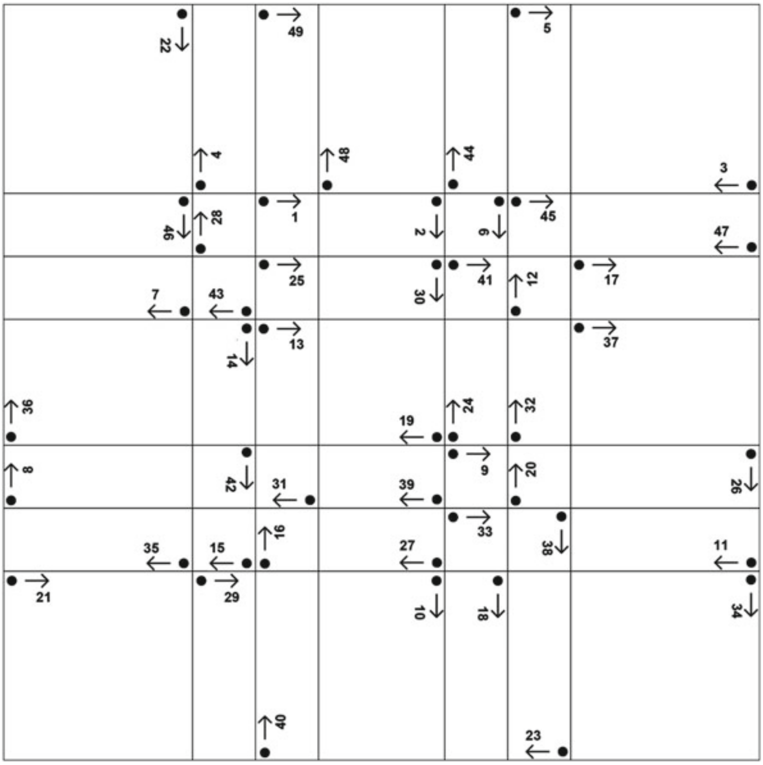


Fig. 7 Sequential positions for adding a motif to the corner of the grid

by 90°. In this process, a change in a single movement of the motif will change the entire design (Fig. 7).

Such consecutive deployment of a motif will generate an entirely unexpected design. Upon removing the grid, the resulting pattern presents a dynamic image with an unrecognizable design (Fig. 8).

The above rule illustrates the possibilities for generating several irregular patterns. By slightly changing the rules, a huge array of different designs can be generated. For example, a motif can be scaled up or down during its placement on the side of the grid. Figure 8 presents a design where a motif is placed on each side of the grid and then stretched or diminished according to the length of the grid. This rule increases the complexity of the final clustered design (Fig. 9).

Following the same principles, the symmetrical or asymmetric motifs can be clustered together. An asymmetric motif increases the complexity of the final design. When larger motifs are used and placed on the grid, the motifs may become overlapped. Therefore, we apply a rule to reduce the number of overlapping parts, and highly complex aggregated patterns are generated as a result (Figs. 10 and 11).

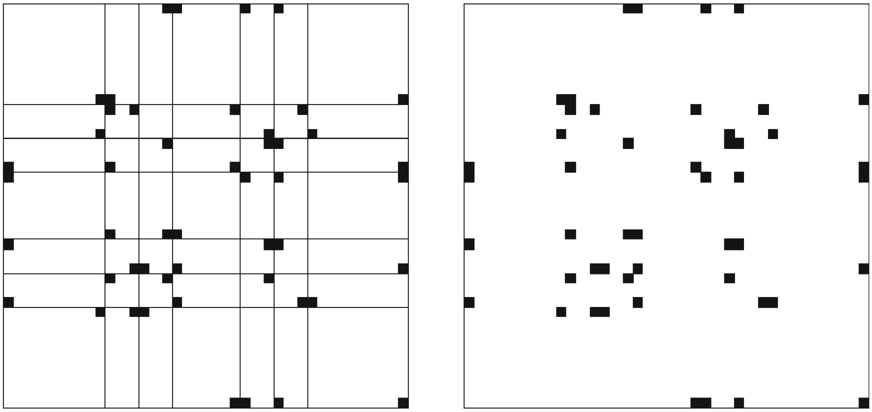


Fig. 8 A square dot is placed on the grid according to the magic square. When the grid is removed, the resulting design is highly complex and dynamic

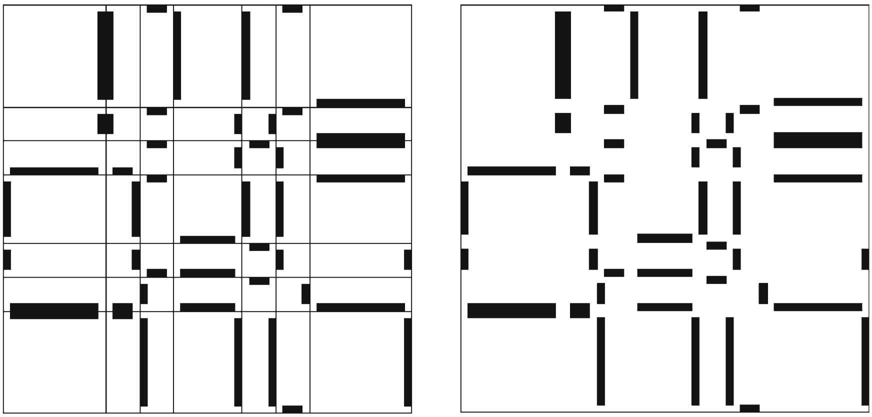


Fig. 9 A pattern where a motif is constantly transformed when moving according to the consecutive numbers of the magic square

A simple set of parametric rules is iteratively applied to generate complex forms. The results of such application are significantly more complex than expected. The parametric rules provide designers with a tool for controlling complex aggregates. By slightly changing the rules, the number of emerging combinatory possibilities is increased. Although the generated final designs are unexpected, their principles can be detected.

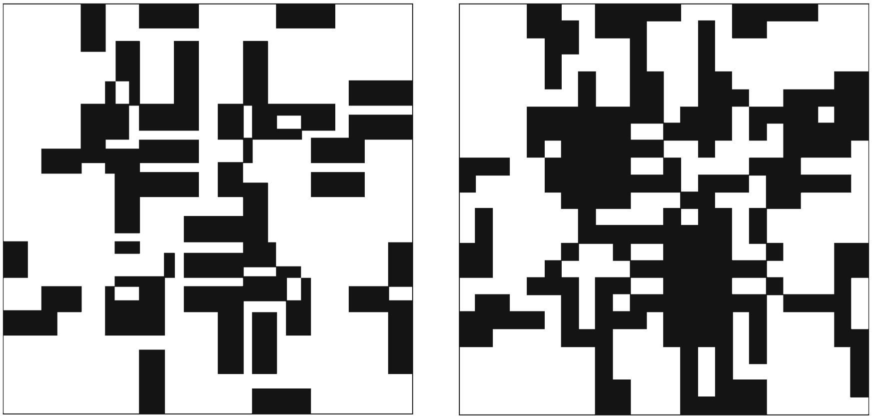
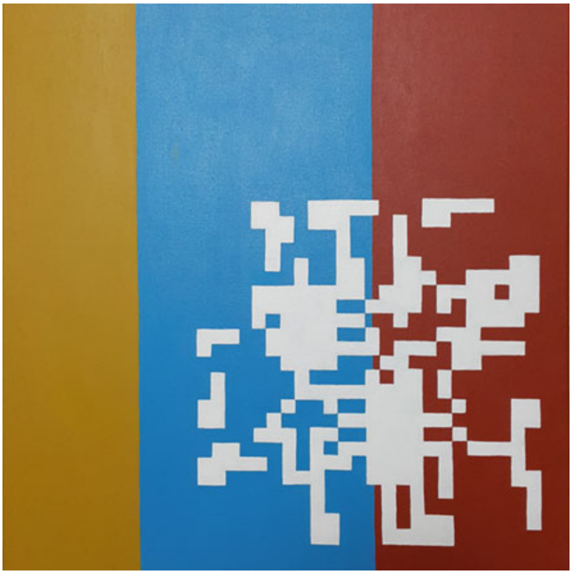


Fig. 10 Designs where the symmetric (left) and asymmetric motifs (right) are aggregated together

Fig. 11 An acrylic painting using a pattern generated in Fig. 10 (painted by the author)



5 Summary

This paper discusses the underlying principles of spatial designs based on magic squares. The basic properties of magic squares are delineated, and some designs of Loshe and Bragdon are presented as examples. Along with the symmetry operations, some complex designs have been generated to illustrate the unique application of these principles. The resulting designs are too complex that their rules and principles are very obscure. Yet, the motifs in the final designs are all tied together to create a cohesive whole. Using magic squares and symmetric operations as underlying principles can facilitate the analysis and construction of complex designs.

Once a series of sequences of operations are developed, further rules are setup and used to create more sophistigated designs. Instead of using a simple rhythmic grid of the same unit, we use a highly complex polyrhythmic grid that we derive from the permutation of three distinctive linear elements. More complex designs can be made by slightly changing grid patterns as well.

This paper presents a novel method to generate a variety of different designs. The results of this study can be further extended and utilized in design practices. In particular, the method can be adopted from small to large scale architectural components such as windows, carpets, wallpapers, housing clusters and complex building blocks.

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Multi-leveled Tridimensional Public Place and Urban Promenade

Jong-Jin Park

Abstract The paper investigates the establishment and development of Place de l'Europe in Flon district, Lausanne. Triangular shape, divers levels and complex system of the public place are singular. Particularly, a mechanical device and its effect on the multilevel plaza is significant for urban dynamics. The main elevator of the plaza takes a main role to control divers tridimensional flows. New time-space experience with visual perception entitled "urban promenade" could be accomplished by the particular mechanical device. This study manifests new trend and potential value of dynamics by architectural machinery in contemporary urban place.

Keywords Mechanical device · Multilevel plaza · Tridimensional flows · Urban promenade

1 Introduction

The transformation of city squares has been one of the main issues to develop the quality of urban life. In all the historical transformations of city planning, the square played an important twofold role. First, it was considered a place where the public could meet and mingle; in a way, it was commons for citizens. Second, the square was the city's focal point, where commerce would take place; most of the administrative functions of the city or state, along with key religious institutions, would circle it [1].

Le Flon in Lausanne is artificially constructed upon a narrow river passing the city center. The large commercial district is characterized by under-level area called as "Downtown." A public space of the Flon district entitled "Place de l'Europe" is in fact very different from traditional squares of many European cities. It is beyond two-dimensional large flat square. In addition, new type of architectural element to overcome height difference of the plaza between city center level and Flon district level has been introduced.

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The paper concentrates on new type of vertical distribution system that accommodates tridimensional flows among the overlapped layers. This study contributes new value of architectural machinery on public place and new form of urban promenade.

The scope of the study is limited by European square cases. The Place de l'Europe of Flon district, which is the main analysis area, was studied as an essential part. In particular, the Place Dauphine and the Place de l'Europe are compared by triangular geometry and environmental characteristics. The historical and morphological analyses of the Place de l'Europe based on maps and Géoportail GIS service data are preceded. The main elevator experiments with varied parameters are applied to clarify mechanical device efficiency and visual perception effect.

2 Dynamic Public Square Examples and Concepts

2.1 Dynamics of Public Space and Architectural Element

"How can we build a dynamic tridimensional public space?" The dynamics is related to multilevel concept and mechanical device in this paper. The multilevel idea transforms plat bi-dimensional space to volume. In addition, the mechanical device can amplify certain movements within the volume. Here, the mechanical device signifies a sort of new architectural element. It specially refers to moving devices such as escalators, lifts and elevators. They not only carry out images of automation and industrialization, but also take a new role and effect on modern life-style. The role the elevator plays in a building of such enormous scale and its revolutionary potential make it a very dangerous instrument for architects. It ridicules our compositional instincts, annihilates our education, and undermines the doctrine that there must always be an architectural means to shape transitions. The great achievement of the elevator is its ability to mechanically establish connections within a building without any recourse to architecture [2]. Moreover, the influence of the elevator on the urban scale will be stronger.

2.2 Different Levels and Discontinuity Problem

The problem of various levels and spatial discontinuity can be ameliorated by using architectural elements such as slope, stair, ramp, and also mechanical device. Firstly, some specific examples of medieval and modern cities are explained.

Siena—a typical medieval city of Italy—was formed by many narrow streets and plazas. Piazza del Campo, the main square closed its border with commercial facilities and residential buildings is famous for its slopes. The Piazza is equally divided into nine triangles and adapts to the topography by accepting the slopes. An inclined public stage in front of city hall was invented. It's a very symbolic place for all citizens. The acceptance of the slopes proves certain advantage for dramatic tension.

The staircase of Piazza del Espanol, Roma (1973-25) is Europe's widest staircase. The monumental 135 steps connect Trinità del Monti cathedral and central commercial area below. The staircase as architectural element allows for impressive pleasure of movement and dynamic effect. Most of all, the panoramic view on the stairs provides particular vista.

Lisbon is famous for slopes and public transportation to overcome various city levels. Elevador Sta.-Justa (1907) vertically links Baixa au Chiado, a grid-shaped central business district and Bairro Alto, a typical old town located at the upper level. It still exists as urban landmark connecting an end of the lower urban center and the higher old city area by the elegant machine. A sensational moving experience and urban continuity can be obtained by the vertical movement machine.

2.3 Modern Squares with Advanced Form

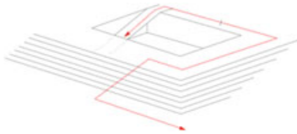
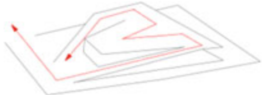
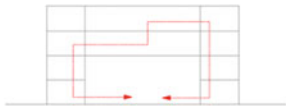
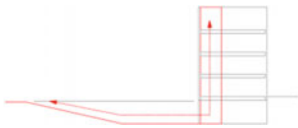
More developed examples of public spaces including deck, stairs, slopes, multilayer structure, sloping plates and escalators can be described.

The western riverside re-development plan in the 13rd arrondissement of Paris (ZAC Paris Rive Gauche du 13ème arrondissement) is a large-scale urban project with new Paris National Library (BNF, Paris). Huge artificial deck as reference level is stand out between four "L" shaped overhead-type offices and under level public library. The outer boundaries of the deck embody wide stairs to solve the problem of levels and link to streets. On the other hand, the underground library actively admits an escalator for main approach from the above the deck level. The symbolic staircase and escalator are main architectural elements with the deck as new dynamic public space.

The Oslo Opera House (Oslo Operahuset 2008) is located in the Bjorvika Sangha Industrial Area. Around the sea-side, several inclined surfaces go over or through the projected volumes to create a continuous public space. The opera building is made up of three concepts: "undulated walls, factories and carpets". Above all, the concept of carpet refers to a horizontal plane covered by marble. The continuous slope becomes a building and also a public place. By comparing with Tadao Ando's Museum of history (Chikatsu-Asuka 1994) showing continuous terraced steps, the endless slope is much more natural on the point of accessibility and continuity.

The MFO Park (Zurich 2002) is a public space realized by the winning international competition project for refurbishment of an old industrial area in the western suburbs of Zurich. In the tridimensional grid structure, the vacant volumes are guaranteed and extended vertically so that they enable the installation of floating multi-story flats connected with stairs, aisles, terraces on above. The greens that climb up, flow down, or exist independently, are also prominent on the point of sustainable tendency. The park shows the concept of transparency, flexibility based on multilayer structure in public space.

Table 1 Contemporary public squares and flow diagrams

Plaza and architects	Year	Main elements	Flow diagram
BNF, Paris, D. Perrault	2007	Steps platform escalator	
Opera Huset, Oslo, Snohetta	2008	Continuous slopes	
MFO, Zurich, Burckhardt + Partner	2002	Steps plats	
Centre Pompidou, Paris, Rogers and Piano	1977	Plaza on slope escalator	

The famous inclined square of the Centre Pompidou (Paris 1977) is a good example of a re-interpreted modern square from the Piazza del Campo in Siena. It is located in the old commercial district and offers 7,000 m^2 of outdoor space linking modern art museums with city. The sloping plaza, which has 3.7 m difference from the road reference level, is gradually lowered toward the entrance of the building. The main building is withdrawn with a distance and various external activities are always possible on the sloping plaza. On the main façade of the building, an escalator combined with lightweight building structure is highly evaluated as a moving system linking together the street, the square and the building itself (Table 1).

These examples show architectural and mechanical elements and ensure particular tridimensional continuity. Those elements engaged in variety of dynamic activities of the public in everyday-life beyond simple bi-dimensional movements.

3 Lausanne Flon, Public Space and Mechanical Devices

3.1 Flon: From Industrial Platform to Central Commercial District

Le Flon, which is the background of the study, is a redeveloped central commercial district of 7 hectares in Lausanne. A huge platform that had maintained Flon's warehouses over 50 years has produced many urban redevelopment projects between two main bridges, the Grand-Pont and Pont Chauderon. Since 2000, the Flon district has become a remarkable multi-center of commerce, culture and entertainment in Lausanne. It has naturally created new public spaces around the renovated buildings. Most of all, the Flon is characterized by its under-level distinguished from the representative city ground level. Besides the change of space organization, it still has to overcome different levels and develop challenging mechanical devices.

3.2 Ponts-Ville and Infrastructures

Bernard Tchumi and Luca Merlini's "Ponts-Ville", which provided a blueprint for the development of Flon district, represented a set of infrastructures as main project elements through the "Gare du Flon" competition (1988). The four bridges are inserted in different ways to connect each side or different levels. The infrastructures are intended to integrate radically with the existing constructions. People notice various elevators and escalators associated with the bridges. New perceptions provided from the diagonal or vertical movement devices towards remarkable landmarks—nature and city—are important. It evokes new type of urban promenade brought by the infrastructure elements and tridimensional public space.

3.3 Flon-Ville, Increased Public Movements and Utilization of Machinery

"Flon-Ville" of Patrick Mestelan Architects, the winner project of the competition for new development of West Flon quartier had been realized by combining old constructions with new ones. The new main buildings are concentrated around a courtyard. It contains Lausanne administration offices and additional complex programs. A stairway, an elevator and a foot-bridge are installed for connection between old city center and the under-level courtyard of Flon-Ville.

Otherwise, a large public parking lot and a rectangular plaza (Espalnade du Flon) are constructed in the middle of Flon district in 2006. The plaza is a multi-purpose event plaza on existing underground parking lots. Around the Plaza, various facilities—cinema multiplex, restaurants, offices, residence, recreational facilities—occupy the surroundings. Several car ramps, stairs and elevators link the underground parking-lot and the plaza.

Another unusual public space is a terrace garden on a banana-shaped building. An elevator located on the southern façade of the building links directly the top and the bottom level. The elevator originated from an ancient cargo during the industrial epoch is re-introduced for public vertical movement today. It allows for convenient and rapid movement from the lower Flon level to the upper city level.

4 Tridimensional Plaza and Mechanical Building Equipment

4.1 Origin and Triangular Form of Place de l'Europe

The Place de l'Europe originates from the Gare du Flon at the end of the 19th century. An empty space between the Grand-Pont and many clustered warehouses were used as a logistic trade place. In 1960s, a floating foot-bridge connecting a part of the Flon Station building and an end of the Grand-Pont was built on a massive building disappeared today. It introduced a triangular aerial connection structure similar to the present one. In 2000, new additional steel structures defined more clearly the plaza. Today, one of the important role of the Place de l'Europe is to gather and disperse diverse urban flows along with passages and transit buildings. The flows of four different public transports (Bus, Tsol, LEB and M2) coexist on different layers between the Flon interface railway and M2 Metro Station. More than 60,000 people visit the plaza every day and it helps people move smoothly.

Most of all, the triangular form of public place in the middle of city could be rare and singular. Even if we consider the popular baroque triangle composition,[1] the essential elements are main axes and monuments as focal points but not inner-triangular space. The Place Dauphine in Paris can be the very representative triangular public plaza in the city history.

The comparison of physical and environmental analysis between two plazas on the basis of triangle shapes help understanding dynamic characteristics of Place de l'Europe. Two places can be translated by two types of triangle such as isosceles and right-angled triangle. They result different types of focal point and movement on the plazas. In addition, the closeness of limit and surrounding programs control people's flow differently. The irregular surface with incorporated architectural elements such as steps, ramp, elevator and escalator intensify dynamics on the site (Table 2).

4.2 Tridimensional Flows and Mechanical Device

By the fundamental problem of discontinuity with different levels, it is interesting to consider adapting architectural elements. Besides long slopes and steps connect old city level and new Flon level, between 1907 and 1914, the emergence of an elevator connecting vertically Grand-Pont and Place de l'Europe was extremely innovative.

[1]Kevin Lynch presents the model of the Baroque city with certain principles. Certain dominant points are naturally defined, from which the structuring symbolic elements are located in the vicinity. Then, they connect to these focal points of the streets, wide enough to support the traffic, and create visual links between the symbolic points. The city is organized on the edges of these streets, giving them unity, using for example arborization, and instituting rules of arrangement: height, alignment, facade, etc. Then, various types of buildings can occupy the less controlled streets of the interior of the triangles. LYNCH Kevin. Good city form, p. 281.

Table 2 Comparison between Place Dauphine and Place de l'Europe

Geometry	Element	Place Dauphine	Place de l'Europe
	Triangle	Isosceles triangle	Right angled triangle
	Symmetry	Considerably symmetrical by main axe	Non-symmetrical by different faces
	Length (m)	75, 72, 51	116, 87, 82
	Height (m)	18	13
	Surface/volume	2,665 m^2 47,970 m^3	3,646 m^2 47,398 m^3
Environment	Topography	Flat	Inclined
	Closeness/Openness	Opening at a vertex and on the middle of a small side	Major openings on two angled sides
	Traffic	Isolated from traffics	Surrounded by traffics
	Programs	Apartments (commerce, restaurant, gallery/ground)	Infra-structures (flexible space with café-bar, expo, info-box)
	Material	Gravel	Asphalt
	Architectural element	Steps	Steps, ramp, elevator, escalator, foot-bridge

This idea has been developed and applied to several spots of the Flon quartier over the next 100 years. Consequently, new vertical movement mechanism that connects the entire flow of Place de l'Europe through the underground and upper floors have taken place as main architectural element in the plaza.

On the board of the Flon-LEB transport facilities and the M2 Subway platform building, the Place de l'Europe having a right-angled triangle is mainly disposed. In addition, the Grand-Pont, a historic infrastructure is located at the eastern and southern borders of the public place.[2] Above the plaza, a floating bridge connected to the extended corridor of the transport building makes a kind of circulation path corresponding to the city level—13 m above the Flon ground level. As a result, a floating system above the plaza appears and completes a sort of tridimensional volume. This upper ring road as supplementary circulation redistributes Lausanne urban flows from the upper city center and the lower Lausanne station. Under-level main flows from the rue Centrale on the east, rue de Genève on the northwest, and avenue de J.-J. Mercier on the southwest gather at Place de l'Europe. From the

[2]The Grand-Pont is the very significant symbol. It serves as stage and also a clear limit of the plaza. In addition, the void space of arches is used as multipurpose space such as exhibitions, cafeterias, sales outlets, and storages. Consequently, the foot-bridge becomes suspended sieges in the air based on "see and seen" concept.

Table 3 Applied devices' properties

Device		Characteristics				
Elevator	N	Name	Floor	Transparency	Speed (m/s)	Cab size, inside (depth $\times$ width)
	1	a. EV public Grand-Chêne	6	Transparent	16/14 (1.14)	2.0 m $\times$ 0.9 m
	3	b. EV Passerelle-commerces M2 direction croisettes	3	Non-transparent	13/22 (0.59)	2.8 m $\times$ 1.2 m
	2	c. Parking-commerces M2 direction Ouchy				
	2	d. EV Passerelle-Flon-LEB	3	Transparent and red dots	13/14 (0.92)	2.2 m $\times$ 1.8 m
Ramp	2	e. Route de Bel-Air (slope: ~ 9.5%, length: 124 m, width: 8 m) f. Entrance to M2 plate-forme (slope ~ 6%, length: 30 m, width: 12 m)				
Steps	7	g. av. de Genève-LEB, h. place de l'Europe-LEB, i, j, k. place de l'Europe-M2 plat-forms, l, m. Point de rencontre-M2 plat-forms				
Escalator	7	n. M1-LEB and M2 direction Ouchy, o, p. M2 plat-forms—Meeting point, q, r, s. M2 plat-forms—Place de l'Europe				

underground level, public transport flows by LEB, M2 and M1 connect to the inner city flows on the Place de l'Europe.

Vertical movement machines are actively involved to coordinate and control complex and multilayer horizontal movements. In particular, a main elevator (Table 3d) efficiently links the various flows on the layers. Vertical movement by elevators and diagonal movement by two ramps along the Route de Bel-Air (Table 3e) and M2 entrance are capable of supply a new type of promenade with more dynamic and sensational views. The central main elevator is composed by transparent glasses and metal structure. It absorbs all smooth horizontal movements including people with bicycles and wheelchairs from each corner on the plaza. It redistributes those movements to the floating bridge and the underground transport platforms. It acts as the backbone of the whole tridimensional space movements (see Fig. 1).

4.3 Perception Experiment with Mechanical Device in a Tridimensional Public Space

I introduce the issue of visual perception and its effects in urban scale. As a mechanical device let pedestrians move automatically in certain direction, it can supply a radical experience with pleasure by the acquired particular perception in movement.

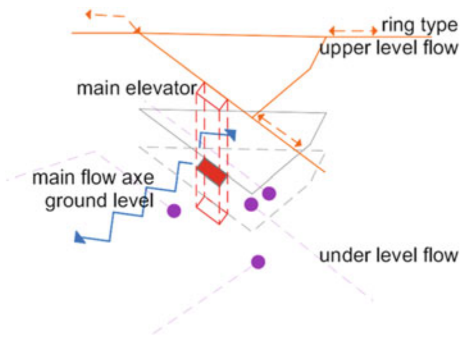


Fig. 1 Flows in tridimensional volume, Place de l'Europe, Flon (*Source* JJ Park)

By analyzing and experimenting the main elevator movement and its effect of the Place de l'Europe on the notion of location, transparency and efficiency, the role and effect of mechanical device in tridimensional public place can be distinguished more clearly.

(1) Location: (South)− < Current disposition < +(North)

Supposing that the elevator displaces horizontally to the north and south under the precondition that it should be linked from the basement to the upper levels at same time. Several visual qualities from each level can be considered.

For example, as you move to the north, the visual link between the main bridge and Flon district decreases and the stiff slope and distance make it difficult to connect with the main pedestrian movement. In addition, the accessibility to the three modes of transportation is less efficient even in the underground level (see Fig. 2a-3, b-3, c-3).

As shown in the analysis diagram according to the movement to the north and south, the legitimacy of the current disposition of the main elevator is evaluated at three angles: visibility, connectivity with main flow on plaza, underground transports connection (see Fig. 2). Vertical movement with mechanical device allows a sort of section view of Flon area. It associates with each level's view revised by continuous vertical movement. In particular, clear visibility toward to grand nature (Jura) and particular landmark (Lausanne cathedral) is advantage of the main mechanical device.

(2) Transparency: (opaque)− < transparency < +(transparent)

The main elevator is based on the steel structure and the glass envelope. These physical characteristics significantly reflect "transparency". What kind of effects can it make on? Through the history of elevator, the transparency is intimately related to kinetics. Portman understood that people are innately interested in movement, for movement means life, and human beings are kinetic creatures. He believed that if he incorporated kinetics within the building, it would strike a responsive human reaction. The atrium design allows people the opportunity to watch and be watched. To accompany the motion of the elevators, the movement of people along the hallways

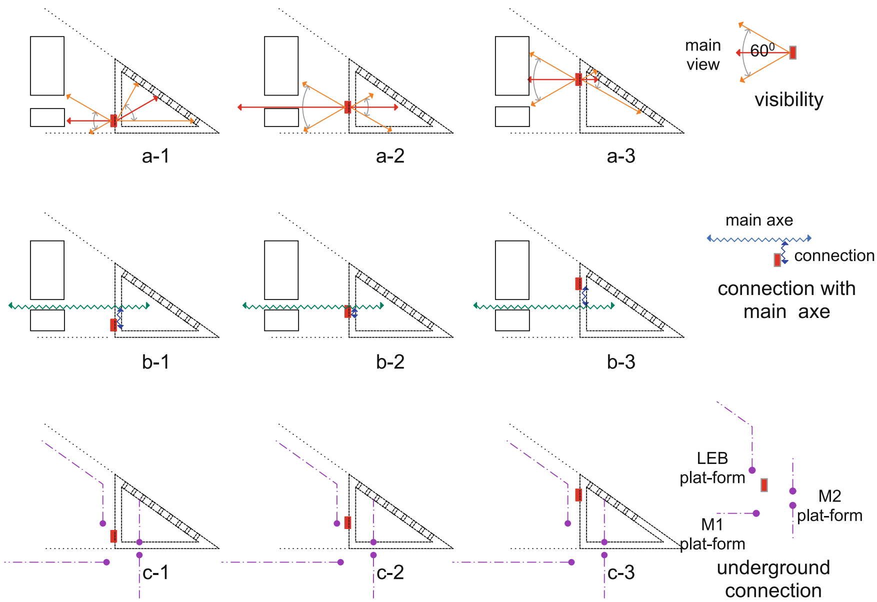


Fig. 2 Three subjects and experimentation (*Source* JJ Park)

circling the atrium and across the atrium floor catches the eye. The design engages the senses and thrills the soul [3]. Depending on the degree of transparency, we can consider particular visual connectivity with sensation.

As shown in the diagram below, as the higher degree of transparency is marked, the higher values are shown in the three sub-categories (see Fig. 3). Besides, the quality of the elevator could be defined by velocity in American building culture. Those measures require particular square composition and enhances the utility of the public space in a sensitive way. The transparent volume of the transport hub has an overall high transparency character mainly for the elevator compare to the horizontal lower volume and the repeated red dot pattern on the glass surface on the bridge.

(3) Mechanical efficiency: (slow)− < current speed < +(fast)

The elevator is mostly utilized for connecting several floors in a vertical space. The principal technical parameters of elevators are rated load Q (kg) and rated speed V (m/s) [4]. Unlike a residence or a workspace, on public space such as plaza, unspecified passengers will use the elevator. It requires different qualities beyond the “quick and a lot”. It permits to re-analyze and re-evaluate the vertical movement device on the point of ‘comfort, view and connectivity’.

Firstly, it could be evaluated that the quality of the comfort and view is inversely related to the travel time (see Fig. 3). It shows that the visual connection and comfort can be considered more important than the rapid movement for the passengers. For example, the speed of the four elevator facilities installed in Place de l’Europe are adapted to different utilities. The speeds could be calculated as ‘a > d > b, c’ (see

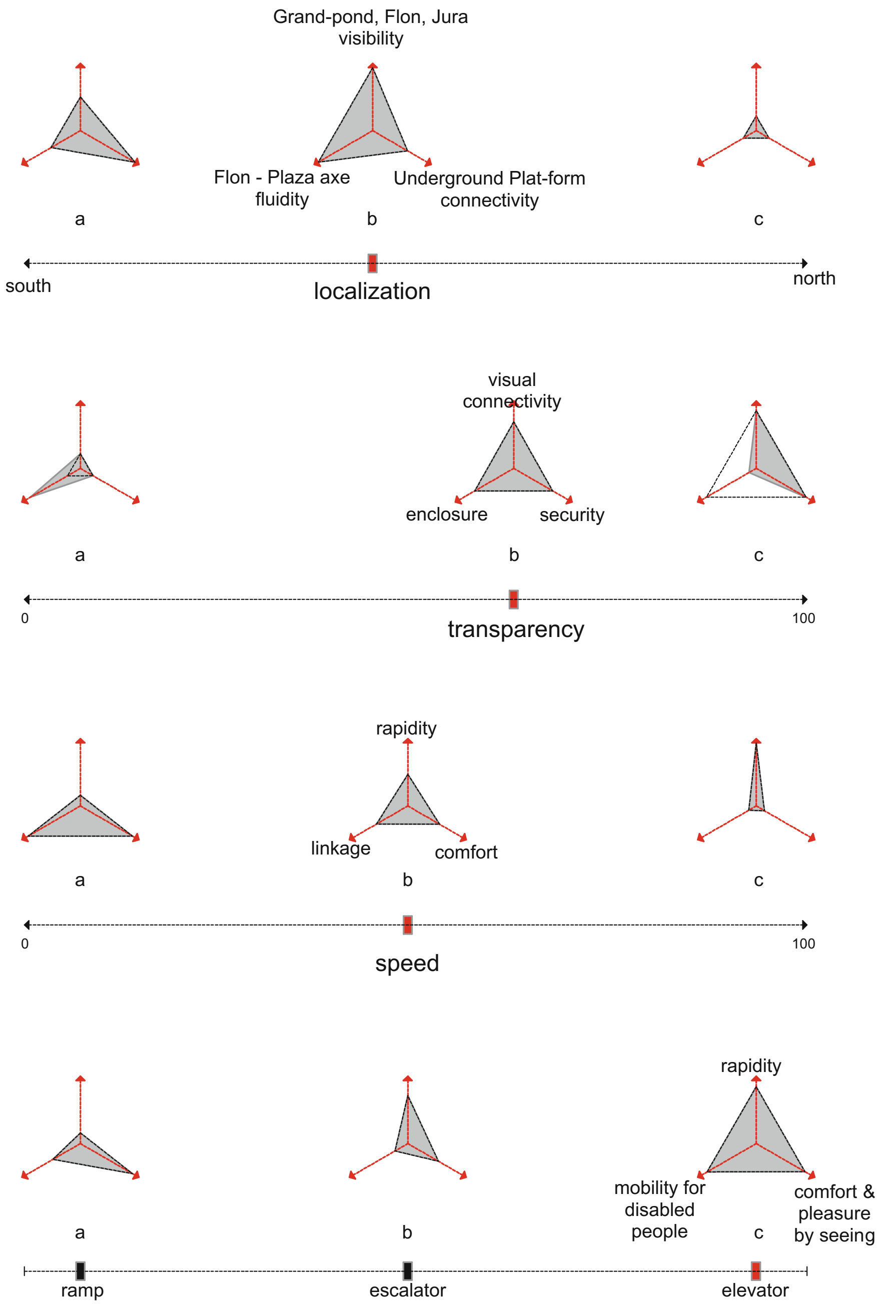


Fig. 3 Three properties and evaluation (*Source* JJ Park)

Table 3).[3] The main elevator (d) located on an edge of the tridimensional volume has a relatively moderate speed, considering the view and comfort for all kind of publics. It also shows the progressive pleasure by accumulation of segmented urban images according to the adjusted moving speed and height. It is expected as a new type of promenade on public place with vertical moving device.

Above analyses could be useful to apply them as evaluation criteria for similar mechanical device installation in other public places by considering other sites' physical conditions.

5 Conclusion

The Place de l'Europe of Flon is intimately related to its historical and topological characteristics. It represents an inventive tridimensional space. New circulation system with multilayer structure was suggested in order to overcome particular triangle shape and different levels.

To apply tridimensional multilayer structure to an urban public place, several points could be considerable as below;

- Inner ring-type circulation system connected with existing road networks on each level
- Completeness of vertical or diagonal mechanical devices for efficiency connection
- Creation of stage and siege based on 'see and seen' notion in new tridimensional space.

More specifically, the localization of main mechanical device is essential because it functions as new center of gravity in tridimensional public place. The device maximizes deep and continuous perception and montage effect by overlapped segments of city images during the movement. It offers new way of perceiving city-scape in motion. Light and transparent skin of moving device influence on different type of boundaries and connection with the main public space and surroundings. Furthermore, the adapted speed and size of moving device supplies comfort and enhanced functionality. It ameliorates accessibility for the aged and disabled people.

New spatial and temporal experiences could be completed and intensified with mechanical devices. It presents new value of movement experience based on mechanical device in urban public place. The simple mechanism for movement deserves new meaning as cultural device related to contemporary cities.

The diagonal mechanical device subject is also interesting in large-scale atrium type buildings beyond general outdoor open squares. The Canopy project (2016) in Paris by Patrick Berger arises from the idea of divers urban flows around multilevel

[3]The norm SIA 106, Art 8. concerning installation and exploitation of elevators and lifts in Switzerland indicates that the speed must not exceed 2.50 m/s, unless special authorization of the competent authority. Besides we can consider the average speed of elevator could be 2.5 m/sec, the moderated speeds such as 1.14, 0.59, 0.92 m/s are applied for the four elevators (a, b, c, d on Table 3.) on Place de l'Europe.

public place. The “circulation effect” of the multi-leveled central plaza with patio and pedestrian areas transforms the site into an open theater for pop-ups, events, and displays in synergy with the commercial and cultural facilities [5]. It demonstrates splendid escalators that are dramatically applied as new architectural element in multilevel public place.

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Fossilisation of Rural Streets Within the Modern City

Kyung Wook Seo

Abstract This research presents the urban transformation process in Suwon, South Korea, in particular focus on Wooman town to analyse the conflict between the old and new street patterns. Through the 1970s and 80s, the city of Suwon went through a huge scale of development with a steep population growth. With the expansion of urban territory, Wooman, a small agricultural village has been incorporated to the wider territory of the city. During this process, the urban grid has been imposed onto the old street network, and at the end, the organic form of the village roads became varied within the new urban structure. The old streets in the village which formed the main circulation network for village people's lives are now hidden, forgotten and abandoned. From the outside, the block of Wooman has a typical modern urban landscape with straight lines of parallel streets. Walking inside it, however, one can find strange irregularity of back streets which used to be a major connection in the old days but are now treated as back alleys, illegally occupied for parking, vegetation and garbage dumping. It is our particular focus in this research to find how this dramatic change of status for these old village streets has happened and how their traces could survive through the mega-scale transformation of the city. We assume these traces are the urban fingerprints though which we can find the embryologic clue to reveal the process behind the formation of the entire city.

Keywords Urban transformation · Historic route · Urban grid · Superimposition Network surplus

1 Introduction

Urbanisation implies growth and condensation in terms of both population and built environment. Some rapid urban development imposes an urban-scale grid on organic townscape. When the urbanisation is gradual and slow, it is often the case that the

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old and new streets co-exist in harmony just as in many European cities. When it's faster and thorough, the original form of townscape is often entirely obliterated. This is frequently observed in the fast-growing Asian cities where mega-scale new developments have been an important national agenda in the process of modernisation, while the value of vernacular landscape is ignored. In some cases, however, we can still find some old rural street patterns intact after the brutal process of urbanisation. With no clear usefulness of maintaining them, they are encased and preserved within the new urban network. How could they be fossilised within the modern city?

Wooman is a town in the city of Suwon in South Korea. Seen from the outside, it has a typical urban scene; far-extending wider roads define the boundary of blocks from the periphery and straight local streets penetrate inwards to its inner structure. Walking inside the block, however, one finds a strange irregular pattern of meandering streets hidden behind the neat alignment (Fig. 1). Is this a vestigial trace of the earlier rural paths? Along these backstreets, all types of houses are allocated randomly without any visible order or harmony. More curiously, here you encounter all differently-shaped small patches of land between buildings that are temporarily utilised for parking or storage yards, and sometimes even farming. This chaos in land use is definitely not what modern master-planners want to see. Presumably, this has been caused by a sudden enforcement of tight urban setup upon the loose fabric of old streets. Thus, its uncontrolled condition might be the internal fracture resulting from the adaptation failure of rural village in modern time. If this assumption is right, then a research question arises: How does an old street operate within the modern block? This paper makes an attempt to answer these questions by space syntax analysis to measure the change of significance of rural paths.

2 From Rural to Urban

In 1974, Wooman was a low density rural village with only 1,300 people mainly working in the agricultural field. The name of the village, Wooman literally means ‘many oxen’. In fact, oxen were the most important and abundant power resource in Korean agricultural scene; so unpaved rural roads were usually labelled as oxcart roads in old Korean topographic maps. However, as its name indicates, it seems quite certain that this particular village kept more oxen than its neighbouring towns. Figure 2 shows its 1974 map (left) and the current map in 2013 (right). The thick boundary line in the old map reflects the current block boundary that will emerge by a major road intervention in the 1980s. As of 2013, there are 18,764 people living in this block which is filled with residential and commercial buildings [1, 2]. The town has gone through a radical transformation process; in just four decades, it was completely changed from a quiet rural agricultural village to a compact urban town, with its population grown approximately 14 times. Before its urbanisation, the town used to have several scattered clusters of farm houses (five dotted ellipses), along the hillside (coloured green) as in Fig. 2. If we draw the circle that passes the centres of the four major hamlet clusters, a circle of 205 m radius appears. The circle also

Fig. 1 Backstreet in Wooman; abandoned patches of plots used for farming, parking, and storage yards

encloses the inner circulation route which looks like a hat or reversed U shape. We will call this link an internal route of Wooman. It is safe to say that the ordinary interaction between villagers in everyday living was happened within this boundary of about 200 m radius. Between the valleys of hills, on plain and mild contour, lie agricultural fields. In all aspects, the village had best natural environment: houses were backed up by hills and overlooking their farm fields in the front.

By mapping the old rural paths onto the modern townscape, we can begin to see some traces of the past from the map on the right in Fig. 2. While the modern map shows a densely woven network with straight streets, it is recognisable that some old paths (red) are embedded within the new setting. More interestingly, the inner route, the old circulation link from 1974 is almost intact in 2013 map with a short missing link. The chaotic backstreet scene we have seen in Fig. 1 also belongs to this remaining old route (near cluster 4). How could these paths survive without any human intention? We can think about this as a natural phenomenon that can happen in any urbanisation process. In a rural area a hamlet slowly grows with several dwellings built next to each other making a cluster. It would be essential for sustainable life that this small settlement finds its location not far away from the inter-hamlet route as in Fig. 2.

Thus, clustering of dwellings and its connection to the main road are the two primary requirements that enable the formation of a rural hamlet. In comparison, in setting up farm fields which occupies wider area, it is less critical to have a closer

Fig. 2 Wooman old map (left) with rural roads (red and orange); and current map (right) with remaining traces of the old roads (red) and new apartment developments (green boundaries)

connection to major road—as long as they are provided with an access of any kind. As hamlets grow, dwelling are more densely packed and intermingled with local paths, generating an organic structure of rural village. During this process, ownership and legal issues are involved; so the irregular patterns of lots and roads are permanently fixed and then registered to a cadastral map (Fig. 3).

When a new urban development is initiated by the government or a local authority, public and private sector developers are involved to build roads, infrastructure, and buildings. For this, they need to negotiate with individual land owners to purchase a huge amount of sites for construction. In this process, the best strategy would be to purchase bigger units of usable land such as farm fields and forest by priority, because it is much easier and faster than purchasing smaller residential plots that might cause more complicated procedure. Therefore, there has been a strong tendency that larger projects such as apartment complexes were built on farm fields or reclaimed forest with their own planned access roads, while old settlements are remained in their original irregular patterns. It is evident in Fig. 2 that the five clusters of old farm houses (blue dotted ellipses) are all sitting outside the boundaries of modern apartment developments, marked with green dotted lines with their construction years in the middle. At the end, fossilised within the modern block, the rural road and its adjacent dwelling plots preserve its irregular morphology. By overlapping the old hamlet clusters and the inner route on the current map as in Fig. 2, we can see this clear separation in the process of urbanisation. There were six apartment complex

Fig. 3 Cadastral map of current Wooman block; large new development (left) and small old plots (right)

developments in Wooman block between 1985 and 1995. Figure 4 shows this more clearly. It is the old map with old hamlets (colored blue) and old streets (red) on which footprints of future apartment blocks (pink) are mapped. As expected, all the new developments have their construction sites off of the boundary of old settlements. As a consequence, the inner route that linked the rural clusters could survive, except for one branch street in the middle, and continue its operation inside a new network that is completely re-configured.

3 Change of Topological Significance of the Inner Route

For deeper understanding of the network, we used DepthmapX 0.30 software [3] and mainly reflected on the segment angular choice value, or 'Choice' in short, for evaluation. Choice is known to represent the potential of each network segment to be selected for the shortest trips between all segments in the network [4, 5]. Thus, it indicates the degree of quantitative significance of a road in the least energy consuming 'through movements' in a system. The boundary of modern Wooman block for our research has roughly 379,310 m^2 area and a periphery distance of 2500 m; and the lengths of its bottom and right sides are 560 m and 530 m respectively. To analyse the wider rural network of old Wooman village, all the main roads within the circle of radius 1000 m were linked and calculated; thus the whole area for analysis was 3,140,000 m^2 which is more than 8 times bigger than our Wooman block. For the purpose of detailed presentation, the image of choice analysis for the wider area was cropped to zoom into our target area in Fig. 5. It shows Choice of R1200 and R220 in the 1974 network. The radius 1,200 m was found to be the threshold; it was observed that radius over 1,200 only highlights the outer straight lines on the bottom

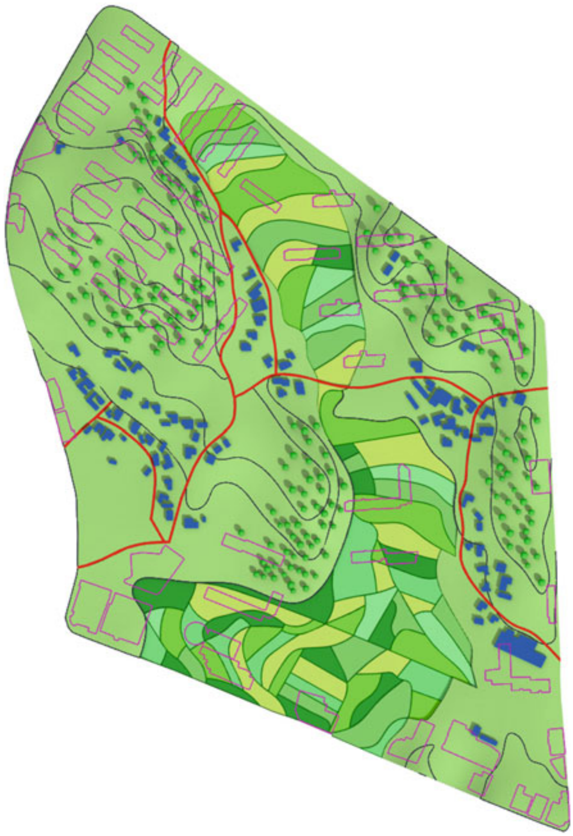

Fig. 4 Old map of Wooman with footprints of modern apartments (graphic by Danilo Di Mascio)

and the right side. At the point of radius 1,200, however, the inner route that passes through the cluster 1, 2, and 3, begins to be the stronger candidate for the shortest trips. Radius 220 m confirms that the same route still remains the most strongest even though its value has been weakened. All the other radii between 1200 and 100 show more or less the same type of result. Thus, in this old network, the inner route connecting village 1, 2, and 3 stands in the most important position for all ranges of shortest local trip under 1200 m. In particular, the junction A is the most essential point where many shortest paths have to pass through.

Geographically, it is a crucial node at the highest point of a hilly road from which one can choose one of the four different routes. In all respects, there seems to be a clear reason why the cluster 1, 2 and 3 had bigger volume with more houses while 4 and 5 had smaller volume. Apparently, the former three hamlets were better linked to their local network, and this provided an efficiency of access, not only to their local neighbours in the vicinity but also to their agricultural fields in the farther distance—if they are less than 1200 m away. It has been discussed earlier that this potentially most through-passed route in the old village has survived during

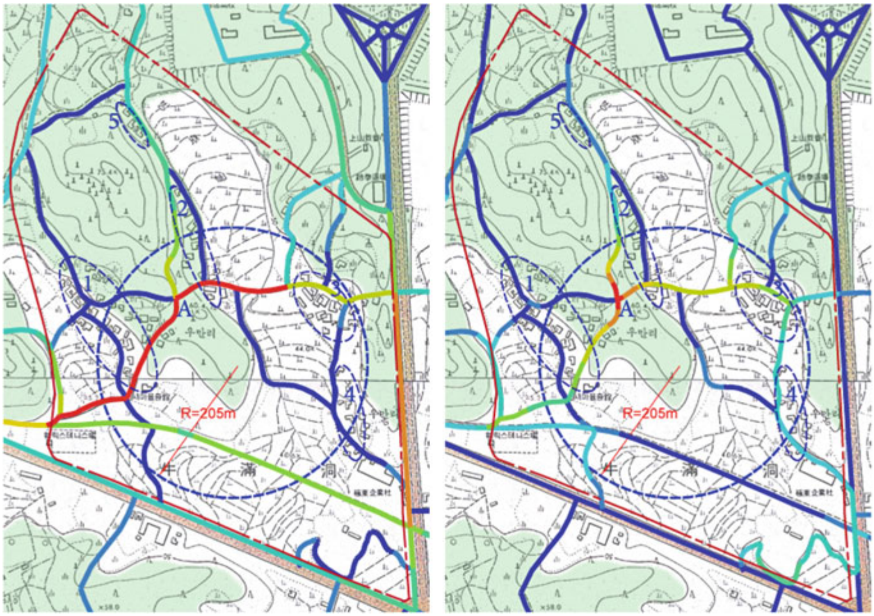

Fig. 5 Angular choice metric R1200 (left) and R220 (right) for the 1974 network

the modernisation process. Now, using the same syntactic analysis, we can start to illuminate how it functions in a new built environment.

The 2013 Wooman is a totally different world. It has eight times larger population than in 1974 with a number of small and large buildings and a complex network of well-paved roads inside. The north-south bound boulevard on the right side of the block connects a local university in the north directly to the urban arterial road in the south. Figure 6 shows an axial choice R3 result and a snap shot of the block taken on Friday 7:00 pm, 19th of December in 2012. It turned out that the two red lines in the axial map were actually the busiest streets by observation. The R^2 regression value for their correlation as a whole network was 0.37, showing some degree of meaningful relation but was not strong enough. Meanwhile, integration values of both local and global showed correlation value of 0.1 with the snap shot value. It seems that the traditional axial analysis still holds good in explaining major movements in the city when illuminated by choice rather than integration.

As we go inside the block, we can find a multiple layers of straight streets parallel to the outer boundary roads. This configuration is surely a modern intervention. We still see, however, some irregularities deeper inside. As noted before, irregular streets are almost always accompanied by irregular housing plots. This out-of-order characteristic causes conflicts with the neatly aligned modern layout. These irregular streets are typically narrow and winding, thus provides less visibility. In addition, there are some unoccupied small patches of land that are utilised for temporary parking, storage, and even farming as seen in Fig. 1. This privatisation, combined

Fig. 6 Axial choice R3 analysis (left) and snap shot with old paths fragments (right)

with its less visibility, renders these old alleys more inaccessible to the outsiders. Moreover, pedestrians can always take alternative modern routes nearby that are more approachable. This is probably the reason that we could rarely find people in the old remaining streets. The grey colored old streets in Fig. 6 shows almost no one walking in them, except for the two streets around the cluster 2 that have been straighten and widen during the urbanisation—thus look more like modern streets. At the end of urbanisation, the inner route which was the most important rural circulation route, became an empty and gloomy backstreet. While the memory of ‘many oxen’ still lives on, it is now almost hidden inside, surrounded by tall buildings and wider modern streets. Does it do any good for the operation of the network? Or is it just a redundancy, not crucial to the whole as it seems? We can start to delve into this question by means of angular choice analysis.

From the angular integration analysis, it is generally reassured that longer and straighter roads gain higher values. As in the old Wooman map, however, the choice value begins to tell us some internally hidden structure. Figure 7 shows the choice value of metric radius Rn on the left and R220 on the right. As Rn value calculates global through movements, we can say the red coloured roads in the centre are the most important connector for the shortest trips for the whole block. It also suggests the bottom and the right-side boulevards are acting as another through passes for shorter movements. As we lower the radius, from around radius 1000 m, the higher values begin to disappear on the periphery of the block. Until as low as 300 m, the inner route is never fully turned on. The radius where the route is most highlighted is

Fig. 7 Angular choice metric Rn (left) and R220 (right); streets with higher values were presented

220 m; at this radius, with several other fragments of higher values around, the route takes on its original shape with red, orange and yellow colours. What does this mean? In the old rural days, this route was an essential choice for a wide range of through-trips in the village, but now there are many other route options competing with it in modern days. However, for the shortest trips within the boundary of approximately 200 m radius, this irregular backstreet route can be the best option to outrun the others who will take the modern routes.

Apparently, the shortest trips within the circle of 200 m radius are not for the urban-scale interaction; rather it is for the 'between neighbours' communication. As traced in Fig. 7, in the traditional village of Wooman, the four major dwelling clusters were linked by the inner route, and their village boundary were assumed to be 205 m radius in approximation. The Choice R220 result suggests that this 200 m boundary works well for the inner community movement, and this can be facilitated by the use of the inner route. Then, how can we revitalise the old route and maximise its utility for the whole network?

4 Conclusion and Discussion

In our analysis of Wooman town in Suwon city, we could find the traces of old roads embedded within the modern street network. The street pattern of the old village retained its organic shape which appeared through a long period of time, but a city scale intervention pushed the mechanism of this original network to an unexpected direction. In the modern block of Wooman, two spatial structures co-exist. On the outer band are high-rise modern buildings along the linear network and on the inner band are low-rise irregular type of buildings and streets. Thus, the old organic network is completely enclosed by the straight urban grids which appeared at later stages. The conflict between the irregularity and regularity caused malfunction and fracture inside the urban block. The syntactic analysis revealed how an excessive number of roads, caused by superimposing two heterogeneous systems, could weaken the efficiency of land use and pedestrian flow in a new setting. For the comprehensive understanding, we collected data from historical documents to trace the periodic change of the area, and converted this into a visual scenario of possible transformation. After this, we observed the current pattern of pedestrian movement and synthesised it with the segment angular choice analysis. At the end, this research illuminated the consequences of imposing a new urban grid on an old irregular street pattern, and suggested how we could reconcile the conflict to humanize the urban environment for the sustainable growth.

The urbanisation in the last century has brought about the two contrasted developmental processes for farm fields and dwelling plots in rural villages. As large scale apartment developments were actively utilising the farm fields, clustered hamlets in the rural village could escape the radical change. However, this has led their village eventually surrounded by tall residential and commercial buildings. Its organic structure of roads could not properly connect to the new network and its irregular plot shapes hindered the old village's necessary regeneration. The inner route, which used to be the main local connector, became a narrow and untraveled backstreet lane. Privatised and abandoned, it did not add to the vitality of the whole network.

The first step to the regeneration of the old part of Wooman town is looking at this old hidden spatial structure not as a problem but as an asset. All master-planned new towns do not have any history and thus no story to tell. Through the research process of this paper, we began to see this irregular pattern of backstreets in a new angle; it can be a hidden treasure. It is quite surprising that the essential spatial structure of an old rural village has been persisting in the heart of an urban block without direct human intervention. The inner route in particular can be an exceptional heritage of the town. With its narrow and winding road that will allow semi-circular promenade inside the block, it has a potential to be a historic identity of the town to bring the whole community together. After several steps of regeneration, it can be extended to make a ring structure for a full circular route. With this bigger picture of vision in mind, each segment of the route needs to be gentrified. We already begin to see some ideal examples.

The left picture in Fig. 8 shows a recent conversion of the abandoned patch of land in Fig. 1 recently landscaped by the city. Obviously, the whole atmosphere of the street has been changed. The picture on the right was taken in another town in Suwon, not far away from Wooman. When an old irregular street pattern is mixed with a new urban grid, it generates network surplus or redundancy, and this is actually one of the reasons why old streets are rarely travelled in Wooman. One best solution to it is to pedestrianise those redundant streets. Marginal space in the city makes us

Fig. 8 Abandoned patch of land in Fig. 1 landscaped (left) and redundant street pedestrianised (right)

breathe and it offers a great opportunity to build a sustainable urban environment. Different paving and landscaping will provide a new stroll path distinguished from car lanes.

Wooman has a unique double layered spatial structure; it has an outer band where new residential and commercial buildings are neatly aligned along the straight lines of modern network; and inner band where the irregular pattern of low-rise residences are fit to the organic network. In general, this dual spatial structure is the result from the last century's fast urbanisation, and many cities in Korea have a similar type of internal conflict between the two heterogeneous spatial structures of old and new. This research attempted to see this conflict in a more diachronic perspective and suggested possible interpretation. We have learned that by combining a proper methodology with historic understanding, a more viable suggestion for the sustainable future can be generated.

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Mods, Hacks, Makers: Crowdsourced Culture and Environment

Andrzej Zarzycki

Abstract This paper discusses the role of prototyping as a vehicle to integrate electronic media technology, materiality, and physical computing into architectural design process and education. It connects a creating-making approach to a broader maker and hacker culture through adaptive and autonomous assemblies and embedded electronic systems. It recognizes the need for a new conceptual dis-course on what constitutes effective design methodology that nurtures innovation and considers all design factors: social, cultural, and technological.

1 Introduction

Apparently unrelated cultural phenomena, such as video game mods, public realm hacking (both virtually and physically), and makers tinkering with everyday products, point to a new collective agreement that significantly informs the current social fabric, culture, and environment. With its broad cultural implications this new phenomenon not only transforms social ranking and relationships but also it impacts economy and types of traits valued in future societies, This new attitude toward the ownership and authorship of the public realm and of collectively shared cultural production is directly related to and driven by technological developments that are democratizing means of production, forms of communication, and ultimately knowledge sharing and development. This democratization occurs on multiple levels with diverse types of audiences. While it is open and accessible to all, it does privilege those with particular capabilities and technological mindsets. It is not always equitable or impartial [14], but it does broaden an innovative base and provide new opportunities for previously untapped talents. It helps to rejuvenate culture with fresh energy and creativity. The democratization manifests itself through the increased vertical mobility for individuals and nations that previously were on fringes of cultural and technological production. The advances of many emerging economies could be seen through this perspective. In most cases, this process takes place with full or at least

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partial social consensus, but there are also moments when the change is accomplished through means that break laws and established customs.

While discussed forms of technology-driven activism encompass broad areas of cultural production with many independent strands, these separate phenomena share many characteristics. Video game mods, or modifications, alter the content and gameplay to operate in a manner different from that originally intended. Hacker users develop mods to gain an advantage over other players, add new assets, or customize the game to meet their individual sensitivities or needs. They often see is a form of contributing to the authorship and entitlement to a shared ownership of technology and knowledge. These modifications represent a form of cultural and creative disobedience that counterbalances top-down culture creation and commercialization. They also provide a broad venue for creative inputs and outputs from individuals who often function on the margins of the mainstream cultural production. In this aspect, mods reappropriate the virtual public realm in a similar way as traditional culture hackers like Ron English [13] or the Improv Everywhere movement [21] do with the physical realm. However, the virtual reappropriation is perhaps even more potent and transformative because it often becomes a parallel or preferred solution for audience and consumers. Hacked virtual environments often become replacements, not mere alternatives, for the original events or frameworks: they supersede rather than simply complement or extend. This tinkering with virtual worlds and products mirrors the maker movement and is reflective of a broader societal aspiration in cultural and creative production. The aspiration that goes beyond democratization of rights and resources, and points to authorship and self-realization.

2 Hacking or New Developments

Hacking signals reappropriation of an established framework. It is an intentional and decisive creative political act that provides alternative outcomes or scenarios. It is different from creating something anew. Hacking economizes on the existing resources, often subverting them. It provides a plurality of solutions through idea forking that ultimately enriches user choices. While it is usually associated with reverse engineering of software or physical products, it can also be understood as form of redirecting resources and redefining relationships. It is probably best described by usual references to versioning of software, such as xxx2.0. It acknowledges a product or service as an evolving entity undergoing continuous refinements.

Bike- and car-share initiatives are often seen as an indication of these changing demarcation lines, since they hack the idea of ownership. However, they may become transitional technologies for companies like Uber and Airbnb that provide analogous services without the need to own or even maintain their assets. While these two directions are not mutually exclusive, and exemplify the idea forking mentioned earlier, they do follow very different financial models that ultimately may impact their effectiveness and longevity. Furthermore, the debate about the legal standing of initiatives such as Uber or Airbnb will surely continue. However, these initiatives are the indicators of a larger cultural shift evident in other areas of life. YouTube a media outlet without a content or message is one of the early examples of this cultural trajectory. It transforms the concept of content ownership, expends authorship, and provides direct financial incentives to sustain its activities. As a side effect of its non-curatorial approach, it also reflects the tastes and aspirations of the general public, as it usually defaults to a common cultural denominator. All these factors provide opportunities and concerns for a new form of cultural dialogue and a new relationship between humans and the environment.

3 Open-Source Culture

Radio is one-sided when it should be two-. It is purely an apparatus for distribution, for mere sharing out. So here is a positive suggestion: change this apparatus over from distribution to communication (Brecht 1926) [15].

The Brecht expectation of two-way communication for then-emerging media such as radio or TV finds its implementation in current electronic networks and social expectations towards media culture. While it is still true that the loudest, most persuasive, or most viral prevail, social media provide a potential voice to all participants. In this new scenario, cities are not only inhabited by people but also authored by them in the form of crowdsourcing. This authoring does not necessarily address changes in a broader physical form, but starts informing society functions by breaking established hierarchical structures and providing direct access to government. This becomes visible in the BOS:311 mobile app [2] (previously Citizen Connect), where Boston residents have a venue to inform the city administration about broken streetlights, street potholes, or uncollected trash. The app allows users to share a photo and a message together with the geo-location data to situate the event. Similarly, other cities experiment with technologies like Twitter to improve civic engagement [17]. The next step is to bring residents into decision-making processes such as planning budgetary expenditures. This is part of the modest initiative in several Polish cities called Budżet Obywatelski (Civic Budgets), in which certain development and budgetary decisions are being voted on online by local residents [3]. While this is limited to relatively small projects, it is a meaningful step toward a better fit between citizens and their local government. It is an interesting test bed for future open-source and crowd-sourced government.

However, this streamlined and unfiltered communication between residents and city governments still relies on intentional actions of the concerned citizens to vote or to report a problem with the infrastructure. The future steps will involve an interface where users indirectly feed information and become sensors of a broader crowdsource network without a need to devote time and effort to it. This approach raises valid privacy concerns, but in some instances the accompanying benefits could encourage users to participate in these networks. The Waze mobile app provides an effective case study of such balanced relationships between users as individuals and users as a group with shared interests. Self-described as the world's largest community-based traffic and navigation app, Waze harvests traffic data from its users by tracking their smartphone movements (car speed) and shares this information with other users. While it does potentially compromise privacy (tracking others while being tracked), it does provide enough benefits to participants to sustain the apps user base.

4 Open-Source Environment

The Internet of Things (IoT) platform, utilizing distributed sensing, actuators, and microcontrollers, allows for a direct integration between embedded objects or buildings and users. Used for security access and controls, building data monitoring, or content authoring, mobile devices effectively extend spatially and conceptually what is considered a building and its perimeter. A mobile interface connects directly to what is often hidden within and defined as a private realm. Smartphones also provide opportunities for greater public participation in authoring media contents, in a similar way as the D-Tower project by artist Q. S. Serafijn and architect Lars Spuybroek (NOX) does. However, the greater conceptual relevance lies in their similarity to artistic media projections done by Krzysztof Wodiczko, projects in the Media Faade Festival such as a SMSlingshot installation by VR/Urban, or works by the NuFormer [10] studio that start redefining the boundary between ownership in public and private domains.

Along the same lines but breaking out of the socially correct framework, Graffiti Research Lab (GRL) develops urban media interventions that challenge the traditional demarcations of public and private, appropriate and inappropriate. Their purpose stated in their motto dedicated to outfitting graffiti- and street-artists with an open source technologies for urban communication is activated through the development of tools of subversion and mass dissent. Like a giant graffiti laser. [6] A certain level of dissent represented in GRLs work moves the center of creative gravity outside the comfort of art galleries into an authentic street art. However, GRL works still do not achieve a guerrilla status like that of Banksy public art. Anonymity is a common denominator of Banksys art and traditional graffiti, and in this case, it is a strong differentiator from prescribed and staged digital installations that feel more like works ported out of the gallery, not home-grown street happenings. This anonymity of street art, and the expressive freedom associated with it, can be put back into digital media installations by developing systems that integrate individual participation through the use of mobile devices.

Laser tagging is a contemporary equivalent of traditional graffiti implemented on an urban scale without the negative associations graffiti tagging brings. Additionally, the GRL Laser Tag Rotterdam event [7] provides an opportunity for greater public participation, since the marking device is separate from the projector. The installation could accommodate unrelated or competing users collaborating or competing for the screen authoring. Furthermore, virtual (augmented reality-based) and projection (projection-mapping) media creations escape the simple societal judgements that are directed at graffiti art or tagging. Since they do not deface or damage private property and often serve an important social role, virtual and augmented transgressions become socially acceptable and often a preferred form of communication.

While new computational and media technologies makes us rethink established modes of creativity and address design concerns that were previously unsolvable (outside a designer consideration), they also open new territories that are both exciting and less familiar. Maker and hacker culture reformulates traditional inert notions of architecture and design production. The built environment will no longer be designed from scratch but rather tweaked and re-appropriated from existing or mass produces elements with a data-driven understanding of its context. This will become significantly more pronounced when the built environment will be defined less by its physical form hardware and more by its software–embedded electronic and media functionalities. The examples discussed above point to new forms of public participation. They question an established ownership by reappropriating, often just symbolically, the public domain.

5 Open-Source Design

While the Maker Movement empowers designers and architects by putting them in a direct contact with the production of the built environment, more importantly it transforms the relationship between creators and users. The participants in the built environment expect a similar level of involvement in and authorship of the public domain as architects have. Being a silent and passive consumer of design and culture no longer is glorified or aspired to. Democratized environments allow users to customize and make them adaptive to their personal and often esoteric needs. This significantly shifts the role of designers and the types of designs they produce. Open-source, open-ended, crowdsourcing are just some of the modifiers of cultural modes of production that define new relationship between the creativity, intellectual property ownership and authorship. This consumer aspiration is being noticed by companies that are developing modular, open-source designs as a base for a do-it-yourself (DIY) movement. For example, Opendesk, [11] a global furniture design platform for local making, allows consumers to download drawings and fabricate furniture themselves or through the network of local fabricators. So-called open making helps designers to get global presence and distribution, makers to meet customers, and customers to have designer products without the designer price tag. Similarly, a mobile app such as Autodesks 123DCatch not only allows for photogrammetric capture of a 3D model but also connects users with 3D printing companies. These initiatives would not be able to succeed without electronic networks that facilitate almost-instant knowledge and technology transfers as well as new forms of collaboration such as crowdsourcing. Collective wisdom and collective authoring (creativity) further redefine maker culture, shifting the center of gravity from an engaged artist or designer into enabled consumers and users. This shift provides opportunities for greater social appreciation of design. However, it also redefines the roles designers play from sole content creators to mentors and facilitators of socially and culturally driven creativity. This repositioning quantifies design as a resultant of collectively and individually made choices driven by value, image, and cultural relevance.

6 Open-Source Hackers

While hacking has been routinely associated with computer programming and security cultures, the concept has much a broader user base and applicability from artists and urban culture hackers, such as Improve Everywhere, to the DIY movement with reappropriated industrial products and embedded new material, to video game mods and modified electronic products. This new and broadly defined hacker culture addresses two critical cultural issues: (1) democratizing the material culture by lowering the participation threshold and (2) providing opportunities for crowd-sourced creativity, its expression, and its adoption outside monopolized industrial and intellectual culture.

In a broad sense, hacking is a form of reappropriation of an object or a system for another purpose than originally intended. It is reappropriating an idea and giving it a new use, often with a meaning that contradicts or challenges the original intent. It is not only defined by the activity but also by the manner in which it is achieved. It explores the space of unintended consequences with highly creative possible returns.

7 Collective Thinking

In studying social groups and networking, researchers are finding that a group of minds possesses a unique power of collective thinking, which cannot be matched by a number of individual minds. James Surowiecki has written about this power, most notably in his book The Wisdom of Crowds, where he examines the evidence suggesting that, “under the right circumstances, groups are remarkably intelligent, and are often smarter than the smartest people in them” [20]. Collective decision making has influenced politics and the economy in both positive and negative aspects, but ultimately contributes to broader, more dynamic and resilient systems. It has become a cornerstone of democratic and free societies. Can this approach be extended to collective collaboration, authorship, and creativity in a similar way to the process by which Wikipedias content is developed? Can the power of crowdsourcing be harvested into effective creative or innovative enterprises?

Howe connects the popularity of crowdsourcing with an increased popular use of electronic, previously high-end, tools by the general public [16]. This is another take on the common observation about digital technology being responsible for the democratization of authoring and production of intellectual work. Democratization of technology reduces the gap between professionals and amateurs, and between developed and developing economies. Opinions on the effectiveness of crowdsourcing are mixed. Enthusiasts often reference the success of consumer-created Super Bowl 2011 commercials for PepsiCos Doritos and Pepsi Max Brands as one of the successful examples. However, this example may not be representative of the aspirations and possibilities associated with crowdsourcing. Consumer-created Super Bowl commercials do not innovate anything; rather, the USA Today ranking evaluates the popularity of a particular advertising concept. While watching these commercials, one is not overwhelmed with their conceptually innovative narratives; rather, they connect with rudimentary and stereotypical ways to promote a product, as is the case with *Pug Attack* [5] which achieved the top ranking in the USA Today Ad Meter.

Nevertheless, there are a number of promising examples that could help to transcend the intellectual status quo and enable new modes of collective creativity. The premise of open-source collective thinking set the conceptual framework of Web 2.0, providing a basis for the success of platforms such as YouTube, Facebook, Craigslist, and even Expedia and Amazon, with users input as a critical component of their business. According to Tim OReilly and John Battelle, organizers of the original Web 2.0 Conference, Collective intelligence applications depend on managing, understanding, and responding to massive amounts of user-generated data in real time [19]. In many ways, collective intelligence is an extension of a fridge poetry game, or of the surrealist exquisite-corpse authoring method, with creative outcomes emerging out of fragmented and independent contributions. These fragmented contributions are biased by personal goals or misconceptions, but often still manage to deliver unexpected and innovative results. The same concept of including diverse viewpoints and averaging opinions applies in the case of Web 2.0-enabled collective authoring.

What opportunities might we find in tapping in to this collective intelligence by integrating the technologies available to us into our public spaces, our buildings, floors, and walls, and synchronizing them with our now-ubiquitous portable devices? Another example of the power of crowdsourcing was the recent DARPA Network Challenge organized by the Pentagons Defense Advanced Research Projects Agency. The challenge was to locate ten red weather balloons scattered in public locations across the continental U.S. in the shortest time possible. The MIT team, relying on digital social networking, realized this task in just 9 h [4, 9]. While the method used by the winning team was relatively low-tech, nonetheless the team was able to mobilize a great number of contributors and ultimately locate all ten weather balloons. This example speaks to the effectiveness not only of digitally facilitated social networking, but also of effective crowdsourcing. An ability to instantly communicate with other crowdsourcing participants makes a social group into an effective network capable of problem solving.

8 The Other Side

Crowdsourcing and open-source culture benefit society through applying distributed intelligence and collective creativity to localized problems such as finding vulnerabilities in the software. However, there are also drawbacks and limitations of the open-source approach. Since these projects are usually self-commissioned and run on voluntary bases, their life span is not predictable. They are often developed only to the extent that they serve original goals or a creator and may not continue without further support or development.

9 The Product Is You

Another and highly controversial repositioning occurring within wired cities is a freebie culture. We are getting quickly accustomed to free perks associated with open-source and crowd-funded products and services such as computer software, email accounts, or Wi-Fi access. While this is a part of the changing perceptions and expectations of what is the basic set of citizen rights and what constitutes social infrastructure, it is also an extension of a new and aggressive business model. What often comes unnoticed is who is funding free services. As it has often been noted, If you are not paying for something, you are not a customer; you are the product being sold. This observation was popularized by Andrew Lewis, [8] but it also builds on previous discussions on consumerism, such as Adbusters video [1] from 1999, The Product Is You.

However, this relationship seems to be, at least to some degree, symbiotic. There are other reasons why free models are attractive to users and developers. For the developers, not paying means not complaining, while for the customers, not paying for the service does not mean an automatic reduction in the quality of service [12].

10 Conclusions

While in the emerging media-based environments many of the offline functions and activities are being ported into the virtualized worlds, this does not significantly redefine the structure of human habitation. Electronic social networks do replace or extend city squares or ancient agoras into new forms of social communications, as pointedly predicted by William Mitchell [18] in City of Bits: Space, Place, and the Infobahn. However, the simple mapping of the city from the physical into the virtual misses a whole new class of users and possibilities. An important message for architects is that the maker and hacker culture ultimately will penetrate the traditional inert notion of architecture. The environment will not be built from scratch, but rather it will be tweaked and reappropriated from existing or mass-produced elements. This will become even more pronounced at the point when the built environment is not only defined by its built form hardware but also its software: embedded electronic and media functionalities.

Finally, what does the hacking culture mean for the built environment? Does it allow for the customization of architecture and user considerations to a greater extent than is presently possible or practiced? A new form of creativity, an alternative form of ownership, a new form of political expression and power: these are all possible answers and future trajectories.

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How Can Computers Learn Building Design Rules?

A KBimCode Mechanism for Translating Sentences in the Korea Building Act for the Purpose of Automated Code Checking

Hayan Kim, Jaeyoung Shin and Jin-Kook Lee

Abstract The increased usage and application of Building Information Modeling (BIM) in the fields of architecture, engineering, construction and facility management (AEC-FM) has significantly impacted the entire building industry. Apart from the general uses of the BIM application for cross-disciplinary coordination and efficiency, we have explored the potential of BIM as an automated code checking tool that can be integrated into the process of reviewing architectural designs for granting building. In this chapter, we describe an essential and prerequisite process prior to the rule-*checking* process: which is the rule-*making* process. In order to automate the code checking process, natural language sentences for building permit legislation should be interpreted and executed by computers. We define KBimCode as a neutral language that is composed of translated building regulations as a computer-executable ruleset file. In this chapter the approach to standardized rule interpretation introduces a logic rule-based mechanism named KBimLogic and its outcome instances named KBimCode, which is an intermediate code that is both human and computer readable. The KBimCode is generated by the KBimLogic mechanism and is accumulated in the database called KBimCode DB. The database also defines the complicated sentence relationship between legislations, including hierarchy, reference, delegation or any other relations descripted in the original legislation context.

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This chapter demonstrates the KBimCode mechanism and related application with specific checklist and Building Act examples.

1 Introduction

The assessment of building design is in the early stages of using Building Information Modeling (BIM) as computational representations of building information [1]. Effectiveness and potentiality of BIM applications are proven by several governments-initiated projects such as CORENET [2], GSA project [3] and SMARTcodes [4]. By increasing the usability of BIM in architectural administration systems, the Korean government has also been proceeding with a project to develop a BIM-based system for evaluating the conformity of building design to the building permit related legislation [5, 6]. The legislation are written in natural language and have a complex hierarchy and cross relation. Therefore, domain experts must figure out the actual contents of checking requirements. As a result, building code checking is a time-consuming, cumbersome, and error-prone process. To overcome these limitations, this chapter suggests a logic rule-based mechanism named KBimLogic, that addresses the restructuring of the Korea building legislation into a computer-interpretable format. KBimCode is an intermediate language that translates the Korean Building Act into a computer-executable form. This chapter introduces the logic rule-based mechanism KBimLogic and its outcome KBimCode.

2 Research Background and Scope

Automated code checking with BIM has been actively advanced by many global government-level projects. In these projects the rule written in natural language must be carefully interpreted and translated into the computer-interpretable format before automated checking can be implemented.

There are several projects that integrate BIM into the building code checking steps such as e-PlanCheck of CORENET (COnstruction and Real Estate NETwork) and GSA (General Services Administration) project. CORENET is Singapore's web-based building administration management system that shares building information and minimizes unnecessary steps in the permission process [2]. e-PlanCheck is a module for automatically checking Singapore building legislations using the privately managed FORNAX platform. Another example is the GSA 3D-4D BIM project that was used for assessing courthouse building design based on BIM [3]. In particular, the space program and circulation-related regulations are analyzed by SMC (Solibri Model Checker) based on PBS (Public Building Service). Through its application on several global projects, including this project, SMC has proven its ability as a code checking software [7]. The program provides the Solibri Ruleset Manager ruleset library that enables users to define their own set of computable rules by regulating

Fig. 1 Overview diagram of the research scope: the rule interpretation of building legislation

predefined parameters. Because it provides limited parameters and objects, a new type of rules or parameters undefined in the SMC library should be customized by hard-coding in JAVA.

Previous studies utilized their own program, private methods, or closed library for rule-checking. In this regard, this chapter proposes a software-independent and explicit approach to translating natural language into KBimCode—KbimLogic, the logic rule-based mechanism for KBimCode as in Fig. 1. In this paper we describe three parts of this process; (1) structuring meta-database, (2) translating target legislation into KBimCode, (3) composing KBimCode based on sentence relationships.

3 Logic Rule-Based Mechanism for Translating Building Permit Legislation

3.1 Translation Scope of Target Legislation

In the Korea Building Act, each legislation is directly or indirectly related to the other regulations. Additionally the range of requirements can be extended through relations of the delegation and reference rules. Consequently, 54 acts are confirmed to include more than building permission-related legislation. Approximately 15,300 sentences are decomposed from the 54 acts and accumulated in the database. Based on the following 9 main non-target types of regulations, detailed target object legislation sentences are selected. Each sentence is fractionated again as the level of paragraph and TAS (Translated Atomic Sentence), the form of clear and exact expression without unnecessary components:

- Demand for a high level of property information
- Demand for the next phase of building permission
- Including information not related to BIM data
- Unnecessary sentences
- Regardless sentences with building design assessment-enactment of acts, definitions, standards, etc.

- Overlapped act sentences by revision
- In relation to non-examination sentences
- Unspecified reference act
- Definition of area calculation.

The legislation database is linked to the website of the Korea Ministry of Government Legislation (http://www.law.go.kr/) [8] so that the latest version of the database can be maintained.

3.2 Objects and Properties from Noun Phrases

The noun phrases of legislation sentences should be extracted, analyzed, and classified for verifying target object to checking. "Object" commonly means the building element that is defined in the Korean Building Act and the definition differs case by case according to the type of regulation. For example, some object definitions can be applied to a wide range of Korean Building Act regulations while other definitions are only valid at the article level. In the other part of a noun phrase, properties are subordinate to objects and are situated in the lower-level of objects. Properties are mainly classified into generality, geometry, relation, calculation, complexity, exception, and reference types [9].

Due to the characteristics of natural language, literal expressions of objects and properties such as homonyms or synonyms exist. However, those objects and properties have to be interpreted and explicitly described for establishing an exact code checking process. Taking these conditions into consideration, approximately 220 objects and 440 properties can be derived and collected into the database.

3.3 Logical Rules from Predicates

Verb phrases are extracted and classified by function to establish representative method components. The logic rule-based methods are intuitive formats that can be understood by general users. The naming convention of the methods derives from the JAVA language which is one of the most advanced programming languages. Consequently, approximately 90 logic rule-based methods are derived from the sentences and classified into four steps, (1) high level—types of instance level of objects, (2) intermediate level—types of properties, (3) low level—representative methods, (4) extension methods [10]. Logic rule-based methods originate from legislation called high-level methods that differ from low-level methods used for implementing code checking software. Among the 90 methods, approximately 30 representative methods and 60 extension methods are defined and organized into a methods database. The methods are classified according to the level of detail such as in in Fig. 2.

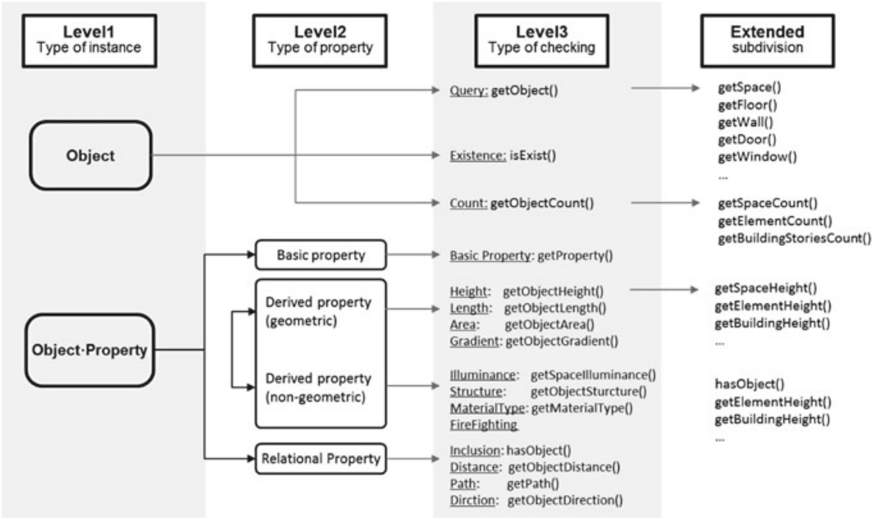

Fig. 2 Classification of logic rule-based methods according to level and example

3.4 Relation of Legislation Sentences

In the process of converting complex and delicate legislation sentence into KBim-Code the original text must be segmented into atomic sentences to remove unregarded context. The atomic sentence (AS) is commonly broken down into two parts; CS (Condition Statement) and KS (Key Statement). Finally, every CS and KS is broken down again into the finest TAS modules. TAS is an organization of the minimum number of mandatory elements needed for code checking. For every result of breaking down atomic sentences, TAS modules are combined again as KBimCode such as the sentence relationship in Fig. 3. Compared with this inner sentence relationship, there is another types of sentence relation referred to as external sentence relations that contain hierarchy, delegation, and reference relation between other provisions or legislations. According to the legislation relation described in original text form, each AS is combined as the last step for compounding all code checking unit into a completed ruleset. There are 13 types of internal sentence relations between CS and KS, and 6 types of external sentence relations [11].

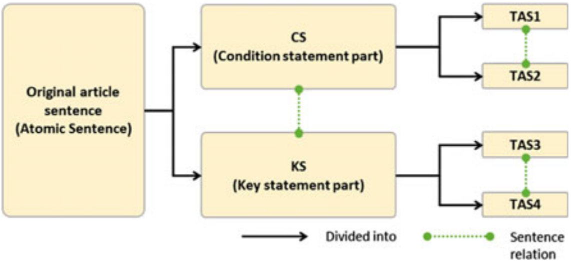

Fig. 3 AS translating process diagram and formation of relation between sentences

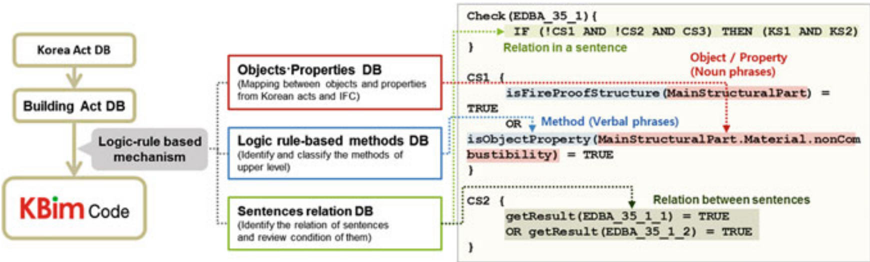

Fig. 4 Example of KBimCode, its components and DB mapping relation

4 Organization of KBimCode

4.1 KBimCode Language Overview

This section describes the KBimCode language syntax and translation process through the example translation of the Korean Building Act Enforcement Decree 35-1 (EDBA 35-1) [12]. The Korean Building Act has intricate hierarchical structures such as article, paragraph, and subparagraph items for delegations and cross-act relations for references. Higher-level regulations roughly depict the requirements of restrictions and delegate them to the lower-level of regulations which specify the detail elements of regulations. Every legislation is refined into ASs and divided into TASs which contains the subject (S) + verb (V) + object (O) as the main structure. This translation process clarifies the target and factor for checking to decrease the ambiguity and vagueness caused by connection and structure complexities. In Table 1. the original text of EDBA 35-1 is translated into the KBimCode which begins with Check (EDBA_35_1) (Fig. 4).

The KBimCode language syntax includes the way to logically and explicitly define complex and implicit rules. In the check declaration of Table 1 the check () control method is the basic trigger for the process of translation and the utilization of statement groups such as myFloor in the TAS3 can reduce the length of KBimCode.

Table 1 Translating process and a component level of KBimCode (EDBA_35_1)

Category	Context		
1) Original Text (AS(Atomic Sentence))	*Direct stairs installed on the fifth or upper floor or the second or lower* TAS3 *underground floor* under Article 49 (1) of the Act shall be *installed as fire* TAS5 *escape stairs or special escape stairs according to the standards prescribed by* TAS4 *Ordinance of the Ministry of Land, Infrastructure and Transport: Provided,* That the same shall not apply to cases where *main structural parts are made* TAS1 *of a fireproof structure or noncombustible materials* and *falls under any of the* TAS2 *following subparagraphs.* -- CS (Condition Statement) — KS (Key Statement)		
2) Declaration of check	Check (EDBA_35_1)		
3) Sentence relation	{IF (!CS1 AND !CS2 AND CS3) THEN (KS1 AND KS2)}		
4) TAS	CS	CS1	isFireProofStructure(MainStructuralPart) = TRUE
			OR isObjectProperty(MainStructuralPart.Material.nonCombustibility) = TRUE
		CS2	getResult(EDBA_35_1_1) = TRUE
			OR getResult(EDBA_35_1_2) = TRUE
		CS3	Floor myFloor {
			Floor.number > 5 OR Floor.number <= -2}
			Stair myStair {
			isObjectProperty(Stair.isDirect) = TRUE}
			hasElement(myFloor, myStair) = TRUE
	KS	KS1	getResult(REFB_9_1) = TRUE
			getReuslt(REFB_9_2) = TRUE
			getResult(REFB_9_3) = TRUE
		KS2	isObjectProperty(myStair.isEscape) = TRUE
			OR isObjectProperty(myStair.isSpecialEscape) = TRUE

After the declaration of checking legislation, its internal sentence relationship is written to understand the connection type between each TAS. Finally, the contents of each TAS are described at the following parts of sentence relationships.

4.2 KBimCode Database

The KBimCode database is the collection of translated KBimCode from the Korean Building Act. Therefore, generated KBimCode can reused for other types of code-checking. Because the database includes the relation information between references, users do not have to find related regulations one by one that have to be checked together. Extracted KBimCode rulesets automatically include their reference and delegation regulations to decrease reiterative searching steps. KBimCodes are also composed of elements in the object, properties, methods, and sentence relation database. By referencing other KBimCode in the database, user can easily find routines to generate KBimCode by example. The KBimCode database is not only for accessing other written KBimCode but also for understanding sentence relationships based on hierarchy and crossing relations such as commission and reference as described in the legislation. For example the KBimCode in this chapter is generated from approximately 15,300 permit-related act sentences. Consequently a total of 1,131 sentences are translated into KBimCode.

5 Demonstration of Composing KBimCode Based on External Legislation Relation

The composition of KBimCode is highly dependent on elaborate relational definitions of each generated KBimCode. Without the relations of hierarchy, delegation, or reference, individual pieces of KBimCode are meaningless for the comprehensive result of checking building permit related legislation. According to the 6 types of external legislation relations in Table 2, KBimCodes are compiled to compose higher levels of legislation. The user can search for the legislation by searching for its name or selecting a check-list to compose a ruleset file. The result of a query includes (1) related legislation (2) original text and (3) KBimCode of queried legislation. Figure 5 shows theKBimCode Composer interface (a) shows related legislations together in row after row, (b) shows original text, (c) shows the KbimCode, and (d) shows the original text and KBimCode together. It is possible to verify all of the checking indexes even if the context of related legislation is not described accurately.

- Building Act: users can search for specific sections of the the Building Act by name and number of the article or paragraph. As in Sect. 3.1 the database of 15,300 sentences is built as the basis for querying target legislation sentences.
- Check List: a checklist is built by using the subject name of a building article for assisting users with easily finding their target legislation. The checklist items can be extended not only in the legislation but also in the design guideline or user defined check list.

As the result, the KBimCode ruleset file is exported in the computer-executable script language file format preceding the code checking software. The ruleset file

Table 2 Various CS relations [IF CS THEN KS] between legislation sentences

Type	CS type	Using frequency	Using proportion (%)
R_1	An assessment result of lower legislations' sentences is PASS among lower legislations' sentences	312	23.87
R_2	Every assessment results of lower legislations' sentences are PASS	738	56.47
R_3	The assessment result of lower legislations' sentences is FAIL	9	0.7
R_4	Certain assessment results of lower legislations' sentences are PASS (especially external reference)	128	9.79
R_5	According to the assessment result of each case from lower legislations' sentences	104	7.96
R_6	Unimplemented	16	1.22

can be exported in any format for execution as a file that is not dependent on any specific code-checking software. KBimCode Composer (Fig. 5) of the KBimLogic application allows users to find all related regulations and to extract them as ruleset files for execution into rule-checking software.

6 Conclusion

This chapter introduces and demonstrates the logic rule-based mechanism named KbimLogic and KBimCode. The established meta-databases of objects, properties, methods and sentence relations support users with finding target building elements and actions for generating KbimCode. Intermediate KBimCodes representing building regulation sentences as computer-executable format are also established as a database to be queried for reference or delegation from other KbimCode. In the research, 1,131 legislation sentences related to building permission are converted into KbimCode. Additionally, the KBimLogic application has been developed to manage the meta-database, edit KBimCode, and compose the codes as ruleset files. As a demonstration in this chapter we extract the ruleset file of a specific section of the specific Korean Building Act (EDBA 35-1, ERCDAPA_2, NFSC504_4) by

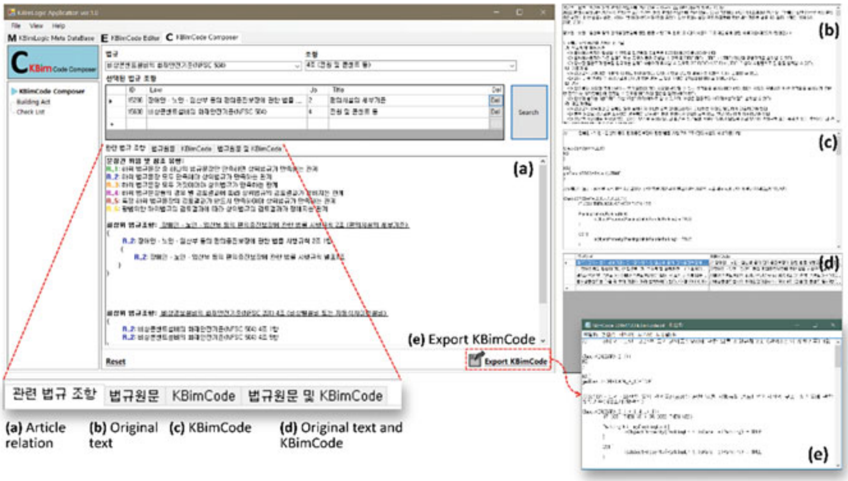

Fig. 5 The result of searching ERCDAPA_2 (Enforcement rule of the act on guarantee of promotion of convenience of persons with disabilities, the aged, pregnant women, etc.) and NFSC504_4 (National Fire Safety Codes 504 about emergency power outlet for fire extinguishing.) in the KBimCode Composer; **a** relation of legislation **b** original text of legislation **c** combined KBimCode according to the relation of legislation **d** both the original text and KBimCode **e** exporting KBimCode as ruleset file

utilizing the KBimCode Composer. Through the application, a potential user could extract a KBimCode ruleset file and check the original text, KBimCode, and external legislation relation. These sequences of the research are still being developed as an advanced mechanism for application to an expanded range of legislation or other guidelines. In addition, elements in the meta-database of KBimLogic and the database of KBimCode will be increased to increase the capacity of target regulations that can be processed by KBimLogic.

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A Sense of Dichotomy in Household Space and Smartphone

Deedee Aram Min, Namwoo Kang, Jimin Rhim and Ji-Hyun Lee

Abstract In this paper, we apply dichotomous aspects discussed in architectural theories to electronic devices and explore the relationship. In order to investigate the similarities and the differences between how people's attitudes change for the sense of individuality-communality and private-public in a household environment and in a product environment as the level of depth increases, we designed an experiment with a scenario that guides subjects to explore through a household space virtually displayed on a large display as well as a smartphone space on an actual phone. At the end of every task, we asked the subjects to complete a semantic differential survey designed using the terms used in architecture that relate to both social and spatial dichotomies. From this experiment, we can suggest that the use of analogy between the two environments is appropriate especially as the depth of navigation increases such as going into a bedroom or accessing a picture folder and that social and spatial dichotomies examined in architectural and geological research fields do exist in a smartphone environment in a way it makes sense such as front and back. Lastly, we realized that while the household environment provided static feeling overall, the smartphone environment provided dynamic feeling.

Keywords Household space · Smartphone · Dichotomy · Private · Public
Individuality · Communality

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1 Introduction

In a household space, there are two dimensions: social and spatial. In the social dimension, a dichotomy of individuality and communality are present. Individual and communal space types are important factors to be considered in the field of geology and architecture design because they represent the binary opposition during the design of social spaces. In other words, should the designer make the space individual or communal is a question to be answered to proceed in the design process. This opposition divides spaces into those that are difficult to be accessed by others as an area only for me (individual spaces) and those that are easily accessed as an area for others (communal spaces). Similarly, in the spatial dimension, a dichotomy of private and public are present. The concepts of private and public spaces are similar to the individual and communal spaces but the difference is that they indicate spatial relations such as inside and outside or front and back. The sense of private and public spaces is also important factors to consider during the design process of spaces as they influence the design elements that make up the spaces. Although the boundary between the pairs are ill-defined and sometimes overlap and interact rather than being in a binary opposition [1], previous researches indicate that the dichotomy is present in our lives continuously affecting our attitudes toward household spaces and our behaviours inside. Furthermore, the social and spatial meanings of individuality-communality and private-public are observed to be different for different cultures. For instance, in far eastern cultures, private space is considered a safe and intimate space while public space is considered a dangerous and strange space [2]. When children need a time-out, parents tell their children to go outside instead of telling their children to go inside to their rooms as the parents of western cultures would do. As such, the environment that surrounds us, especially the household space in this paper, is composed of feelings of inside and outside and private and public constantly affecting our attitude toward space and social meaning of space.

In this paper, we explore the same dichotomous aspects in electronic devices and systems. During the design process of devices, metaphors from our living space are often adopted. For example, the Windows operating system uses the term, ‘window’ which is a component in our environment that represents an element that provides a view from one space to another. Another example is a home button on our smartphones where ‘home’ in our living space represents the reference point of our travel or a safe place, while ‘home’ in the smartphone device represents the reference point for navigation. While the metaphors are often used during electronic device designs, there is a lack of research attention toward how these metaphors alter in meaning when transferred to electronic devices and influence user-product interaction.

In order to investigate the similarities and the differences between how people’s attitudes change for the sense of individuality-communality and private-public in a household environment and in a product environment as the level of depth increases, we designed an experiment with a scenario that guides subjects to explore through a household space virtually displayed on a large display as well as a smartphone space on the actual phone. At the end of every task, we asked the subjects to complete a semantic differential survey designed using the terms used in architecture that relate to both social and spatial dichotomies. From the experiment, we were able to see patterns in the sense of individuality-communality and private-public while navigating deeper into a virtual household environment, as well as the patterns in the sense of the two dichotomies while navigating deeper into a smartphone environment. By comparing and contrasting the patterns observed in two environments we were able to see a relationship between the two. By investigating the presence of the dichotomy—individuality-communality and private-public—as well as the meaning of dichotomous similarity and difference between the household environment and a smartphone environment, this paper initiates the exploration of user-product interaction in a metaphorical sense.

2 Literature Review

Dichotomies of Home Environment. An architect, Amos Rapoport points out that "people shape and give a meaning to their own environment which endures times, is passed on to other cultures, and has permanence with regard to variations in environment, context or situation" [3]. In this sense, the relationship between home and the occupants is complex and multi-dimensional where there is a dynamic interaction between the occupant and space. In Turgut and Çahantimur (2002)'s research [4], in an attempt to further investigate the dimensions and interaction, the concepts of dialectics home are explained and constructed based on previous studies. In their approach, they divide the home into two different aspects: social and spatial. In the social aspect, the dichotomous concepts are *individuality* and *communality*; in this sense, privacy constitutes a dialectic boundary that defines whether a person is accessible to some people and inaccessible to others depending on the relationship with them. In the spatial aspect, the dichotomous concepts are *private* and *public* in the context of home and near home environment. The dichotomies in social and spatial dimensions are summarized in Table 1.

Semantic Polarization. In addition to the research work in [4], Seo (2012) explores the sematic polarization of inside and outside even further suggesting that the concepts of inside and outside are "embedded at the unconscious level affecting the social attitudes" [5]. By analysing Korean traditional house structures, Seo (2012) extends the semantic polarization of inside and outside by integrating the hidden dimension of level distinction in which inside is elevated and outside is not elevated. From this level distinction, there are changes in human behaviours as well as attitudes. For instance, elevated spaces are places where people sit and have less movement while non-elevated spaces are places there people are mobile continuously moving around; elevated spaces are places where people takes shoes off and keep the place clean while non-elevated spaces are where people wear shoes and are dirty. In response to these behavioural polarizations, attitudes toward spaces change where elevated spaces are 'sacred' while non-elevated spaces are 'profane'. The semantic polarization of inside and outside is illustrated in Fig. 1 taken from [5]. This research

Table 1 Dichotomies in social and spatial dimensions (Taken from [4])

Social dimension		Spatial dimension	
Individuality	Communality	Private	Public
Individual	Society	Inside	Outside
Identity	Communality	Familiar	Strange
Inaccessibility	Accessibility	Secure	Dangerous
Unavailability	Availability	Order	Chaos
Self	Other	Rest	Movement
Host	Guest	Up	Down
Invisibility	Visibility	Night	Day
Male	Female	Front	Back
		Clean	Dirty

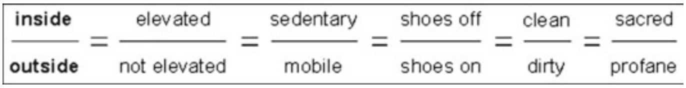

Fig. 1 Semantic polarization of inside and outside (Taken from [5])

indicates that within a household space, a dichotomy is present through structural difference influencing occupants' behaviours and attitudes.

Sense of Dichotomy in Product Designs. In the field of product designs, only a few researches have explored the concept of public and private. One research by Richins (1994) explored the sense of possession value by examining the public and private meanings of the goods the subjects possess [6]. Richins (1994) conducted three studies where the goal of the first study was to identify the private meanings of possessions valued by consumers, the goal of the second study was to assess shared public meanings in the possessions, and the goal of the third study was to explore the differences and similarities between public and private meanings. According to the research, the public and private meanings of possessions are related and for the goods that have limited interaction with the possessor develop little private meaning leaving only the public meaning. In addition, even though the respondents were of similar backgrounds, the sense of public and private meanings toward possessions differed for individuals indicating that the emergence of public and private meanings depend highly on personal experiences and the values that people possess. Meanwhile, this research opens up the discussion for the sense of private and public in possessed goods, it is at the level of individual goods suggesting further investigation regarding the public meanings of goods. In our paper, we investigate the sense of private and public not at the level of individual goods but at the level of each task a user interacts with one product—a smartphone. In this way, how and at what point public meanings emerge can be revealed.

Table 2 The 1–7 scale for semantic differential

	1	2	3	4	5	6	7	
Individuality	O	O	O	O	O	O	O	*Communality*
Inaccessible	O	O	O	O	O	O	O	Accessible
Unavailable	O	O	O	O	O	O	O	Available
Self	O	O	O	O	O	O	O	Other
Invisible	O	O	O	O	O	O	O	Visible
Private	O	O	O	O	O	O	O	*Public*
Inside	O	O	O	O	O	O	O	Outside
Familiar	O	O	O	O	O	O	O	Strange
Front	O	O	O	O	O	O	O	Back
Static	O	O	O	O	O	O	O	Dynamic

3 Methodology

Construction of Semantic Differential Scale. In order to investigate the pattern for the dichotomy in the social and spatial dimensions, a semantic differential rating scale is used. Semantic differential scales are often used to measure attitude toward an object, experience, and concept. For the construction of semantic differential scale, we use the terminologies mentioned in the literature review that reflect the social and spatial dichotomies: individuality-communality and private-public. After listing the words, we filtered out the pairs that are not applicable for smartphone environment and made a set of eight pairs for the efficiency of the survey. In the social dimension, we chose inaccessible-accessible, unavailable-available, self-other, and invisible-visible semantic pairs. In the spatial dimension, we chose inside-outside, familiar-strange, front-back, and static-dynamic semantic pairs. The semantic differential scale used in the survey is illustrated in Table 2 where the linear scale from 1 to 7 is used to differentiate the paired terms. The survey sheet shown in Table 2 was presented to the subjects after each task that they were asked to complete.

Scenario Design. In order to keep the subjects within the context of a household space during the survey stage of smartphone space, we designed a scenario to keep the subjects within the same context. The ultimate goal for the subjects is to go into your friend's house where you have never entered before (See Fig. 2) and find your friend's smartphone to find a passport photo your friend saved in his phone (See Fig. 3). The scenario asks the sense of individuality-communality and private-public at appropriate points to investigate how the senses shift from one space to another in a household environment and a smartphone environment.

In detail, the first part of the scenario asks the subjects to first virtually explore a house by going through the six tasks shown in Table 3. These six tasks guide the subjects to explore deeper into the house from a space with the highest connectivity (a living room) toward the space with the lowest connectivity (a computer room). After the completion of each task, the subjects are to mark their feeling while accomplishing the task on a 1–7 semantic differential scale. The second part of the scenario asks

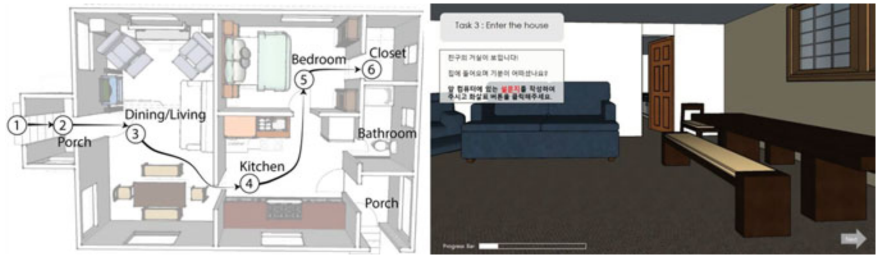

Fig. 2 Scenario design for household environment. Left: the household environment the subjects explored through. Right: one of the scenes from the scenario

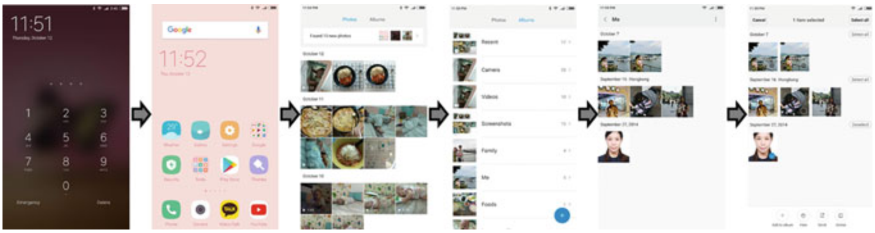

Fig. 3 Screenshots of the scenario design for smartphone environment

Table 3 Corresponding tasks in two environments

Tasks	Household environment	Smartphone environment
1	Approach the front door	Turn the phone on
2	Open the door using the passcode	Enter code to unlock
3	Enter the house (a living room)	Flip through the pages
4	Enter another space (a kitchen)	Find a gallery button for pictures
5	Enter a room (a bedroom)	Find a folder
6	Enter another room (a computer room)	Find a passport photo

the subjects to explore a phone they have never used before to find a passport photo by following the six tasks also shown in Table 3. Similar to the experiment setting for navigating through the household space, these six tasks guide the subjects to navigate deeper into the smartphone in correspondence to each of the tasks given in the household environment. A total of twelve tasks are summarized below.

Survey Setting. To keep the scale of spaces different as we are comparing the household space and the smartphone space, we use a large display environment for the first part of the scenario where the user has to explore through a household space. Meanwhile, for the second part of the scenario, we use an actual smartphone to guide the subjects through the tasks (See Fig. 4). We recruited ten subjects for this preliminary research each with two sets of six tasks in the order of household space to smartphone space. For the surveys and follow-up interview, the subjects spent 15–20 min.

Fig. 4 Experiment Setting. Left: large display for navigating the household environment. Right: actual smartphone placed under the display for subjects to find and navigate

4 Results and Discussion

From the survey results, we were able to interpret two aspects from the household environment and the smartphone environment: the fluctuation between the dichotic set of words as the tasks were carried out and the points of lowest and the highest values that represent a relatively strong sense of a particular word either on the individuality/private end or the communality/public. In addition, we were able to infer similarities and differences between the two environments.

Patterns in Household Environment. In the household environment, there were three notable fluctuations as the tasks were carried out. First, as indicated in cyan in Fig. 5, 'self-other' dichotomy stayed consistent throughout the tasks within a range of 4.6–4.9. This indicates that the survey subjects felt more 'other' than 'self' in a household environment. A possible reason for this is because the house that the subjects virtually navigated through was someone else's. Second, 'inside-outside' dichotomy decreased in the average value as the tasks were carried out (indicated by a grey line in Fig. 5). In other words, the subjects felt more 'inside' as they approached the bedroom. However, it was interesting that the subjects felt relatively more 'outside' (1.50) when going into another space from a bedroom. Third, 'front-back' dichotomy fluctuation (indicated by a solid red) observed from our experiment reflected the sense of "backyard" used in our daily lives because the subjects felt more 'back' as they navigated deeper into the house.

Furthermore, the lowest value was observed in the inside-outside dichotomy during the task of entering a bedroom with a value of 1.40 indicating that the subjects felt a strong sense of inside when entering a bedroom. The highest value was observed also in the inside-outside dichotomy during the task of approaching a house with a value of 5.40 meaning that the subjects felt a strong sense of outside. We can come down to a conclusion that the sense of inside and outside has a large effect on people's minds when dealing with a household environment where people physically enter and exit.

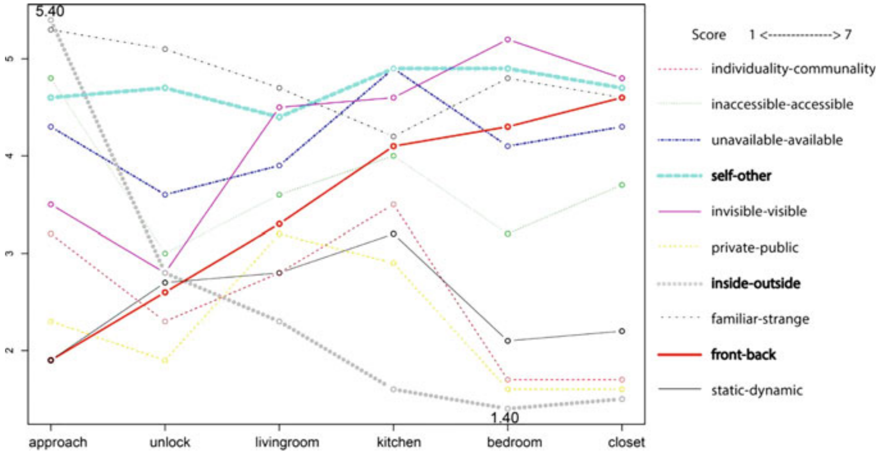

Fig. 5 Dichotic fluctuations in the household environment

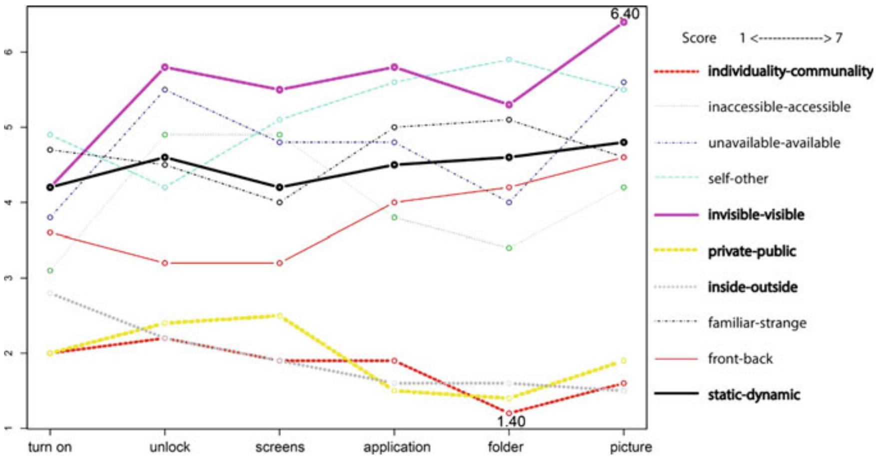

Fig. 6 Dichotic fluctuations in the smartphone environment

Patterns in Smartphone Environment. In the smartphone environment, there were two notable fluctuations as the tasks were carried out. First, as indicated in magenta in Fig. 6, 'invisible-visible' dichotomy showed a large fluctuation throughout the tasks generally changing from invisible to visible. A possible reason for this may be due to the increase in the amount of information displayed in the phone which leads the subjects to feel more visible than invisible. Second, as indicated in black solid line, 'static-dynamic' dichotomy stayed relatively consistent throughout staying in the dynamic end of the scale.

The lowest value during navigating smartphone was observed in the individuality-communality dichotomy during the task of opening a folder in a camera application

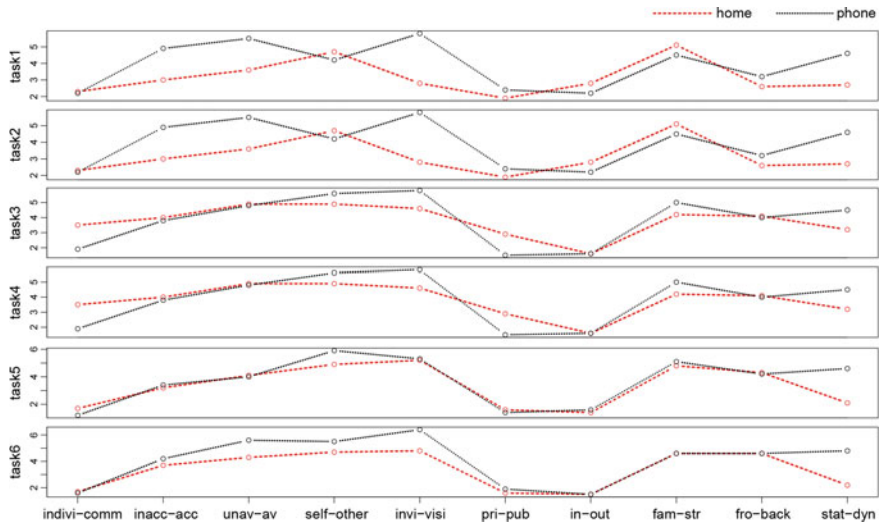

Fig. 7 Dichotic differences for each task

with a value of 1.40 indicating that the subjects felt a strong sense of individuality when opening a folder in a camera application. The highest value was observed in the invisible-visible dichotomy during the task of finding a picture with a value of 6.40 meaning that the subjects felt a strong sense of visibility when finally finding the picture in the scenario.

Comparing the Patterns. Unlike the patterns observed in the household environment, there is another interesting pattern in the smartphone environment: the three dichotomies in Fig. 6—'private-public' (yellow), 'individuality-communality' (dotted red), and 'inside-outside' (grey)—stayed at the low end of the scale throughout the tasks. This indicates that a smartphone environment is different from a household environment in that overall when navigating within a smartphone environment, people feel and stay feeling 'private', 'individualistic', and 'inside' compared to when navigating in a household where people feel greater fluctuation on average between the individualistic/private end and the communality/public end.

While the average range of fluctuation is observed to be greater in a household environment, when observing the differences between the dichotomies felt in a household environment and the smartphone environment, there are a couple of tasks that show similar sense. As shown in Fig. 7, task 5 shows little difference especially. The task 5 is composed of entering a bedroom in a household environment and clicking a pictures folder in a gallery application. For most of the dichotomies, the values were similar except for the 'static-dynamic' dichotomy which might indicate that there is another factor causing the subjects to feel more dynamic in the smartphone environment.

5 Conclusion

In this research, we observed patterns in the sense of social and spatial dichotomy in a household environment and a smartphone environment by first constructing a semantic differential scale through literature reviews, second designing a scenario with six tasks in both household environment and a smartphone environment, and third surveying ten subjects. From our experiments, we found out that the sense of inside-outside is strongly visible in a household environment compared to other dichotomies. The strongest sense of individuality/private was observed when entering a bedroom (inside), and the strongest sense of communality/public was observed when approaching the house (outside). Another interesting result to point out is that in a smartphone environment, the fluctuation between invisible-visible was large meaning that the concept difference between the two is clear. Moreover, we observed that the act of navigating through a smartphone gives a feeling of more dynamic than static. The strongest sense of individuality/private was observed during the task of accessing a folder (individuality), and the strongest sense of communality/public was observed during the task of finding a photo (visible). From the experiment, we noticed that in a smartphone environment, people felt more private, individual, and inside in comparison to a household environment. Finally, from the results, the pairing of two environments with highest analogy relevance is the entering of a bedroom and accessing a folder in the photos.

From these findings we found that the use of analogy between the two environments is appropriate especially as the depth of navigation increases such as going into a bedroom or accessing a picture folder. Also, the social and spatial aspects dichotomies examined in architectural and geological research fields do exist in a smartphone environment in a way it makes sense such as front and back. For example, while the level of 'back' increased throughout the tasks in a household environment, a similar trend was observed throughout the task in a smartphone environment. Lastly, we realized that while the household environment provided static feeling overall, the smartphone environment provided dynamic feeling.

During our experiment, we had several limitations in the experiment setting. One was that the subjects were guided through the household environment virtually on a screen rather than moving in the actual space. If the subjects were guided through an actual space, there may have been a different result. Another limitation was that the subjects were led through a household environment first, then a smartphone environment which does not take order effect into consideration. Lastly, as a preliminary research to explore how the results will appear, we only surveyed ten subjects which is a very minimal number not enough for us to analyse the data in detail using statistical measures. Nevertheless, we were led to interesting questions from our experiment. For instance, what makes people feel dynamic during the usage of smartphones and what makes people feel static while occupying a space? In addition, we were led to think whether if we can design the smartphone user interface or experience to be more static using the elements observed in a household environment. If so, is a static user experience in smartphone environment necessarily better than a dynamic user experience? For our future work, we plan to investigate the dichotomies of static and dynamic further.

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The Need for a Cultural Representation Tool in Cultural Product Design

Yu-Hsiu Hung and Wei-Ting Lee

Abstract The purpose of the study was to demonstrate the need and usefulness of using a cultural representation tool in cultural product design. In this study, it is believed that culture can be conceptualized with critical cultural elements that define the core features of culture. These elements were called cultural DNAs. To demonstrate the need and the impact of having a cultural representation tool in product design, a between-subject experiment was conducted with 18 student participants majoring in Industrial Design. The participants were tasked with designing mugs that addressed the Confucius culture and were divided into two groups—one was provided with a written representation of Confucius culture (the experimental group) while the other was not (the control group). Results of participants' design outcomes showed that participants who were given a representation tool of the Confucius culture used more types and higher numbers of cultural DNAs in their design. This study also found that the cultural elements used by the experimental group were more relevant with Confucius. Results of this study showed the need of a cultural representation tool in cultural product design.

1 Introduction

At the age of a highly competitive market, organizations are seeking approaches to develop products that are unique and appealing to customers. There are generally two methods used to establish and maintain the uniqueness and worthiness of products. The first method is investigating customer values and integrating them into goods and/or services. The second method is embedding culture attributes with product features. These methods have been recognized important in the product developmental process as they help ensure products hard to be imitated by other companies [1].

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Culture is a design element leading to good user experience. Cultural design (from individual to brand products) [2, 3] has been penetrating the consumer markets and can be easily seen in our surroundings. Studies indicated that customers' thoughts and values have profound influence on the success of a product [3]. Customers' cultural backgrounds, aesthetic views, and experiences are correlated with their emotional resonance of products, which affect purchase intentions [4]. According to Röse [5], in the global market, products are more likely to be exported; design will fail if the culture of targeted countries is not considered. In addition, culture-orientation is one essential element for good user interfaces. Consideration of culture in the standard product development lifecycle becomes necessary and imperative.

Efforts have been made globally to develop cultural products to appeal customers. For example, in Taiwan, Lufu (a product design studio) designed a series of Japanese sealing talismans with the attempt to bring good fortune or toward off evil/illness for local customers. The tourist center of the Maokong Gondola (a popular scenic spot with a gondola lift transportation system that carries tourists around the Taipei zoo area) introduced visitors a variety of cat figurines (as the souvenirs). In Japan, Okinawa, the tourist center of the Gyokusendo Cave (a 5 km long cave full of stalactites and stalagmites) introduced crystal balls resembling features of stalactites for promoting tourism. Nevertheless, the above cultural products mostly were not designed to carry/address the right cultural rites/values which could have led to customer confusion. For example, it might be hard for local Taiwanese people to relate Japanese sealing talismans to their daily lives, as well as to understand why cat figurines are used to represent a scenic spot that historically does not contain any piece of cat information. In addition, for Japanese people, they might not be able to see the fit of crystal balls (originated from the western world) to their culture.

Thus, without the integration of culture elements in product design, customers would have difficulties to understand or interact with cultural products [6]. As noted by Boztepe [7], customers are not able to effectively perceive the meanings and values of cultural products Therefore, helping designers integrate cultural elements and meanings into product design becomes essential.

The purpose of this study was to demonstrate the need of a cultural representation tool in product design. In this study, we presumed that culture can be conceptualized with/described by differing levels of cultural elements [8]. These cultural elements were considered critical that form culture and we called them cultural DNAs. A between-subject experiment was conducted with two groups of student participants (one was provided with a representation of cultural DNAs while the other was not) to investigate the differences of their mug design that addressed Confucius culture. Results of this study demonstrated the need to take into account cultural attributes in cultural product design.

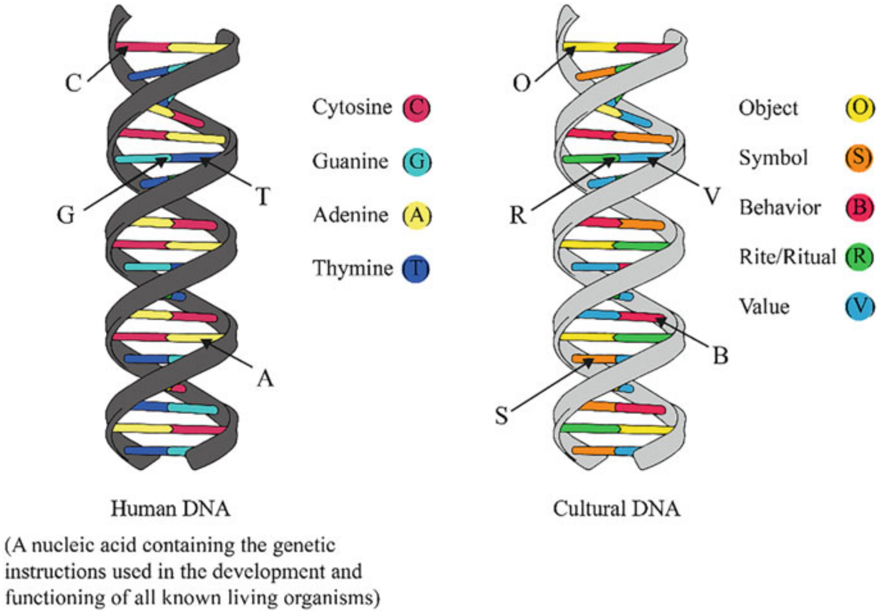

Fig. 1 The human DNA versus cultural DNA

2 Decomposition of Culture: Cultural DNAs

This study utilized the Onion Model [8] as a framework to analyze culture. The Onion Model helps designers decompose culture using the following four layers:

- First, the *objects and symbols* are the tangible elements with the meanings of individual recognition.
- Second, the *behavior* depends on environmental stimulation or other interactive persons in response to individual actions.
- Third, *rituals/rites* demonstrate symbolic values with a series of actions/behaviors which contain the cultural representations of various forms and enrich the conveyed effects during the interactive processes.
- Fourth, *values* are the shared meanings, assumptions, and ideas of a crowd that show traditions and pursuits. Based on the above cultural levels, researchers/designers can clearly define/analyze the characteristic features of a target culture.

In this study, the cultural layers and elements described by the onion model were used to represent cultural DNAs as they are carriers of genetic information of culture (conceptualized in Fig. 1).

3 Method

3.1 Participants

Purposeful sampling was used in this study. Eighteen undergraduate students who majored in Industrial Design were recruited as participants. Nine participants were randomly assigned to the experimental group while the other 9 participants were randomly assigned to the control group. Each participant was required to have completed basic training of hand drawing and sketching in school.

3.2 Equipment

Before the experiment, the researchers provided each participant with A4 papers, makers, and color pencils. Participants in the experimental group received a paper sheet containing a written cultural representation of the Confucius culture (obtained from semi-structured interviews with 30 random participants), which contained cultural DNA information at the levels of objects/symbols, behavior, rituals/rites, and values. Participants in the control group were not provided with the information given to the participants in the experimental group. Participants in the experimental group were told that they did not have to use the provided information to do their design. Participants in both groups were supplied with laptops and were allowed to freely use them to support their brainstorming process.

3.3 Variables

The independent variable was the provision of a written cultural representation (containing two levels: Yes vs. No). The dependent variable were the types and numbers of cultural DNA elements utilized by participants in their sketches.

3.4 Task and Procedure

The task of the experiment was to design a mug that reflected Confucius culture. Prior to the experiment, the researchers ensured that participants understood the goals of the study. All participants were instructed to use the provided pencils and drawing tools to generate at least 5 ideas within 3 hours.

To ensure the quality of the design outcomes, participants were required to (1) name each idea, (2) provide descriptions on the design features of every idea; (3) indicate and explain the used cultural DNAs; (4) add colors and textures to their design. Participants were not allowed to talk to other participants. Both groups of participants performed their design activities in separate conference rooms. To compensate the participants, this study gave each participants a movie ticket after they completed the tasks of the experiment.

4 Results and Discussion

Results of the study are shown in Tables 1 and 2. Participants in the control group drew 52 sketches; participants in the experimental group drew 46 sketches. For both groups, the most used cultural DNAs were objects and values, suggesting that objects and values were the most easily captured cultural DNAs to be integrated into product design.

Table 1 also shows that the cultural DNAs used by participants in the control group were not necessarily relevant to the Confucius culture. The DNAs that were irrelevant to the Confucius culture were identified by researchers and were confirmed by the participants. Comparing the results with those in Table 2, it suggests that participants in the experimental group were more able to use adequate and relevant DNAs to address culture.

Moreover, participants in the control group tended to use fewer number of symbols, behaviors, and rites in their sketches than those in the experimental group. This suggests that participants in the experimental group were influenced by the provision of cultural DNAs, and that participants in the control group were less able to catch cultural DNAs at the level of symbol, behavior, and rite due to the limited relevant information of cultural symbols, behavior, and rites on the Internet.

The statistical analysis (the Mann-Whitney U test) on the average numbers of DNAs per sketch between the two groups indicated that participants in the experimental group averagely used higher numbers of DNAs in their sketches ($U = 108.5$, $p = 0.046$) than the control group did. This suggests that the representation tool of culture inspired participants and made them use more cultural DNAs in the design process.

5 Conclusions

The purpose of this study was to demonstrate the need and usefulness of using a representation tool of culture in cultural product design. In this study, the cultural elements that form and construct culture were called cultural DNAs. A between-subject experiment was conducted with two group of student participants (one was provided with a representation tool of cultural DNAs while the other was not). The aim was to investigate the differences of participants' mug design and to study the effectiveness of the tool. Results of the analysis of participants' design sketches showed that participants who were given the representation tool could integrate higher numbers of and utilize relevant cultural DNAs in their design. The outcomes of this study indicated the need to provide designers with a representation tool to

Table 1 Control (C) group: The number of cultural DNA elements

Participant	O	S	B	R	V	Total # of DNAs	Total # of sketches	Total # of DNAs irrelevant to the Confucius culture	Average # of DNAs per sketch
C1	6	0	0	0	0	6	5	3	1.20
C2	4	0	0	0	0	4	4	1	1.00
C3	6	0	0	0	3	9	6	0	1.50
C4	6	0	0	0	4	10	6	0	1.67
C5	6	1	0	0	0	7	6	3	1.17
C6	3	0	0	0	1	4	5	1	0.80
C7	2	0	0	1	3	6	5	0	1.20
C8	6	0	0	1	3	10	5	0	2.00
C9	11	0	0	0	7	18	10	0	1.80
Total # of DNAs	50	1	0	2	21	74	52	8	
Average # of DNAs	5.56	0.11	0	0.22	2.33				

Note: O = Object, S = Symbol, B = Behavior, R = Rite/Ritual, V = Value

Table 2 Experimental (E) group: The number of cultural DNAs

Participant	O	S	B	R	V	Total # of DNAs	Total # of sketches	Average # of DNAs per sketch
E1	2	2	1	1	2	8	5	1.60
E2	5	2	1	3	0	11	5	2.20
E3	5	0	2	1	1	9	6	1.50
E4	4	0	1	1	2	8	5	1.60
E5	3	0	0	0	3	6	5	1.20
E6	4	0	0	0	4	8	5	1.60
E7	7	1	0	2	4	14	5	2.80
E8	5	2	0	1	3	11	5	2.20
E9	5	0	1	0	5	11	5	2.20
Total # of DNAs	40	7	6	9	22	84	46	
Average # of DNAs	4.44	0.78	0.67	1	2.44			

Note: (1) Participants in the experimental group did not use any cultural elements irrelevant to the Confucius culture; (2) O = Object, S = Symbol, B = Behavior, R = Rite/Ritual, V = Value

support them perform cultural product design. Future studies are needed to investigate whether or not real customers would prefer the design outcomes generated from using the cultural representation tool.

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User Defined Conceptual Modeling Gestures

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Abstract Gesture and speech based interaction offers designers a powerful technique to create 3D CAD models. Previous studies on gesture based modeling have employed author defined gestures which may not be very user friendly. The aim of this study was to collect a data set of user generated gestures and accompanying voice commands for 3D modeling for form exploration in the conceptual architectural design phase. We conducted an experiment with 41 subjects to elicit their preferences in using gestures and speech for twelve 3D CAD modeling referents. In this paper we present the different types of gestures we found, and present user preferences of gestures and speech. Findings from this study will be used for the design of a speech and gesture based Cad modeling interface.

Keywords Conceptual architectural design · Gesture based modeling · Natural user interface · Gesture studies · Human computer interaction

1 Introduction

This research aims to address the issue of computer support during the conceptual design stage, when problems are ill-defined and designers formulate the initial parameters for an artifact [1]. Conventional CAD systems use graphical user interfaces that rely on input devices such as mouse and keyboard, which are seen to constrain human-computer dialogue [2]. Gesture and speech based interaction offers a natural and flexible interaction technique for designers for 3D modeling during conceptual

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design stage, when ideas are fluid. Gesture-based interaction is inherently intuitive, because humans use their body, rather than a device, to interact with machines [3].

Although there have been a number of studies on gesture and speech based CAD modeling, they have largely focused on gesture recognition techniques using small sets of author defined gesture sets, overlooking the specific needs of architects and designers. Critics have argued that users should not have to learn an artificial gestural language that is device or application dependent [4]. Furthermore, a robust speech and gesture based modeling system must be flexible and extensible. It should adapt to users' needs and gestural techniques [5].

We concur that a robust gesture based CAD modeling interface must be based on empirically grounded knowledge instead of arbitrary gestures designed by authors of a system. Hence, we conducted an experiment with individuals with architecture and engineering product design backgrounds to elicit preferences of gestures and speech for CAD modeling referents. The study was designed to elicit gestures and speech preferences for basic, low level CAD modeling commands for primitives, manipulations and navigation of views (we use the generic term "referents" to refer to these subsequently).

We conducted an experiment using a motion capture system with 42 subjects to elicit their preferences in using gestures and speech for twelve 3D modeling operations and three modeling sequences. Collected data was analyzed and ranked for effectiveness. An evaluation session with 4 expert designers was conducted to evaluate the representative modal sample for effectiveness for the description of 3D modeling operations. In this paper, we present findings of four navigation gestures, namely pan, zoom in, zoom out and orbit. We present a categorization of the gestures, and elaborate user preferences for speech terms and hand poses. We also present findings on the ease of use and effectiveness of the gestures based on subjects' and coders' ratings and experts' judgment.

The compiled gesture and speech data set will be used for the design of a user interface for a mainstream 3D modeling platform. Our hypothesis is that an interface that is based on gesture sets elicited from professional users and that learns from them would be more user friendly than current systems that employ author defined gesture sets.

2 Background

We define gestures as hand and arm movements in free space, which convey meaningful information. The main limb segments involved in performing such gestures are the hands, wrists, forearms and upper arms. The gestures investigated in this research are mid-air, touch free, bimanual gestures. We are especially interested in pantomimic gestures, which imitate practical actions or shapes [6]. Pantomimic gestures are perceived to be more intuitive, easy to perform and natural for users [7].

Speech and gestures are central to human to human communication, wherein they play a complementary role. When speech is ambiguous, listeners rely on gestural cues of the speaker [8]. Gestures are known to communicate the speaker's intentions more accurately than speech [9]. Previous research has reported the synergic relationship of speech and gestures for creating virtual spatial configurations. It has been theorized that while gestures are particularly suitable for dealing with spatial issues such as shape and size, language can be used effectively for descriptive tasks [10]. Restricted speech strings can communicate sufficient information about the form of the object [11].

Gestural interaction offers a natural and flexible interaction technique for designers for 3D modeling during conceptual design stage, when ideas are fluid. Previous studies have argued how gestures not only provide the spatial context for form exploration, but also aid in spatial thinking and the memorability of the location of forms [12]. Gesture studies focus on how people use their hands and other parts of their body for communication. Previous research has established the crucial role gestures play in the development and communication of design ideas and in collaborative team meetings [13].

Speech based input has rarely been used independently for CAD modeling, and has mostly been used in conjunction with other modalities. Studies in using speech as input for CAD modeling include 'Talk and Draw' [14], speech and glove based gesture input [15], and speech with gesture pen strokes [16]. Speech was used for disambiguation in another study [17].

Recent research has employed user studies to test gesture and speech based interaction for 3D CAD modeling. These studies confirm that users found gesture based interaction easy to learn and use [18, 19] and that it allows users to quickly and efficiently conceptualize potential solutions [1, 20]. Recent studies using both speech and gestural input for CAD modeling include the works of Nanjundaswamy et al. [18], who concluded that users preferred the use of speech over Brain Computer Interfaces (BCI) to invoke optional CAD functionality.

Even though gesture based interaction has developed considerably in the recent years, many gesture-based interfaces still make the hands function mainly as a mouse with a limited number of gestures [21]. Previous studies in gesture based CAD modeling have largely focused on aspects of the user interface, hand tracking and gesture recognition techniques, employing author defined gesture and/or speech sets [1, 20, 22–24]. Such an approach requires users to learn a gesture vocabulary and its associated commands, hence adding to users' cognitive load [25]. It may be noted that user-defined gesture sets are easier to recall than predesigned gestures, as they require less effort and are less time-consuming [26]. Furthermore, research has pointed out that most users prefer to define gestures themselves [21].

Fig. 1 Gloves and jacket with reflective markers worn by subjects during the experiment

3 Method

3.1 Overview of User Experiment

An experiment was conducted individually with 41 subjects, from architectural and engineering product development backgrounds, over a period of two weeks at the Robotics Innovation Lab in Singapore University of Technology and Design (SUTD) campus. 52% were female, 48% male. The subjects comprised the following ethnicities: Chinese (60%), Indian (24%), Caucasian (9%), and other (7%). All except one subject were right-handed. 70% of the subjects were from the age group 22–30 years, followed by the age group 31–40 years (15%) and 18–21 years (10%). 50% of the subjects were from Architecture background, and 50% from Engineering Product Development background. 79% of the subjects reported English as their first language. 93% of the subjects were familiar with one or more CAD software. The aim of the experiment was to collect gesture input and voice commands that communicated 3D modeling operations such as creating and manipulating 3D objects and navigating views.

A Vicon motion capture setup consisting of 8 motion capture cameras was used to track the motion of the subjects' upper bodies (especially hands and arms). Subjects were asked to wear a light jacket and a pair of gloves with a set of IR reflective spherical markers, 11 of which were placed on the arms and shoulder blades and 13 on each hand glove (Fig. 1). Nexus (a Vicon software) was used to create segments between these markers, and to output their coordinates at 100 Hz with respect to the origin of the motion capture system (Fig. 2). Two video cameras and a microphone were also used to record the movements and voice of the subjects.

The experiment was conducted in two sessions of about 20 min each. The subjects sat facing a screen where a repertoire of pre-recorded 3D modeling operations and objects (referents) were shown to them one by one. Each referent was shown for 15 s on a large screen (Fig. 3).

The subjects' task was to describe four categories of 3D modeling referents: primitives, operations, navigations and modeling sequences (Fig. 4). The categories and referents were randomized for all subjects. There were 15 referents in four

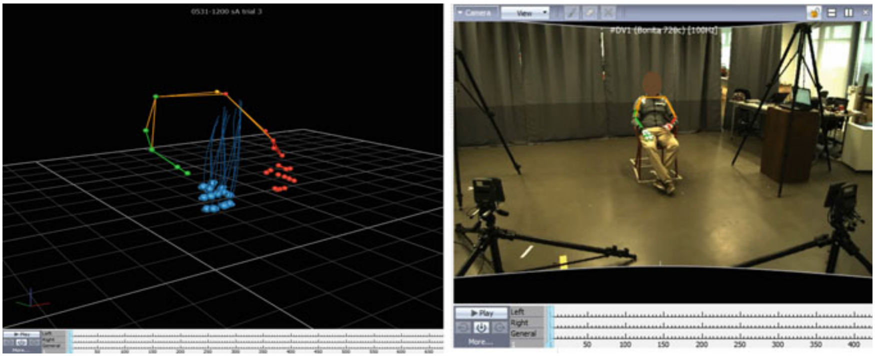

Fig. 2 Segments and trajectories recreated by Vicon Nexus software (left) of the subject describing a referent with gestures (right)

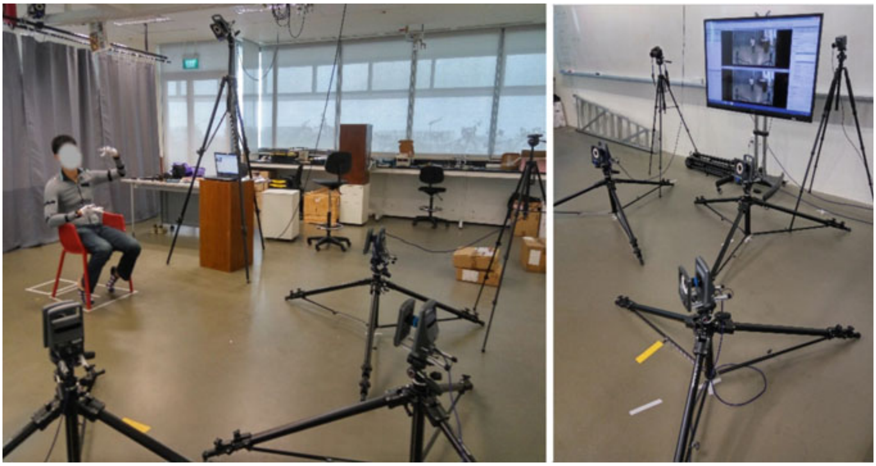

Fig. 3 The Vicon motion capture system setup design for the experiment

categories in each session. Some referents were represented as a still image, and some as animations to show a navigation or manipulation sequence.

In session A, the subjects were asked to use only gestures to describe the 3D referents. In session B, the subjects were free to use gestures and speech to describe the referents on the screen. The order of the sessions was counter balanced, such that half of the subjects did session A first, and the other half did session B first. After each gestural input, the subject was asked to rate the ease of the task and their own performance of the task on a 5-point scale. After the experiment, subjects were asked to fill out a questionnaire that queried their ethnicity, cultural and language background, design expertise, experience level and their preferences on the use of gesture and speech. Figure 5 presents the flow of the experiment as a diagram.

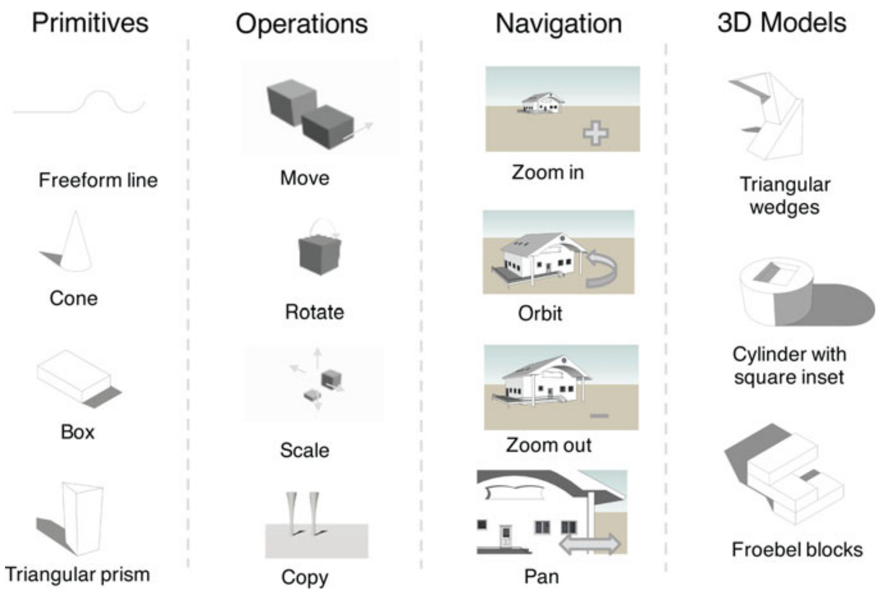

Fig. 4 The 3D modeling referents shown to the referents during the experiment

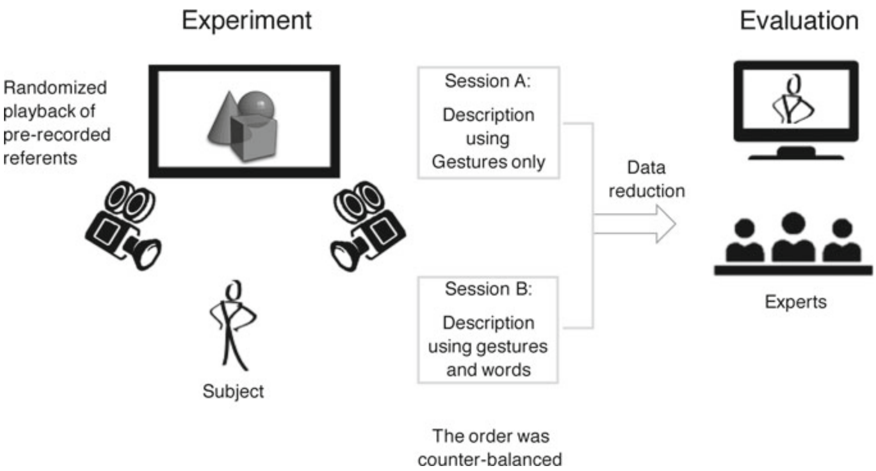

Fig. 5 The flow of the experiment

The referents were all low level, basic CAD modeling commands classified in three categories: (1) Navigation, which involved changing the view, (2) Manipulation, (3) Primitives, and (4) 3D modeling. Every category had one referent which was not easily described by words (freeform, orbit, copy). Figure 4 presents the referents and their categories.

3.2 Pre-test Briefing

The words 'intuitive' or 'gesture' were not used in the pre-test briefing given to the subjects. Subjects were given a scenario in which they informed that Laura was a designer sitting in the other room and needed assistance in recreating the object that the subject saw on their screen. Laura could see the first frame of the referents that are represented as animations, but could not see the still images. In session A, the scenario was that Laura could see the subject but cannot hear the subject. Hence the subject's job was to give a clear set of instructions using their hands and arms to Laura so that she could recreate the object. Subjects were not allowed to use lips or facial expressions for communication. In session B, the scenario was altered so that Laura could hear as well as see the subject. Therefore, the subject was free to use hand gestures or speech, as per her/his preferences.

3.3 Data Analysis Technique: Coding

In total 984 gestures from both sessions were logged. Speech data from session B was transcribed and coded. The identification of a gestural unit was based on function. For the purpose of this research, we only marked the main stroke of the gesture; and disregarded the preparation and the retraction of the hand. We ignored instances of gesticulation.

The video data was analyzed independently by three coders, one of which was a researcher on the project, and two of which were Ph.D. students with architectural background. The aim of the video data analysis was to identify common themes in each category of data sample and to code their attributes.

Both authors jointly reviewed all samples to establish the common themes in each category, which were established by identifying commonalities in hand and arm movement in each category.

A coding manual was prepared, and weekly training sessions were held for the coding of each category. Ten percent of the sample from each data category was coded by all three coders and was used to calculate inter-coder reliability (Krippendorf's Alpha and percentage agreement). The reliability sample was included in the final sample using the rule of the majority. Coders also rated the effectiveness of each observation. The inter-rater reliability for each category was over 0.7.

Data from both sessions A and B was considered to compile the results for the navigation data in the following section.

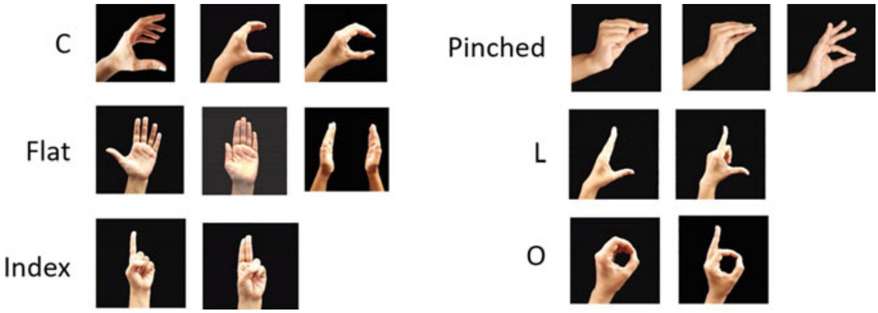

Fig. 6 Standardized hand poses for ease of coding

4 Results

Based on the number of hands used, we classify gestures as follows:

- *Unimanual*: the main gesture is performed by one hand; the other hand is at rest.
- *Bimanual-symmetrical*: Both hands are used symmetrically (and simultaneously) to articulate the gesture
- *Bimanual-action reference*: One hand performs the gesture, while the other hand serves to identify a reference point, plane or object.

We define hand pose as the posture of the hand when the gesture is performed. Hand poses could be static: when the hand pose is constant over the course of the gesture; or dynamic: when the hand pose changes while the gesture is being performed. Hand poses were generalized in order to aid the coding [27] (Fig. 6).

The navigation referents shown to the subjects were pan, orbit, zoom in and zoom out. For orbit, the view changed in an anti-clockwise direction, starting from top front of the house. The themes of gestures identified for orbit were (a) trace circle (subject traces a circle with their hands), (b) wrist or hand rotation (subject uses their wrist as pivot) (c) trace opposite Cs (subject traces two Cs in opposite directions with hands or fingers).

For the referent pan, the subjects were shown a video clip in which the view panned across the front façade of a house from right to left. We found that to communicate this referent, nearly half of the subjects move their hands from right to left, and the other half move their hands from left to right.

For the referents zoom in and zoom out, the subjects were shown a video clip in which the view closed into a house from a distance, and vice versa, respectively. The themes that were identified for the referent Zoom in were: (1) Push hands towards screen (Metaphor: go close to object) (2) Pull hands towards self (Metaphor: Bring the object close to me), and (3) Pull hands or fingers away from each other (Metaphor: Make the object bigger). The themes identified for Zoom out were (1) Pull hands back (Metaphor: Move camera away from the object) (2) Push hands towards screen (Push the object away) (3) Bring hands or fingers close to each other (Metaphor: Make the

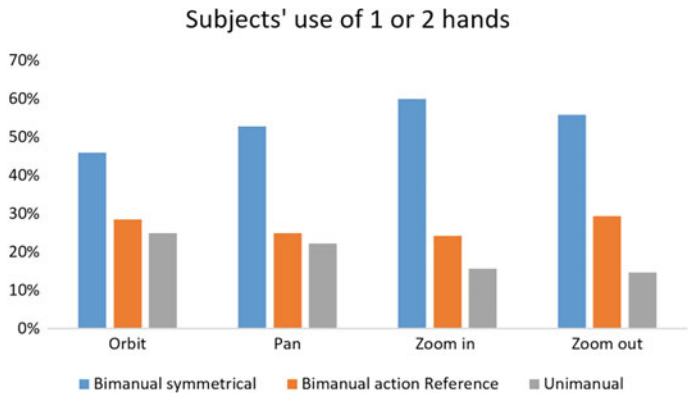

Fig. 7 Subjects' use of 1 or 2 hands for navigation gestures

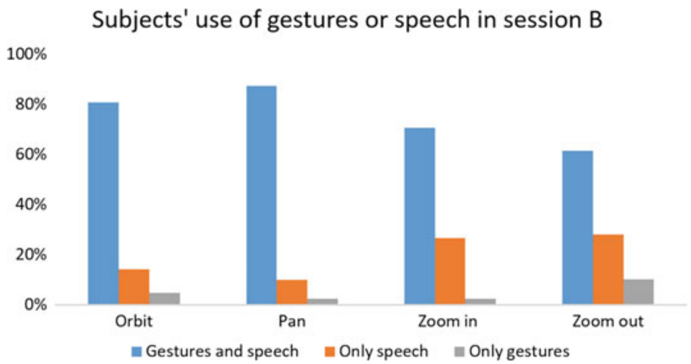

Fig. 8 Subjects' use of gestures or speech in session B for navigation gestures

object smaller). We found that the most frequently occurring theme for zoom in was Push hands toward screen and for zoom out was Pull hands back. For most referents, a larger percentage of subjects employed bimanual symmetric gestures, followed by bimanual action reference gestures. Figure 7 presents the results for navigation gestures. We found that 'Flat' and 'C' were the most frequently employed hand poses for navigation gestures.

In session B, the subjects were free to decide whether to employ only gestures, only speech or a combination to communicate with Laura. Overall, a significant percentage of subjects chose to employ both speech and gestures for communicating CAD functions. For most referents, less than 20% chose to employ only speech, and only a negligible percentage chose to employ only gestures. For the referents Zoom in and Zoom out, slightly over 20% employed only speech (Fig. 8). With the exception of Pan, subjects perceived the task to be easier in session B, and rated their own performance higher in session B.

5 Conclusion

Results show that most subjects show preference for using bimanual gestures, and prefer to employ both gestures as well speech for communicating 3D operations. Although a significant percentage of subjects employed only speech in session B, only 10% of the subjects used only gestures in session B. We found that 'Flat' and 'C' were the most commonly used hand poses for navigation gestures; and that static hand poses were employed more than dynamic gestures.

Speech and gestural interaction has the potential to transform the way designers create 3D models. It will be a major improvement from the conventional technique of point and click input that has widespread use currently. User elicited gestures that have a clear association with physical shapes and practical actions are easier to recall, and imply a low learning curve in gesture based CAD interfaces. Hence, such an interface will be especially relevant for beginners and students. Although previous research has employed speech and gesture input for 3D modeling [18, 19], this study offers a more conclusive proof on the function of speech and gestures in 3D modeling as it is based on a controlled investigation and carefully designed lab experiment. Hence, a 3D modeling interface based on the findings from this study promises to be more user-friendly. The research will influence and potentially change designers' way of thinking when conceptualizing and modeling an artifact in a digital 3D modeling environment.

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A Universal Basic Robot

Mathew Schwartz and Michael Ehrlich

Abstract While the idea of advancing technology and society are often of primary interest to academics, the general public is frequently challenging the integration of these advancements within society. This complex issue is most often discussed around the role of robots in manufacturing where both repetitive and dangerous tasks performed by humans are being replaced by robotic counterparts that in many cases, can also perform these tasks more accurately. Similarly, the idea of automation through artificial intelligence poses a risk to workers far beyond physical labor, a topic highly discussed for the past few years. From this concern, theories on bringing your own robot to work, analogous to the bring your own device to work movement, have been brought up as a way into the future. Separately, in order to offset the economic downsides of the changing human labor force, and among other reasons, recent political discussions have been actively pursuing the idea of a universal basic income. This paper poses an alternative idea, one in which the advantages of robotics continues to benefit the laborers in which it replaces, and takes the bring your own robot to work to a macro scale: a universal basic robot. These two past proposals, one in which people bring their own robot to work, and one in which a universal basic income is given, have large differences in the way society itself will transform. This paper discusses the trends of technological development that lead to the robotic workforce and the economic challenges of implementing such an idea.

1 The Race for Time

Maybe the most important question of all the discussion about automation is simply: why? Today, the fear of AI replacing nearly every job is discussed within politics,

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labor unions, and corporations. Still, and right before AI, industrial robots were the downfall. Before that was the computer, and before that was some other technology. What has been especially true over time is the increased productivity of people due to technical innovations. The strongest motivating factor for the adoption of technology has been the quest for more time, whether it is time that can be added to life through pharmacology and medicine, or time that can be saved through engineering. This generally holds true with societal adoptions of technology, as long as it is a person's time being saved, and not their companies.

A prime example of the quest for more time is the enormous success of the home cleaning devices [1]. This invention and continued development has been and still is a direct threat to the household services industry. From vacuum machines to dish washing machines, the low cost and efficient household appliances contributed to the change in industry positions available [2]. Importantly, none of these devices were marketed to remove jobs, but rather to increase free time of the people doing the work. At a certain point in the efficiency of a machine, people who are hiring a worker to complete a task can leverage the efficiency of the machine to perform the task themselves, allowing for time to be spent in other ways without an increase in cost. It is easy to put automation from companies as the reason for job displacement, however, numerous jobs have been displaced by the general population's desire to have more of their own free time. Whether a machine is washing clothes or a person is not important until cost is factored in. As the use of a maid or personal cleaner would be limited to the rich, these advancements help instigate a system of equality and equal access to a basic standard of living, in the case of a vacuum, a clean home.

More generally, the desire to save time can be seen in the creation of instant foods. In the west, and especially in America, the TV dinner epitomized the fight for time. Using a sectioned plate, foods could be rapidly prepared through a single oven. This process became even more popular as microwave ovens were introduced, allowing consumers to cut down even further on the time between retrieving a meal from the freezer and eating. At nearly the same time as the introduction of the TV dinner in America, instant noodles were being introduced in Japan. The ability to go from a package to ready food by adding hot water was important enough for it to be considered the best invention of the twentieth century [3].

In general, it is not just a matter of corporate productivity that automation has dominated, but rather a basic human need to want more time to do more of what they want. In order to create this extra time, aspects of least interest are then automated, such as cleaning, or food preparation. As a society, however, the automation of basic and undesirable tasks to create more free time applies to the majority of people. As such, more time is available towards economically productive and financially rewarded tasks.

With automation of daily tasks enabling more time to be spent in other ways, it is clear the predictions in the past of the leisure market have remained true. In the 1983 paper The Service Sector Revolution, the leisure services industry making up 1.1% of US jobs was predicted to reach 2% by 2000 and the services industry as a whole to make up 80% [4].

As society nears full automation and abilities of robots comparable to humans, the ability to be two places at once becomes more realistic. In a simplistic example, the idea that someone can be both at work and with family at the same time is naturally impossible. Yet as already seen in factories, robots are able to replace the work once done by humans. In the task based view, the work that needs to be done, and the family that is desired to be with, can be done at the same time. This is reflected in the robotic vacuum cleaners, where the house work, or daily life tasks, are automated at a point the human can focus on financial gain or family time. It is therefore conceivable that, given a robot that can do universal tasks, it can be applied in two standard ways. (1) The robot is used to achieve the work once done by the person, enabling time to be spent on non-financial gain activities. (2) The robot is used for non-financial gain activities which enables the person to work.

This paper discusses the relationship between automation and free time with regard to societal advancements and financial stability. As Leontief states in a 1982 paper The Distribution of Work and Income,

> In the long run, responding to the incipient threat of technological unemployment, public policy should aim at securing equitable distribution of work and income, taking care not to obstruct technological progress even indirectly. [5]

The following sections address this idea by assuming the technology of humanoid robotics will be at the performance capabilities that is assumed through the fear of job loss from AI and robotics and integrating it with the role and responsibilities of government and corporations.

2 Universal Basic Income

Universal basic income (UBI) which is also sometimes known as Universal Income, Basic Income, or Basic Guaranteed Income is an unconditional government income transfer to all citizens. This represents a simpler and more transparent way of providing social security than traditional welfare systems and could be more effective as a means to reduce poverty. Without the heavy administrative burden of means testing and enforcing rules for working, job seeking, and other hard to monitor social behaviors, the new system should cost significantly less than the apparent payments. UBI would substitute for many other social and administrative costs as it replaces welfare and could reduce poverty related costs including healthcare and policing [6].

Support for UBI has grown as citizens experience the loss of freedom due to poverty. People can make some pretty horrible decisions because they need the money, including human trafficking. As we remove the fear of starvation and homelessness, people have the ability to make choices and regain the power to say no to work that is demeaning and demoralizing.

There are many concerns about the implementation of UBI. There are obvious concerns about how people would use the money. These paternalistic concerns about bad choices include vices like drug use or giving it away carelessly. On a more macro level, economists believe that UBI would reduce work incentives and could reduce GNP growth. Reduced GNP growth could reduce tax receipts which could undermine UBI [7]. There are unanswered questions about how significant these effects might be.

There are also many ideas which are related to UBI. Social dividends are returns generated from public enterprise or assets and represent another form of citizen payment. One related idea generated at the birth of the U.S. was a citizen capital dividend suggested by Thomas Paine. Just over fifty years ago, a group of 1200 economists led by James Tobin, Paul Samuelson, and JK Galbraith suggested the implementation of a Guaranteed Minimum Income as a means tested supplement to alleviate poverty. This idea was taken up by President Richard Nixon and was debated in Congress but was never adopted [8].

Perhaps the greatest challenge for modern economic participants is the rate of technological change. For a welder who trained and became an expert to be replaced mid-career by a more efficient and more accurate robot leaves them with a sudden loss of human capital that may not be replaceable. A younger person can go back to school to reinvest in new updated skills and an older person can retire soon, but if the rate of technological change is so fast that many mid-career workers get trapped with useless human capital, then the short run costs can be very large. If the corporate beneficiary tax can be structured so that rapid technological change is taxed more than slower technological change, then perhaps that will induce slower adoption of new labor-saving technologies and hence reduce the short-run costs.

Ultimately, the establishment of a Universal Basic Robot would broaden the ownership of technological assets. It would also broaden the ownership of the means of production, in contrast with the UBI which only shares the benefits of increased production efficiencies. There may be options for additional sharing of technological assets such as providing consumer payments to compensate for people who share data that trains AI or robotic actors.

2.1 Alternative Models

One of the most direct tests of UBI came from Iran. Iran adopted a basic income cash grant in 2011 which was set at 29% of median income or about $1.50 per head of household per day. Due to concerns within the government about reductions in work and the high expense, the Iranian Parliament cut the program in 2016. Subsequent economic analysis suggests that there was little effect on working hours by beneficiaries and some even used the funds to expand new business opportunities [9].

Earlier this year, Finland adopted a UBI trial program. This two year experiment, which began in 2017 and is expected to expand in 2018, currently provides 560 Euros per month. There is some argument that this in an income supplement, or partial UBI, as it would not cover the high cost of living in a Nordic country like Finland. While we don't yet know the results, this program is politically popular [10].

Brazil adopted a basic income strategy with the Bolsa Familia in 2002. This is not a traditional UBI as the payments are targeted to supporting low income families who want to improve their human capital. This targeted plan currently benefits about 25% of Brazilians and supports students who want to gain further training. Critics have been concerned about reduced work incentives and have called the payments addictive but the World Bank has done studies which suggest that the program has been effective in improving human capital of low income Brazilians and has not reduced working over the longer term [11].

The social dividend strategy was implemented in Alaska in 1976 with the creation of the Alaska Permanent Fund. At least 25% of the proceeds from Trans-Alaska Pipeline was put in to a public benefit corporation which is dedicated to future generations when oil will no longer be an available resource. The annual payments ranging from a few hundred dollars to over $2000 per Alaskan have reduced overall income inequality but they don't seem to have had measurable effects on work hours [9].

The Norwegian Sovereign Wealth Fund recently became the largest public benefit fund in the world with over $1 trillion dollars under management. These funds were generated from the surplus funds from the Norwegian oil sector. Officially known as the Government Pension Fund Global and representing over $190,000 per Norwegian, these funds, based on the common ownership of state assets, support the government budget. Unlike Alaska, The Norwegian fund does not provide a direct citizen dividend. By law, no more than 3% of the fund can be spent by the government, but this now represents over 7% of GDP. As a result, Norwegian tax rates have continued to fall as the fund has grown [12].

2.2 Funding Options and Challenges

In some cases, governments have been able to dedicate public resources to establish funding for public benefit systems. The most common examples are from oil-based funding as in Alaska and Norway. The Chinese leadership once proposed the privatization of the state industrial and banking sector as a source of funding for a new social security system, but this idea has not gained traction [13]. The US has used gas tax funding for roads and, in principle, this model could be expanded. More likely, we will need to establish new general taxes to support the implementation of a Universal Basic Robot.

Recently there has been significant debate about Corporate versus Personal taxes. Since only actual people are people and the legal personage of corporations is a fiction under the law, it must be recognized that ultimately people pay all taxes either directly or indirectly through their corporate ownership. Even still, the form of the taxes matters as political support requires apparent fairness and transparency [14].

One principle of fairness would suggest that an equitable distribution of tax costs would tax the largest beneficiaries the most. In the short-run it is obvious that the adoption of new technology by corporations drives job losses from displaced workers, while improving the profitability of corporations. Individuals who own corporations should expect to benefit relative to regular workers who lose their jobs or must work at lower wages. Therefore, the principal of beneficiary taxation suggests raising corporate taxes to pay for Universal Basic Robots, rather than wage based income taxes.

While the short-run effects of technological changes such as corporate adoption of robots or AI are reasonably obvious, the long-term effects are unclear. There is historical evidence that adoption of new technologies reduces long-run unemployment. There are compensatory effects from the creation of new work and through lower prices that may benefit the newly unemployed. It is notoriously difficult to predict the future though many have tried [15]. Since the Industrial Revolution and through subsequent periods of rapid population growth some (Malthus) have predicted food shortages and economic disaster while others (Says Law) have predicted that the newly available supply of labor will create its own demand.

3 A New Workforce

In a 1984 paper on High Technology and Job Loss, the author states,

> The concern over technological job loss has now resurfaced, triggered by the recent recession and the highest unemployment rate since the 1930s.[2]

Three decades later, this same conversation is occurring after the 2007–2012 great recession. Much of the work done by hand in the past has been enhanced and automated by computers. From tax accountants to architects, the computer has been a topic of great debate when it comes to replacing workers, even in these non-manual labor jobs. Further making a parallel to the arguments of AI and robotics today, Rumberger states,

> Future job displacement is likely to be different from past job displacement because the technologies affecting displacement differ greatly. Past technologies - fueled by the development of powerful machines -primarily displaced unskilled physical labor and, to a lesser extent, skilled labor in some craft areas. But future technologies-fueled by the microelectronics revolution-will displace mental as well as physical labor at both skilled and unskilled levels. This displacement, moreover, will not be concentrated within particular jobs and industries, as in the past, but will occur throughout the economy. [2]

While microelectronics have had a profound impact on nearly every industry, as predicted, the effects of this impact on unemployment rates are small, with a current unemployment rate lower than when this quote was written.

The key difficulty in understanding the role of new technology within the workforce is understanding the dynamics a more productive or accurate tool creates within an industry. In 1983 a paper discussing the advent of E-COM (electronic computer-originated Mail), the author correctly predicts the profound effect the technology will have once it is connected to every home. However, the author questions,

> Once mail can be electronically delivered, how many of the current 512,00 mail carriers and postal clerks will be needed? [4]

Although the concept makes sense: electronic mail replaces physical mail so less postal workers are needed, the changes in logistics have created a different usage. The impact of home delivery for nearly any device was not accounted for in the prediction of postal workers unemployment rate. Rather, the 2016 rate in the Postal Service stood at 608,900 jobs [16].

Another emblematic issue within architecture and job loss has been the role of the drafter. While predictions using mathematical modeling had been made that by the year 2000, drafting jobs would no longer exist [17]. As the number of drafting jobs stood at 296,000 in 1978, the current employment of 207,700 in 2016 shows another example of misunderstood futures in jobs [18]. Although CAD/CAM has increased productivity, the role of the drafter to convert designs and models into manufacturing and/or construction drawings remains. Even so, the Bureau of Labor Statistics repeats the arguments for why the job of a drafter, albeit without claiming the occupation will disappear, by stating,

> However, computer-aided design (CAD) and building information modeling (BIM) technologies allow engineers and architects to perform many tasks that used to be done by drafters, which is expected to temper demand for all drafters. [18]

As data and machine learning are further embraced by the architectural discipline, one can imagine a new position that the drafter exists within. As the design of buildings incorporates data-driven approaches, the aggregation of the correct and meaningful data for a building must be gathered. While BIM may temper the demand for the drafter to draw a technical diagram, it may increase the demand for the drafter to aggregate and represent the data used to drive the design.

When considering the increased productivity in architectural design, it is important to note the types of buildings and construction techniques that have changed alongside the technology. The benefit of doing a task in a shorter amount of time is not only on the corporate side of reduced labor costs, but is often actualized in the advancement of society. While CAD programs are reducing the time to make a drawing, rather than the architect working less, they are able to design more. This extended time in design directly leads to new and alternative manufacturing/construction processes, that pushes the boundary further for other industries as well.

The ongoing revolution of AI and robotics merging into ultimate tools of productivity then offers an alternative to more free time; the ability to impact society and culture at a scale and quality not currently possible. Likewise, the extreme capabilities possible with this mergence affords alternative methods of contributing to society.

3.1 Equal Right to Work

While a basic income for everyone is an obvious way to increase living standards for people unable to work, in particular people with disabilities, it lacks the empowerment of accessible ways to make a living. Moreover, the universal X arguments have been focused around human rights, such as universal healthcare in which all people have access to medical treatments, while the universal basic income has been conceived of as a method to acquire rights. As society progresses, what is considered the standard of living changes with it, as do individuals preferences. Likewise, the implementation of a basic income may do worse for improving conditions as it is set to the current standards. Instead, providing the people with the tools needed to obtain independence, similar to education, creates opportunity for productivity by all members of society. Furthermore, through the introduction of a basic robot, those with disabilities are enabled to utilize this robot for income generation, or in the case of retired elders, a robot that is able to help in their everyday life tasks.

Reliance on physical ability when mental capacity is not suitable for some jobs is dangerous and unproductive. In general, physically demanding work leads to higher injuries, which leads to less time able to work, which lowers productivity and increases the expense on society. If the only goal is to increase the number of jobs, as some recent political conversations have revolved around, it would be much easier to revert progress of modern society. By increasing the number of people smoking or using chemicals, a higher percentage of people will be sick, which requires more doctors. More people not working and instead spending time in the hospital means more people needed to replace them at work during this time. Essentially, unreliable employees require an employer to substitute higher employee salaries with a lower salary distributed among more people in order to create stability.

If the argument against robots is the loss of jobs due to higher productivity by the robot, the reverse must be stated as well; reduction in employee productivity leads to higher employment. This logic brings back the point that it should not be job creation as the goal, but rather the ability to contribute within society. Between mental and physical illness, the access to employment is not equal, and therefore contributions to society are not equally accessible, a problem for a growing society. At the same time, in addition to contributing to society, responsibilities towards family and children have brought massive stress to those struggling to make a living. If the argument to be made for a universal income due to job loss from intelligent robots, the ability for these robots to do other tasks such as take care of household problems should be true as well. The universal robot would then empower people to decide where this robot should be applied.

3.2 Humanoids

While at present much of the discussion in replacing human workers is with industrial robot arms, the research and advancements being done in humanoid robotics begs a larger question for robotic workers. In specialized tasks, a custom built robot is likely the most efficient method for completing the task [19]. This customization is more similar to the decades of manufacturing machines developed after the industrial revolution. The common industrial robot arm, with joints resembling the degrees of freedom of a human arm, is more generalized than the manufacturing machines. This allows a single robot to be re-programmed and re-applied to a variety of tasks [20].

When looking at the human, the possibilities of these tasks are near limitless, as is the mobility of the human in unstructured environments. Unlike the limited track an industrial arm may move along, or the wheels of a mobile robot, the bipedal aspect of a humanoid allows it to navigate the same environments as humans. As early as 1996 during the first conference dedicated to humanoid robotics researchers had recognized the use of humanoids in both housework and factory work [21]. In the case of housework, the caring of elderly and people with disabilities is an important use. However, if given a situation in which someone requiring at-home care has a person that can take care of them or work at a factory, and a robot that can also do both, the care and interaction with a human is likely to outweigh the usefulness of the humanoid. In any case, the versatility of the humanoid enables the person to make this choice.

The abilities and applications of humanoid robots have most recently been exemplified in the DARPA robotics challenge (DRC). In the DRC, robots were given the challenge of completing numerous tasks that required interaction with human built environments. The challenge was in response to the nuclear plant meltdown in Fukushima Japan, where the radiation levels became too dangerous for humans to directly fix the problems. The setup of the DARPA challenge was a semi-autonomous robot controlled by tele-operation [22]. While the robots themselves were not fully autonomous, the workflow and approach clearly reached a level of the robot becoming an avatar, or extension of a person, to complete a task.

When looking for a universal robot, the versatility of a human and the objects and spaces designed for them are a key factor. While a car can be robotically controlled with no steering wheel, it eliminates the persons ability to drive the car. However, a car with a steering wheel that a human can drive, can become autonomous with the application of a humanoid robot as the driver. This extends to a robot vacuum cleaner versus a robot using a vacuum cleaner, or a robot with an arm that is designed for cutting, versus a robot that picks up a cutting tool, as was done in the DRC [22].

4 Implementation

4.1 Progress Through Employees

Many arguments can be had for why the bring your own device (BYOD) to work became popular. Most of these come down to productivity and profits. Either workers are more happy with their own devices, making them more productive, and (or) the company saves money by not purchasing these devices. It is then not irrational to believe a mutually beneficial relationship would occur when employees bring their robot, and not just their phone, to work.

When the capacity of a person's productivity is reached, corporations are able to invest in themselves, through additional employees, infrastructure, or alternative methods, such as robotics. A large part of an investment is the return over time.

Therefore, the investments of a company are more beneficial when a low initial investment is required for a longer period of time. When people are invested in, the ability to layoff these workers, or the fear of them leaving, becomes more important. In the same way, a company investing in tools or infrastructure holds a lower risk in the investment not providing a return in the future. To mitigate risk on an investment return, or when the investment required is not financially feasible for the need, companies are able to outsource work elsewhere. The outsourcing of work is most often a place with cheaper human labor, or cheaper labor through robots. This latter option is what can be modified to be beneficial for all.

If every person was given a robot that was able to work for them, companies would be able to outsource work to its own employees. While current research is showing the possibilities for supervised robotic learning and collaborative human-robot manufacturing, it should be realized at some point the robot will be able to fully take over. When each person maintains ownership of the robot, the transition into a fully robotic system remains beneficial for both the individual person and company. To push this benefit even more, one can imagine a state in which new hardware or updated systems are delivered through the employee, rather than the corporation.

A more relevant factor to progress leading to economic growth is the societal demands on innovation. Commonly discussed as design thinking, or sometimes generalized as research and development, the creation of problem statements to be solved is unlikely to be formulated by machines. While an AI may be able to calculate the chances of certain products succeeding in the market based on previous data, or even figure out how to manufacture something, the leap outside the normal trend to create something innovative and beneficial will be hard to shift onto a machine. The famous 10% time once given to Google employees epitomizes this philosophy of human creativity for the finding and solving of new problems. As robotic technology evolves, the latter issue may be a threat to jobs, while the former requires human employment. More likely than society being completely free of work and machines automatically producing everything, the time applied to manufacturing may rather be spent on philosophical and theoretical questions, likely then solved and implemented by robots.

By looking at a recent example of job loss, the idea of a universal basic robot could be seen as beneficial for both parties. A key business decision from a corporate standpoint is the return on investment over a specified time frame. By replacing massive numbers of workers with robots, the investment into the robots must pay-off. There is also little that can be done from the employee side without legal regulations put in place. Unlike the papers thirty years ago [2, 4, 5, 17] the situation with robots replacing jobs is current, and not speculation into the future. Within the last few years, the large microelectronics manufacturer Foxconn has been able to replace 60,000 factory workers with robots [23]. In that same report, McDonalds former chief executive was quoated in regards to an increase of minimum wage to 15$/h by saying,

> It's cheaper to buy a $35,000 robotic arm than it is to hire an employee who is inefficient, making $15 an hour bagging French fries. [23]

While this quote comes from a former executive and holds no bearing on the actual actions of the corporation, it clearly defines the problem statement from the corporate side.

From the corporate perspective, a large financial investment in robotics to create a sustained productive workforce was followed by a reduction in financial costs of human labor. At the initial technology integration, the company must keep humans to supervise many of the robotic functions, but cannot justify the same cost of the humans time. On the employee side, the company has invested in a technology to replace their job. With a universal basic robot, the company does not need to invest in a new workforce, but rather the human employees implement their own robot, achieving the same productive workforce. Furthermore, when technology improves and sufficient economic growth is achieved, the employees robots can be upgraded in a similar manner to inflation. These new robots can replace the ones implemented previously, making the upgrade process for the companies such as Foxconn, Ford, or McDonalds, an investment free situation.

4.2 Sustaining the Model

While in the simple thought experiment, we may suggest that every person gets an individual humanoid robot, this would be hard to maintain over time. The robots themselves would require periodic maintenance and updates to their software. Robot owners might not be capable of managing their new technological resource to maximum benefit for themselves.

To deal with these issues, it may make sense to follow a mutual fund model where the robotic assets are jointly held and managed for the benefit of passive holders. Experts could maintain the robots and could maximize their market value for those who just want an economic return. For others who want to engage their robots for direct work, new creative work, or for personal/home-work it should be possible to withdraw ones robot for personal use, with an ongoing warranty for maintenance.

In this version, people would be able to either gain a steady income while giving up day-to-day control of their robots, which would mimic the performance of Universal Basic Income. Or people could withdraw their robots and use them creatively to enhance their work or to work on their behalf. People could create new work through entrepreneurial endeavors supported by their Universal Basic Robots.

While the implementation of a universal basic robot and its effects are not easy nor clear, neither is a full scale rollout of universal basic income. By the time humanoid robots have developed into a machine that can truly replicate the physical abilities of a person at a cost that matches that of a workers salary, the issues hindering a larger rollout regarding cost and maintenance will be far better defined.

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Paperless Grammars

Athanassios Economou and Thomas Grasl

Abstract A workshop in formal composition using machine-based specifications of parametric shape rules is presented. The workshop is structured along two different trajectories: one starting from existing grammars and one starting from scratch, and both in a rising complexity in the specification of the rules and the ways they affect design. Rules, productions and designs in corresponding languages illustrate the findings. A speculation on a new design workflow whereas the designers seamlessly design and test their rules within their design processes is briefly discussed in the end.

Keywords Shape grammars · Shape computation · Computer implementation
Formal composition · Rule-based design · Symmetry

1 Introduction

Designing grammars is not different from designing any other artefact. The formidable shape grammar computations published at the early 70s and 80s showcased an intellectual edifice that was meant to be appreciated and used as a complete, flawless project—in point of fact, a visual machine that could exemplify logical rigor and stylistic consistency. The manual execution of the sleek and carefully crafted rules of the ice-ray grammars [1], the Palladian grammar [2], the Mughal garden grammar [3], the Japanese tearoom grammar [4], the Hepplewhite chairs grammar [5], the Terragni façade grammar [6], and so many more, whether in paper and pencil, or painstakingly in the 90s and 00s simulated in AutoCAD or a similar software always provided a clear window of the precision, clarity and insight that each grammar respectively brought in the constructive understanding of the class of artefacts that the grammars modelled.

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Still, there has always been a great part of the design process that the grammars themselves always left polemically out of the question, namely, the design process of the design of the grammar itself. This is not the same with the ability of a grammar to capture the design process that characterizes the design of a class of artefacts; a good example would be the relation of the ice-ray grammar and the ice-ray lattice Chinese windows [1]. Clearly, the grammar captures the design processes that most probably have been followed by the medieval Chinese artisans. Here instead, the question shifts in the design of the rules themselves: Is it important to know how the author (the shape grammarist, not the Chinese artisan) came up with these rules and not some others? Did she try some other approach that did not work? Are there better ways to deal with specific kind of problems than others? Are these rules applicable only to the specific problem they address in that particular grammar or can they be applicable to other sort of problems in other domains? And such questions do not remain on the analysis of the thought processes of the author side and role; even more questions arise when the questions shift to the user role and the student at large who studies these rules to generatively understand the language at hand. If a computation fails, it is clear who is to blame? Did the user of the grammar followed rightly all the rules when she attempted to make a production of her own? Did he erase the labels properly? Did he apply the rules in all possible parts before he would move one to the next stage? If a mistake happens, is it in the designer's side? Is it in the publisher's side? Is it on the reader's side? And so on. A most satisfying effort, and a great lesson to learn for everyone involved, but error prone too.

And yet, all such reservations are immaterial; the most important point in this process of seeing, understanding and doing design is that one never learns a rule by looking at a page but by actively drawing the rule and seeing with her own eyes the possibilities that this rule opens up, both in the parts of the design that the rule can apply to and in the effects that this rule infers on the design once it is applied.

The machine-based specification of shape rules and parametric shape rules in rule schemata has been the subject of a growing field in computational design and computer-aided design discourse [7–16]. Among these shape grammar interpreters, the parametric shape grammar interpreter GRAPE [16] has emerged as a robust computational framework that allows the itinerant decomposition of existing designs in various non-anticipated ways and the visual specification of labelled shape rules and labelled parametric shape rules. The technical specifications of the application and its ongoing development is given in [16–18]. The ways that these types of rules could begin to work in design practice and research is the subject of this work.

The setting for the testing of the GRAPE parametric shape grammar modeller involved a successive series of workshops in an academic setting having students trying out rules, known and new ones, and exploring on their own the expressiveness of the rules and the software itself. The workshops were structured along two different trajectories: one starting from existing grammars and one starting from scratch, and both in a rising complexity in the specification of the rules and the ways they affect design. The key idea in the first series of studies was the implementation of known rules in the literature—and there are many to admire—to produce the designs that have manually been produced in the original papers, additional ones that are in principle possible by the original grammars, and new ones by purposefully playing with the rules, i.e. the transformations under which the rules apply, the assignment of the values of the parametric shape, the shapes themselves in the schemata rules, and so on. The key idea in the second series of studies was the implementation of new rules designed from scratch to produce the designs that were selected to provide the corpus for the grammar, additional ones that are in principle possible by the grammars, and new ones by purposefully playing with the rules. Both types of studies relied extensively in a critical comparison between shape rules and rule schemata in terms of their expressive and productive features in design inquiry [19]. A brief description of both experiments follows below along with some examples from each case.

2 From Rules to Rules

The first series of studies foregrounds a hands-on constructive understanding of existing grammars in the literature. The students are encouraged to copy rules from the literature, see on their own how the rules were supposed to apply in the original design setting and what they can make, and once they get a command of their expressiveness and generative power, start editing them in a variety of ways to make them their own. The range of techniques used to edit the rules is open-ended; once the copy and implementation of the rule has been considered successful, the students are encouraged to alter the rules in some way to accommodate design ideas and insights that might have emerged through the computations with the existing rules. A sample of three studies is given below to showcase some of the findings of the workshop in GRAPE. Each grammar is briefly discussed in terms of some of its key rules, one or more productions and a list of designs automatically produced in GRAPE. The authors of the grammars are specified in parentheses within the brief account of each project.

2.1 Pinnacle Grammar

The nested square rule [20] is one of the most popular rules in the shape grammar discourse because it shows a nice example of visual recursion and an effortless visual transition from squares to triangles, pentagons, hexagons and all sorts of other more exotic shapes [20, 21]. The workshop builds up on the initial rule in Fig. 1 cast in the rule schema $x \rightarrow x + t(x)$, for t a similarity transformation consisting of a product of a rotation and a scale transformation, to a series of identity rules cast in the rule schema $x \rightarrow x$ to facilitate the understanding of the seamless shifting between different decompositions in the design, and ends with the design of a new series of rules cast in the rule schemata $x \rightarrow x + y$ and $x \rightarrow y$ whereas the spatial relation between the two squares is considered now as a starting point for the design of a new

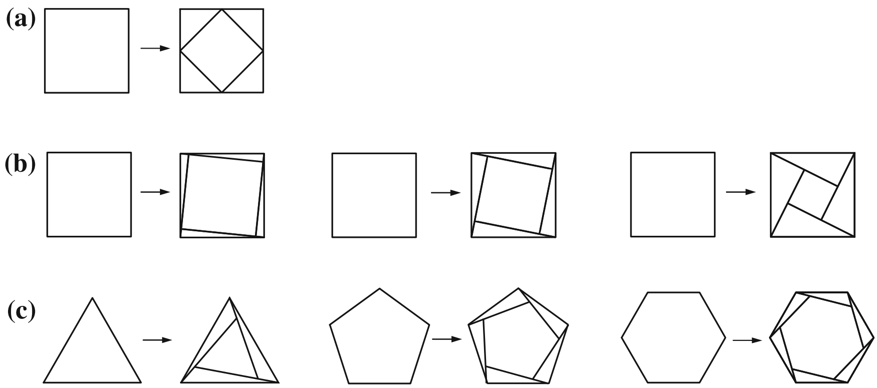

Fig. 1 The pinnacle grammar (Hong Tzu-Chieh) **a** Original nested square rule; **b** Substitution of the inside smaller square by a series of whirling squares with rotational handles; **c** Extension of the parametric rule to the class of regular polygons

design idea. The pinnacle grammar takes on the lessons found in the recursive point symmetry of the initial shape rule in Fig. 1 and extends them to explore natural growth exhibiting 3-fold, 4-fold, 5-fold, 6-fold point symmetry, and so forth. The grammar is not meant to be exhaustive for the generative description of the form of specific class of biological formations but instead it uses these initial symmetrical configurations as a departure point for the exploration of designs that all have a point symmetry in a nested configuration one within the other. The rules of the grammar are extremely simple and their visual interest lies in their itinerant recursive applications, a front that computers—and GRAPE, excel. Some of the rules of the pinnacle grammar are shown in Fig. 1; clearly many more are possible and a more definitive treatment still remains to be undertaken.

The itinerant applications of the rules of the pinnacle grammar in different versions and settings is rewarding. A series of productions and final designs in the language is shown in Fig. 2 for the regular triangle, square, pentagon and hexagon. Note that all the designs shown are produced by versions of the rules that erase the circumscribing square every time they apply. The elimination of the bounding exterior polygons foregrounds the emergent spatial relations in the centre of the shape and the spiral growth of the pattern.

Significantly all the derivations in Fig. 2 are produced by a singular shape rule applying in an identical manner every time. A much greater variety can be achieved by applying the same parametric shape rule under different assignments and the applications of these rules can be orchestrated and altered in significant ways. For example, the rules in Fig. 1b show three different instantiations of the same parametric shape rule for different sizes of inserted squares and different degrees of rotation within the original circumscribing one. The different sizes and rotations produce distinct series of spiral growth and even more their rhythmical interchange within each size and among all sizes produce interesting visual counterpoints not entirely anticipated till the moment the rules are executed by the machine. A series of designs

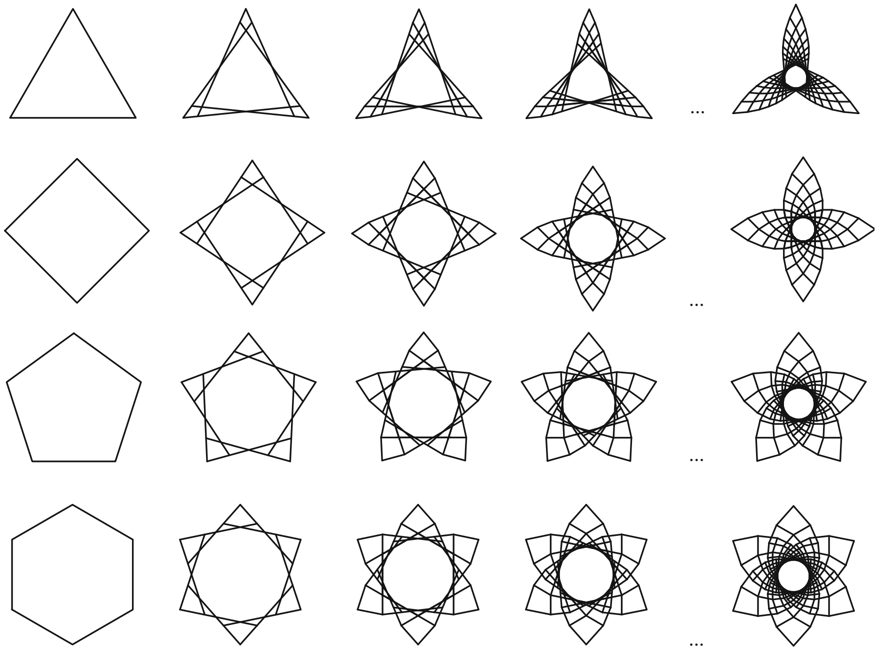

Fig. 2 The pinnacle grammar (Hong Tzu-Chieh). Four productions showcasing different parametric shapes inserted as predicates in the same flower schema rule

in the language of the pinnacle grammar featuring four-fold symmetry is shown in Fig. 3.

2.2 Checkerboard Lattice Grammar

The checkerboard lattice designs, a specific subset of the Chinese lattice designs that fill window frames [1] provide a great initial framework to discuss key ideas in formal composition including repetition, recursion, modularity, grid, frame, boundary, proportion, symmetry, and many more. The additional constraint of a labelled grid that gets filled by different modules whose combinations make produce predictable or unpredictable results provides a rewarding visual context for taking on in a constructive way the ideas of formal analysis and synthesis and the specification of a whole series of diverse designs that all share a common framework. The two schemata typically used for the casting of the labelled shaped rules are the schema $x \rightarrow x + t(x)$ for the generation of the underlying rectangular lattice, and the schema $x \rightarrow y$ for the generation of the different substitute motifs upon the square or the rectangular module. Figure 4 shows three of the shape rules of the ice-ray lattice grammar redrawn in GRAPE. Figure 4a shows two of the shape rules of the original grammar that define the underlying structure of the design: the first adds a second labelled

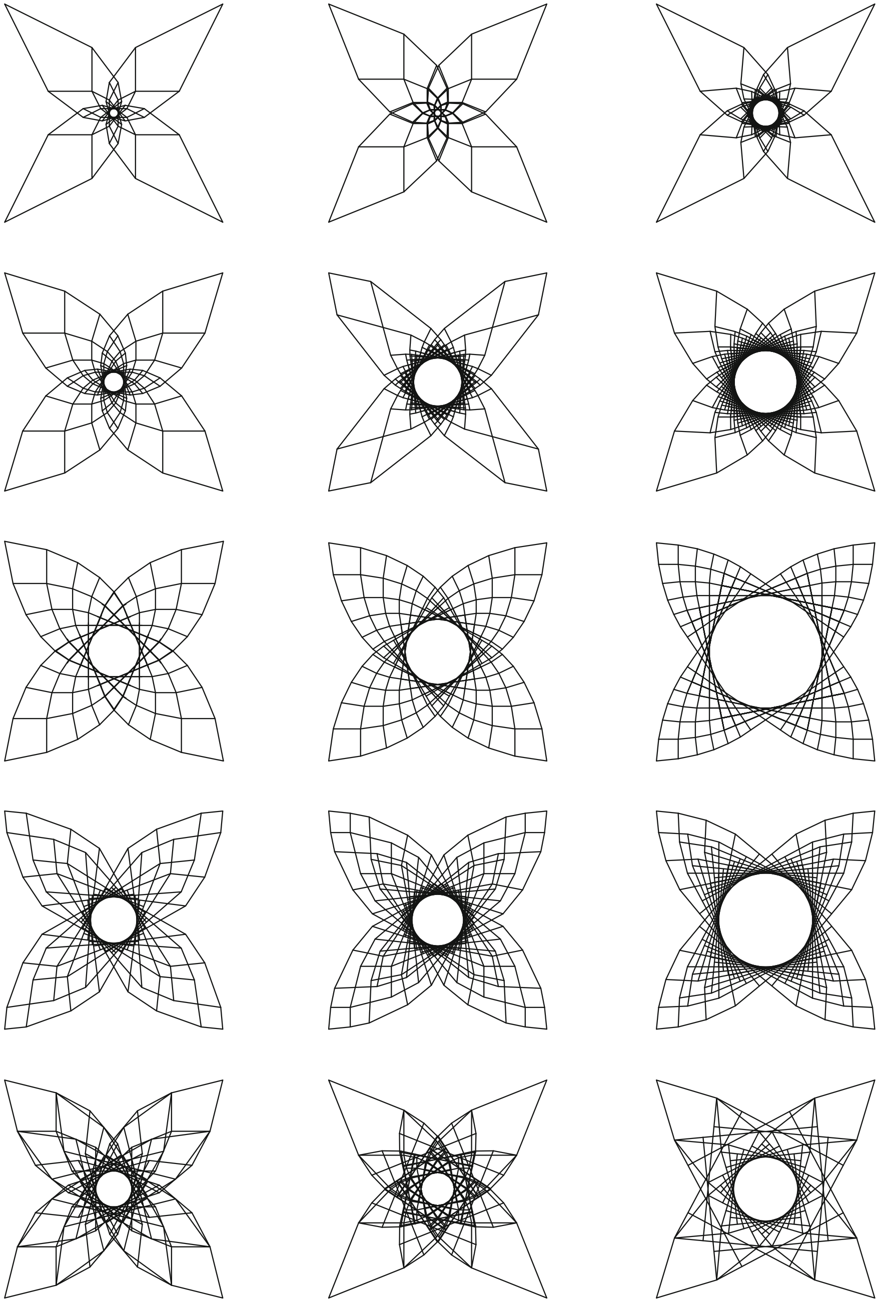

Fig. 3 The pinnacle grammar (Hong Tzu-Chieh). Some designs in the language of the pinnacle grammar featuring four-fold symmetry

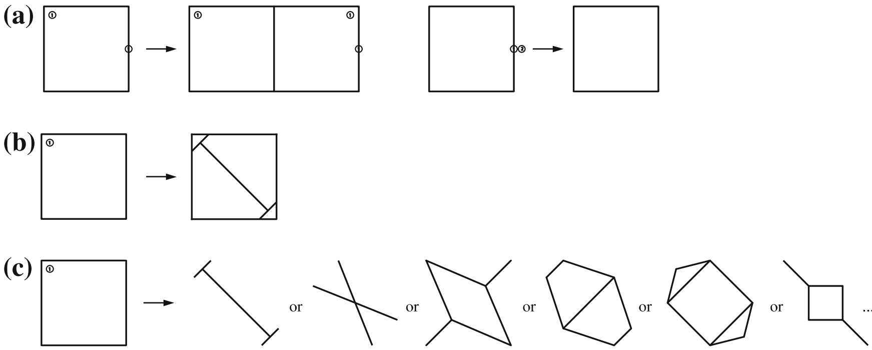

Fig. 4 The checkerboard lattice grammar (Stephanie Douthitt): **a** Shape rules 1 and 5 in [1]; **b** Termination rule (Rule 6 in [1]); **c** Some possible new termination rules. The RHS of the shape rules are given in a single array for brevity

square to an initial square and removes the label from the right edge of the square of the left-hand side (LHS) to the right edge of the second square at the right-hand side (RHS) (Rule 1 in the original grammar); and the second removes both labels from the square of the LHS of the rule (Rule 5 in the original grammar). Figure 4b shows the terminal rule that substitutes the labelled square in the LHS of the rule with the square with the diagonal pattern in the RHS of the rule (Rule 6 of the original grammar). Clearly, the differences of the checkerboard lattice grammar here with the original are few and immaterial: the line shapes of the original grammar have been substituted by squares; the circular black labels have been substituted by white labels with the symbol 1 and the triangular black labels by white labels with the symbol 2; and the label deletion rule has been substituted by the erasure labelled shape rule. In other words, what is emphatically insisted in this detailed account is to show that the visual specification of the labelled shape rules in the original publication, can be copied and drawn in a straightforward way in the GRAPE environment.

Figure 5 provides a complete derivation of the lattice described in the original ice-ray grammar. The derivation here is based on a version of a grammar that does not use the initial shape of the frame but uses instead the rules 3 and 4 of the original grammar to achieve the boustrophedon deployment of the grammar, that is, the bidirectional production unfolded from left-to-right and left-to-right in alternate lines. The application of the termination rule in the complete lattice takes place in one square at a time in a random manner. Still, what is more interesting is the different treatment of the sixth rule in the grammar: The series of designs in Fig. 6 showcase nicely the substitution of this rule with the shape rules in Fig. 4c that create very diverse designs. In this series, the shape in the RHS of the rule was drawn and tested on the fly in GRAPE to test the design, see how the symmetries of the RHS partake of the overall symmetry of the lattice, and explore different versions of the rules in different schemata too, for example, eliminate the frame of the square module to foreground and enable other relations in the overall design including quadrilaterals, pentagons, hexagons, octagons and so forth.

2.3 Mughal Gardens Grammar

The Mughal gardens grammar is one of the earliest labelled parametric shape grammars in print [3] and one of the most didactic showcasing in an exemplary way the layering of formal analysis in shape grammar discourse starting from a concept, here the idea of the paradise, to the history of its design, its geometry, and finally the postulation of a formal grammar that can capture its salient features. The implementation of the Mughal garden is by no means a simple feat as it requires the implementation of several rules and relies extensively on parametric definitions of rules in GRAPE. The most challenging aspect of this implementation has been the implementation of the rules 19, 20 and 21 in the original grammar that are offered there as three samples of treating the corner of the inner squares of the garden to allow for inflections in three distinct ways. The resolution of these conditions has repercussions for the rest of the rules in the grammar. A sample of the parametric shape rules drawn explicitly in GRAPE to account for the instantiation of these conditions are shown in Fig. 7.

Most rules in the grammar are cast in the schema rule $\sum t(x) \rightarrow \sum t(x+y)$ whereas $t(x)$ is one of the transformations of the symmetry group of the square, the underlying framework of the garden and $\sum t(x)$ the complete symmetry group of the square. In this sense, a rule that may apply, say, in the upper left quadrant of the design has to apply to other corresponding parts of the design and depending on the exact location of the part, the rule may apply in seven more locations (for a total of 8) or three more (for a total of 4), or one more (for a total of 2) if the rule has already some symmetry built in that aligns with the overall symmetry of the part. A sample of a complete production in the grammar is given in Fig. 8.

The implementation of the complex grammar in GRAPE required some restructuring work in the underlying engine so that the software would be able to execute all the possible matchings of a rule in a design and expedite the design derivation. Figure 9 show instances of nine Mughal gardens in the language that represent instances of the nine configurational unique possibilities produced by the grammar. Clearly, architectural elements such as the ornamentation of the reservoir of water at the centre of the canals in a square or an octagonal form, the ornamentation of the endings of the water canals, and the parameterization of the dimensions of the borders and the canals, can provide a rich palette for an expressive language with unique characteristics. Still, while this first implementation resulted in a series of designs that indeed captured the initial grammar, there were indeed great difficulties with the implementation and the running time of execution of each rule, and certainly the project remains to be redone in a way that can conclusively demonstrate the visual subtlety of the original parametric shape grammar.

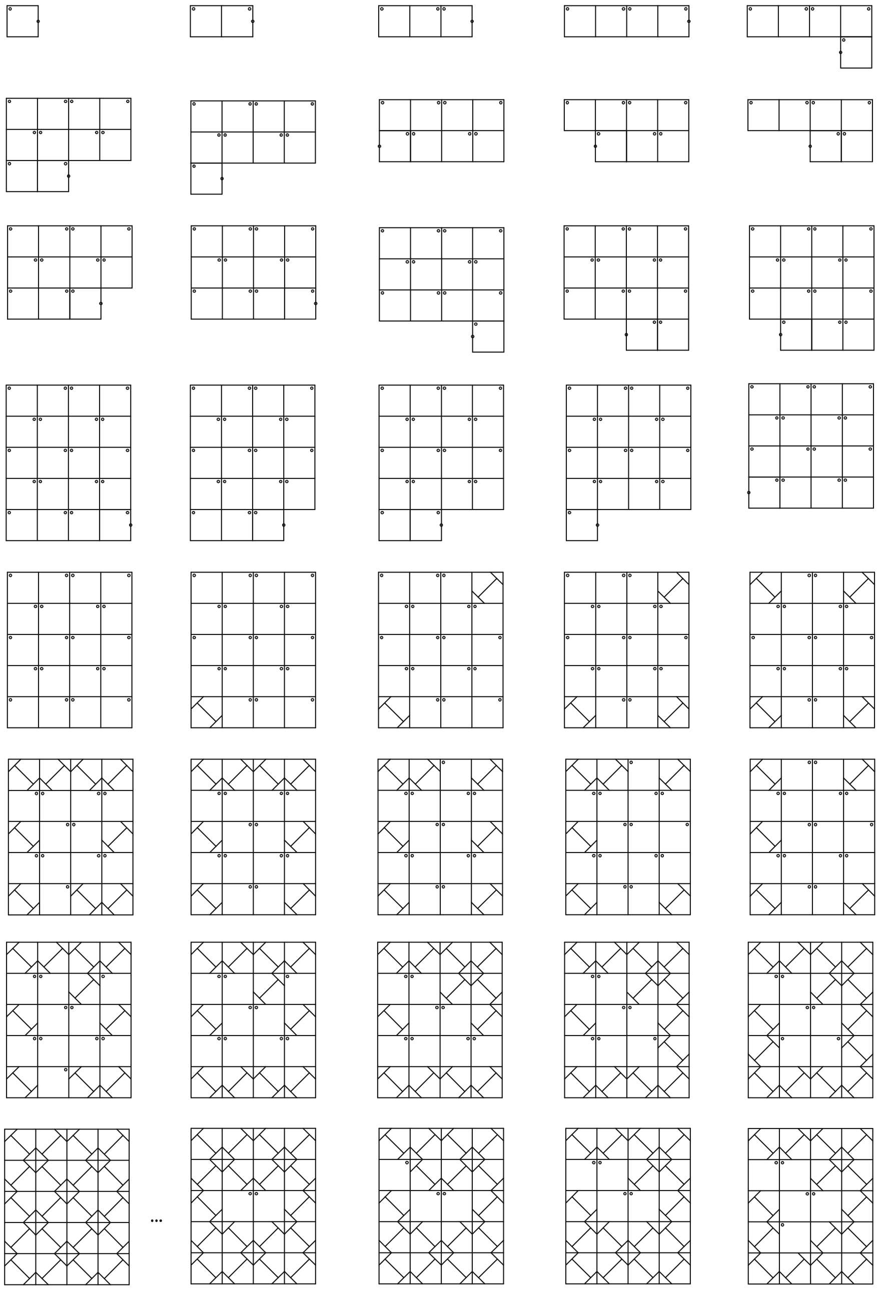

Fig. 5 An automated derivation of the original ice-ray checkerboard lattice grammar (Stephanie Douthitt). The productions are laid out automatically in a boustrophedon manner

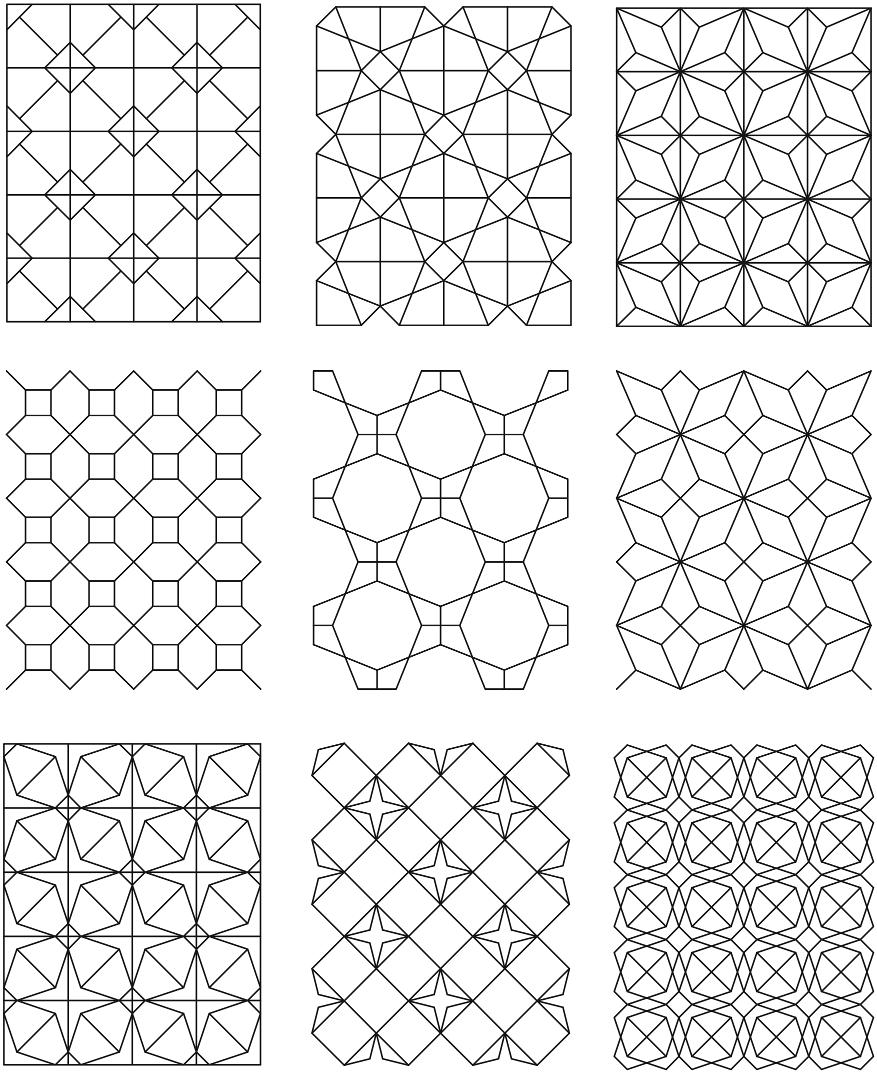

Fig. 6 Some designs of the checkerboard lattice grammar (Stephanie Douthitt)

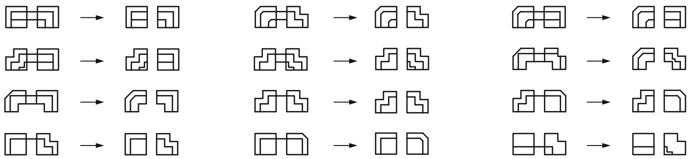

Fig. 7 Some of the parametric rules of the Mughal garden grammar (Nirvik Saha).

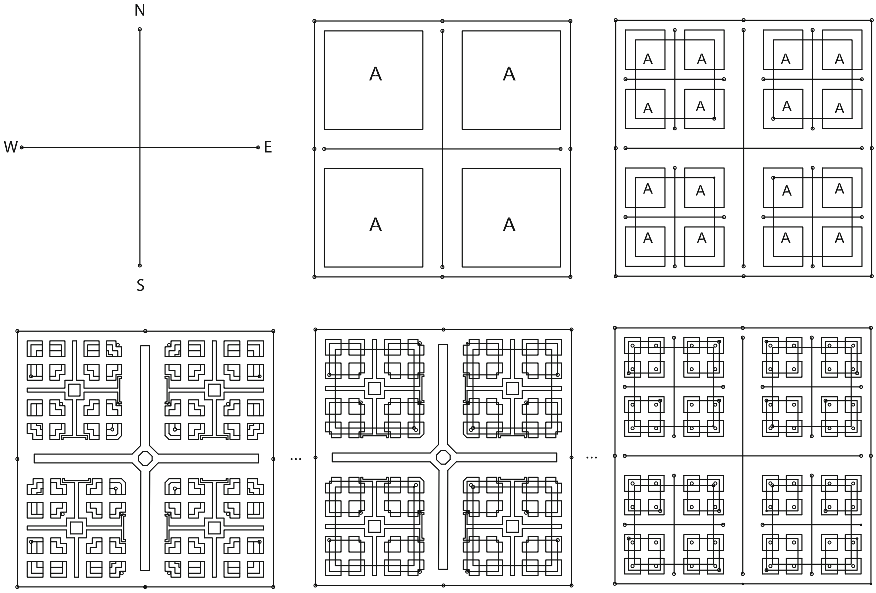

Fig. 8 The Mughal garden implemented in GRAPE: An automated production depicted in a boustrophedon manner (Nirvik Saha)

3 From Designs to Rules

The second series of studies foregrounds a hands-on constructive inquiry on new grammars in the literature. The students are encouraged to come up with a list of existing artefacts or buildings they want to explore, or alternatively, a brief for the design of some new artefact or building. In either case, the rules for the generative description of the existing designs or the new ones, do not exist and the students have to think them through, design and test them in GRAPE. The goal in this exercise is not the complete formal specification of a set of artefacts or buildings, existing or new; rather, it is the testing of how existing artefacts or briefs can be used constructively in the design of new rules. Again, the range of techniques used to design rules is open-ended; once the design of a rule has been deemed successful, the students are encouraged to take advantage of the rule in some way to accommodate additional design requirements and constraints that might have been observed in the corpus or given explicitly in the design brief. A sample of three studies is given below to showcase some of the findings of the workshop in GRAPE. Each grammar is briefly discussed in terms of some key rules, one or more productions, and a list of designs produced in GRAPE. The authors of the grammars are specified in parentheses within the brief account of each project.

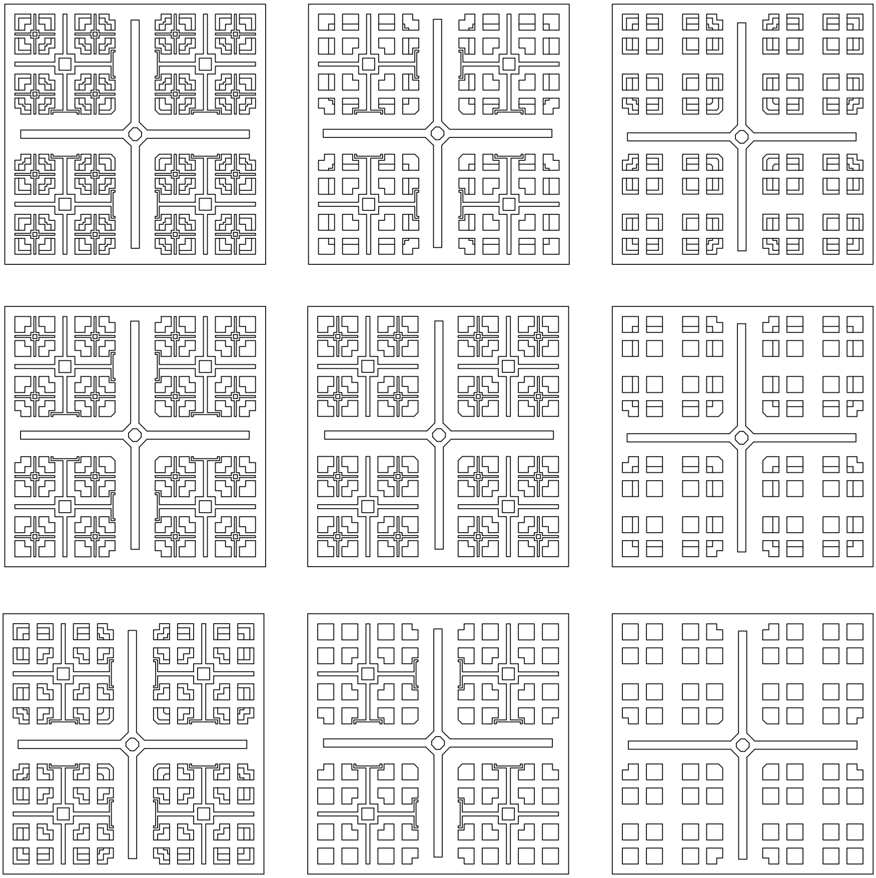

Fig. 9 The Mughal garden implemented in GRAPE: The nine basic configurations of borders and canals in the Mughal garden language (Nirvik Saha)

3.1 Ad Quadrant Grammar

The ad quadrant grammar takes on the ad quadrant division schema, a basic compositional schema used in the design of artefacts, buildings and town plans across many cultures and times as diverse as Hellenistic and Roman ones to twentieth century and contemporary one. The ad quadrant grammar is based on March's Speculation 8 [22] and its range of nucleated and linear distributions from 10% to 90% coverage within an abstract square configuration. Clearly any subdivision of a square by $n \times n$ squares creates a simple division based on the square number sequence and any combination of such divisions nicely illustrates the ideas of recursion and emergence too, the two

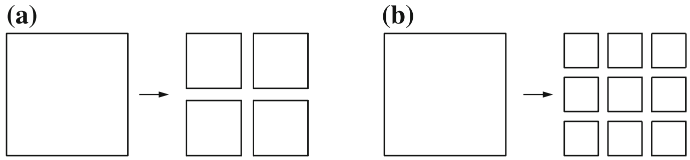

Fig. 10 Two rules in the ad quadrant grammar (Abigail Smith): **a** Division to 4 squares; **b** Division to 9 squares

paramount characteristics of shape grammars, and the ability of GRAPE in capturing both in the application of the division algorithms upon the nested smaller copies of the square. Two rules of the grammar are given in Fig. 10 for a division of a square to four and nine squares respectively.

The simplicity of these two rules hide the delightful complexity they can generate once they apply recursively and at different scales within the design production. The straightforward application of each rule creates the familiar series of configurations 1, 4, 16, 64, 256, …, and 1, 9, 81, 729, 6561, …, respectively. A production in the grammar is given in Fig. 11. The first rule that instantiates a square is encoded in the software but omitted here for brevity. The production here applies for the total matches of the LHS rule in the design simulating a fractal derivation: Because the symmetries of the LHS and the RHS are the same and embedded one-to-one the rule applications match the number of discrete squares present at each stage. The production is generated in a boustrophedon manner as an output at the end of the derivation and the double arrows between each step are omitted.

More interestingly, the combinations of the rules a and b in the Fig. 10 in various sequences, say, ababab…, bababa…, aabbaa…, bbaabb…, aaabbb…, bbbaaa…, and so forth, and in other non-regular series too, immediately shows the inexhaustible possibilities that emerge out of the different sequence of rule applications and the corresponding designs all with their own visual characteristics. And clearly, the incorporation of specific ratios between the diminishing squares produces interesting densities and frit effects in the overall configuration. More importantly, the definition of the rules in the schema $x \rightarrow x + t(x)$ rather than the $x \rightarrow t(x)$ retain the original circumscribing square from the LHS to the RHS of the rule and produce a whole new range of designs that show interesting and complex patterns of emergent spatial relations between squares at various scales. A sample of designs in the language of the ad quadrant grammar is shown in Fig. 12. Additional designs utilizing square numbers for prime numbers using any of the techniques outlined above are readily available too.

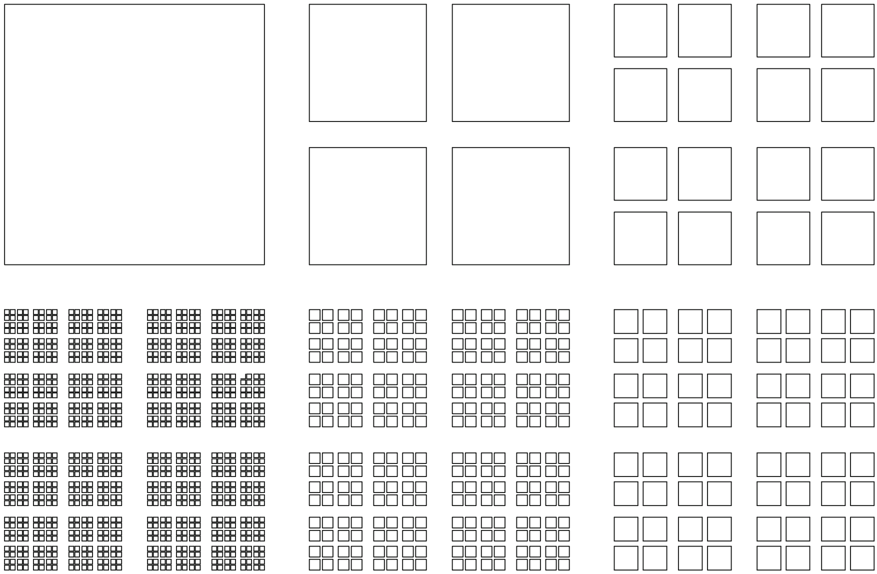

Fig. 11 A production in the ad quadrant grammar (Abigail Smith)

3.2 MCE Grammar

The MCE grammar takes its inspiration from M. C. Escher's recursive tilings [23]. The grammar is not meant to be exhaustive for some given corpus of the Dutch graphic artist but playfully uses his idea of substitution regular shapes or the division of the plane with some spatial idea or motif that typically recalls a biomorphic association. The complete grammar consisting of 6 rules is given in Fig. 13.

The first rule in Fig. 13a captures the initialization of the grammar and the instantiation of the initial shape. The core of the grammar is the rule in Fig. 13b that showcases the replacement of an isosceles Root2 (R2) triangle with three copies of itself, an identity R2 triangle and two smaller R2 triangles whose sum measures exactly the original one to produce a square. Interestingly, the smaller triangles within the original R2 triangle function as labels to guide the computation. The rule in Fig. 13f produces the visual stylistic effect of the Escher language by substituting the original R2 triangle with a complex shape featuring a half-turn line along the hypotenuse of the R2 triangle and a meandering right-angle line in the right angle of the R2 triangle. Clearly other shapes are possible and several were explored interactively in GRAPE before the designer committed to this final substitution. A production in the grammar is given in Fig. 14. The production is generated in a boustrophedon manner directly in the software and the double arrows between each step are omitted.

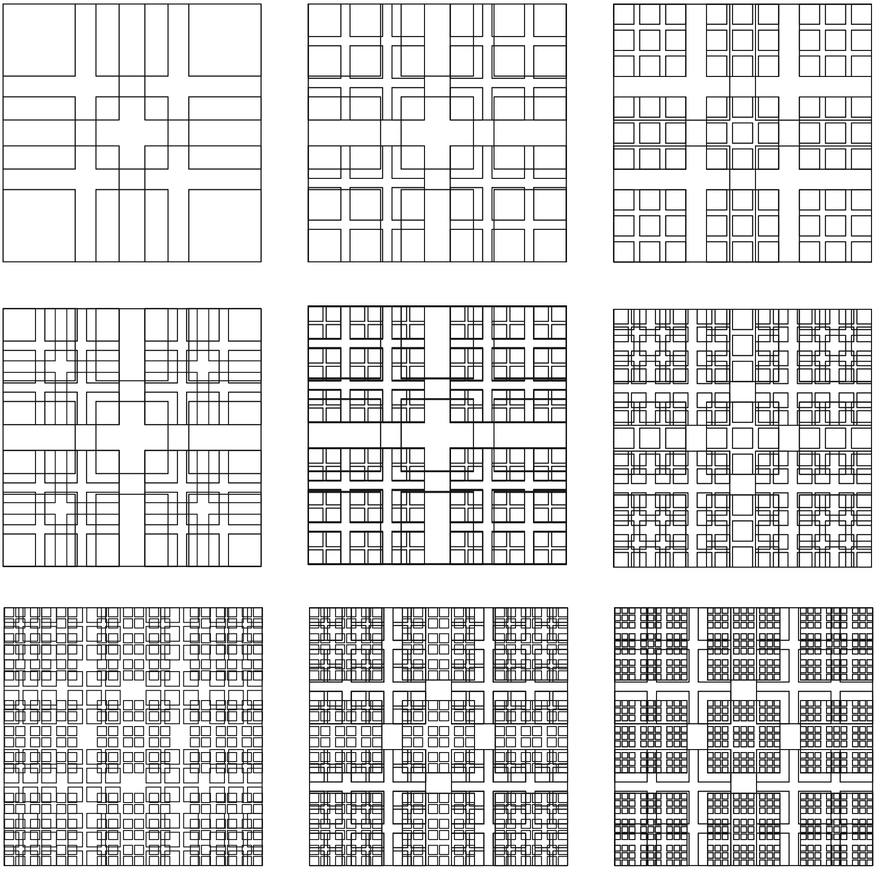

Fig. 12 Some designs in the ad quadrant language (Abigail Smith). All designs use the rules in Fig. 10 defined in the schema rule $x \rightarrow x + \sum t(x)$

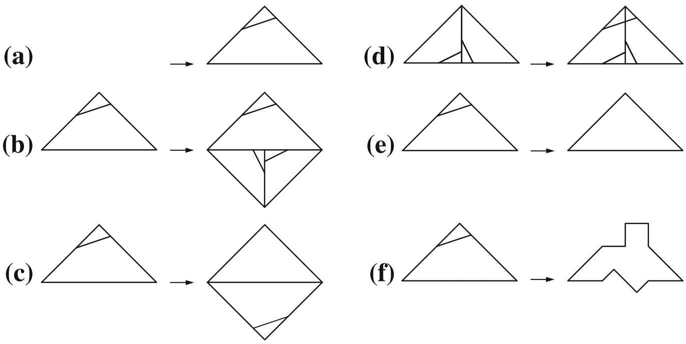

Fig. 13 The six rules of the MCE grammar (Kelsey Kurzeja)

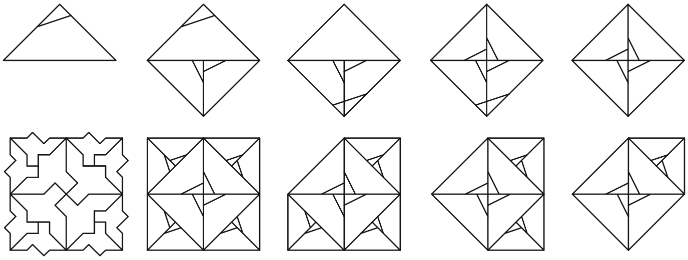

Fig. 14 A production in the grammar MCE grammar (Kelsey Kurzeja)

The derivation of the design in Fig. 14 shows nicely the reasons of the design of the other rules in the grammar and their role in guiding the generation of the design by reflecting or erasing the smaller triangles that function as labels in diverse ways. A catalogue of some possible designs in the language is given in Fig. 15. These designs showcase alternative ways of using the grammar either by applying shape rules manually to specific parts in the design, or by applying a shape rule simultaneously to all possible matches within the design.

3.3 The Dirksen Grammar

The Dirksen grammar provides a generative specification of Mies Van Der Rohe's Everett McKinley Dirksen United States Courthouse in Chicago, US [24]. The grammar postulates its basic rules from a set of 135 sketches produced by the office of Mies during the design process of the courthouse and documented in the Mies van der Rohe Archive at the Museum of Modern Art. Significantly, the rules are thought, represented and implemented in GRAPE all in a truly three-dimensional form. The project is quite ambitious in the sense that it attempts to take on several fronts in the formal analysis of the work, and more specifically, cast light in the design process of Mies' office, articulate the compositional aspects of this project that embodied the architect's mature view on architecture and law, showcase the ways that Mies' architectural language is deployed for this building type, and foreground the sectional principles in the arrangement of the program. A sample of the three-dimensional parametric labelled shape rules of the grammar is shown in Fig. 16. The complete grammar consists of 68 parametric rules and is currently under preparation for a formal publication.

The Dirksen grammar is so far the most ambitious project in GRAPE taking on the complexities of writing new rules from scratch to specify a given corpus, parameterizing them fully to be able to capture specific proportional ideas, model everything in three-dimensions in a uniform way and implement all directly in a computer-aided design system. Clearly these ambitions do not come without challenges. All rules here are implemented in the GRAPE for Rhino version and are encoded directly

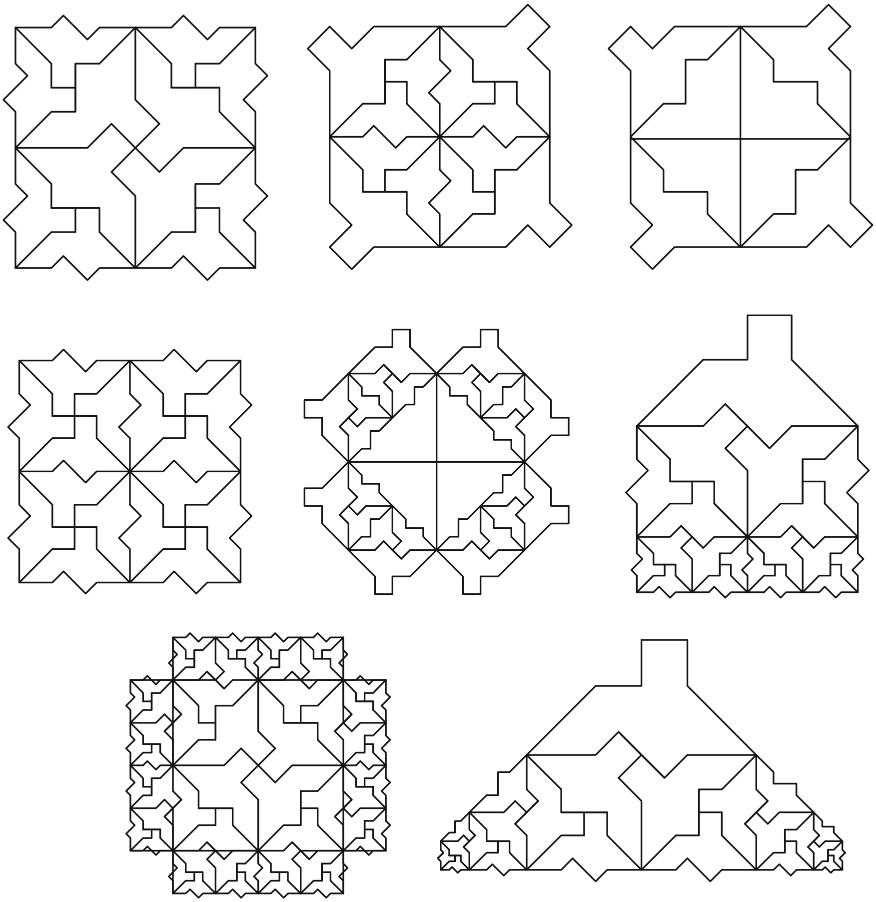

Fig. 15 Some designs in the MCE language (Kelsey Kurzeja)

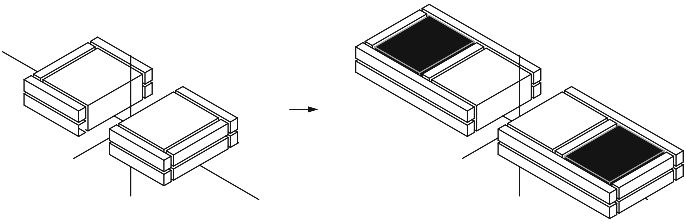

Fig. 16 The Dirksen grammar (James Park). A parametric 3D labelled shape rule that specifies the addition of two courtrooms (in black) in a bilaterally symmetrical manner around the dual service core of the floor plate (Rule 17 in original grammar)

in the scripting environment, an interface quite distinct from the visual one in the web version of the software. Still the current state of the work is very promising in that it manages to produce models that can be exported and used in a variety of other applications for reviewing, rendering, slicing, printing and so forth. Interestingly enough, the majority of the rules in the grammar follow the schema rule $x + R(x) \rightarrow (x + y) + R(x + y)$, for R a reflection, that is, a similar schema rule to the one used in Palladian grammar capturing Mies' rule for bilateral symmetry along the short axis of the courthouse. And interestingly enough too, the Dirksen grammar provides a three-dimensional analog for the Palladian one by modelling the empty spaces of the building and having the walls emerge as poché walls in a specific state of the production. Figure 17 shows a complete production in the grammar starting from the initialization of the grammar to the generation of the complete envelope.

A set of six three-dimensional courthouse models produced by the Dirksen grammar in GRAPE for Rhino are shown in Fig. 18. All models feature a core of 24 courtrooms in various configurations per floor. The model in Fig. 18a shows a 4 courtroom per floor plan in a 1-2-1 variation and 6 double floors. The model in Fig. 18b shows a 3 courtroom per floor plan in a 1-1-1 variation and 8 double floors. The model in Fig. 18c shows a 2 courtroom per floor plan in a 1-1 variation and 9 double floors. The models in Figure (d–f) show corresponding configurations of courtrooms per floor but in different spatial relations. Interestingly, the first three models (a–c) are models that are found in the archives of Mies' office. The last three models (d–f) are theoretically possible designs in Mies' language. All six models are derived by manual applications of the rules of the Dirksen grammar within the GRAPE for Rhino environment and are shown here in sectional axonometric projections manually prepared in Rhino for illustrative purposes.

4 Discussion

A key motivation underlying the work described is the speculation on a new design workflow whereas the designers seamlessly design and test their rules within their design processes. While shape grammars applications have been developed for over 40 years and especially over the last 10 years integrating early pioneering work on shape representation and computation and recent advances in emerging applied technologies including parametric design tools, generative design tools, procedural modelling tools, information modelling applications and rule-based design systems, still no parametric shape grammar interpreter has emerged to address comprehensively the range of issues that have emerged in the discourse over the years. It is precisely what this model is all about: to propose a single engine that takes on effectively the issue of maximal element representation of shape and to manage to technically encode it in a software application that allows the community to freely write, exchange, inspect, and use parametric shape rules in any conceivable way.

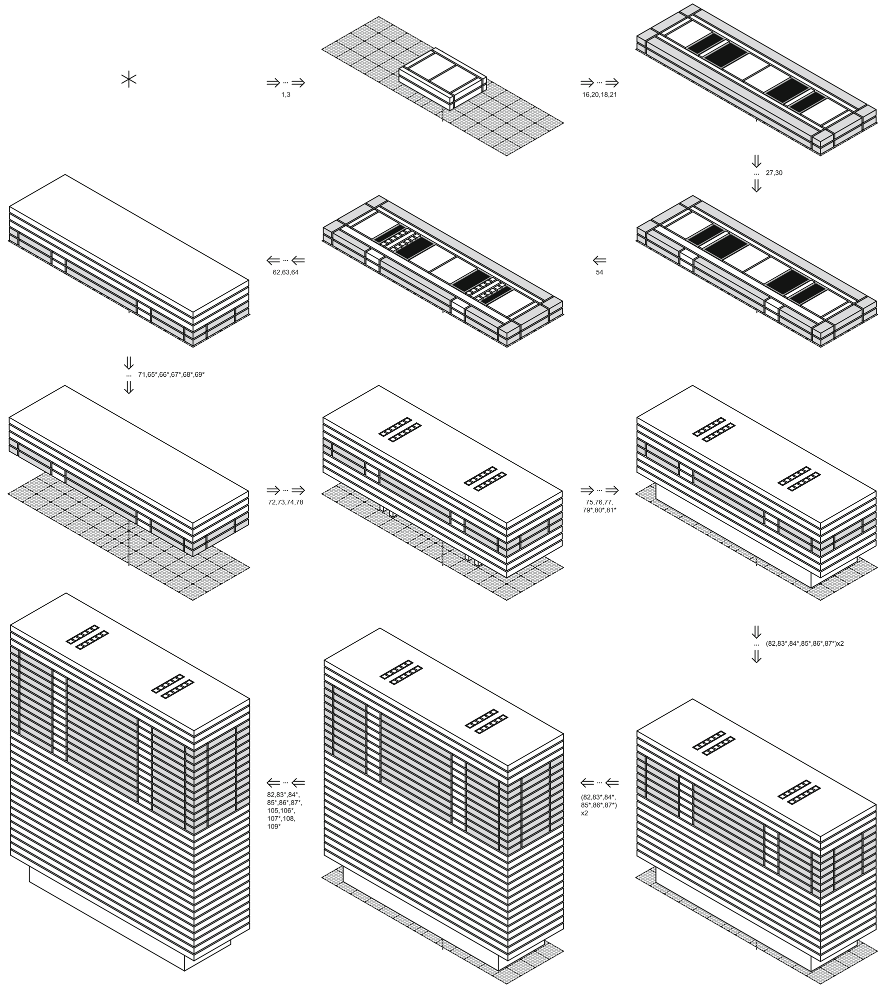

Fig. 17 The Dirksen grammar (James Park). A production in the grammar showcasing a complete derivation of three-dimensional model in Mies' courthouse language

(a) (b) (c)

(d) (e) (f)

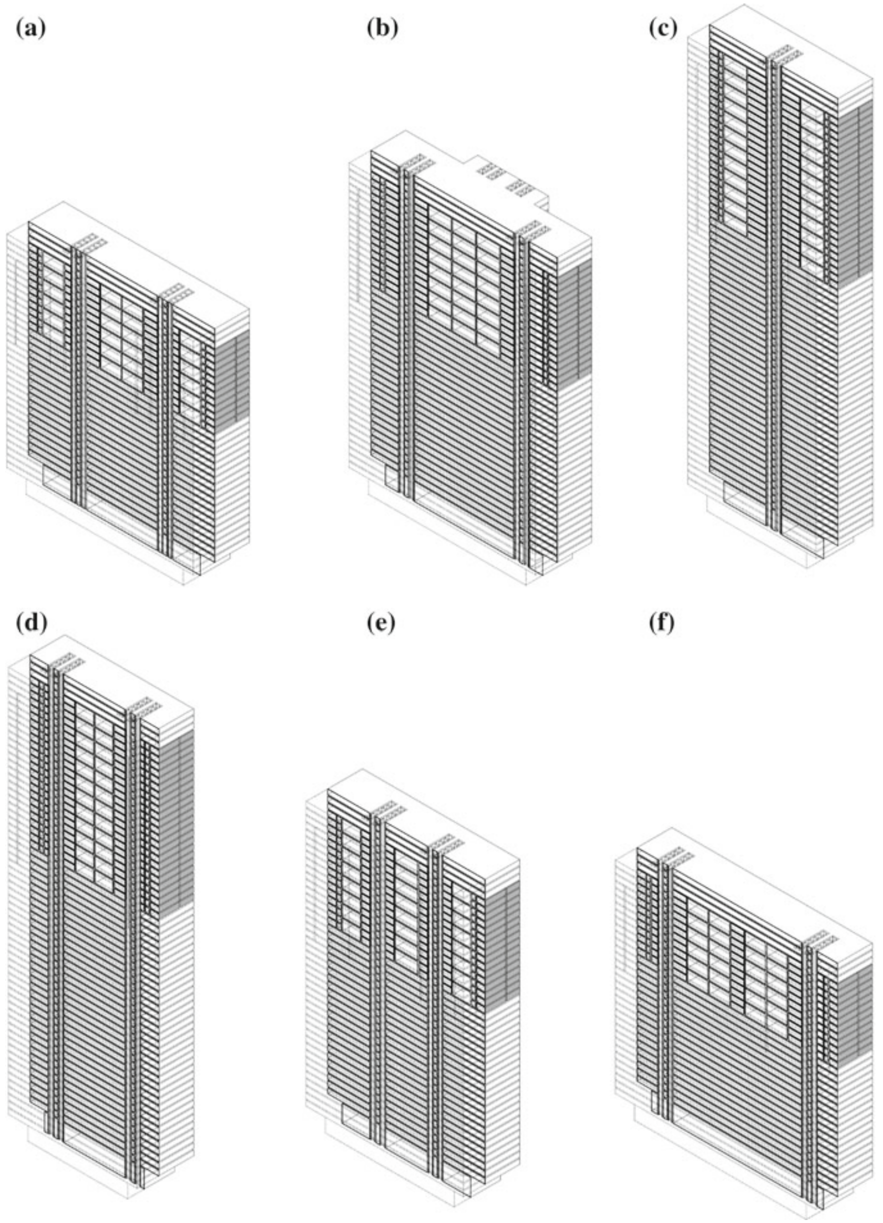

Fig. 18 A set of six sectional axonometric models of Miesian courthouse designs (James Park). All models feature a total of 24 courtrooms in various arrangements. Models (**a**–**c**) showcase designs that are found in the archives of the design process. Models (**d**–**f**) showcase possible hypothetical designs in the language

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A Practical Shape Grammar for Chinese Ice-Ray Lattice Designs

Rudi Stouffs

Abstract Different explications of Stiny's shape grammar for Chinese ice-ray lattice designs found in literature are explored and their 'practicality' is assessed in terms of the number of construction elements included in a representative shape rule and the number of potential matches that the matching algorithm must consider when applying this rule to a representative shape. Alternative explications are suggested that score well with respect to both measures. The exercise is meant to provide insights and requirements for the development of a general shape grammar interpreter, with flexibility and ease of use in mind.

Keywords Shape grammar · Parametric shape grammar · Shape schema grammar · Description grammar

1 Introduction

Shape grammars have extensively been used to capture the cultural DNA of designs, for example, expressing Chinese ice-ray lattice designs [1], the design of Mughal gardens [2], Queen Anne style houses [3], Taiwanese traditional vernacular dwellings [4], traditional Turkish houses [5], the architectural style of the Yingzao fashi [6], classical Ottoman mosques [7], Passura' carvings [8], etc. Most of these examples, however, have limited practical value for design. This is not simply due to the fact that they reflect on historical designs; in fact, considering the importance of cultural DNA, we may wish to integrate elements from historical designs, whether functional, configurational, relational, aesthetic, etc., into contemporary designs. Instead, they are analytical grammars that are thoroughly constrained to generate only both formally and semantically correct designs [9]. For practical design purposes, however, shape rules should be easy to understand, apply, create and modify.

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Ease of use, whether in rule application or the creation of new or modified shape rules, is ultimately dependent on both the intent of the user and the expertise of the user. Nevertheless, we can reasonably hypothesise about the ease of use of specific grammars or case studies, and reflect on the requirements for shape grammar implementations to support such ease of use. Specifically, we consider two measures for 'practical' shape grammars. The first one is the number of 'construction' elements (i.e., points, labels, etc.) in a rule, that is, those elements that serve to constrain rule application but are not part of the design as such. Though the term construction element may seem ambiguous, we must distinguish it from the number of non-terminal elements; even when line segments form part of the terminal vocabulary of shape grammars, they can still serve as construction lines/elements (e.g., Fig. 3, though the 'construction' line segments in this example are labelled and, thus, could potentially be distinguished as non-terminal elements). As such, the number of non-terminal elements included in a rule only forms a lower bound for the number of construction elements in that rule. Instead, construction elements can be defined as those elements that do not form part of any shape in the language produced by the shape grammar. Short of generating the entire language, the number of elements in a rule that are not part of any specific shape in the language forms an upper bound for the number of construction elements. Note that construction elements do not necessarily constitute a problem—we use construction lines in architectural drawings as well—as long as they are used sparingly and with a clear purpose.

The second measure is the number of potential matches the rule matching algorithm may have to consider. In the worst case, finding a triangle within a set of n line segments may require looking at $\binom{n}{3}$ combinations of three line segments. Obviously, both measures are somewhat mutually opposed, as construction elements are commonly used to constrain rule application and thereby the number of potential matches.

We consider the generation of Chinese ice-ray lattice designs as a case study, an example that is conceptually quite simple and, as such, draws quite a bit of attention. This case study constitutes a parametric shape grammar. A parametric shape is a shape with open terms [10], that is, certain points are specified in terms of equations or constraints. Though most analytical shape grammars are conceived as parametric, no general shape grammar interpreter supports parametric shape rules. Woodbury [11] presents the mechanisms of a shape schema grammar, a grammar specifying parametric shape rules that operate on parametric shapes. However, the algorithm is intractable, no shape grammar interpreter yet exists, and there is no indication as of yet of how designers would use shape schema grammars or rules. For all the power of parametric shape rules, many examples are limited to rectangles of varying proportions (e.g., Palladian grammar [12], Malagueira grammar [13]) and most apply only to non-parametric shapes.

In this paper, we explore different explications of Stiny's shape grammar for Chinese ice-ray lattice designs found in literature and assess their 'practicality' in terms of the number of construction elements and the number of potential matches as explained above. We suggest alternative explications that may achieve high marks with respect to both measures. Nevertheless, we acknowledge that these measures are not absolute and we stop short of actually quantifying these measures. Finally, we do not relate our analysis to any particular shape grammar interpreter. The exercise is meant to provide insights and requirements for the development of a general shape grammar interpreter, with flexibility and ease of use in mind.

2 Chinese Ice-Ray Lattice Grammar

Stiny's [1] grammar for Chinese ice-ray lattice designs is a classic parametric shape grammar, defining only four constructive rules (and one termination rule) that apply to either any triangle, any convex quadrilateral or any convex pentagon. Each rule allows for a convex polygon to form two new convex polygons by placing a single line between two of the original polygon's edges. Specifically, the rules state that any triangle, convex quadrilateral or convex pentagon, with area greater than some given constant, can be augmented by placing a line between two of its edges to form, respectively, a triangle and a convex quadrilateral, a triangle and a convex pentagon, two convex quadrilaterals, or a convex quadrilateral and a convex pentagon (Fig. 1).

The rules presented in Fig. 1 are visually pleasing but are obviously not practically applicable; while the number of construction elements is zero, the number of potential matches is in the order of n^3, where n is the number of segments in the current shape. Furthermore, nothing indicates that these are parametric shape rules, or that the inside of the polygon should be empty for the rule to apply. Instead, Stiny [1] does quite an excellent job to rewrite the rules as parametric shape rules.

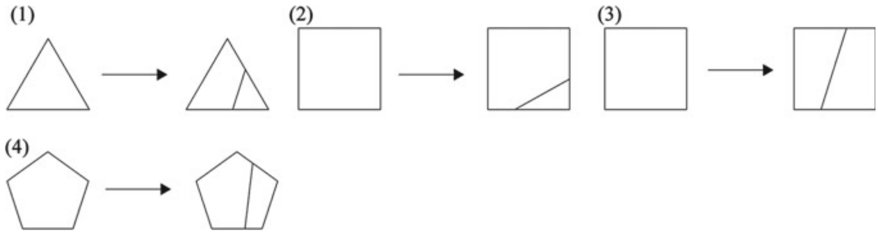

Fig. 1 Four constructive rules that split a triangle, convex quadrilateral or pentagon into two new convex polygons (either a triangle and a quadrilateral, a triangle and a pentagon, two quadrilaterals, or a quadrilateral and a pentagon) by placing a single line between two of the original polygon's edges

2.1 Stiny's Parametric Shape Rules

Stiny [1] assigns parametric coordinates to two of the triangle's vertices, identifying the three vertices as (0, 0), (x_0, 0) and (x_1, y_1) (Fig. 2). These coordinates can be further constrained as $0 \leq x_1 \leq x_0$ and $0 \leq y_1$, as rule application takes place under an isometric transformation, including translation, rotation and reflection. Scaling is not considered; rule application is only allowed if the area of the triangle is greater than a specified constant, here $x_0\, y_1/2 > c$. If scaling were included, this constraint would lose its effect, as parameter assignment precedes shape transformation. In addition, Stiny adds a single 'construction' point inside the triangle with parametric coordinates (x_2, y_2) located at a distance rA_1/A_2 from the centroid of the triangle, where r is the radius of the greatest circle contained in the triangle centred on the centroid, A_1 is the area of this circle, and A_2 is the area of the triangle. rA_1/A_2 can easily be computed from the coordinates of the vertices of the triangle. Nevertheless, the resulting constraints on the coordinates of the point are complex, also because the distance r is the minimum of the distances from the centroid to any of the three sides of the triangle. Stiny [1] explains this condition with the purpose to prevent the shape rule from applying to the same triangle more than once. However, it is unclear why simply constraining the location of the point to coincide with the centroid of the triangle such that $x_2 = (x_0 + x_1)/3$ and $y_2 = y_1/3$ would not achieve the same purpose.

For the sake of simplicity, we assume the point instead to be constrained to the centroid. Thus, there emerge two types of constraints. Constraints of the first type are directly related to the parameterisation of the triangle and need to be part of the parameterisation in order to be able to resolve the parameter values before computing the isometric transformation under which the rule applies to a given shape. These are the constraints on the coordinates x_1, y_1, x_2 and y_2. In Woodbury's [11] shape schema grammar, the constraints $0 \leq x_1$ and $0 \leq y_1$ can be assigned directly to the coordinates (real schemata) x_1 and y_1, while the constraint $x_1 \leq x_0$, rewritten in terms of the points rather than their coordinates (e.g., $p_0 \cdot p_1 \leq p_0 \cdot p_0$), can be assigned to the line segment (schema) with vertices p_0 (x_0, 0) and p_1 (x_1, y_1). The constraint on the location of the point p_2 (x_2, y_2) necessary forms part of the shape schema, as it relates the point to the endpoints of the line segments (i.e., $p_2 = (p_0 + p_1)/3$). On the other hand, the constraint on the area of the triangle is not required

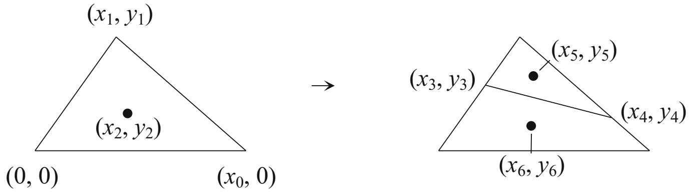

Fig. 2 A parametric shape rule splitting a parametric triangle into a triangle and a quadrilateral by placing a single line between two of the original triangle's edges (after [1])

in order to resolve the parameter values and can be evaluated separately to check for rule application. Thus, this constraint can be written as part of a parallel description rule, on condition that the description rule can access the information in the shape rule [14] (see, also, Sect. 2.3). The advantage of presenting the constraint on the area of the triangle as a description rule is that it clearly distinguishes additional constraints on the application of the rule from the application mechanism (including the parameterisation) itself.

Apart from Woodbury's [11] shape schema grammar, graph-based shape grammar implementations [15–17] can also be used to implement this parametric shape rule. Graph-based implementations can be used to find polygons of a specified number of sides or vertices, while additional constraints can be specified on (the coordinates of) the vertices, in a similar way to the shape schema grammar. Strobbe [18] demonstrates a graph-based implementation of the Chinese ice-ray lattice design grammar. Unfortunately, he does not indicate how the rules are expressed, showing only a simplified visual representation of the shape rules.

However, there remain two issues with Stiny's [1] parametric shape grammar for Chinese ice-ray lattice designs. The first is very minor: it is entirely possible, though probably not very plausible, that the point associated with one polygon, may also be associated with another, larger polygon, especially if the point is not required to coincide with the centroid of the polygon, but allowed some variability in its position. However, ignoring this possibility, a larger issue lies with the efficiency of the rule matching mechanism. Determining which polygon is properly associated with the point potentially requires all possible polygons to be considered, as the rule implies but does not explicate the fact that the polygon should be the smallest possible polygon enclosing the point. Shape grammars, even parametric shape grammars, do not commonly allow for the absence of geometric elements to be explicated (see, instead, [19]).

2.2 *Alternative Parametric Shape Rules*

Tapia [20] considers a parametric shape grammar using inscribed polygons to distinguish the polygons to be subdivided (Fig. 3). It addresses the efficiency issue above, but at the cost of visual clarity. During the derivation process, each polygon is marked by an inscribed 'construction' polygon consisting of labelled lines and points, which has the same shape and centroid as the actual polygon, but only half the size. Considering the centroid $p_c = (p_0 + p_1)/3$ of the triangle in Fig. 3, the vertices of the inscribed triangle can be described as $p_2 = (p_0 + p_1)/6$, $p_3 = (4p_0 + p_1)/6$ and $p_4 = (p_0 + 4p_1)/6$, with coordinates $x_2 = (x_0 + x_1)/6$, $y_3 = y_2 = y_1/6$, $x_3 = (4x_0 + x_1)/6$, $x_4 = (x_0 + 4x_1)/6$, $y_4 = 2y_1/3$. Similar constraints can be defined for the vertices in the right-hand-side of the parametric shape rule. Only when the process ends and the termination rule is used to remove all inscribed polygons will the final result become clearly visible. Tapia [20] hides the inscribed polygons in the exemplar derivation, obviously for readability purpose. Such can be done in general, distinguishing the

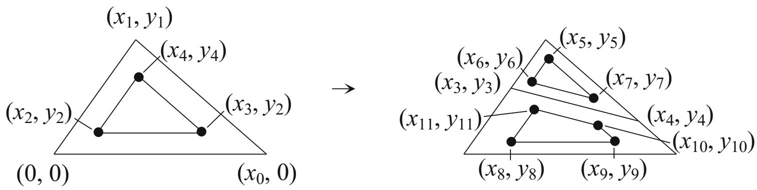

Fig. 3 The parametric shape rule from Fig. 1 considering Tapia's [20] inscribed polygon representation

resulting elements from the temporary, construction elements, however, at the cost of understandability of the rules and therefore of the ability for the user to edit the rule on the fly.

Stouffs and Wieringa [21] revisit Stiny's Chinese ice-ray lattice grammar, adapting its shape rules to apply to 3D surfaces. However, their implementation is not of an actual shape grammar, instead, it could be better described as a set grammar. The current shape consists of a set of polygons and, at each step in the derivation, a polygon is taken from the set and replaced with two smaller polygons. In this way, no auxiliary elements, such as labelled points, are required in the specification of the parametric rules. Nevertheless, we can achieve a similar effect using a parametric shape grammar interpreter (or, potentially, a shape schema grammar interpreter) using unique labels to identify the shape elements that belong together.

2.3 *Parametric Shape Rules Specifying Labelled Line Segments*

Labels can serve to uniquely identify spatial elements that belong together. For example, assume the line segments of the triangle in the left-hand-side of the shape rule (rule 1 in Fig. 1) to be constrained as having the same attribute label. When we apply the shape rule, the attribute label can be replaced with two attribute labels where the first one is assigned to all line segments belonging to the top triangle and the second one is assigned to all line segments belonging to the bottom quadrilateral. Note that these are not the full line segments as found in the left-hand-side shape, but only those parts that belong to the resulting convex polygon. Note also that the line segment that was added belongs to both polygons and as such will have both attribute labels.

Since attribute labels are generally not considered parametric, instead, we can use descriptions [22]. In fact, parametric label rules can be considered as a special instance of description rules where the description only contains the label and the description rule specifies a single parameter referencing this label. Descriptions can be considered as an attribute to line segments. For example, in Fig. 4, each line segment in the left-hand-side of the shape rule is specified to have the same

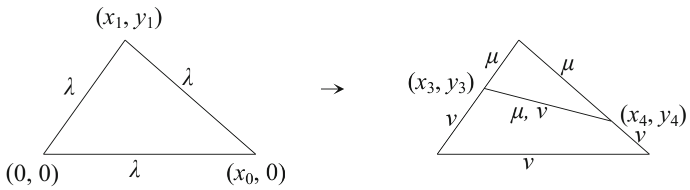

Fig. 4 The parametric shape rule from Fig. 1 considering parametric labelled line segments

description parameter λ thus requiring the same parameter value. In the case of the right-hand-side shape, six line segments are distinguished, two of them having a description parameter μ, three of them having a description parameter ν and one segment having both description parameters μ and ν. As can be seen from Fig. 4, the line segments with description parameter μ constitute one polygon (a triangle) and the line segments with description parameter ν constitute another polygon (a convex quadrilateral). The values of μ and ν can be derived from another description that tracks the total number of polygons already created, such that a unique parameter value is assigned to each polygon and the parameter values reflect on the order in which the polygons were created.

As an alternative, line segments may be considered as an attribute to descriptions. Stouffs [23] presents an example of the latter, offering an explication of a description function for a shape grammar over a domain of squares, as first described by Brown et al. [24].

The line labels (or descriptions) serve as construction elements. Line segments can have up to two labels as they belong up to two polygons. The number of potential matches is constrained by the number of unique labels and thus corresponds to the number of polygons available for further subdivision.

Extending a graph-based shape grammar to allow for the inclusion of descriptions and description rules supports the specification of the Chinese ice-ray lattice grammar using only line segments and description labels. Another approach would be to extend the notion of shape schema grammars to augmented shape schema grammars. Here it is assumed that the augmentation is also schematic (parametric) and description schemata can be conceived for this purpose. Shape schemata are conceived by Woodbury [11] as being expressed with line schemata, point schemata and real schemata. Specifically, a shape schema consists of a set of line schemata; a line schema consists of a pair of point schemata, and a point schema consists of a pair of real schemata. Each schema additionally contains a set of (optional) constraints specified over the constituting schemata. Similarly, at a minimum, a description schema could be expressed with tuple schemata, string schemata and real schemata. Then, a description schema can consist of a set of tuple schemata, where each tuple schema consists of a tuple of one or more string schemata and/or real schemata. An augmented shape schema that supports labelled line segments would then consist of a set of augmented line schemata, where each augmented line schema contains a line schema and an optional set of description schemata. For example, in Fig. 4, the left-hand-side of the rule can be represented as an augmented shape schema containing three augmented line schema, each containing a line schema and a singleton description tuple schema specifying a single real schema, where the parameters of the three description real schemata are constrained to have the same value. On the other hand, the right-hand-side of the rule in Fig. 4 specifies an augmented shape schema containing six augmented line schema, five of which contain a line schema and a singleton description tuple schema (specifying a single real schema), while the sixth contains a line schema and a set of two (singleton) description tuple schemata (each specifying a single real schema). Again, each schema may additionally contain a set of constraints specified over the constituting schemata, where the constraints themselves may be expressed as numerical and string expressions, possibly including functions.

2.4 Parametric Shape Rules Specifying Labelled Plane Segments

Stouffs and Wieringa's [21] implementation actually represents the polygons as faces. Thus, in two dimensions we can consider a representation with plane segments rather than line segments. In fact, Stouffs and Wieringa complement the faces with line segments. Both faces and line segments receive a numeric label reflecting on the derivation step in which the line segment is created. The numeric label of a face is the numeric label of the original face it is derived from through rule application plus one, and the numeric label of a line segment equals the numeric label of the face it is created as an edge of. In this way, the ice-ray lattice can be transformed into a façade structure by assigning an extrusion profile to each line segment, the size of which is inversely related to its numeric label.

Assigning numeric labels to plane segments also allows us to treat plane segments with different numeric labels as maximal with respect to one another. Since each derivation step leads to the creation of two adjacent polygons, a different numbering should be used, or an additional label, to distinguish both adjacent polygons. Furthermore, while polygons may be distinguished, the shape rule also needs to include the polygon boundaries as line segments in order to ensure that the entire polygon is the subject of rule application. That means that the boundary line segments must be labelled accordingly in order to ensure the efficiency of the matching process. As a result, this would simply extend on the previous solution by adding the plane segments, with or without labels. Only when the presence of the plane segments is important for other than efficiency reasons does this become a valuable solution.

3 Towards a Practical Implementation

Though we have performed the exercise above simply with the intention to provide insights and requirements for the development of any general shape grammar interpreter, nevertheless, it is valuable to consider an actual implementation of the parametric shape rules specifying labelled line segments in order to evaluate the validity of the above results. Our aim is not to demonstrate the efficiency of this solution but, instead, to assess the finer details of an implementation of Stiny's [1] shape rules. For this purpose, we make use of the *sortal* grammar interpreter (SortalGI) [25], which supports both parametric and non-parametric shapes, in two and three dimensions, with varying attributes including descriptions. Additionally, SortalGI supports compound rules that are each composed of a shape rule and one or more description rules operating simultaneously (in parallel). The rule components of a compound rule can be considered to be linked, e.g., a description rule may reference data within the shape rule or vice versa, such that they not only operate in parallel but also interact. For this application, we rely on compound rules composed of a parametric shape rule and one or more description rules. SortalGI adopts a graph-based representation for parametric shapes, however, different from other graph-based implementations [15–17], it does not use any sub-graph matching algorithm but instead relies on a combinatorial enumeration of potential matches. In general, graph-based, parametric subshape recognition is non-polynomial, even with a hypothetical, linear time subshape detection algorithm [26]. In comparison, a combinatorial enumeration, searching for k maximal elements within a set of n (distinguishable) maximal elements, yields a tight bound of $O(n^k)$. Note that, depending on the size of k, this bound is exponential in the worst case, although one can use labels to limit the combinatorial explosion, as is the case for the parametric shape rules specifying labelled line segments.

Stiny [1] specifies three constraints for any rule to apply to a polygon. Firstly, a rule only applies if the polygonal area is greater than some specified minimum value; secondly, the polygon cannot have been previously split; thirdly, the absolute difference between the areas of the two polygons arising from the splitting rule is less than some specified minimum value. The first condition ensures a minimum size (area) for a polygon to be split. The second condition has already been addressed by adding a unique label to the line segments of any polygon arising from a splitting rule. The third condition ensures that the resulting polygons have more or less the same size (area). In order to express the first and third condition, we consider parametric shape rules to specify both labelled line segments and (labelled) plane segments. Then, a description expressing the first condition may include a reference to the (labelled) plane segment, retrieving its area and checking this with respect to a specified minimum value:

minArea: $c? <$ planeSegP.area $\rightarrow c$

Here, minArea is the name of the description and planeSegP is the name of the *sort* of parametric plane segments [28]. planeSegP.area references the value of the area property of the single planeSegP instance in the left-hand-side of the

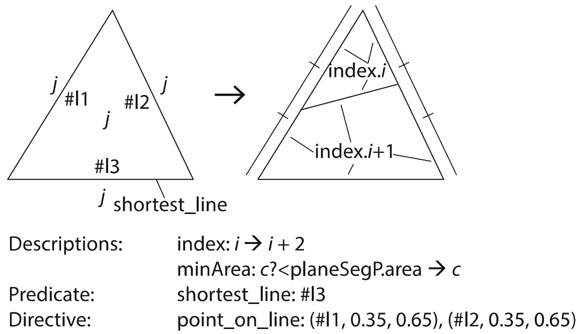

Fig. 5 A graphical representation of the implementation (using SortalGI) of the parametric shape rule from Fig. 1 considering parametric labelled line and plane segments, as well as descriptions, predicates and directives. Note that all thin lines are not part of the shape but indicate relationships between labels and spatial elements, or serve the graphical expression of predicates or directives

shape rule (Fig. 5). *c* is a parameter that matches the current (given) value of the description. '?' indicates a condition is specified on the parameter *c*; the condition specifies that the value *c* must be smaller than the area value of the planeSegP instance. Otherwise, the rule doesn't actually do anything as the right-hand-side of the description rule specifies the same parameter *c*; the value of the description therefore remains unchanged to the specified minimum value.

Before we attempt to address the second condition, let us review the other components of the compound shape rule in Fig. 5. The index description rule tracks the total number of polygons already created, in order to assign a unique parameter value to each polygon, while reflecting on the order in which the polygons were created. The index value *i* is increased by two as two smaller polygons are created. The right-hand-side of the shape rule references this index description in order to assign the correct description labels to the line and plane segments. The shape rule additionally includes a shortest_line predicate and a point_on_line directive [27]. Predicates constrain rule application, while directives assist in the spatial construction of the shape resulting from rule application.

The shortest_line predicate identifies a particular line segment of the triangle to be the shortest line. Though not required, it helps in reducing the possible matches and avoids splitting the shortest line of the triangle. To identify the particular line, all three line segments are tagged as, respectively, #l1, #l2 and #l3, where the last one is identified as the shortest line (Fig. 5). Graphically, tags are presented as labels, though tags are temporary constructs assigned within the application of the rule and are only valid until the application is resolved.

Stouffs and Wieringa [21] offer an implementation of the Chinese ice-ray lattice grammar where the endpoints of the splitting line are constrained to lie between a (user-specified) minimum and maximum parameter value, e.g., 0.35 and 0.65 where the edge's endpoints have values 0 and 1. Hereby, they ignore Stiny's [1] third constraint, constraining the absolute difference between the two newly created polygonal areas. Instead, the actual parameter value of the endpoint is randomly selected by the system within the specified parameter value range. The point_on_line directive implements this behaviour. It identifies one of the line segments that will be split (by its tag), as well as the minimum and maximum values within which range a random parameter value is generated for the endpoint of the splitting line (Fig. 5).

In fact, we've similarly omitted Stiny's [1] third constraint in Fig. 5. The reason for this is that this constraint on the relative areas of both polygons is not a constraint for rule application, but only a constraint on the spatial construction of the shape resulting from rule application. Constraints on rule application can be embedded in the left-hand-side of the shape rule or in the left-hand-side of any description rule that is part of the same compound rule. Constraints on the spatial construction of the shape resulting from rule application, however, can only be embedded in the right-hand-side of the shape rule, either in the spatial specification or via a directive. As the shape rule is parametric, the right-hand-side of the shape rule does not directly reflect on the actual shape and thus it is impossible to embed a constraint with such dependencies—the respective areas being dependent on the coordinates of the endpoints of the splitting line with respect to the coordinates of the corner points of the triangle—directly into the right-hand-side of the shape rule. Instead, a directive may be required, e.g., area(#p1/2, #p2, #p2 * 2), assuming the plane segments are tagged with #p1 and #p2 respectively, and the directive is read as the middle value being constrained between the first and last value. Such a directive is currently not supported in SortalGI.

An alternative manner to express such a constraint would be to express it as a description rule that is not part of the same compound rule, but is applied immediately after the splitting rule in order to check if the splitting line fulfils on the constraint. However, if the description rule would fail, the compound rule would not be expected to apply once again simply with different random parameter values for the endpoints of the splitting line. Instead, the compound rule would only apply if a different match can be found, for example, switching the lines tagged #l1 and #l2. This is obviously not as intended, as the compound rule had already been matched.

4 Discussion and Conclusion

We have explored and presented four alternative explications of Stiny's shape grammar for Chinese ice-ray lattice designs and assessed their 'practicality' in terms of the number of construction elements included in a single, representative shape rule and the number of potential matches the matching algorithm must consider when applying this rule to a representative shape. While Stiny's [1] explication uses few construction elements, it is far from efficient. Tapia's [20] explication resolves the efficiency problem, but at the cost of many more construction elements. Nevertheless, we demonstrate it is possible to address both objectives with an explication adopting labels, or rather descriptions, for line segments. While Stiny's explication predates the introduction of a description function to augment a shape grammar [22], Tapia's does not though it does predate any other exemplar applications of a description function—or description grammars for that matter (see [14] for an overview of all accounts of description grammars in literature). As such, we can attribute the oversight of the solution here suggested on the one hand to the lack of more recent explications of a shape grammar for Chinese ice-ray lattice designs (Strobbe [18] does not present an explication). On the other hand, we can also attribute it to the fact that very few shape grammar explications and, for that matter, shape grammar interpreters consider labels or descriptions as attributes to geometric elements other than points.

Thus, we can conclude that a general shape grammar interpreter should allow for a wider range of combinations, and relations, of geometric and non-geometric information. *Sortal* grammars [28–30] address this issue in a general way. In addition, in order to support practical applications of shape grammars, a shape grammar interpreter must support parametric shape grammars or shape schema grammars. Combining parametric shape grammars with varying shape grammar formalisms within a general shape grammar interpreter, possibly supporting the extent of *sortal* grammars, should be an important milestone in order to support practical applications of shape grammars for design, as exemplified in Sect. 3.

As an aside, but in support of flexibility in expressing shape grammar rules or, rather, augmented shape schema rules, we revisit the conception of description schemata. Specifically, Stouffs [14] explores a wider range of descriptions than considered above and it may be possible to extend description schemata to support this wider range. This would require the conception of open schemata next to string concatenation schemata. An open schema has a variable type and consists of a single variable. In principle, this variable can match any description schema type, specifically, a tuple schema, a string concatenation schema, a string schema, a real schema or another open schema. However, the possible description schema types may be constrained and an open schema may be additionally constrained to a subpart description schema. For example, a string concatenation schema can be expressed as a tuple of string schemata, real schemata and/or open schemata, where the open schemata are constrained to be subpart string concatenation schemata, string schemata or real schemata. A tuple schema can be expressed as a tuple of tuple schemata, string concatenation schemata, string schemata, real schemata and/or open schemata, where the open schemata are constrained to be tuple schemata, subpart tuple schemata, string concatenation schemata, string schemata or real schemata. Finally, a description schema can consist of a set of tuple schemata, string concatenation schemata, string schemata, real schemata and/or open schemata, where the open schemata are constrained to be tuple schemata, string concatenation schemata, string schemata or real schemata. Note that this extension is hypothetical as there are at least two complications to address. The first is that, different from shape schemata that have a straightforward three-level decomposition into line schemata, point schemata and real schemata, description schemata may consist of nested tuples, on the one hand, or a single string or real schema, on the other hand, allowing any (finite) number of decomposition levels. The second complication is that where matching shape schemata necessarily have the same structure, that is, the same number of lines (as well as points and reals), matching description schemata may have different structures. Firstly, a single open schema may match any other description schema, including a nested tuple schema. Secondly, a string concatenation schema may match a single string schema.

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Visual Structures of Embedded Shapes

Iestyn Jowers and Chris Earl

Abstract Shape computations recognise parts and create new shapes through transformations. These elementary computations can be more than they seem, inducing complicated structures as a result of recognising and transforming parts. This paper introduces, what is perhaps in principle, the simplest case where the structure results from seeing embedded parts. It focusses on lines because, despite their visual simplicity, if a symbolic representation for shapes is assumed, lines embedded in lines can give rise to more complicated structures than might be intuitively expected. With reference to the combinatorial structure of words the paper presents a thorough examination of these structures. It is shown that in the case of a line embedded in a line, the resulting structure is palindromic with parts defined by line segments of two different lengths. This result highlights the disparity between visual and symbolic computation when dealing with shapes—computations that are visually elementary are often symbolically complicated.

Keywords Shape grammars · Shape structure · Embedding · Visual palindromes

1 Introduction

Representations of shapes conventionally employ a structure of parts. In computer-aided design (CAD) these parts might be points and labels, lines and curves, planes and surfaces or bounded solids; higher order structures arise from assemblies of these parts. However, the cultural, artistic and design applications of shape often require a diversity in part descriptions with different designers or artists entertaining different descriptions. What is the origin of these diverse structures and what are their characteristics? This paper explores these questions by proposing that recognition of parts induces a part structure, and presents an analysis of the resulting structures, with part recognition formalised in shape rules.

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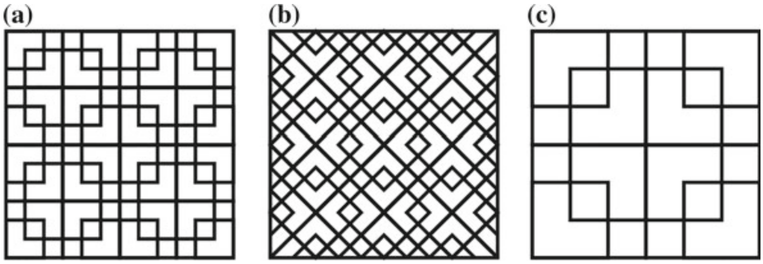


Fig. 1 Korean lattice patterns

Shape structures can range from a predetermined structure, as is the case for CAD models, to random assignation of parts. In terms of the cultural, artistic and design perspectives, relevant part structures for shapes seem to be in the middle of this range, with structures defined differently in different contexts. Shape computations formalise these structures in shape grammars where rules recognise parts and create new shapes through transformations. But such computations can be more than they seem, inducing complicated structures from seeing (recognising parts) and moving (transforming parts) [1]. This paper examines shape computations and the properties of part structures, the complexity of which can be surprising, even for elementary shape computations. It develops arguments presented by Stiny [2], which explore the diversity of part structures necessary to support shape computation.

As an illustrative example consider the lattice patterns in Fig. 1. Such patterns are common in the Republic of Korea, where they are used to ornament doors and windows. They have an intricate visual structure and can be viewed in different ways. For example, the pattern in Fig. 1c could be recognised as the motif for the patterns in Fig. 1a, b. Alternatively, all three patterns can be viewed as compositions of overlapping and abutting polygons, such as squares, rectangles, and crosses. The different ways of viewing the patterns give rise to different part structures which are not predetermined as required in a CAD model, nor are they random. The part structures are a consequence of seeing and change dynamically according to parts recognised by the viewer.

Shape rules can be used to formalise the different ways the patterns are viewed, and application of rules in a shape computation gives rise to different structures according to the different parts recognised. For the patterns in Fig. 1, this can be illustrated by considering the two simple configurations, highlighted in Fig. 2. The first consists of two adjacent squares of equal size while in the second the squares are of different size.

The shape rule in Fig. 3a is a shape identity rule [2] that recognises squares, and it can be applied under Euclidean transformation and scale to the patterns in Fig. 1 to identify embedded squares in the patterns. Application of an identity rule does not visually transform a shape, but it does impose structure in order to accommodate embedded parts [3, 4]. Focussing, on the configurations identified in

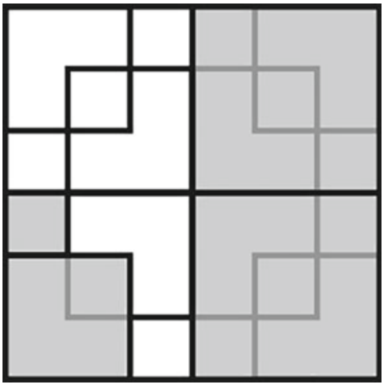


Fig. 2 Configurations embedded in a Korean lattice pattern

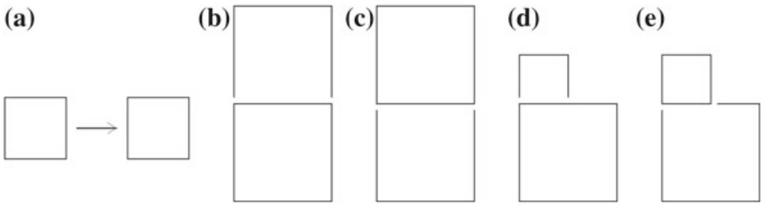


Fig. 3 **a** Identity shape rule, **b**–**e** part structures resulting from rule application

Fig. 2, applying the rule to different embedded squares gives rise to different part structures as illustrated in Fig. 3b–e.

Visually, two squares are immediately apparent in the configurations, but in order to make both the squares apparent symbolically a more complicated structure is necessary. For the first configuration, composed of two adjacent squares of equal size, this structure is trivial and requires only that the common edge is included in the description of the part, as illustrated in Fig. 4a. For the second configuration, composed of two adjacent squares of different size a more complicated part structure is required, in order to account for the edge of the small square embedded in the edge of the large square, as illustrated in Fig. 4b. This structure supports application of the shape rule to either of the squares apparent in the configuration, but large and small squares have different structures necessitating two versions of the rule to accommodate them.

The shape structures illustrated in Fig. 4 are examples of a phenomenon which occurs when rules, even elementary rules, act on shapes, to recognise and transform parts, e.g. [5–7]. This paper explores this phenomena with reference to the class of shapes exemplified by the two configurations illustrated in Fig. 2, and the part structures that result from recognising their embedded parts. It focusses on applications of the identity rule in Fig. 3a to shapes composed of two adjoining squares which share a common edge and a common end point, as illustrated in Fig. 5.

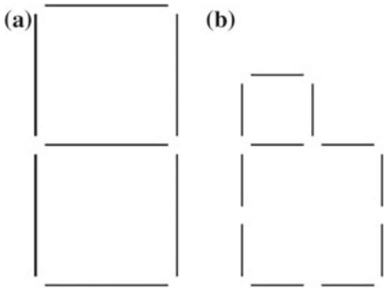
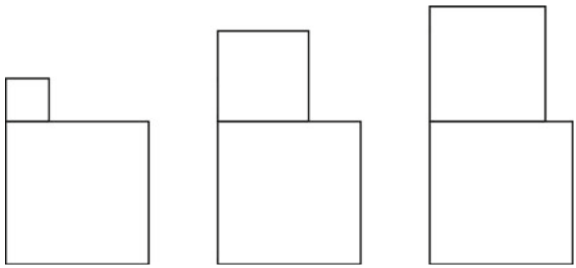


Fig. 4 Part structures that accommodate recognition of two squares

Fig. 5 Example shapes, composed of two adjoining squares



The rule, applied under Euclidean transformations and scale, can select either of the squares, and each selection gives rise to a different part structure, according to the decomposition of the common edge. Visually, this is an elementary problem. But finding a symbolic description of the shape that accounts for both part structures is more of a challenge. The shared edge is the key characteristic of this particular shape computation, and consequently the problem is equivalent to finding part structures that accommodate the elementary operation of embedding a line inside another line. The paper identifies structures that account for this embedding relation, thereby providing symbolic representations of shapes that account for visually apparent parts.

2 Lines Embedded in Lines

Lines embedded in lines can give rise to more complicated structures than might be intuitively expected. This is illustrated in Fig. 6, where the part structures that arise when two squares share a common edge are identified. Here, the lengths of the edges are denoted l and n, with $n < l$, and the squares adjoin such that an edge of the smaller square is embedded in an edge of the larger whilst sharing an end point. In these examples a part structure has been identified that accommodates all applications of the rule in Fig. 3a, and also

(1) accounts for the smaller edge embedded in the longer edge

(2) retains the symmetric properties of the edges/squares.

The triangles are included on the common edge to illustrate part structures while highlighting their symmetry. Each triangle correlates with a line segment embedded in an edge, and these are subdivided into finer structures, representing lines embedded in lines. Embedded lines associated with triangles are symmetrical, and their subdivision into embedded parts is symmetrical; in this sense, the triangles represent the structure of the edges as visual palindromes.

The structures of the decomposed line segments are also illustrated in the decomposition of the top edge of the smaller square and the bottom edge of the larger. In each example, the edges of the larger square and the smaller square have a different part structure, but shape computations that result from applying the rule in Fig. 3a can accommodate this by having two versions of the rule.

In Fig. 6, the structures shown are the simplest that allows a short edge to be embedded in a long edge while retaining the symmetric properties of the two squares. Intuitively, it might be expected that embedding a short edge as part of a longer edge would simply result in a decomposition of the longer edge to accommodate the shorter. But this intuitive decomposition only occurs in the first of these examples. In the other examples a finer decomposition of both edges is necessary, and the reason for this is illustrated in Fig. 7, where a process of deriving the part structures of the edges is presented. This process involves resolving the symmetries of the visual palindromes corresponding to the part structure of the edges.

Figure 7a illustrates the high-level structure of the edges where, to account for the symmetric properties of the squares, each edge is identified as a visual palindrome, represented by a triangle. Figure 7b illustrates the embedding of the shorter edge

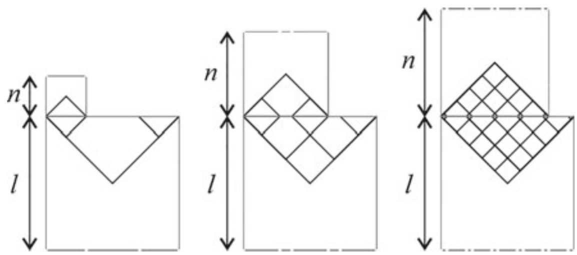


Fig. 6 Examples of part structures resulting from embedded lines

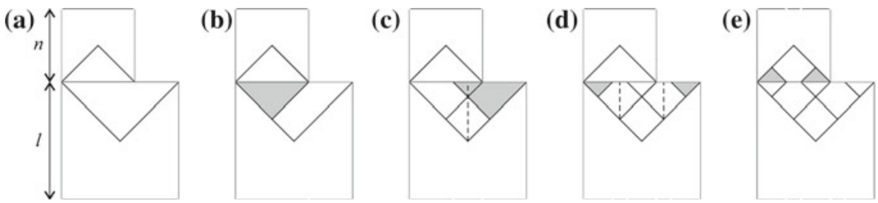


Fig. 7 Deriving the part structure of embedded lines by resolving symmetries

in the longer; the structure of the longer edge now incorporates an embedded line that is the length of the shorter edge, represented by the triangle highlighted in grey. This new structure breaks the symmetry of the longer edge, which is addressed in Fig. 7c by reflecting the smaller triangle in the illustrated axis of symmetry. A new triangle is defined by the overlap, and this represents further subdivision of the visual palindrome; it is this emergent form that requires a finer decomposition of the edges than might be intuitively expected. Figure 7d resolves the symmetry of the longer edge by reflecting the emergent triangle in the illustrated axes of symmetry. Finally, in Fig. 7e, the structure of the shorter edge is subdivided according to the structure of the longer edge. The resulting part structure accounts for the symmetric properties of both squares, and allows the edge of the smaller square to be embedded in the edge of the larger square. The result is a periodic palindromic structure where the shorter edge can be described by the string *uvu* and the longer edge can be described by the string *uvuvu*, where u and v represent line segments of different lengths, determined by the ratio of the lengths of the edges, l and n, as illustrated in Fig. 8.

Figure 8 explores the different part structures that arise when two squares share a common edge. Here, the arrangement of the squares is constrained such that the edge of the smaller square is embedded in the larger, with both sharing an end point, and l, the edge length of the larger squares, is kept constant while n, the edge length of the smaller squares, increases from Fig. 8a–h. Again, triangles are included to illustrate the part structures, whilst highlighting their symmetry, and this structure is also reflected in the decomposition of the top edge of the smaller square and the bottom edge of the larger.

In Fig. 8a, $n < \frac{1}{2}l$ and embedding the shorter edge in the longer edge results in the part structure that is intuitively expected: the structure of the shorter edge remains unchanged and the structure of the longer edge includes the shorter edge as an embedded part. As a result, the structure of the shorter edge can be described by the string u, where u represents a line of length of $l_u = n$, and the structure of the longer edge can be described by the string *uvu* where v represents a line segment of length $l_v = l - 2n$.

Increasing the edge length of the smaller square results in an increase in the length l_u, and a decrease in the length l_v. Specifically, as $n \rightarrow \frac{1}{2}l$, $l_u \rightarrow \frac{1}{2}l$ and $l_v \rightarrow 0$, and, in Fig. 8b, when $n = \frac{1}{2}l$, $l_v = 0$ and the longer edge can be described by the string *uu*.

In Fig. 8c–h, $n > \frac{1}{2}l$ and the embedded shorter edges overlap resulting in the emergence of more complicated structures, as illustrated in Fig. 7. When $n > \frac{1}{2}l$ embedding the shorter edge in the longer edge results in a decomposition of both edges, and as n increases the symbolic descriptions of the resulting part structures can be categorised according to the following cases:

- In Fig. 8c, $\frac{1}{2}l < n < \frac{2}{3}l$,, the short edge can be described by *uvu* and the long edge by *uvuvuv*. As $n \rightarrow \frac{2}{3}l$, $l_u \rightarrow \frac{1}{3}l$ and $l_v \rightarrow 0$
- In Fig. 8d, $n = \frac{2}{3}l$, $l_u = \frac{1}{3}l$ and $l_v = 0$, the short edge can be described by *uu* and the long edge by *uuu*
- In Fig. 8e, $\frac{2}{3}l < n < \frac{3}{4}l$,, the short edge can be described by *uvuvu* and the long edge by *uvuvuvu*. As $n \rightarrow \frac{3}{4}l$, $l_u \rightarrow \frac{1}{4}l$ and $l_v \rightarrow 0$

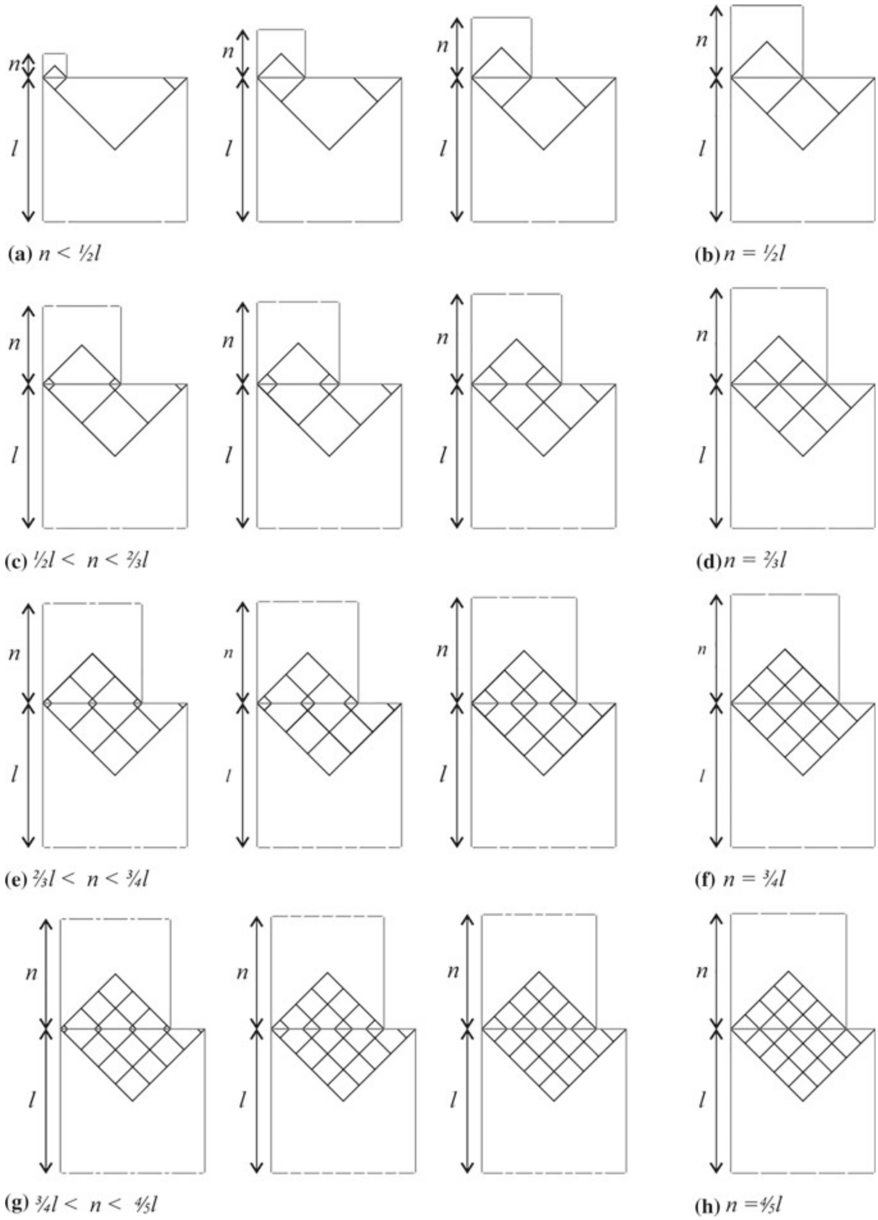


Fig. 8 Part structures resulting from two squares sharing a common edge

- In Fig. 8f, $n = \frac{3}{4}l,\ l\ = \frac{1}{4}l$ and $l_v = 0$, the short edge can be described by *uuu* and the long edge by *uuuu*
- In Fig. 8g, $\frac{3}{4}l < n < \frac{4}{5}l$, , the short edge can be described by *uvuvuvu* and the long edge by *uvuvuvuvu*, and as $n \rightarrow \frac{4}{5}l$, $l_u \rightarrow \frac{1}{5}l$ and $l_v \rightarrow 0$
- In Fig. 8h, $n = \frac{4}{5}l$, $l_u = \frac{1}{5}l$ and $l_v = 0$, the short edge can be described by *uuuu* and the long edge by *uuuuu*.

The pattern identified here continues, tending towards the limiting case where $n = l$ and the two squares are the same size, with the edges of both squares represented by a single line, as illustrated in Fig. 4a. But, as $n \rightarrow l$, $l_u \rightarrow 0$, and the part structure of the edges gets get finer and finer with the number of line segments increasing. This structure is always defined according to line segments of two alternating lengths, and it can always be described as a periodic palindrome over two atoms, *u* and *v*. In general, the structure of the shorter edge can be described by the string $(uv)^k u$, and the structure of the longer edge can be described by the string $(uv)^{k+1} u$, where *u* and *v* represent lines of length l_u and l_v, respectively, and *k* is a positive integer.

3 The Combinatorial Structure of Embedded Lines

The part structures that result from embedding one line in a second line can be further explored symbolically, by considering the combinatorial structure of words [8]. In the study of the combinatorics of words, a finite set of symbols is said to be an *alphabet*, denoted Σ. *Words* are sequences (either finite or infinite) of letters from Σ, for example $A = a_1, \ldots, a_n$ and $B = b_1, \ldots, b_m$, are words over Σ if the characters a_i and b_j are members of Σ, for some integers *n* and *m*, with $1 \leq i \leq n$ and $1 \leq j \leq m$. Two words, *A* and *B*, are equal, denoted $A = B$, if $n = m$ and $a_i = b_i$ for $1 \leq i \leq n$, i.e. $a_1 = b_1, a_2 = b_2, \ldots, a_n = b_m$. The empty word is composed of no letters and is denoted ε.

The set of all finite words, denoted Σ^*, is generated by Σ under an associative operation defined by concatenation. For example, if $A = a_1, \ldots, a_n$ and $B = b_1, \ldots, b_m$, are words over Σ, then they are members of Σ^*, and the word $A \cdot B = AB = a_1, \ldots, a_n\, b_1, \ldots, b_m$ is also a member of Σ^*. The set of all finite words is a free monoid with ε as the identity element under concatenation, since $A \cdot \varepsilon = A = \varepsilon \cdot A$. Repeated self-concatenation is denoted by superscript. For example, $A^3 = A \cdot A \cdot A = AAA = a_1, \ldots, a_n\, a_1, \ldots, a_n\, a_1, \ldots, a_n$. The length of a word *A* is denoted $|A|$, and is recursively defined so that the ε has length 0, and for any word *A* in Σ^* and any letter *a* in Σ, $|Aa| = |A| + 1$.

A word that is embedded as part of a second word is either a factor, a prefix or a suffix. For two words *A* and *B*, these are defined as follows. *A* is a *factor* of *B* if the words *X* and *Y* exist in Σ^* such that $B = XAY$. *A* is a *proper factor* of *B* if $A \neq B$. *A* is a *prefix* of *B* if there exists a word *X* in Σ^* such that $B = AX$. *A* is a *proper prefix* of *B* if $A \neq B$. Similarly, *A* is a *suffix* of *B* if there exists a word *X* in Σ^* such that $B = XA$. *A* is a *proper suffix* of *B* if $A \neq B$. *A* is a *border* of *B* if it is both a prefix and suffix of *B*, and it is a proper border if $A \neq B$.

The part structures identified visually in Fig. 8 arise readily in combinatorics, when words with identified parts are equated with each other, as summarised in the following lemmas, reported in [9], and illustrated in Figs. 9 and 10. The first of these is concerned with the structure that arises when two words with distinct parts are equated with each other, and the second is concerned with the structure that arises when two such words share a common part, identified as the prefix of one word and the suffix of the other.

Lemma 1 *If A, B, C and D are words in* Σ^**, such that* $AB = CD$ *and* $|A| \leq |C|$*, then there exists a word V in* Σ^* *such that* $C = AV$ *and* $B = VD$*. This is illustrated in Fig. 9, where words are represented by rectangles.*

Proof Let $m = |A|$, $n = |B|$, $p = |C|$ and $q = |D|$. Given that $AB = CD$ and $m \leq p$, C can be expressed as $C = c_1, \ldots, c_p = a_1, \ldots, a_m\ c_{m+1}, \ldots, c_p = A\ c_{m+1}, \ldots, c_p = AC'$ where $C' = c_{m+1}, \ldots, c_p$. Also $n \geq q$, and B can be expressed as $B = b_1, \ldots, b_n = b_1, \ldots, b_{n-q}\ d_1, \ldots, d_q = b_1, \ldots, b_{n-q}\ D = B'D$ where $B' = b_1, \ldots, b_{n-q}$. Since $AB = CD$, this gives $AB'D = AC'D = AVD$, and Lemma 1 holds with $V = b_1, \ldots, b_{n-q} = c_{m+1}, \ldots, c_p$. ☐

Lemma 2 *If A, B and C are words in* Σ^**, such that* $AB = BC$ *and* $A \neq \varepsilon$*, then* $A = UV$*,* $B = (UV)^k U$ *and* $C = VU$ *for some words U, V in* Σ^**, and some integer* $k \geq 0$*. This is illustrated in Fig. 10, where words are represented by rectangles.*

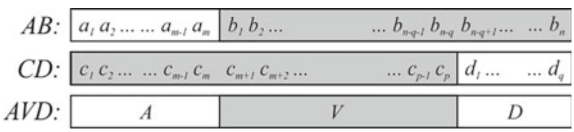


Fig. 9 Illustration of Lemma 1, with words represented by rectangles

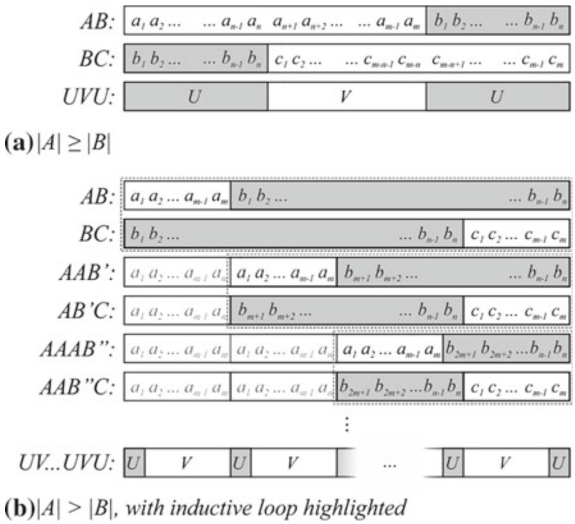


Fig. 10 Illustration of Lemma 2, with words represented by rectangles

Proof Let $m = |A| = |C|$ and $n = |B|$. If $n \leq m$, then from Lemma 1, $A = BV$ and $C = VB$, and Lemma 2 holds with $U = B = a_1, \ldots, a_n = c_{m-n+1}, \ldots, c_m$, $V = a_{n+1}, \ldots, a_m = c_1, \ldots, c_m$, and $k = 0$, as illustrated in Fig. 10a.

If $m < n$, then again by Lemma 1, $B = AB$' for some word B' in Σ^*, where $B' = b_{m+1}, \ldots, b_n$. This gives $A^2B' = AB'C$, and therefore $AB' = B'C$. $A \neq \varepsilon$ so that $|B'| < n$ and Lemma 2 follows from induction on n, as illustrated in Fig. 8b, with $U = a_1, \ldots, a_{n-km} = c_{n-km+1}, \ldots, c_m$, $V = a_{n-km+1}, \ldots, a_m = c_1, \ldots, c_{n-km}$ and k is the number of steps necessary to subdivide B into parts of length less than m, and is given by $\lceil n/m \rceil - 1$, where $\lceil n/m \rceil$ is the ceiling function, giving the smallest integer greater than n/m. □

The combinatorial structures that result from Lemma 2 are analogous to the edge structures identified in Fig. 8. This is because the symmetry of the squares requires that edges with identified parts be equal to their mirror images, which themselves contain the same parts. But, this condition of symmetry is stronger than the conditions under which Lemma 2 holds, and the structures of embedded lines can be further explored by considering words under similar symmetry constraints.

As one-dimensional strings, the symmetry group of words is defined by one-dimensional translation and reflection. Translation results in periodic words, where an infinite sequence $S = s_1s_2, \ldots$ is called periodic if there exists an integer $p \geq 1$, called a period, such that for each $n \geq 0$, $s_{n+P} = s_n$. A finite word A in Σ^* is called periodic if there exists an integer $p \geq 1$, such that A is a prefix of an infinite sequence with period p. The period of A is the smallest such integer. For example, the word *abaaba*, has periods of 3, 5, and 6, and its period is 3. Lemma 2 shows that equal words with common parts are intrinsically periodic in nature, with a period of $|U|+|V| = m$, and the same is true for lines embedded in lines, as illustrated in Fig. 8.

Reflection of a string can result in palindromic words. If $A = a_1, \ldots, a_m$ is a word over Σ^*, then $\bar{A} = a_m, \ldots, a_1$ is the word obtained by reflecting A, i.e. reading A backwards. A *palindrome* is a word that is equal to its reflection: A is a palindrome if $A = \bar{A}$, so that $a_1 = a_m$, $a_2 = a_{n-1}, \ldots$. For example, *rotavator* is an example of a palindrome, and trivially, the empty word ε and all words of length 1, are also palindromes.

In Fig. 8, the symmetry of the squares requires that the decomposition of edges are palindromic, which in Lemma 2, equates to the requirement that B is palindromic and that $W = AB = BC$ is also palindromic. This requirement imposes further constraints on the structure of embedded parts. In particular, A and C are reflections of each other because if $W = \bar{W}$ then $AB = \bar{C}\bar{B}$ and $B = \bar{B}$ gives $A = \bar{C}$. Also, U and V are palindromic because if $B = \bar{B}$ then $(UV)^kU = \bar{U}(\bar{V}\bar{U})^k = (\bar{U}\bar{V})^k\bar{U}$ so that $U = \bar{U}$ and $V = \bar{V}$.

In light of these conditions, Lemma 2 accounts for the structures observed in Fig. 8, with words and their parts analogous to lines and their parts. To make this explicit, let W represent a line of length l, A represent a line of length m, and B represent a line of length n. Embedding B in W, such that W and B retain their reflective symmetry, gives rise to a palindromic periodic structure,

$$W = AB = UV\,(UV)^k\,U = (UV)^{k+1}\,U$$

where U is a line of length l_u, V is a line of length l_v and k is given by $\lceil n/m \rceil - 1$. The period of this structure is $l_u + l_v = m$, and given that $W = AB = (UV)^{k+1}U$ and $B = (UV)^k U$, the lengths l and n can be written as

$$l = (k+2)\,l_u + (k+1)\,l_v$$
$$n = (k+1)\,l_u + kl_v$$

and it follows that

$$l_u = (k+1)\,n - kl$$
$$l_v = (k+1)\,l - (k+2)\,n$$

For example, if $n = \frac{5}{8}l$,, then $m = \frac{3}{8}l$ and $k = \lceil 5/3 \rceil - 1 = 1$, $l_u = \frac{1}{4}l$, $l_v = \frac{1}{8}l$.. This confirms observations of Fig. 8c, where the edge of the larger square is composed of three line segments of length l_u and two line segment of length l_v, so that $l = 3l_u + 2l_v$, and the edge of the smaller square is composed of two line segments of length l_u and one line segment of length l_v, so that $n = 2l_u + l_v$.

In Fig. 8, part structures are differentiated according to values of k, with $k = 0$ in Figs. 8a and b, $k = 1$ in Fig. 8c, d, $k = 2$ in Fig. 8e, f, and $k = 3$ in Figs. 8g, h. The limits identified for any given value of k result from definitions of l_u and l_v, so that as $n \rightarrow (k+1)l/(k+2)$, $l_u \rightarrow l/(k+2)$ and $l_v \rightarrow 0$. This was identified in Fig. 8, where in Fig. 8a, as $n \rightarrow \frac{1}{2}$, $l_u \rightarrow \frac{1}{2}l$ and $l_v \rightarrow 0$, and in Fig. 8b, $n = \frac{1}{2}l$, $l_u = \frac{1}{2}l$ and $l_v = 0$. Similarly, in Fig. 8c, as $n \rightarrow \frac{2}{3}l$, $l_u \rightarrow \frac{1}{3}l$ and $l_v \rightarrow 0$, and in Fig. 8d, $n = \frac{2}{3}l$, $l_u = \frac{1}{3}l$ and $l_v = 0$.

Also, as $n \rightarrow l$, $m = l - n \rightarrow 0$, so that $k = \lceil n/m \rceil - 1 \rightarrow \infty$, and the part structure of the edges get finer and finer with the number of line segments always increasing. But, at the limiting case where $n = l$, this structure disappears and $l_u = l$. This final point highlights the difference between words and shapes.

Shapes are defined on the continuum, e.g. a line can take a length of any real value, and they can always be decomposed into finer and finer parts. Conversely, words have a fixed granularity defined by a single letter, and consequently can only take integer lengths, and have a maximum decomposition into individual letters. Despite this difference, consideration of words is useful for understanding the part structure of embedded shapes, but it should be noted that the resulting conclusions cannot in turn be applied to words.

4 Discussion

This paper has examined the part structures arising from an elementary shape computation, namely application of a shape identity rule which recognises embedded squares. This rule, illustrated in Fig. 3a, was applied to a range of shapes composed of two squares adjoined at a common edge and sharing a common end point, and it was shown that in order for a symbolic shape structure to accommodate all possible applications of the rule, the shapes require a periodic palindromic structure, the nature of which depends on the relative positioning of the two squares.

The diversity and complexity of possible part structures necessary to accommodate application of elementary shape rules is in marked contrast to applying symbolic surrogates for shape rules in a purely combinatorial manner where parts that are created remain separate and do not merge and disaggregate. There are several consequences of the complexity and diversity of part structures required by shape computation. Fitting these structures together in a coherent way so that a rule (and its induced parts) progresses seamlessly to the next rule (and its corresponding structures), is a problem in its own right. One lesson of this paper is that it might be expedient to 'lose' structures between rule applications in a dynamic reinterpretation of structure. Carrying the baggage of past structures and ensuring the consistency among these structures has marginal benefit in design where current novel and innovative interpretations are emphasised. Although interpretation history (though tracking past structures) seems central for the cultural context of shape designs this is not necessarily an argument for maintaining an accumulating part structure which mirrors history especially when that structure quickly becomes unwieldy. Alternatively the generative reconstruction of possible histories as required may be more effective.

The diversity of part structures induced by shape rules is greater in shape computations than in their symbolic mirrors. The extent of this diversity reflects the different perceptions and interpretations of shapes adopted by different participants in the cultural, artistic or design environment. However, with the possibility of diverse and complicated part structures arising from each rule (to recognise or transform a shape), this paper identifies a significant combinatorial challenge in creating coherent part structures. Continual reinterpretation becomes a critical strategy in shape computation. This necessity may not be apparent when shapes are represented symbolically and rules comprise algebraic operations on these symbols. CAD representations of shapes which work with such symbolic operations are fundamentally constrained in their flexibility to generate designs according to artistic and cultural drivers. These constraints increase as the differences between parts decreases. Although part structures induced by elementary shape rules present finer divisions as differences between the embedded line and its host decreases, the structure remains finite, increasing in complexity until embedding reaches equality and the part structure flips to identity, the shape itself.

In general, the complexity and diversity of part structures is extensive. This paper systematically explored what is perhaps the simplest case, when the shape consists of a line segment and an embedded line with an identity rule which can be applied, under Euclidean transformations and scale, to each of the lines. Research is ongoing to investigate the complexity and diversity of part structures for more complicated shapes and other rule schemas beyond identity. For example, the diversity in part structures consequent on rule application is extended in the elementary embedding of two lines in a third, as exemplified in the configuration highlighted in Fig. 11, where three squares share a common edge. The resulting part structures do not all

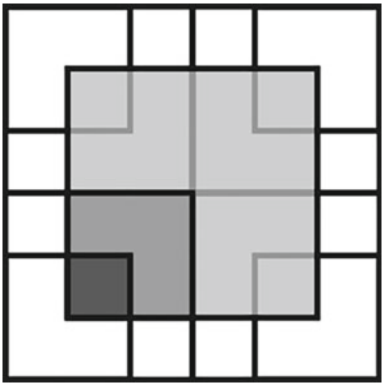


Fig. 11 Configuration embedded in a Korean lattice pattern

appear to be extensions of the finite structures of parts for one line embedded in another. For certain dispositions and sizes of two or more embedded lines it appears that finite part structures are not always possible. This further divergence between the properties of visual shape descriptions and those used in conventional computations which are finite and symbolic, will be examined in detail in a subsequent paper.

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A Design Grammar for Identifying Spatial Uniqueness of Murcutt's Rural Houses

Ju Hyun Lee and Ning Gu

Abstract This chapter presents a design grammar to analyse and measure spatial uniqueness within a specific set of Murcutt's domestic architecture. The research defines the design grammar that consists of four phases and 11 rule sets, from the first rule set generating pavilions to the last termination rule. After examining the tendency of the applied rules in the ten selected cases, each case is then characterised through a mathematical abstraction, so called 'normalised distance (ND)'. ND enables measuring a group of main functional zones in each design as well as their uniqueness in the language of design. The design grammar can be applied for the creation of new design instances, consistent with their spatial characteristics. This computational approach is thus applicable in the broader design domains to extend other shape grammar studies.

1 Introduction

A shape grammars specifies a set of rules delineating how a design can be composed from shapes. Shape grammar begins by defining an initial shape and then iteratively applies a set of rules (each specifies a particular operation or a set of operations) until an end-state is reached. Shape grammar considers design as a rigorous and rational process. This conceptual understanding about design process is central to most grammatical studies. Shape grammar allows researchers to rigorously capture possible processes for generating a language of design [1, 2]. It is through this generative aspect the designs are analysed and interpreted.

Since Stiny and Gips' 1972 seminal article [3], shape grammar as a design formalism has been developed over the past four decades. Knight [4] argues that a shape grammar is a set of shape rules applied in a step-by-step manner to generate a language of designs. The grammar can be descriptive as well as generative. Shape grammar allows for analysing exiting designs of a typical style and then generate

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design instances in an extension to the original language [5]. Thus, it can be considered as both a language identifier and a generator. The traditional analyses are largely descriptive through the definitions of the shapes in the style. By contrast, this chapter proposes an alternative approach to grammatically measure the uniqueness in a language of design (an architectural style), and including functional uniqueness through quantitative means. The measurement is represented as 'normalised distance'.

The chapter starts by introducing a design grammar for grammatical analysing selected Murcutt's domestic architecture. After describing the design grammar this chapter records the frequency of the applied rules within the set of the ten designs. This information indicates a tendency to select a particular rule or pattern, and can be used to develop each rule's normalised distance (ND). Based on the rules applied to generate the ten cases and ND of each applied rule, this chapter measures the functional uniqueness of each design instance in the specific language of designs. The quantitative measurement enables a critical analysis and a comparison between designs, which is also discussed in this chapter.

2 A Design Grammar for Murcutt's Domestic Architecture

Most shape grammar studies in the field focus on two dimensional (2D) shapes, typically floor plans [6, 7]. The Murcutt's shape grammar developed in this chapter adopts this convention. Logical structures are common in shape grammar research that rely on procedural design steps. For example, Hanson and Radford [8] describe 12 steps to generate their design cases. Stiny and Mitchell [6] use a form-making process consisting of eight successive stages: grid definition; exterior-wall definition; room layout; interior-wall realignment; principal entrances-porticos and exterior-wall inflections; exterior ornamentation-columns; windows and doors; termination. This linear, procedural way of conceptualising the design process is central to many important grammatical studies of architectural styles.

The design grammar developed in this chapter for Murcutt's domestic architecture has 11 rule sets contained within four phases (Table 1). It starts by generating pavilions and concludes with a termination rule. The theoretical basis of the design generation typically involves both abstracting the properties of the shapes used in architecture and decomposing them using a modular system.

The first phase has two rule sets for generating pavilions and basic modules. The first rule set also has two sub-rule sets to generate pavilions. Depending on the site contexts or design strategies, the shape grammar can be used to generate a pavilion that has a single-pavilion shape or a two-pavilion shape. Rule1.1 generates a single-pavilion shape, while Rule1.2 generates a two-pavilion shape, including two space units and a hall unit (see Fig. 1). For example, the left-hand side of the shape rule, as indicated below in Rule1.1, consists of a labelled point (*I*) and the coordinates of the point (x_1, y_1). The right-hand side of the rule consists of a labelled point (*O*), a four-point polygon, and an initial room label (R_0). The labelled point (*O*) is the

Table 1 Rule sets of a design grammar for Murcutt's domestic architecture

Stage	Rule set
Phase 1	1.x. Generating pavilions 2.x. Generating basic modules
Phase 2	3.x. Configuring a core unit 4.x. Configuring public zones (e.g. living room, kitchen, and function room) 5.x. Configuring private zones (e.g. bedroom and studio) 6.x. Configuring transition zones (e.g. veranda and court) 7.x. Configuring hall units 8.x. Configuring a garage
Phase 3	9.x. Defining a main entrance 10.x. Defining sub entrances
Phase 4	11. Termination

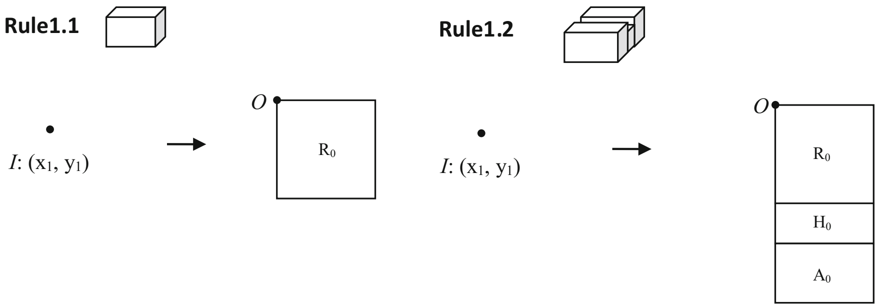

Fig. 1 The first rule set generating pavilions

upper left corner of the polygon. By applying this rule, the initial point label (I) is replaced with the point label (O). Therefore, this rule cannot be applied again.

The second rule set generates basic modules (structural or functional bays) to form enclosed spaces. The bays can be simplified using a rectangular grid, which conforms to the repetitive column layout found in Murcutt's domestic architecture. While the dimensions of the enclosed spaces may vary in different designs, the column lay-out characterises each house. For example, the Marie Short House (Case 8 in Fig. 1) consists of two types of modules (room-type and hall-type modules). The exact dimensions of modules are not considered to simplify the number of variables used. Further the exact dimensions depending on the design context are less relevant at the conceptual design stage. The second rule set contains three rules—Rule2.1 generates modules consisting of a room space (R_n); Rule2.2 generates a series of modules consisting of a room (R_n), a hall unit module (H_n) and an attached room unit module (A_n); Rule2.3 generates a series of modules consisting of a room space (R_n) and a hall unit module (H_n) (see Fig. 2). The width (a) and the length (b) of the left-hand side of the shape rule define the basic module (grid) of the entire plan. Each rule generates modules to the number defined by a variable (n). c represents the length of an attached hall unit.

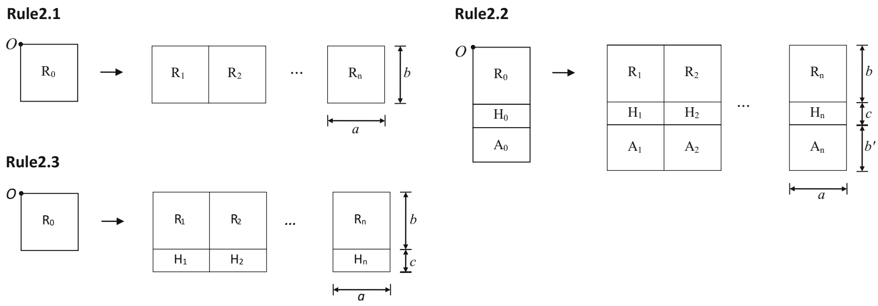

Fig. 2 The second rule set generating basic modules

The second phase involves six rule sets to configure walls according to spatial functions. The rule set 3 configures a core unit (see Fig. 3), as a starting point of the remaining configuration, which will include a main entrance in the ninth step of the grammar. Rule3.1 develops a room module into a defined core unit (R_C), while two space modules are changed to a core unit, which results in a double-size room unit (2a) through Rule3.2. Rule3.3 combines a room unit and a hall unit as a core unit. Rule3.4 integrates a room unit, a hall unit, and an attached room unit into a core unit.

The other five rule sets in the second phase relate to configuring functional zones and also considering the spatial relationships between zones. Table 2 indicates the rule categories within each rule set. The categorisation is changeable according to the purpose of the research. Thus, it can be differently classified from the other

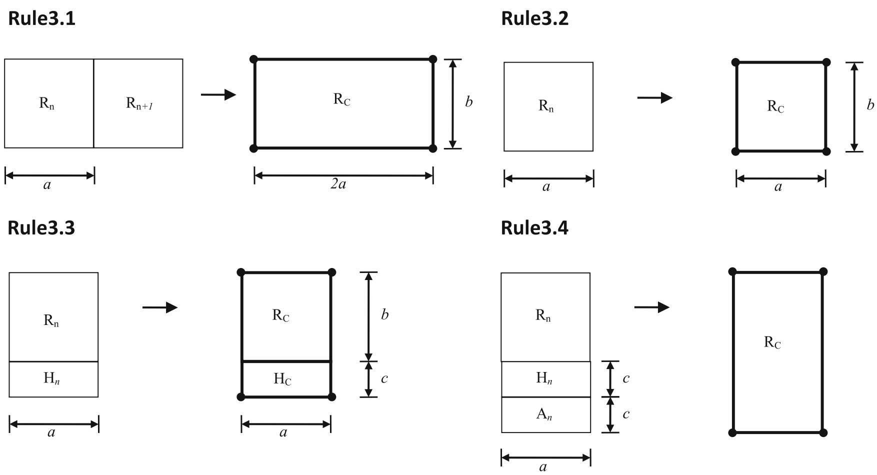

Fig. 3 The third rule set configuring a core unit

Table 2 Rule sets configuring functional zones

Rule set	Rule	Description
Rule4.x	4.1 4.2 4.3 4.4	Generating one public zone (LDK, LD + K) from the side of a core unit Generating separated public zones Generating public zones including a core unit Generating other public zones such as a music room
Rule5.x	5.1 5.2 5.3 5.4 5.5	Generating one bedroom from the side of a public zone Generating two bedrooms from the side of a public zone Generating a bedroom from the side of a core unit Generating two bedrooms from the side of a core unit Changing a core unit into a bedroom
Rule6.x	6.1 6.2 6.3	Skipping and going to the next rule set Developing verandas Defining a court as a transition zone
Rule7.x	7.1 7.2	Developing hall units into a hall unit Changing part of a core unit into a hall unit
Rule8.x	8.1 8.2	Defining a garage unit Skipping and going to the next rule set

perspectives. However, the computational analysis will follow the same sequence as presented in this chapter.

To accurately configure room modules, a rule will need to consider three application properties, i.e., direction (D), width (w), and length (l). For example, a particular rule (4.x) in the fourth rule set can be represented as ‘Rule4.x$(R_n)_{D,w,l}$’. Figure 4 illustrates an example shape rule from this rule set with the three properties. For example, Rule4.2 in Fig. 4 consists of (i) Rule4.2$(R_c)_{right,4a,\,(2b+c)}$, (ii) Rule4.2$(R_c)_{left,2a,\,(1.5b+c)}$, and (iii) Rule4.2$(R_c)_{null,2a,\,(b+2c)}$.

The third phase includes two rule sets. There are three rules for defining a main entrance: Rule9.1 defines a main entrance in a hall space; Rule9.2 defines a main entrance in transition zones; and finally Rule9.3 defines a main entrance in public zones. Defining sub entrance can be triggered multiple times. There are five rules for such purposes: Rule10.1 defines a sub entrance in a garage unit; Rule10.2 defines a sub entrance in a hall unit; Rule10.3 defines a sub entrance in public zones; Rule10.4 defines a sub entrance in private zones; and Rule10.5 skips to execute the ‘Termination’ rule. The final phase (the rule set 11) has one sole purpose which is to terminate the generation process for the shape grammar.

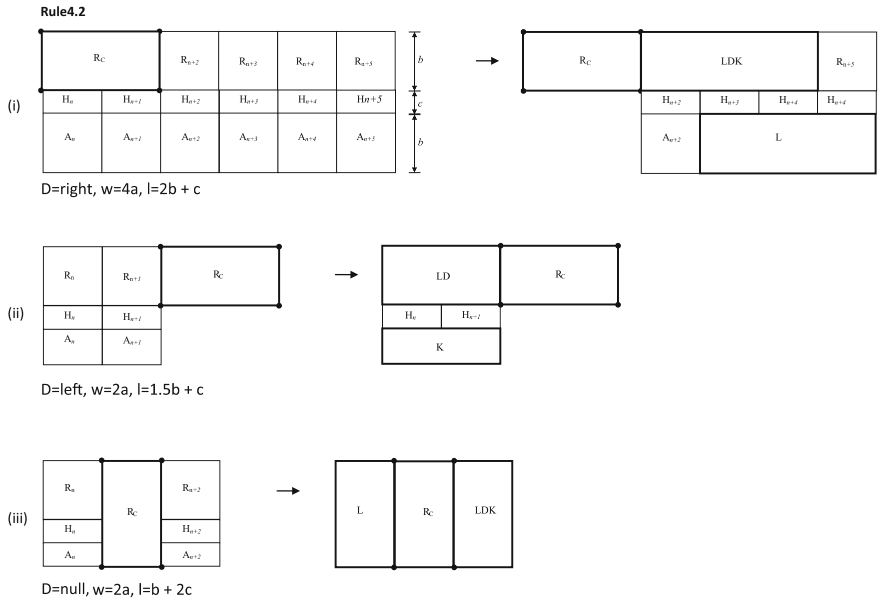

Fig. 4 An example shape rule, Rule4.2, from the fourth rule set, with direction (D), width (w), and length (l)

3 Grammar Application

3.1 Frequencies of the Applied Rule Sets

This section uses ten houses by Glenn Murcutt (built between 1975 and 2005) to demonstrate the application of the shape grammar (See Fig. 5). These selected cases have been syntactically examined in Ostwald's works [9, 10]. The first part of the section examines the tendency of the applied rules in the selected cases. The second part of the section illustrates an alternative way to characterising each case through a mathematical abstraction using the frequencies of the applied rule sets, the so called 'normalised distance'.

Table 3 lists the rules applied to generate the ten cases by Murcutt. For example, to generate the first case, the shape grammar application uses the set of rules, 1.1, 2.1, 3.1, 4.1, 5.3, 5.5, 6.1, 7.2, 8.2, 9.1, and 10.5. For generating Cases 1–6, Rule1.1 is applied in the first rule set to generate single-pavilion shapes. Rule1.2 is used to generate the two-pavilion shapes for Cases 7–10. Table 3 provides fundamental information to conduct the mathematical analysis on the application of the grammar.

Table 3 Rules applied for generating the ten Murcutt houses

Rule set	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
1.x	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2
2.x	2.1	2.1	2.1	2.1	2.3	2.3	2.2	2.2	2.2	2.2
3.x	3.1	3.1	3.2	3.2	3.3	3.1	3.4	3.1	3.1	3.1
4.x	4.1	4.1	4.1	4.1	4.1	4.2, 4.4	4.2	4.3	4.3	4.2
5.x	5.3, 5.5	5.4	5.1, 5.4	5.4	5.1, 5.3	5.2	5.1, 5.2	5.1, 5.2	5.2	5.1, 5.3
6.x	6.1	6.2(2)[a]	6.1	6.1	6.1	6.1	6.3	6.2(2)	6.2	6.1
7.x	7.2	7.2	7.2	7.2	7.2	7.1(2)	7.1	7.1(3)	7.1(2)	7.1
8.x	8.2	8.2	8.1	8.1	8.2	8.1	8.1	8.2	8.2	8.1
9.x	9.1	9.1	9.1	9.1	9.1	9.3	9.2	9.2	9.2	9.3
10.x	10.5	10.5	10.1, 10.3, 10.4	10.1, 10.3	10.2	10.1, 10.2, 10.3	10.1, 10.4	10.1, 10.2(2)	10.2, 10.3	10.1, 10.2

[a]The number inside parenthesis indicates the number of times the rule is applied

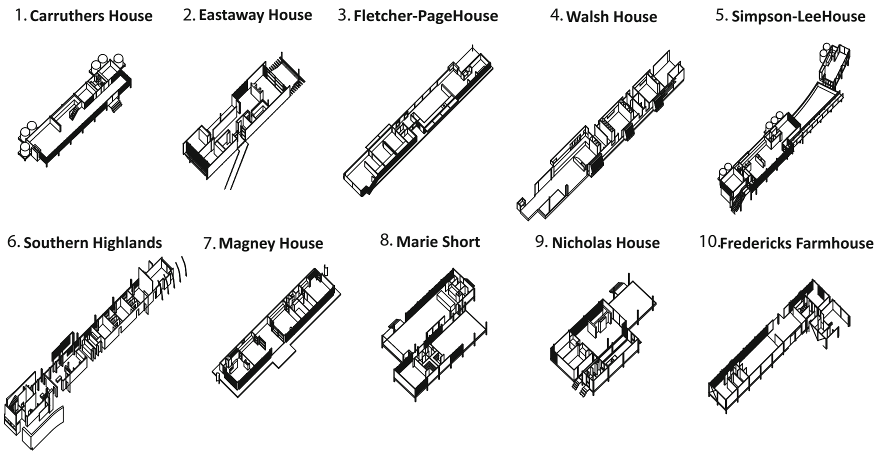

Fig. 5 Ten cases of Murcutt's domestic architecture

Table 4 Frequencies of each applied rule

Rule set	x.1	x.2	x.3	x.4	x.5	Mean	SD
Rule1.x	6	4	–	–	–	5.00	1.41
Rule2.x	4	4	2	–	–	3.33	1.15
Rule3.x	5	3	1	1	–	2.50	1.91
Rule4.x	5	3	2	1	–	2.50	1.71
Rule5.x	5	4	3	3	1	3.20	1.48
Rule6.x	6	5	1	–	–	4.00	2.65
Rule7.x	9	5	–	–	–	6.50	3.54
Rule8.x	5	5	–	–	–	5.00	0.00
Rule9.x	5	3	2	–	–	3.33	1.25
Rule10.x	6	6	4	2	2	4.00	2.00

3.2 Normalised Distance

Table 4 indicates the frequencies of each applied rule in the grammar when generating each case. Using the information contained in Table 4, the remaining of the chapter introduces an alternative approach to analysing the grammar application and to visualising the characteristics of each case in terms of its generation process.

The frequencies of the applied rules can be recorded within the set of the ten cases. They suggest the level of tendency to select a particular rule or pattern during the generation process. The tendency of each rule can therefore form a typical language or style of Murcutt in terms of the shape grammar application. In order to thoroughly investigate this tendency issue, we firstly sorted the applied rules at each step of the grammar application. Secondly, the frequency of each applied rule was calculated. Finally, the most frequently applied rule was set to the first sub rule (x.1) and the next

Table 5 Normalised distance of each applied rule

Rule set	x.1	x.2	x.3	x.4	x.5
Rule1.x	0.00	1.41	–	–	–
Rule2.x	0.00	0.00	1.73	–	–
Rule3.x	0.00	1.04	2.09	2.09	–
Rule4.x	0.00	1.17	1.76	2.34	–
Rule5.x	0.00	0.67	1.35	1.35	2.70
Rule6.x	0.00	0.38	1.89	–	–
Rule7.x	0.00	1.41	–	–	–
Rule8.x	0.00	0.00	–	–	–
Rule9.x	0.00	1.60	2.41	–	–
Rule10.x	0.00	0.00	1.00	2.00	–

frequently applied rule was set to the second sub rule (x.2), and so on. This means that the rule closes to the first sub rule in each rule set can generate a dominant archetype in the language of design because it is most frequently applied in the shape grammar application (see Table 5).

Table 5 provides the normalised distances that have been calculated by each applied rule's normalised frequency in relation to the rule that is most frequently applied. Each normalised value indicates the standardised frequency based on each mean frequency. It is denoted by $Rule_x = (x = 1 \text{ to } 10)$. $Rule_x = \{Rule_{x.y}\text{: y} = 1, 2, 3, \ldots, \text{k}\}$, k = max number of sub rule y in the rule set, $Rule_x$. The normalised frequency of one of the rules $Rule_{x.y} \in Rule_x$ is:

$$F_{normalised}(Rule_{x.y}) = F'(Rule_{x.y}) = \frac{F\left(Rule_{x.y}\right) - \overline{F\left(Rule_x\right)}}{SD} \quad (1)$$

where:

F is the frequency of each rule being applied in the grammar for generating the ten houses, SD is the standard deviation of the frequencies of $Rule_x$. Each rule's normalised distance is then calculated by the absolute value of each normalised frequency subtracted by the normalised value of the most frequently applied rule. The sub rules of each rule set have been sorted by the application frequency in generating Murcutt's ten houses (see Table 3). That is, sub rule $Rule_{x.1}$ is the most frequently applied rule in each rule set. Thus, the normalised distance (ND) of the frequency of one of the rules $Rule_{x.y} \in Rule_x$ is:

$$\text{ND}\left(Rule_{x.y}\right) = \left|F'(Rule_{x.y}) - F'(Rule_{x.1})\right| \quad (2)$$

4 The Uniqueness of Murcutt's Domestic Architecture

Pritzker-prize-winning architect Glenn Murcutt has created his own design style in his domestic architecture regardless if it was originally intended. There are obviously unique design principles in his work, e.g. the use of long corridors or corrugated metal roof sheets for the long-narrow forms. However, only a few studies [10, 11] have conducted comparative analyses on his specific language of designs. This section presents a quantitative way to grammatically measuring the uniqueness of Murcutt's domestic architecture through the normalised distance of each case.

4.1 Grammatically Measuring the Uniqueness in Language of Designs

Table 6 indicates the normalised distances (NDs) of the applied rules to generate each case. The sum of the NDs can be understood as an indicator for the uniqueness of each case because it represents how far the applied rules from the most typical ones. In this way, Cases 3 and 4—Fletcher-Page House (1998) and Walsh House (2005) that are more recently built—may be regarded as typical instances in terms of the properties and modular systems of the shapes most frequently used in Murcutt's domestic houses. This is a very interesting finding because it is evident that both have shown a typical syntactic pattern as suggested in the other research using a Justified Plan Graph (JPG) grammar [11, 12]. This result indicates that the shape grammar developed here can also capture the syntactic properties in architecture. In particular, rules in the second phase of the grammar, relating to configuring spatial relationships, may have caused this similar outcome achieved through the JPG grammar.

By contrast, Case 7, Magney House, may be a less typical one of the entire group, which can be treated as the most unique case in this particular language of designs. This is because rules that are relatively rarely applied in generating this case (see also Fig. 6), for example, the composition of a room unit, a hall unit, and an attached space unit to form a core unit (Rule3.4); a court to become a transit zone (Rule6.3); to define a sub entrance in a private zone (Rule10.4).

Figure 6 illustrates examples of designs generated by each rule set and the values that can suggest their uniqueness in language of designs. Since the first sub rule is the most frequently applied rule in the rule set, its ND is always zero. The farthest sub rule is Rule5.5, whose distance is 2.70. Thus, the NDs can easily demonstrate the disparity of each rule from a typical rule in the set. When we generate new design instances using the grammar, the values of the above measurements can guide the selection of rules or the transition between rules to suit different design purposes. The design instances generated by the grammar can freely scale between being most consistent to and being most unique from the original Murcutt language. In other words, the values of NDs of the applied rules can support the quantitative analysis as well as the grammatical generation of language of designs.

Table 6 The NDs of the applied rules for generating each case

	1.x	2.x	3.x	4.x	5.x	6.x	7.x	8.x	9.x	10.x	Sum
Case 1	0	0	0	0	2.03	0	1.41	0	0	2.00	5.44
Case 2	0	0	0	0	1.35	0.38	1.41	0	0	2.00	5.14
Case 3	0	0	1.04	0	0.68	0	1.41	0	0	1	***4.13***
Case 4	0	0	1.04	0	1.35	0	1.41	0	0	0.50	***4.30***
Case 5	0	1.73	2.09	0	0.68	0	1.41	0	0	0	5.91
Case 6	0	1.73	0	1.76	0.67	0	0	0	2.41	0.33	6.90
Case 7	1.41	0	2.09	1.17	0.34	1.89	0	0	1.60	1	***9.50***
Case 8	1.41	0	0	1.76	0.34	0.38	0	0	1.60	0	5.49
Case 9	1.41	0	0	1.76	0.67	0.38	0	0	1.60	0.50	6.32
Case 10	1.41	0	0	1.17	0.68	0	0	0	2.41	0	5.67
Mean	0.56	0.35	0.63	0.76	0.88	0.30	0.71	0	0.96	0.73	5.88

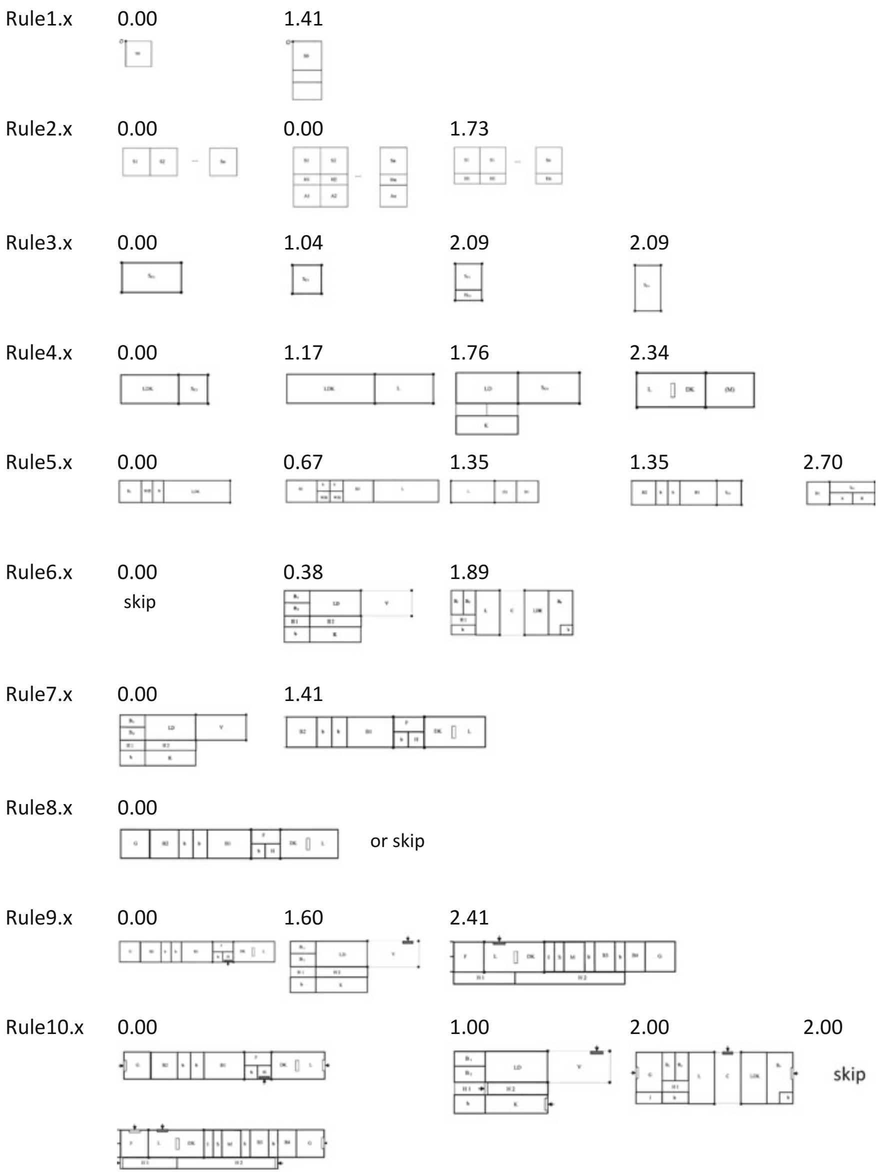

Fig. 6 Designs generated by each rule set and values suggesting their uniqueness

4.2 Grammatically Measuring the Spatial Uniqueness

The second phase of the grammar configures spatial functions, and the other aspect of our grammatical analysis is about capturing the functional uniqueness of each case. This section focuses on three (rule sets 4, 5, and 6) out of six rule sets in that phase.

Table 7 Applied rules for the development of three functional zones and their related NDs

	Applied rule			Normalises distance (ND)		
	Rule4.x (Pu)	Rule5.x (Pr)	Rule6.x (T)	Rule4.x (Pu)	Rule5.x (Pr)	Rule6.x (T)
Case 1	4.1	5.3, 5.5	6.1	0	2.03[a]	0
Case 2	4.1	5.4	6.2(2)	0	1.35	0.38[a]
Case 3	4.1	5.1, 5.4	6.1	0	0.68[a]	0
Case 4	4.1	5.4	6.1	0	1.35	0
Case 5	4.1	5.1, 5.3	6.1	0	0.68[a]	0
Case 6	4.2, 4.4	5.2	6.1	1.76[a]	0.67	0
Case 7	4.2	5.1, 5.2	6.3	1.17	0.34[a]	1.89
Case 8	4.3	5.1, 5.2	6.2(2)	1.76	0.34[a]	0.38[a]
Case 9	4.3	5.2	6.2	1.76	0.67	0.38
Case 10	4.2	5.1, 5.3	6.1	1.17	0.68[a]	0

[a]The average value of the NDs of the applied rules

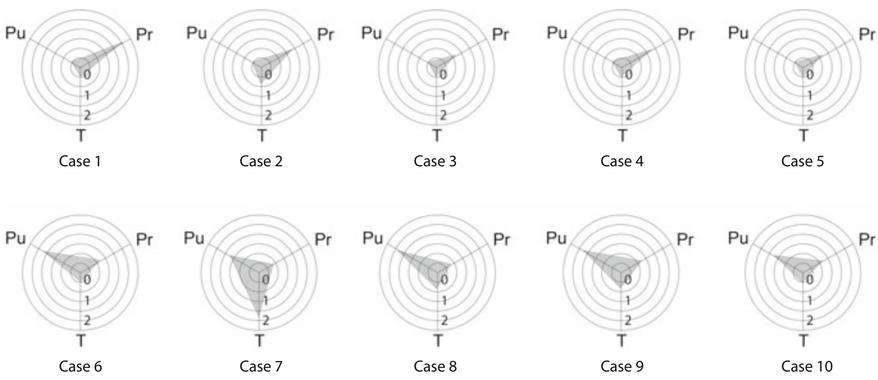

Fig. 7 Visualising the NDs of the applied rules for generating three functional zones in each of the Murcutt cases

The rule set 4 relates to configuring public zones. The rule set 5 configures private zones. In addition, rule set 6 configures transit zones and this is often considered as one of the interesting characteristics in Murcutt's domestic architecture. Table 7 indicates the rules to generate the three functional zones in the development of each design and the relevant NDs. Figure 7 illustrates the three quantitative variables (i.e., NDs) on three axes, for public zone (Pu), private zone (Pr), and transition zone (T) respectively.

The research uses the radar chart (Fig. 7) to graphically display the multivariate data in Table 7. This allows us to visually compare those properties of each case in terms of functional relations. In this chapter, we apply these visualisations of functional, spatial relations to define and compare 'spatial uniqueness' between the selected cases. Interestingly, the first five share a similar pattern in configuring their private zone, while the last five have more common configurations in their public zone with Case 7 varying in the transit zone.

5 Conclusion

The computational analysis of design instances presented in this chapter is a general method that can be applied to the other Shape Grammar studies. It articulates the measurements through the design grammar in terms of the frequency of the applied rules and the categorisation of rule sets. These allow for the exploration of an architectural language or style. In particular, the grammatical analysis demonstrated in this method is through ND, which is based on the frequencies of the applied rules for generating the language of designs.

The shape grammar introduced in this chapter has a sequential or linear process with 11 steps over four phases, but in design practice, there is always complexity such as involving recursive processes and with varying steps. However, as many previous studies have suggested, ‘selectively adopting sequential design steps’ can help to discover a logical analogue of the grammatical design process embedded in architecture. This is especially effective in terms of design analysis.

Through the application of the grammar to Murcutt’s domestic architecture, this research has showed that this grammatical approach allows for quantitatively analysing designs in a particular language of designs or style by characterising the uniqueness of design, capturing both dominant and unique patterns. The statistical tendency of each rule is then calculated and visualised, which support the generation of an archetype. The probability of the applied rules will also enable us to mathematically investigate the generation of design instances. Thus, this approach could be used to explore both analytical and generative issues in design.

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Craft, Performance, and Grammars

Terry Knight

Abstract Recent interest in new digital and computational ways of making has been paralleled by rising interest in traditional making and craft practices. Most efforts to merge digital and craft practices focus on the things produced, with attention to process only to the extent that it informs results. However, the socio-cultural, aesthetic, and creative dimensions of a craft practice are expressed in its performative, temporal aspects as much as in its products. A new computational theory of making offered by *making grammars* points to new possibilities for the study of temporal performance. In this paper, I use traditional *kolam* pattern making in India as a case study to probe the potentials of making grammars to represent craft performance, in contrast with the use of shape grammars to represent craft designs. Different generative strategies are revealed in the comparison.

Keywords Shape grammar · Making grammar · Craft · Performance Temporality

1 Introduction

Recent interest in new ways of making and in computational tools, technologies and theories to support them has been paralleled by rising interest in traditional making and craft practices. Researchers look to by-hand techniques and traditional materials to advance digital fabrication with new materials. Conversely, hand-crafters experiment with digital fabrication and new materials to expand the possibilities of their craft. "Digital craft" [1] is a phrase often used for work fusing made-by-hand and made-by-machine methods. In architectural design, craft techniques such as sewing or weaving are emulated in fabrication processes [2], and traditional materials such as bamboo are combined with digital fabrication [3].

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Fig. 1 Calligraphy performance by Mohri Suzuki ©TOKYO-SKYTREETOWN (left) and Turkana (Kenya) women weaving baskets © http://www.safari254.com (right, retrieved from [5])

Most efforts to merge craft sensibilities and practices with new making technologies and computational strategies focus on the things produced (from buildings to jewelry), with attention to making processes only to the extent that they facilitate or inform results. Relatedly, important socio-cultural dimensions of craft are often left behind in the borrowing or emulation of craft techniques. Socio-cultural aspects of craft, along with aesthetic and creative ones, are expressed in the products of craft practices. But, just as important or even more so, they are expressed in the *performative*, temporal aspects of craft. Craft activities, weaving and calligraphy for example (Fig. 1), are often public or communal activities—performances in time—meant to be shared or viewed. They may be deeply imbued with unique cultural values and expressive of cultural identities. Understanding and making explicit, even formalizing and computing, the performative aspects of a craft may help provide new insights into its cultural dynamics as well as its creative and generative possibilities. However, the performative nature of craft—its embodied, improvisational, and time-based qualities—may seem an uncomfortable fit with formal computation, especially computation of the digital kind.

A new computational theory of making offered by *making grammars* [4], though, points to new possibilities for the study of craft practice. Making grammars are an adaptation of shape grammars, a long-standing computational theory of design. In this paper, I use traditional *kolam* pattern making in India as a case study to probe the potentials of making grammars to understand and represent craft performance, in contrast with the use of shape grammars to understand and represent craft designs. In particular, I consider how making grammars might be used to express temporal aspects of craft performance. While I do not consider explicitly the socio-cultural aspects of craft, or kolam in particular, my work here suggests a computational basis for socio-cultural and other inquiries.

2 From Shape Grammars to Making Grammars

Shape grammars provide a unique, computational theory of design, one aligned especially well with creative design practice. They are distinctive for their visual approach. The rules of a shape grammar generate designs by computing directly with shapes made of basic spatial elements (points, lines, planes, and solids), rather than with symbols, words, numbers, or other abstract structures that represent visual shapes indirectly. Computations with shape rules involve seeing and doing. In each step of a computation, the user can choose what shape to see and then what action, or rule, to apply next.

Designing with shape grammars is thus a kind of performative, making activity. Shape grammar theory offers a natural basis for a computational theory of making. Designing with shape grammars is about *doing* (drawing) and *seeing* with *basic spatial elements* to make *shapes*. George Stiny and I [4] have recently extended this definition of designing to a definition of making: making is *doing* and *sensing* with *stuff* to make *things*. I summarize the details of our work here, beginning with informal definitions of the terms we use. *Doing* is any physical action such as drawing, knotting, folding, typing, throwing, stomping, and so on. *Sensing* includes any one or more of our senses. Both doing and sensing can be done with "tools". Tools might be our bodies' "tools" such as our hands or our eyes, or tools might be extensions of our bodies, for example, pencils or eyeglasses. Both doing and sensing might include actions or sensings by a machine as well as by a person. *Stuff* includes physical materials like gases, liquids, or solids with properties that can be visual, acoustic, mechanical, geometric, and so on. A little more abstractly, stuff can be points, lines, planes, and solids. *Things* are finite objects made of stuff.

With these definitions in hand, Stiny and I adapted shape grammars for computing or making shapes to *making grammars* for computing or making things [4]. The rules of a making grammar are based on both the thing being made and a person's sensory interactions with that thing. Thus, a making grammar is a theory of both the constructive and the sensory aspects of a making activity. Of course, a making grammar, like any finite description, can never capture all aspects of a making activity and can only approximate it. The rules are limited to particular aspects of interest.

A making rule has the general form M → N where M and N are sensed things. More specifically, M and N are things with any sensory interactions with them indicated in some explicit fashion. Details of these sensory indications may vary according to the things made. The arrow → denotes "replace with" in the usual, formal way. In terms of making, though, the arrow → stands for a particular doing and/or sensing.

A making rule M → N applies to a (sensed) thing T being made, when the maker can identify a copy of M in the thing T. Then the thing M can be changed into the thing N. Depending on the thing being made, the formal definition of "copy" might be the same as that for shape grammars, or it might be specific to the things computed.

A making rule can be distinguished as either a *sensing rule* or a *doing rule.* A *sensing rule* represents a perceptual change in a person, through the person's sensory actions (moving hands, eyes, etc.) with a thing. It represents a change, shift, or (re)focus of attention in how a thing is perceived. A sensing rule A → B says: If a (sensed) thing A is a part of a current (sensed) thing being made, then (re)grasp, (re)focus on, attend to it (with eyes, hands, nose, etc.) as shown by the (sensed) thing B. A *doing rule* represents a physical change in a thing through a person's physical actions (folding, drawing, etc.) with the thing. A doing rule X → Y says: If a (sensed) thing X is a part of a current (sensed) thing being made, then do something to it as shown by the (sensed) thing Y.

Separating sensing and doing in a making activity is subjective and represents a particular perspective on that activity. Sensing and doing may sometimes be inseparable. In this case, a making rule may represent sensing and doing simultaneously, in other words, a simultaneous change in a person and in a thing through the person's sensory and physical actions.

In our preliminary work on making grammars, Stiny and I gave an example of a making grammar for knotting strings, a highly tactile making activity inspired by *khipu*, the knotted strings made by the Incas as a physical recordkeeping and communication language. The knotting grammar generates single and multiple overhand knots along a string. In this grammar, the things are knotted strings, the stuff is fiber, doing is knotting (looping, pulling, etc.), and sensing is touching (grasping, focusing attention, repositioning) with the hands. The rules include doing rules for knotting and sensing rules for touching or grasping, as well as a combined sensing and doing rule. The grammar is a highly schematized version of an actual knotting process. But it is suggestive of the possibilities for making rules to encode temporal qualities of knot making. As Stiny and I noted in our paper, the rules capture natural stopping or stable points in a continuous tying process. Readers can refer to [4] for more details of this example and making grammars in general.

3 Making Time and Making Grammars

A key feature of making is time. Craft practices, and making activities in general, are continuous, temporal events.

Making sense of and participating in a craft practice not only involve structuring in some way the spatial aspects of the things being made, they also involve structuring the temporal actions involved in the making of those things. Such structuring might be retrospective and deliberative—as in analysis—or it might be impromptu and on-the-fly—as in real time making. Shape grammars focus on the spatial qualities of designs and the ways that rules structure designs by segmenting them spatially through visual perception. Making grammars offer opportunities to explore the temporal qualities of making things, and the ways that rules structure and segment things and their making both spatially and temporally.

Formal studies of the temporal dimensions of craft and other creative making activities are sparse. Exceptions include a proposal for a grammar of human movement related to architecture [6], and some studies of movement segmentation and perception in dance [7, 8]. However, research on the temporal dimensions of routine, everyday activities and events, such as making a bed or drinking a cup of coffee, is more prolific. Research of this kind is pursued in different fields and with different objectives. In philosophy, debates revolve around the formal concept of an "event", including, for example, how an event is related to space and time and how it is represented [9]. In cognitive science and psychology, researchers investigate how people perceive and comprehend the continuous, fluctuating, multi-sensory stream of actions in the world. A central idea here is that in order to perceive, understand, learn, predict, and act in the world, people discretize the continuous flow of events into temporal chunks, each with beginning and end boundaries [10]. Analogies are made between event perception and object perception: both events and objects can be segmented and organized hierarchically into bounded parts. In computer science, AI, and robotics, researchers take a more functional and application-oriented approach. Here, the overall objective is to understand human motion in order to build computational models (and robots) to recognize, represent and generate human-like actions and gestures [11]. The temporal segmentation of motions into discrete, primitive actions is central to this enterprise, as well as the segmentation of the objects and people engaged in motions. Linguistic approaches using rules and grammars for representing actions are common [12, 13]. Notational systems from dance, for example Laban movement analysis, are also sources for computational models [14]. In general, researchers aim for automated segmentation strategies that will be applicable across diverse human activities. At the same time, the temporal segmentation of continuous activities is recognized as complex, ambiguous, and subjective [15].

The idea behind making grammars intersects with some of the ideas above, in particular the roles of spatial and temporal segmentations in understanding and generating events and actions. Making grammars, though, make no claims for generalized knowledge about the way people segment the world. The rules for different making activities, and the ways rules segment making activities, can vary as widely as the things studied and the people who make them. Also, making grammars are directed toward creative human activities—not cutting an apple. Moreover, making grammars are limited to representations of things and how they are sensed. Other context, such as the maker or performer, the physical setting, and so on, which are sometimes included in computer science work, are not included in making grammars.

A making grammar can describe and structure both the spatial and temporal aspects of things and their making through its rules. Making rules describe spatial aspects of things by segmenting things spatially in the same way that shape rules describe spatial aspects of shapes by segmenting shapes spatially. More specifically, a making rule defines a spatial segmentation of a thing when it is applied in a computation. When a making rule $M \rightarrow N$ is applied to a thing T, it segments T into M and other parts of T.

Making rules also suggest the possibility to define temporal segmentations of the making of a thing. In a making rule M → N, the replacement operation → can be interpreted as a doing or sensing action in time. A making rule defines a temporal segmentation of the making of a thing when it is applied in a computation. When a making rule M → N is applied to a thing T to make another thing T', it segments a continuous making process into temporal breakpoints defined by T and T'. Additionally, the duration of the action represented by a making rule might be described by associating a clock or timer with the rule as Stiny and I discussed in our introductory work on making grammars [4].

In the following section, I use the traditional craft of kolam making in India to suggest how a making grammar might be used to study the performative, time-based nature of a craft practice in contrast to how a shape grammar is used to describe the products of a craft practice.

4 Kolam: Easy to Design, Hard to Make

Kolam are traditional, ritualistic patterns made in the southeastern state of Tamil Nadu in India. They are customarily made by women on the thresholds of their homes (Fig. 2). Kolam making is a highly skilled practice, taught to girls from a young age by their mothers or other female relatives. Traditional kolam, called *kampi* kolam, are abstract, but many contemporary patterns include representational or figurative elements.

Kolam are made daily, early in the morning. After they are completed, they are meant to be walked on so that by the end of the day they are worn away. Patterns are created with finely ground rice powder that is trickled in a thin stream from between the fingers onto the ground. First, a regularly spaced grid of dots or *pulli* is laid out on the ground. Then the rice powder is dropped to form a line that loops around

Fig. 2 Woman making a kolam pattern from rice powder (retrieved from [16])

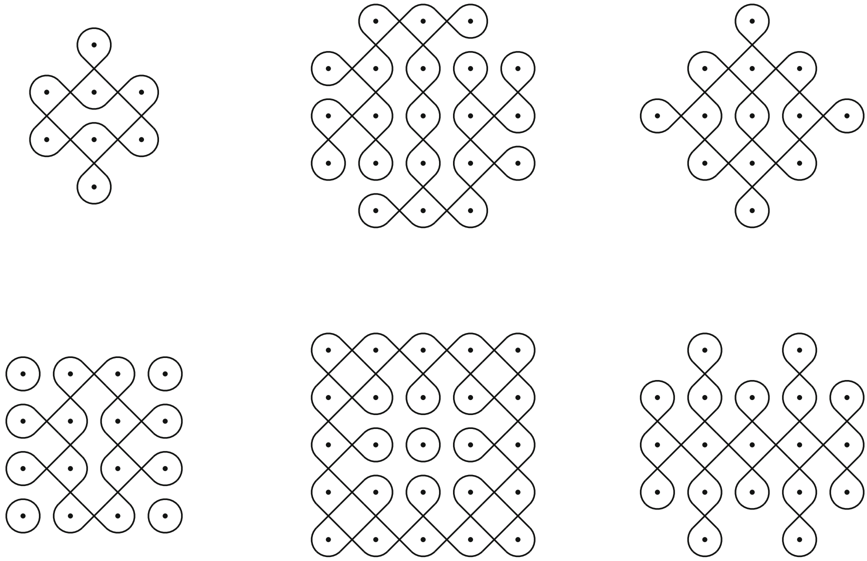

Fig. 3 Some traditional, abstract kolam patterns

the dots, intersecting itself repeatedly. Some kolam patterns are formed with one continuous self-intersecting curve that ends where it begins; others with multiple continuous closed curves. Patterns generally have reflective or rotational symmetry. Figure 3 illustrates some traditional, abstract kolam patterns.

Kolam are rich with aesthetic and cultural significance. They are ritual markers of the space between public and private worlds, they pay homage to the goddess of the earth and good luck, and they are tied to various other value and belief systems. The performance of kolam making is an important aspect of kolam folklore and is considered the locus of creativity [17].

Most studies of kolam focus on the completed patterns. Their formal properties, in particular, have attracted the attention of computer scientists and mathematicians who have analyzed the patterns in terms of graphs, combinatorics, array grammars, and L-systems (for example, see [18–20]). Much less has been written about the execution of kolam patterns. One notable exception is a study by the anthropologist Amar Mall [17], which describes the improvisational, creative, and social aspects of kolam making. It is one of few studies that references first-hand reports from women practitioners. According to Mall, women may do some preplanning of a pattern, possibly on paper, but the performance is live without a plan in hand. The execution of a kolam pattern may rely to some extent on the memory of a plan, but only as a basic model or prototype to follow. It is otherwise improvisational. The practitioner may change a plan she had in mind on-the-fly to accommodate a mistake or miscalculation, or to pursue a new idea triggered by the pattern in progress. The maturation of an initial design concept or intention evolves with its material enactment [17: 75]. The art historian Renate Dohmen also examines kolam making from a performative perspective, but with less attention to the specifics of kolam execution and more to its socio-cultural dimensions [21].

Formal analyses of the structural and mathematical properties of kolam have little bearing on the way the patterns are made as continuous lines drawn on the ground. These include generative analyses such as the shape grammar I developed for generating kolam designs [22]. The calculation of abstract designs with this grammar is very simple. However, the calculation of a kolam in real time, by tracing lines through a grid of dots so that they close back on themselves, is another story. Designing a kolam pattern algorithmically is easy. Making one is hard, requiring years of practice.

In the following three sections, I present three grammars to illustrate some differences between generating abstract kolam designs and making them—differences between plans and performances. The first grammar is the shape grammar I defined previously. It generates designs by placing motifs in a modular grid, a strategy that has little relationship to how kolam are made. The second grammar is also a shape grammar. It generates designs based on the concept of mirror curves. It begins to parallel the live process of making kolam. The third grammar is a making grammar. It attempts to capture performative aspects of kolam making. The three grammars are not illustrated here in full. Rules are given in just enough detail to convey the main generative strategies. For example, labels controlling rule applications are omitted. Also not shown are "pre-processing" and "post-processing" stages, including the initial shape and rules for defining an organizational grid at the beginning of a computation, and rules for erasing a grid and labels at the end.

4.1 A *Modular Motif* Shape Grammar

The *modular motif* shape grammar generates kolam designs by placing different motifs within a modular square grid. Motifs are placed within the grid to create continuous line patterns with rotational or reflective symmetries. The grammar begins with a symmetrical grid of square cells. The specific reflective or rotational symmetry of the grid is assumed to be indicated in some fashion, for example, by showing the point of rotation and/or axes of reflection. Each cell of the grid is marked with a dot denoting a pulli. The six rules of the grammar are shown in Fig. 4. Each rule places a different motif within a cell of the grid. Each motif touches the boundaries of a cell at one, two, three, four, or none of its four sides. Motifs are placed so that the vertices of motifs touch, creating continuous line patterns. The bold lines marking the edges of cells not touched by a motif vertex ensure that a connectivity constraint is satisfied—that designs are of one piece and cannot be partitioned into separate designs. The bold lines are shown here only as they relate to the second grammar described below. To ensure that designs are symmetric, rules must apply in parallel with respect to the reflection axis (or axes) or point of rotation in the starting grid. In other words, when a rule is applied to add a motif to a grid cell, then it applies

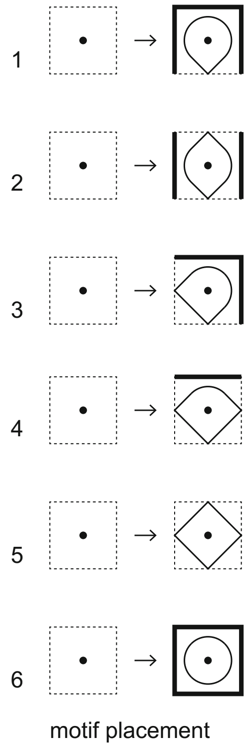

Fig. 4 The rules of the *modular motif* shape grammar

at the same time to add its symmetrical counterpart to all other cells in the grid, as necessary to maintain the overall grid symmetry. Readers can refer to the original shape grammar described in Knight and Sass [23] for further details.

A computation of a kolam design with the rules is illustrated in Fig. 5. The computation begins with a grid with vertical and horizontal axes of reflective symmetry indicated. In each step of the computation, a rule is applied in parallel to add motifs symmetrically in the grid. In the final steps, labels and the grid are erased. The final design is a new, hypothetical design. Figure 6 shows other new designs generated by the shape grammar. These designs, and all others generated by the shape grammar, are in the tradition of the original ones.

The modular motif grammar provides a neat, elegant way to compute kolam patterns. But it bears no resemblance to the way practitioners execute and compute kolam. In general, a modular grid approach to pattern generation can be simple and effective. But this approach may lack descriptive appeal when fidelity to physical or constructive features of designs is a goal, as suggested by Jowers and Earl in their work on a shape grammar for Celtic knotwork [23: 628–631].

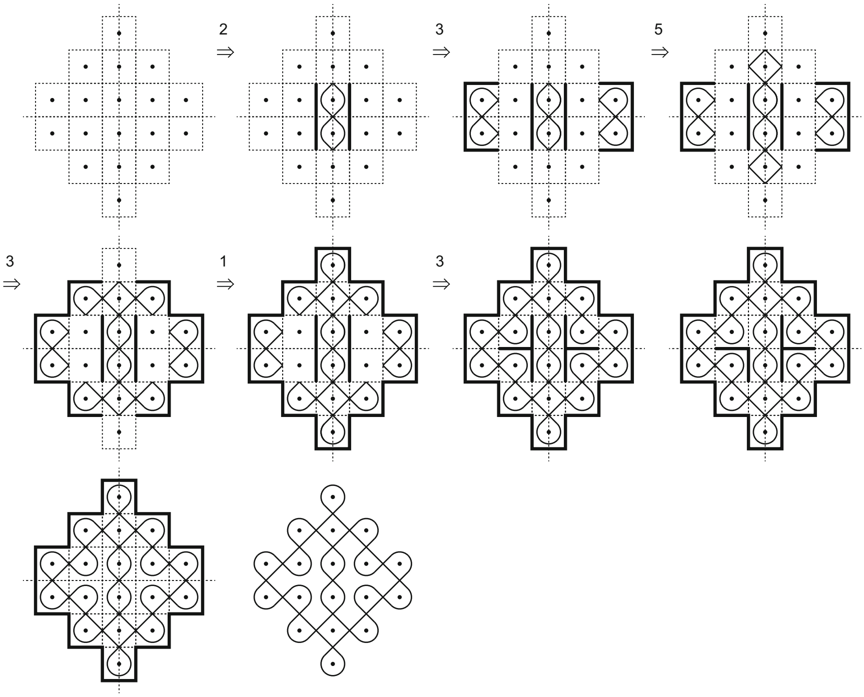

Fig. 5 A computation of a new kolam design with the *modular motif* shape grammar

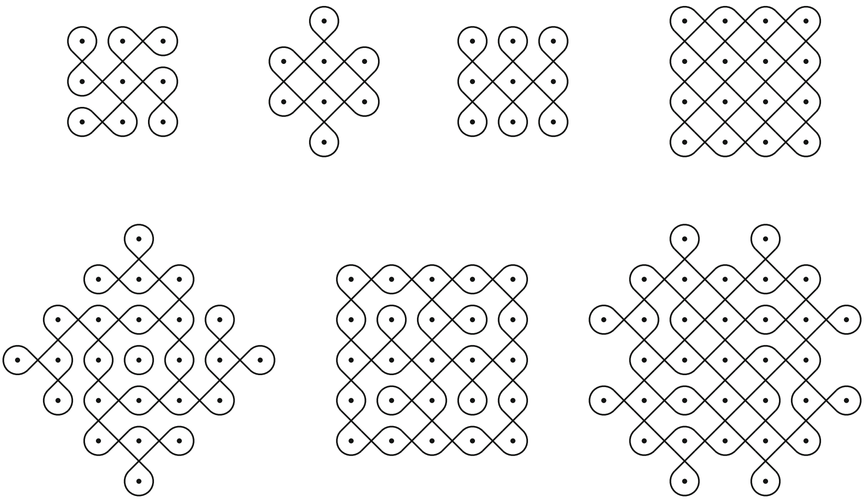

Fig. 6 New designs generated by the *modular motif* shape grammar

4.2 A *Mirror Curve* Shape Grammar

The *mirror curve* shape grammar begins to suggest a live kolam performance. It is based on the mathematical concept of a mirror curve. Mirror curves have been proposed by the mathematician Slavik Jablan and others [24] as a means for understanding and generating various cultural pattern languages, including kolam. Mirror curves are constructed beginning with a square grid which is bounded by imaginary mirrors and with internal, 2-sided mirrors coincident with some internal edges of the cells of the grid. If an imaginary ray of light is projected into the grid at a 45° angle from the midpoint of one of the boundary cells, it will bounce off any mirrors it encounters and eventually return to its starting point. Jablan illustrates the construction of a kolam by tracing a light ray, or line, cell-by-cell through a grid to create a continuous closed curve [25]. The mirror curve shape grammar formalizes this process with a few simple rules.

Like the modular motif grammar, the mirror curve grammar begins with a symmetrical square grid. The grid is then bounded with mirrors. These initial steps are not illustrated here. The main rules of the grammar are illustrated in Fig. 7. Rule 1 applies to place mirrors coincident with internal edges of the cells of the grid. Mirrors are represented by bold lines. These bold lines have the same function as the bold lines in the rules of the previous grammar. (Bold lines here might be considered as either weighted lines or labels.) Additionally, this rule must apply in parallel, in the same way as the rules of the previous grammar, to ensure that designs are symmetric. Rule 2 places a line in any cell to begin the computation of a closed curve. Rule 3 continues a line through to the adjacent cell when no mirror is present. Rule 4 bounces a line off a mirror to deflect its path 90°.

A computation of a kolam design with the rules is illustrated in Fig. 8. The computation begins with the same grid as in Fig. 4. In the first step, the grid is bounded by mirrors. Subsequent steps show how a continuous line is computed cell by cell to derive the same design computed by the modular motif grammar. The rules of this shape grammar define exactly the same set of design possibilities as the modular motif grammar.

The mirror curve grammar provides another simple and elegant way to compute kolam patterns. Because it generates kolam by drawing a continuous line, it is more suggestive of kolam making than the previous grammar. But the instantiation of mirrors at the start suggests a fixed, preplanning of a design that may not be reflective of actual performance. Also, the step-by-step, cell-by-cell drawing of a line seems an inadequate segmentation of an actual temporal performance. With the next grammar, I look at ways to address these inadequacies.

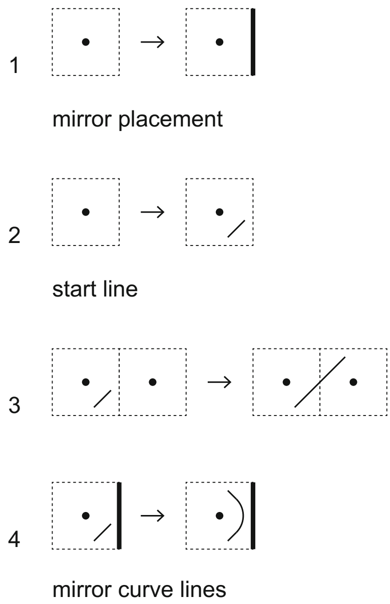

Fig. 7 The rules of the *mirror curve* shape grammar

4.3 A *Line on a Walk* Making Grammar

The real-time making of a kolam is a complex physical, perceptual, and cognitive activity. The maker may begin with a plan in mind, but the plan might change in the making. According to practitioners, creativity—the emergence of novel patterns—lies in unanticipated departures from an initial plan [17: 70]. I sketch out a making grammar here to capture some of the live aspects of kolam making, aspects which are not as readily described with a shape grammar. Representing a kolam activity with making rules is still a challenge, but this first attempt reveals generative strategies different from those encoded by the two shape grammars above. A different perspective on the art of kolam is suggested.

The main characteristics of kolam making, drawn from my observations of video recordings and from documented first-hand reports [17], are summarized as follows. A pattern begins with the placement of a grid of pulli, which determines the size, proportions, and bounding shape of a final kolam pattern. Pulli might be added to change the overall shape of a kolam as the pattern is being made. The starting line of a kolam begins between two pulli along the boundary of the grid. The line is extended by weaving it between pairs of pulli, one or more pairs at a time. The default strategy is to draw a straight line along a diagonal at a 45° angle to the grid boundary, between one pulli and an adjacent one in succession, as shown in Fig. 9. When a line reaches a boundary pulli, it is deflected from its path by 90° to loop around the pulli. Before a line reaches a boundary pulli, it can be deflected in its path internally by 90°, 180°, or 270° around an internal pulli and then return to a straight path. It can also make

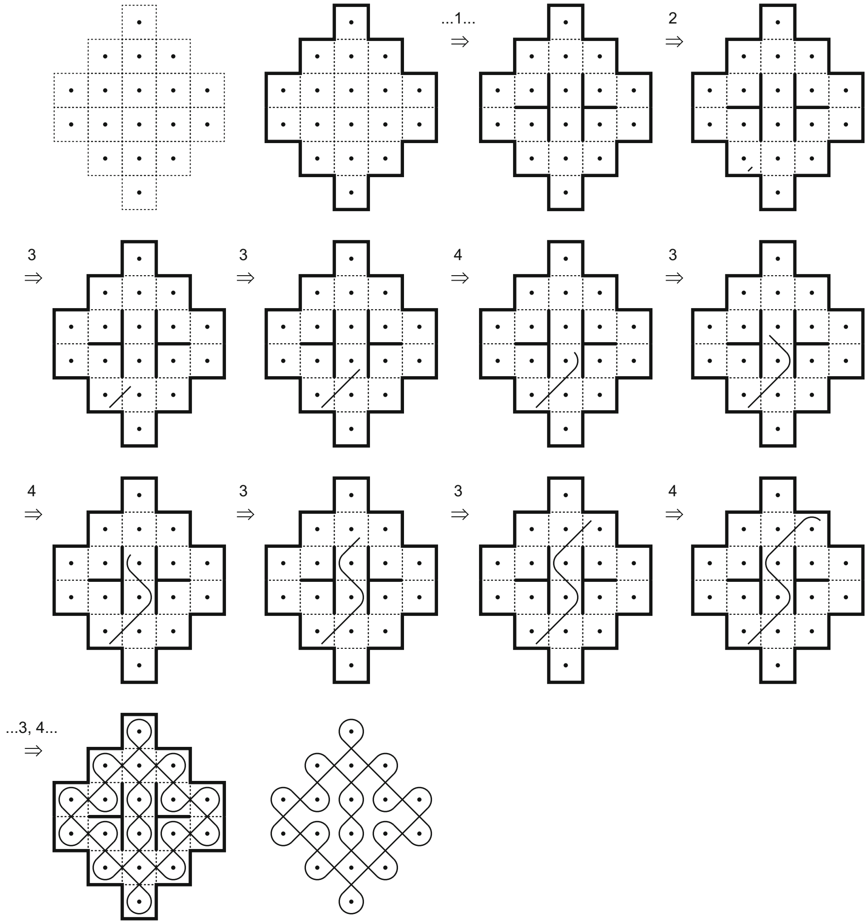

Fig. 8 A computation of a new kolam design with the *mirror curve* shape grammar

a 360° turn to form a circle. Also of note, a line can be continued from either of its endpoints, including the starting point. A line is advanced in segments defined by the maker's gestures; the lengths of segments and time they take to make seem to depend on whether and how the line curves, the size of the overall pattern, the quantity of powder in hand, and the skill and personal habits of the maker. A line continues to be extended until its two endpoints meet or the line overlaps itself. If some of the pulli in the grid have not been enclosed by a line, then the process begins again starting with an open, boundary pulli. Thus, the final kolam pattern may be made of multiple, overlapping closed curves. Multiple closed curves are always laid out in sequence and symmetrically to produce an overall pattern with symmetry.

A making grammar that approximates this process is outlined in Fig. 10. There are considerably more rules in this grammar than in the previous grammars in order

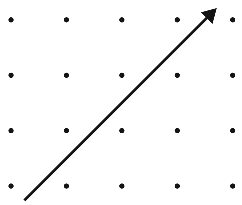

Fig. 9 A straight line through the pulli grid

to express the different variations of weaving that go into the making of a kolam. Computations are longer—take more time—as well. The grammar is called *line on a walk* after the artist Paul Klee's well-known portrait of a line. The continuously advancing, self-intersecting line that generates a kolam is like Klee's line "out on a walk", a line as a "point that sets itself in motion", in other words, a line as the trace of movement [26: 105]. The rules of the grammar correspond to how a kolam maker sees, draws, and calculates a line as she moves around the pattern emerging on the ground. The making rules are divided into sensing rules and doing rules. Sensing rules are limited to seeing, and doing rules correspond to drawing. Seeing rules and drawing rules come in pairs. Seeing is always followed by drawing. The idea is that the kolam maker continually looks ahead to see where the next pulli are to decide which way the line should go.

Like the previous shape grammars, the making grammar begins with a symmetrical grid of pulli. However, an organizational square grid is not shown. Only the pulli are shown, as in an actual performance. Rule 1 begins a line. The seeing component of the rule identifies a pulli with which to begin, indicated by a red dot. The drawing component initiates a line. The line has a red arrow at each of its endpoints indicating that the line can continue from either end. (The square made of dashed lines in this rule and the following ones is used only as a registration mark to indicate the locations of dots in the rules. It does not occur in a computation.) With this rule, a line can begin anywhere in the pulli grid; in practice, however, a line usually starts at the grid's boundary. The following pairs of rules 2–12 are variations of the basic weaving principle for kolam making. They are grouped according to how a line takes its walk: on a straight path, or a path with a 90°, 180°, 270°, or 360° turn. The seeing component of each pair of rules looks ahead to adjacent pulli identified by red dots. The drawing component then weaves the line between the identified pulli.

Applying the making rules segments the making of a kolam into discrete seeing and drawing actions in time. As noted above, the way a kolam is segmented in actual performances varies. Drawing segmentations appear to be driven by practical constraints and the skill of the maker. In the making grammar, drawing segmentations are defined in terms of the length of a line and its curvature—that is, more or less by the complexity of a single gesture as observed in recorded performances. Drawing rules either weave a line through two consecutively adjacent pulli when the degree of curvature is low, or through just one adjacent pulli when the degree of curvature is higher. Seeing rules segment making time too. Here it is assumed that seeing segments are short and might even be simultaneous with drawing. The segmentations defined

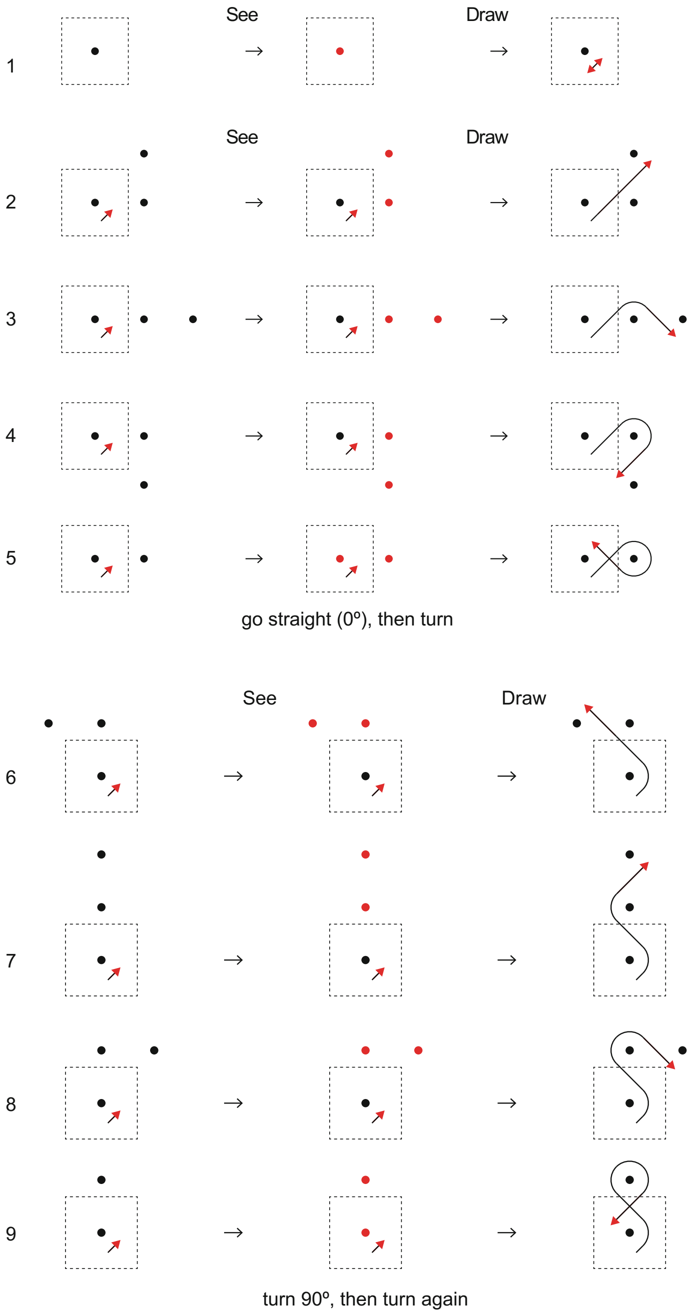

Fig. 10 The rules of the *line on a walk* making grammar

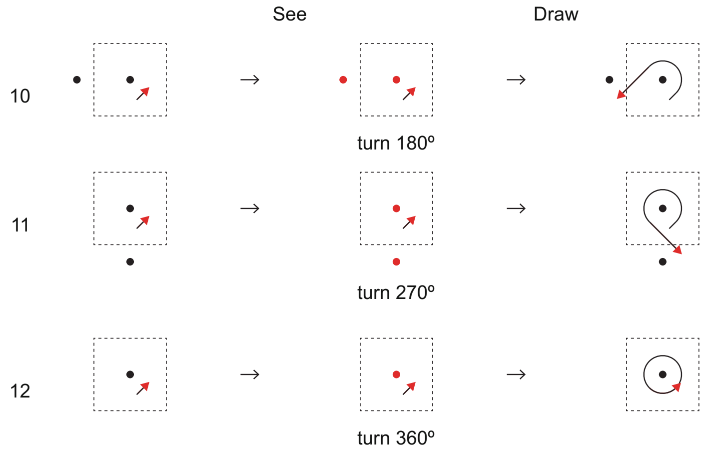

Fig. 10 (continued)

by the grammar are conjectural and simplifications of the many variations that can happen in actual performances. Nonetheless, they suggest a way to understand a spatio-temporal structure in kolam making.

Figure 10 shows the details of rules and their groupings. Rules 2–5 in the first group weave a line through two successively adjacent pulli. Each rule continues a line on a straight path through a neighboring pulli, then either continues straight or turns 90°, 180°, or 270° through the next pulli. (Rule 2 could be parameterized to extend a straight line through more than two pulli, as is often the case in actual kolam making.) Rules 6–9 in the second group also weave a line through two successively adjacent pulli. Each rule turns a line through 90°, then either continues straight or turns 90°, 180°, or 270° through the next pulli. (Rule 9 requires a very skillful drawing maneuver and might be broken into two steps.) Rules 10–12 in the last group define shorter drawing segments with greater turns. A rule either weaves a line through just one adjacent pulli with a 180° or 270° turn, or weaves a 360° turn around itself.

Turns or deflections from a straight path in this making grammar correspond to the bold lines or mirrors in the previous shape grammars. With the making grammar, deflecting mirrors are not given explicitly or at the start of the generation of a pattern. The maker might have a plan for turns in mind, or might decide them on-the-fly. But wherever a turn is made (and a mirror is implicit), the maker must then implement another one symmetrically in the continuation of the pattern. This planning or decision making on-the-fly, and attendant symmetry constraints, are not indicated in the current grammar. The ability to add pulli as a kolam is made is also not included. As they are now presented, the rules are more open-ended than the two shape grammars, and also do not cover some essential performative aspects of kolam making.

A computation of a kolam design with the rules is illustrated in Fig. 11. The computation begins with the same grid as in Figs. 4 and 8. It extends a line continuously from one of the starting points (arrows) but could easily be redefined to extend a line from either of the endpoints of a line. In the first several steps, applications of

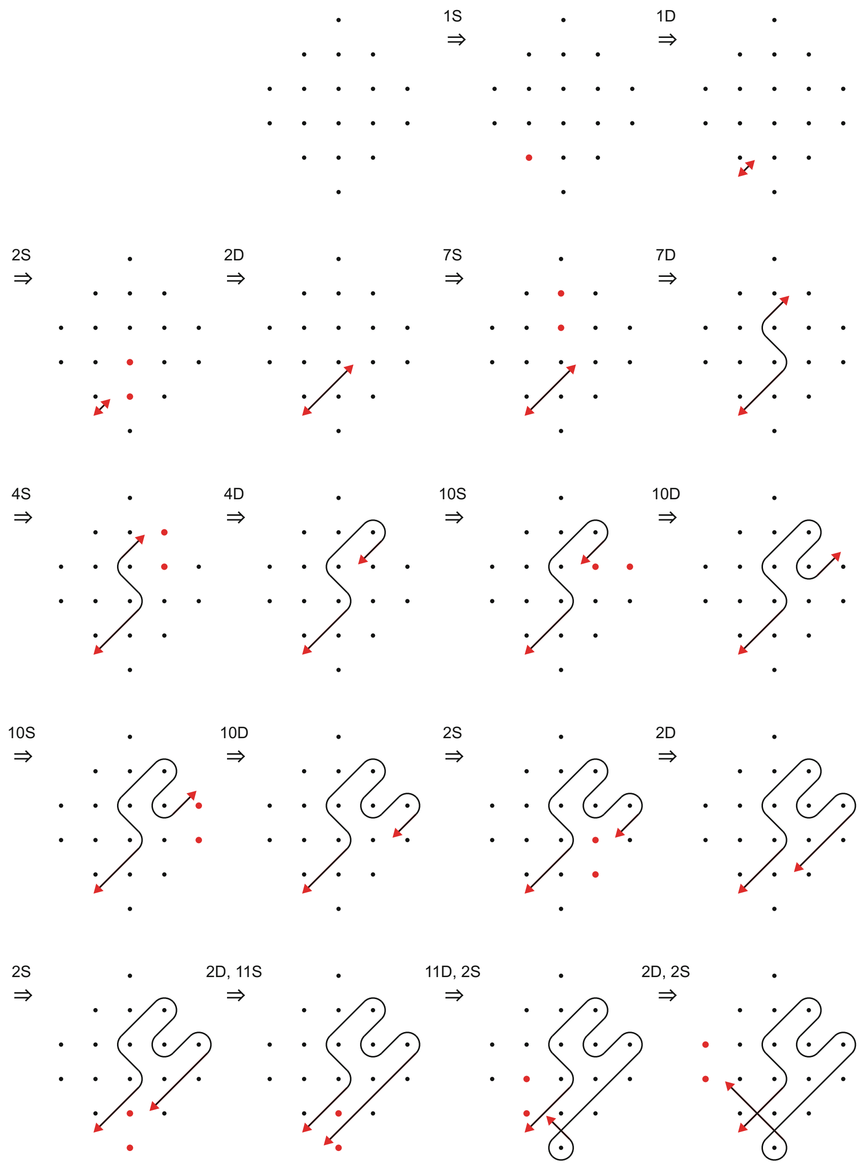

Fig. 11 A computation of a new kolam design with the *line on a walk* making grammar

seeing and drawing rules are both shown to illustrate how seeing and drawing go hand-in-hand. In subsequent steps, drawing and seeing are collapsed into single steps for brevity. The red dots and arrowheads are enlarged for legibility. The computation illustrates the continuous weaving process underlying kolam making.

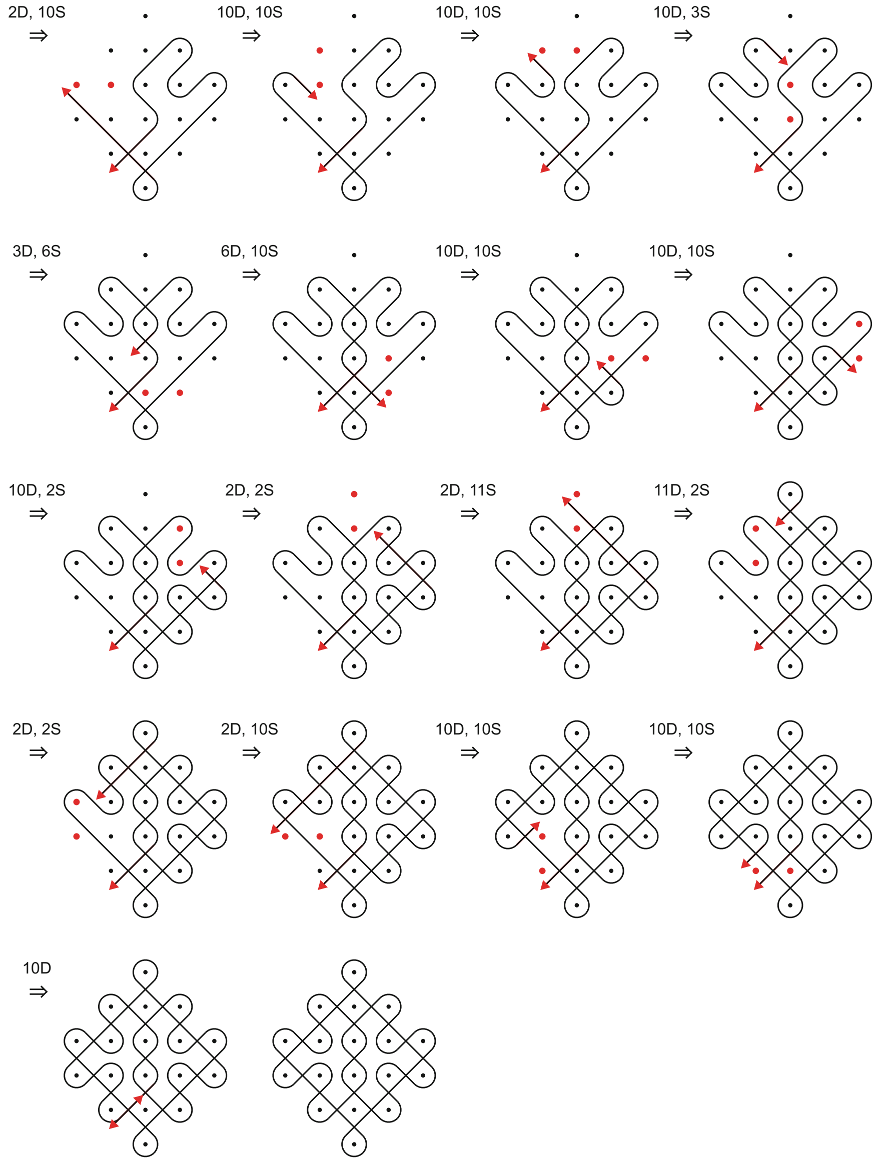

Fig. 11 (continued)

5 Discussion

Making grammars offer a new, computational means for understanding and representing craft practice and performance. They illuminate both the doings and sensings in a making activity. Here, I begin to show how making grammars can also convey temporal qualities of making. The rules of a making grammar not only describe how things are made spatially, they can also describe how things are made temporally. They can express gestures or actions in time that correspond to parts or segmentations of a continuous making process. Speculation about the temporal parts of a making activity may provide insights into how people make things. Playing with alternative temporal parts of an activity or with rearrangements of parts may suggest new ways to make things. The temporal segmentations defined by the kolam making rules correspond to routine gestures. Changing the segmentations might not lead to new pattern possibilities. But playing with temporal segmentations for other craft activities might suggest novel outcomes. The timing or duration of segmentations, not explored here, might also have creative implications.

A making grammar may be more complex than a shape grammar that generates a comparable set of designs. The kolam making grammar is certainly much longer than the simple kolam shape grammars. But the explanatory aims and value of a making grammar may be different than those for a shape grammar. Very different generative strategies were expressed through the kolam making grammar compared with the original kolam shape grammar—weaving is not like modular design. The generative strategies expressed through a making grammar may also help support or develop historical, socio-cultural, or other theories about a craft practice. In kolam making, for instance, the rice powder weaving that a woman performs to generate a kolam can be related to a belief that a kolam will weave around and ensnare evil spirits and prevent their entry into the home [17: 76]. A making grammar can be the opening to myriad scholarly and creative inquiries.

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