

A MORPHOLOGY OF PATTERN FOR KINETIC FACADES

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Abstract: Kinetic facades offer new compositional opportunities based on the design of patterns of movement. There is the capacity for novel form, but minimal knowledge in the design of kinetics. As a way forward, this research addresses two questions - what is the range of kinetic patterns, and what nomenclature may robustly describe pattern range? Results from a series of scripted animations utilizing a range of techniques are analyzed, and from this a set of terms for describing the morphology of kinetic pattern is developed. Kinetics is conceived as state change: the terms used to describe states are wave, fold, and field; a full range of patterns can be described as variants of these three simple states; or as intermediate or compound state transitions.

Keywords: design, kinetic, façade, morphology.

Résumé :

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Keywords: Up to 5 keywords separated by commas.

1. Introduction

Within contemporary architecture there is a growing interest in kinetics. As evidenced by intelligent facades, the possibilities are for a responsive membrane that adapts to changing environment conditions and user occupancy (Wigginton and Harris, 2002). Media facades by contrast, are driven by an interest in the recasting of architectural surface as a zone of interactivity, with the potential to engage users with public art works or embed socio cultural information (ag4, 2006). Regardless of the design intent, the emerging field of kinetic facades offers the challenge of developing a sophisticated approach to the design of movement. There is a lack of fundamental knowledge on the range of possibilities, which this paper addresses through the lens of morphology.

1.1 Scope of research

A clear distinction needs to be made between kinetics and other approaches to designing for movement and time. Typically theory and practice have engaged with 'movement' in terms of: (1) architecture as an artifact awaiting transformation through the event of occupation (Tschumi, 1994); (2) physical movement of the surveyor (Bois and Shepley, 1984); (3) a sense of movement due to the optical effects of changes in light or the presence of moisture (Holl et al., 2006); (4) the weathering of materials and effects of decay (Mostafavi and Leatherbarrow, 1993). While acknowledging the value of these traditional approaches, the focus here is on the implications for design when building components move in space: through geometric transformation i.e. translation, rotation, scaling; or through controlling material properties of thermal expansion, elasticity or mass. Translation, rotation and scaling are the basic building blocks of kinetics, which can be combined to produce more complex motion, such as a directional twist or roll. The second part of the definition of scope incorporates physical movement through controlling material properties, such as thermal expansion (e.g. shape memory alloys). This concentration on the spatial movement of components, allows a distinction between kinetics and kinetic effects, i.e. motion graphics via projection screens, LED's or pattern effects generated by lighting, are outside the scope of this research.

1.2 Previous work: kinetics conceived as decision planes

A model for conceiving key design decisions that influence kinetic pattern has been developed from two sources: Sanford Kwinter's visualization of complex systems as the interaction of parameters over time (Kwinter, 1993); and the input-control-output (ICO) paradigm that has its origins in cybernetics and systems theory (Glanville, 2007). It was argued that ICO as used for kinetic facades, requires more detail, tuned to the particular requirements of architectural design. Adopting Kwinter's model, key decisions are represented as parameters on three interrelated decision planes adapted from the ICO paradigm - sampling, control and tectonics. This enables design to be conceived as the *interaction of parameters* located in X and Y axis, *over time* represented by the Z axis. As illustrated in Figure 1, the model describes the key design decisions in terms of three groups of parameters. *Sampling*: data source, with a range between quantitative and qualitative; data type, with a range between discrete measures or continuous data variation. *Control*: reflexivity, using distinctions from an overview of cybernetics (Hayles, 1996), with a range between homeostasis where the intent is to produce a consistent 'steady state', to techniques from artificial life, where outcomes are relatively emergent; control area, distinguishing

between facades controlled as single entity or as multiple spatial zones; *Tectonics*; kinetic type, using a distinction between geometric translation produced by mechanics and movement based on controlling material properties ; facade granularity, distinguishing a range between coarse (comparatively few, larger components) and fine (multiple small components). *Time* is considered a design parameter for all planes, with outcomes being affected by the temporal scale at which they operate, and parameters from each plane interacting over time to produce complex behavior.

The decision plane model allows the conceptual mapping of design variables that influence kinetic pattern. In terms of a required shift in design focus the model highlights that approaches to data sampling and control systems are key design decisions, alongside the typical architectural emphasis on tectonics.

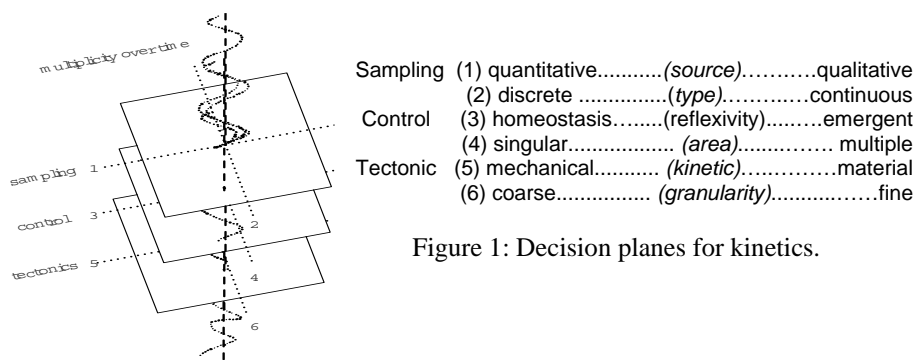


Figure 1: Decision planes for kinetics.

1.3 Research Aims

While there is innovative research in technology and fabrication of working prototypes, there is minimal discussion of the design of ‘movement itself’. This phrase, which has its origins in the realistic manifesto (Gabo and Pevsner, 1920), highlights the opportunity and challenge for architecture. There is the capacity to develop new compositional approaches based on the design of movement, but there is minimal knowledge. This research addresses this gap through a study of the morphology of kinetic pattern. The emphasis is on the visual outcomes of kinetic facades, which are termed here as movement patterns. Three interrelated questions have shaped the research: what are the main variables that influence kinetic patterns, what is the theoretical range of pattern, and what nomenclature may robustly describe pattern range?

The material presented here addresses the second and third questions. The research is framed within the critical tradition of formalism, where the

emphasis is on the visual outcomes of architectural design (Mitchell, 1990). The motivation underpinning both questions is to provide a resource for designers and theorists, interested in the visual potential of kinetic facades. For the design of static architectural facades, composition has typically been based on interrelationships between parts, and the manner in which parts relate to the composition of a whole. For kinetic facades it is argued that composition shifts to the design of *patterns of movement* – the manner in which parts move in relation to each other over time. Examining the state of contemporary practice and experiments from the 1970's, it is apparent there are a lack of built examples, or theoretical studies that examine the range of movement patterns. Furthermore, there is a need for a nomenclature to describe the morphology of kinetic facades - a set of terms that locate the distinctive features of this new design landscape, and some of contours in-between. The aim of the research is thus twofold - to explore range of pattern, and secondly to develop a robust design terminology to describe the morphology of these patterns.

2. Approach

The decision plane framework outlined in the previous work, is a general model that enables the conception of a holistic range of design variables. An instance of this model is used to structure a methodical series of animations. Not all variables are utilized: the sampling plane is not included; nor is the modeling of kinetics based on material properties attempted. The emphasis is on producing a wide range of patterns at an abstract morphological level. Morphology is a non-scalar abstract approach typically used in architectural design to theorize range (Steadman, 1983), and for these purposes data source and type, and the simulation of exact material transformations are not necessary. The animations are initially analyzed through the use of a *provisional* taxonomy. This is based on definitions, which describe types within a quantifiable set of criteria. Through discussion of the *failure* of this classification system an alternate nomenclature is developed.

2.1 Animation variables

Maya software has been programmed to generate a wide range of animations. The scripts map kinetics at the scale of a singular part, to distinct approaches to computationally controlling part-part kinetics. There are three general types of control scripts utilized - proportional, noise, and kinetics based on algorithms used in the computational generative arts. Proportional is based on part-part differentiation by numerical ratio of which there are two sub-types: amplitude, where parts are actuated simultaneously but by differing amounts; period, where parts or groups of parts, are actuated at

proportionally different times. The third general type, noise, produces controlled variation using random values. The animation script uses three commonly used noise variants - perlin, brownian and worley. The fourth approach to control scripts uses algorithms typical in the generative computational arts: life-like cellular automata (CA); cyclic CA; and flocking algorithms.

2.2 Abstraction versus realism

Clearly there are an extremely large number of permutations possible. If a range of geometric configurations are also considered, such as the proportion shape and scale of the kinetic facade, the number of permutations increases exponentially. All configurations will not be utilized, nor is this required to meet the research objectives. Using the precedent from studies in architectural plan morphology (Steadman, 1983), the facade patterns are dimensionless. They consist of hexagonal units, which in pilot studies were evaluated as providing the best mix of feature recognition (Derrington et al., 2004) and multi-directional tiling. The computer visualization is also deliberately abstract: a fixed orthogonal camera; ambient grayscale lighting; 4:3 aspect ratio. There is no attempt to simulate construction logic or to address the phenomenology of architectural perception. The objective is to identify the key features of the morphology of kinetic pattern - the underlying structure of part-part-whole visual patterns. Utilizing this approach, a wide range of animations can be generated and analyzed in terms of difference by degree and kind.

2.3 Classification as a heuristic tool

The approach to analysis of the outcomes, is to utilize a provisional classification system, developed from the work of a key figure in kinetic art. This is used speculatively, as a heuristic device to undertake the identification of pattern range. In turn the robustness of the classification is evaluated, to enable the proposition of a more robust nomenclature for describing range. The initial classification is developed from the writing of George Rickey, a seminal kinetic artist. Rickey used the movement of a ship at sea (pitch, roll, yaw etc.) to articulate a vocabulary of motion for kinetic art (Rickey, 1963). Rather than the ship at sea, it is proposed that the motion of the sea surface, is more appropriate for kinetic facades. Movement patterns for facades are typically aggregates of individual moving parts, and the descriptions used to describe sea patterns provide a rich source of terms, which describe different types of granular patterns. From these, six are chosen for the capacity to describe a wide range of kinetics - at one extreme the periodic motion of a wave and at the other the irregular action of

multiple peaks and chops. These six classes, when combined, produce fifteen possible hybrid dual-patterns, providing a total nomenclature of twenty one.

3. Animation Outcomes and Analysis

The animations were undertaken in two stages. In the first, animations were generated by using seven distinct kinetic types: translation, rotation, scaling; and four composites twist, yaw, roll and bounce (in pilot studies these composites produced the widest range of outcomes). The seven kinetic types were activated by nineteen control scripts (variations of the proportional, noise and artificial life algorithms described in the approach) resulting in 133 animations. Stage two, designed to expand on the possibilities revealed by the matrix of kinetic type and animation script, resulted in another 236 animations. Of these, sixty-four were selected, as representing the widest range of outcomes.

3.1 Provisional classification definitions

Six classes, which articulate a range between the periodic movement of waves to the irregular action of multiple peaks and chops, were utilized to identify pattern range. Distinctions between classes were based on granularity (% of total area), relative proportion of area of kinetics (width to height) and movement orientation.

Swell: large scale directional undulation

[Scale > 25%] [proportion < 1:4] [linear / radial]

Eddy: small scale undulation ; oscillating within a constant spatial zone

[Scale < 25%] [proportion < 1:4] [linear / radial]

Wave: large scale directional ridge

[Scale > 25%] [proportion > 1:4] [linear / radial]

Ripple: small scale directional ridge, typically occurring in groups.

[Scale < 25%] [proportion > 1:4] [linear / radial]

Chop: multiple non-directional distortions occurring within a spatial zone

[Gran. > 7:1] [proportion = any] [multiple]

Peak: Isolated 'point' distortion

[Gran. < 7:1] [proportion = any] [multiple]

In addition to these six primary classes, provision needs to be made for animations that exhibit dual characteristics, or what are termed here as hybrid patterns. The mix of two primary classes may be present simultaneously but spatially differentiated, or the animation may transform

over time from one characteristic pattern to another. There are fifteen hybrids possible.

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[ swell ] ---- [ eddy / wave / ripple / chop / peak ]
[ eddy ] ---- [ wave / ripple / chop / peak ]
[ wave ] ---- [ ripple / chop / peak ]
[ ripple ] ---- [ chop / peak ]
[chop ] ---- [ peak ]
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3.2 Stage I Animations

There was strong correspondence between script and assigned pattern classification. The proportional scripts based on amplitude, where grayscale images were sampled to produce different movement speeds, consistently produced swell animations. There was a similar correspondence between script and classification for those using periods based on number series. The method for these scripts was to sequentially trigger discrete spatial areas, (typically columns) in a periodic series: arithmetic / geometric progressions; sine algorithms, and prime numbers. In addition, one script triggered individual parts according to a function of their position, using x and y coordinates. All but the position determined period, generated animations that meet the requirement for waves. A clearly defined ridge of movement, with proportions greater than 1: 4 was the typical result. The exception, the position determined period, produced a mix of swell and wave patterns.

The relationship between script and pattern classification is less consistent with the noise and rule based scripts, but there are some strong trends. Of the 28 animations controlled by noise scripts, all but four were considered to be chop or peak hybrids. The generative scripts were the least consistent in terms of correlation. Two thirds were considered to be non-attributable; with six being attributed as swell chop variants. Of these six, all but one was produced by the cyclic algorithm, which consistently produced localised zones of movement interspersed with small scale variation.

In summary, the stage two animations demonstrated a very strong correlation between movement pattern and controlling script, independent of the type of movement. The part-to-part relationship taxonomy developed in order to structure the study, would appear to be the primary determinant of movement pattern. The majority of the stage two scripts were either amplitude or period proportional relationships, with a corresponding dominance of swell and wave patterns. There was a less marked connection between the noise algorithm scripts, but in general these produced swell - chop hybrids. The cellular automata patterns were the most difficult to classify, with two thirds found to be non-attributable.

3.3 Stage II animations

The outcomes from stage I were consistent enough to propose movement type at the scale of a part (i.e. translation, rotation, scaling and composites thereof) has minimal impact on the formation of patterns. Given this observation, the method adopted for stage three was to explore the capacity of the control scripts to produce greater variation, through use of one movement type. Arguably any could have been chosen, but during the undertaking of the stage two animations it was observed that rotation produced the most varied outcomes. Using this one kinetic type, experimentation with script variables was undertaken, in an attempt to challenge the typically consistent relationship between script type and outcome. Exploring different combinations of variables produced 236 animations, evenly spread between proportional, noise and generative scripts. These were reviewed using the classification measures and sixty-four were selected, as representing the widest range of outcomes. Twenty one variations of swell and waves were selected, with each being distinct in terms of spatial scale, relative proportion and orientation. There were thirty-three hybrid patterns, representing nine of the fifteen possible dual combinations. However, of the sixty-four animations selected as being distinct movement pattern types, ten were considered non-ascribable within the terms of the nomenclature.

4. Discussion

The animation studies have produced a wide range of pattern types, of which a significant number are deemed to be non-ascribable within the classification. These non-ascribable examples indicate the use of the classification system, derived from terminology to describe the surface of the sea, is not robust.

4.1 Limits of Classification

When confronted with such a gap, one approach is to propose new classes to describe examples outside the classification. Adding additional classes to cover deficiencies in the original set of definitions may address the non-ascribable animations, but it raises a question on the limits of the approach. Classification systems define boundaries between objects, events or phenomena based on a reference to fine grained and typically quantifiable definitions. They produce expanding trees of classes and sub-classes. Cases that do not meet existing definitions give rise to a new class or sub-class. This may be useful in circumstances where the population under study is relatively fixed, such as fauna or flora. The classification tree will eventually describe all found examples, and once established, the 'family' of classes will

be stable within typical time frames. Kinetic facades allow experimentation with a new form of composition, and it is likely that many more movement patterns will be developed to challenge the definitions used here to analyze the motion study outcomes. Already, there is a rich array of possibilities, especially with the hybrid dual-patterns. Hybrids based on three or more would seem likely to produce distinctive outcomes. More classes could be defined to describe these outcomes, but where would this end? The essence of kinetic facades is their dynamism. The non-ascribable animations from the motion studies, represent one pole of this dynamism. They are in a constant state of change, reforming into a seemingly endless array of movement patterns. A classification system based on a rationalization of the sea nomenclature has led to fixed boundaries, identified by relative proportion or granularity expressed as ratios and percentages. This has been useful to quantify the range of animations, but the approach is inflexible and will lead to an escalating set of definitions to cope with the inherent dynamism of kinetic facades. What is needed is a simpler, more robust system, which maps out range in relation to a small number of clearly communicable and recognizable pattern types.

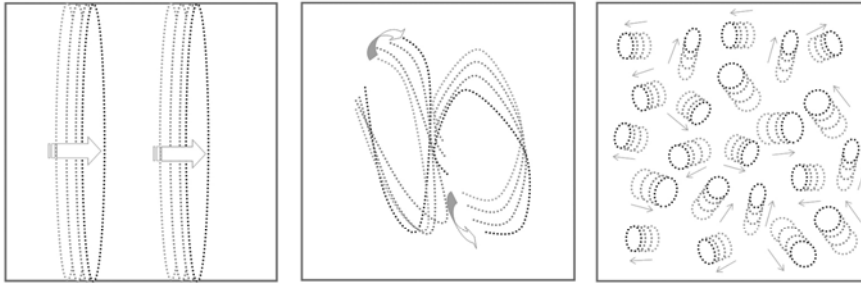
5. State change: the precedent of clouds

From the enlightenment onwards attempts were made to classify the formation of clouds, all of which failed to reach consensus due to poorly defined terminology and the futility of trying to describe the large number of possible cloud formations. In 1802 Luke Howard proposed a new approach - rather than a classification tree he described cloud patterns in terms of three basic forms that were under continual modification. The breakthrough was the emphasis on modification - that forms were under constant change, but that modification could be described in relation to three basic forms. Moreover, Howard recognized not only was there variation within the three modifications, but that there were a number of characteristic transitional states between them. As described in a recent critique. "Clouds could change both generically and specifically by effecting transitions between their forms. They could pass, one into the other, not only between individual modifications but between entire families of forms" (Hamblyn, 2001).

Howard's nomenclature was based on three "simple" modifications, two intermediate modifications between these, and two compound modifications. Although Howard used the established binominal Linnean classification of the period, his emphasis on what he termed modifications and the recognition that, for the case of clouds, there could be transition within and between states was seminal. The taxonomy allowed for transitions between types, as well as internal difference within the three types.

5.1 Three states

Over time, a facade may stay within the bounds of a singular pattern, or be in transition between patterns i.e. they are in a constant state of modification. It is proposed that an approach to describing movement patterns for kinetic facades can be developed along similar lines to Howard's taxonomy of clouds. In developing the state change approach, two issues need to be addressed. On what basis are states defined, and how many states will capture the range of movement patterns? It is proposed that three states can be used to describe the full range of movement patterns, as generated by the animation studies. In terms of a nomenclature, wave is carried over from the previous classification system, as it clearly describes a significant number of animations. The second term is fold, which describes another general state of modification, clearly distinguishable from a wave. The third state name is field, which appropriately describes the third typical set of animations, made up of a continuous aggregate of non-uniformly moving parts.



	wave	fold	field
Shape	ridge	patch	fragment
$(X : Y)$	$> 1:4$	$< 1:4$	$< 1:2$
Dynamic	constant, uniform,	constant, non-uniform,	irregular
<i>(direction)</i>	<i>linear or radial</i>	<i>intertwining / expansive.</i>	<i>multi - directional.</i>

Figure 2 State definitions.

5.2 State shape

Shape describes the geometric area that is in motion. That is, a shape is a spatially contiguous number of facade parts that move simultaneously as an identifiable group. As illustrated in Figure 2 wave, fold and field can be distinguished by characteristic shapes, respectively ridge, patch and fragment. A ridge is an elongated shape, with width to length (X:Y) proportions of approximately 1:4 or above. Ridges may be linear or curvilinear, have a constant proportion, or be tapered. They may occur singularly, or as sets of ridges that are moving in a similar direction. In

contrast to a wave, the shape corresponding to a fold is much less elongated, with width to length proportions below 1:4. The area of movement of a fold is typically an irregular geometry and is termed here as a patch. When compared to a ridge, the boundaries of a patch are dynamic, subject to constant change in geometry, or expansion / contraction. A patch may occur as one entity within a facade, or as a number of patches of intertwining movement. In contrast to either a wave or fold, which are geometric areas, a field movement pattern consists of multiple 'point' shapes or what are termed fragments (typically below a 1:2 proportion). A simple field pattern would be one contiguous area of irregular moving fragments.

5.3. State dynamic

The second criterion for distinguishing state is the movement pattern dynamic - the manner in which the shape is changing spatial location relative to the overall facade. The dynamic of a wave is a consistent linear or curvilinear movement - across, up, down or at an oblique angle to the overall geometry of the facade. Typically the dynamic of a wave ridge will be at a discernable velocity in a constant orientation. In contrast to the uniform linear or curvilinear dynamic of a wave, a fold dynamic is typically an interweaving movement along edges, or an expansion and contraction between boundaries. Rather than a defined movement of the patch relative to the overall facade, as is the typical case for a wave, the dynamic of a fold occurs in a relatively constant location. The characteristic folding and interweaving dynamic may rapidly expand or contract across a facade, but this is typically incremental and non-linear. The dynamic of a field state is one of irregular multi-directional movement of the individual fragments. There may be a general overall direction of the fragments of the whole, but typically this is disturbed by individual directional change or change in velocity of individual fragments. The dynamic of a field is one of constant minor variation punctuated by inconsistent behavior of singular or small groups of fragments

5.4. Intermediate and compound states

As illustrated in Figure 3, the simple states are supplemented by three intermediate and one compound state. The intermediate conditions are a mixture of two simple states. The combination of features may be relatively stable over time, or these may be constantly reforming as the pattern undergoes state change. As annotated on the diagram, change from one simple state to another will have a characteristic shape and dynamic. Transition from a wave to a fold will typically involve a *swelling* of the wave shape, while the reciprocal state change from fold to wave, typically

involves a *stratifying* of the fold shape. As a wave changes state from a wave to a field there is a distinctive *atomizing* of the ridge shape. The reverse, from field to wave would produce a *ribboning* shape as fragments form into strands of similar movement. A field to fold state change involves a similar process of *aggregation*, but the forming shapes are less elongated and form in a slow interweaving pattern. The last of the intermediate state changes, from fold to fields, involves the *disintegrating* of folds into smaller and smaller shapes and a shift to irregular and non uniform movement. The characteristics of the compound state *turbulence*, is atypical, with the three states present to varying degrees.

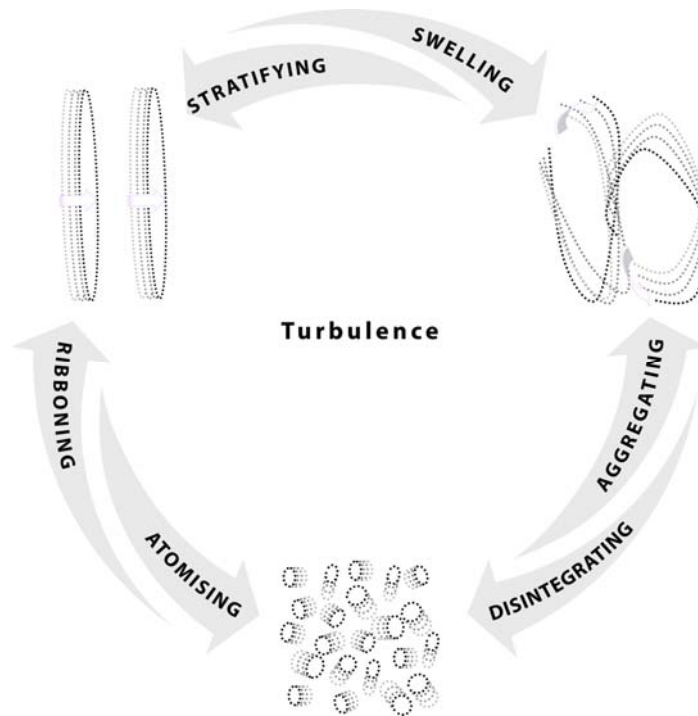


Figure 3 Intermediate and compound state transitions.

6. Summary and Further Work

An original method for describing the morphology of kinetic pattern has been presented. The animations used to develop the morphology are clearly not all inclusive, but they map a significant number of design possibilities. Moreover, the morphology is based on the proposition of three primary states, and a theoretically infinite number of between states. That is it provides a robust structure, which is extendable and allows designers to

communicate ideas at the early stages of design. The animation scripts will be further developed, and ultimately an online resource documenting the full range of animations will be provided. A next step would be to move from abstract to more realistic simulation and ultimately, fabrication of working prototypes. Earlier work on the specification of software calibrated to physical constraints (Moloney,2007) will be revisited with the aim of adapting animation software to simulate typical construction. From these working scale models will be produced using CNC fabrication.

7. Typical Examples

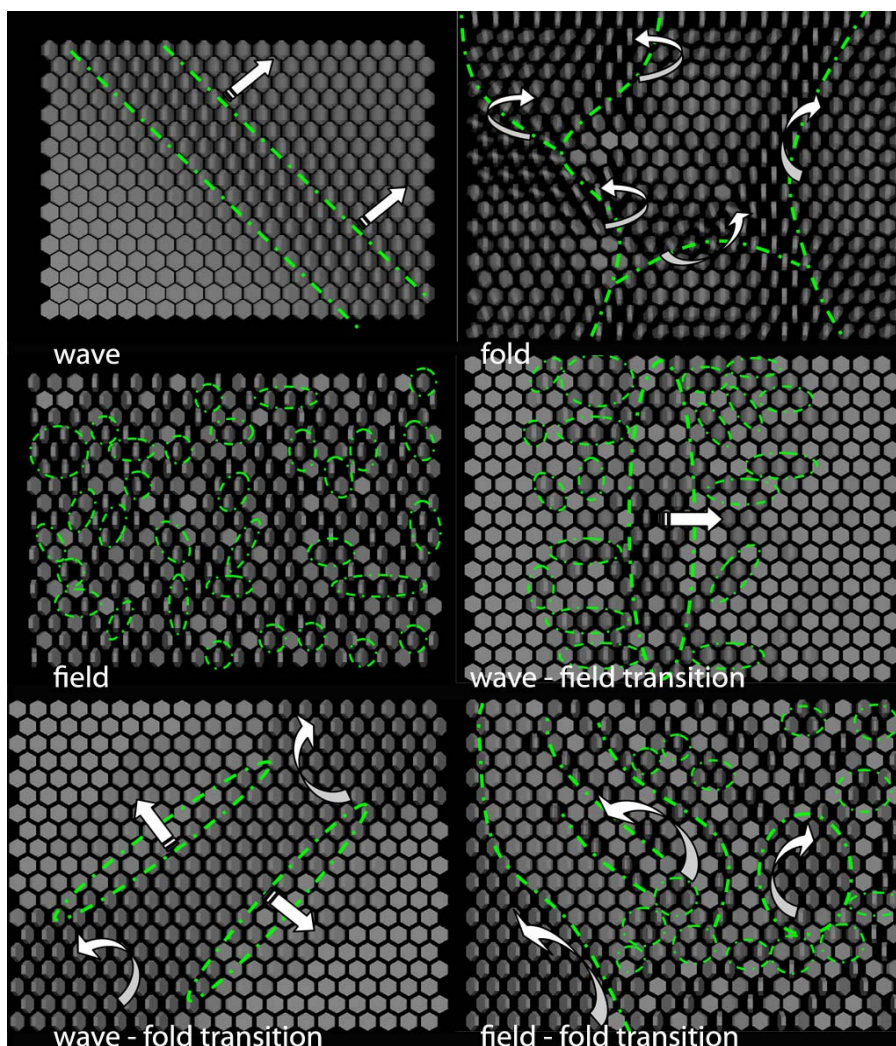


Figure 4 Typical simple and intermediate state examples.

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