Realizing an Aesthetics of Movement for Architecture

Paper - Topic: Architecture

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Abstract
This paper summarizes the theoretical basis for the aesthetics of "movement itself" (Gabo & Pevsner, 1920) for kinetic architectural facades and presents the design of a prototype façade system. The theory is based on the simulation of a wide range of algorithmically generated kinetic patterns, where the parameters that determine kinetics were identified and used to generate 1200+ animations. Analysis of these led to a theory of movement - State Change (Moloney, 2011). For the purposes of describing the range of animations, state is used as an alternate word for type. Its adoption makes explicit that movement patterns are snapshots of form in motion, that State Change is the distinguishing feature of this fledgling practice. The aesthetic in the context of architectural facades, can be distinguished by a characteristic spatial form or shape, and secondly in terms of temporal behaviour or dynamic. Kinetic shape and dynamic enable the identification of three states – wave, fold, field – and the transitions between these - stratifying, swelling, atomizing, ribboning, aggregation, interweaving. Algorithmically generated, State Change provides a morphology of pattern that maps the aesthetics of movement for architectural facades.

The translation of this theory to the pragmatics of hardware, tectonics and economics is challenging. Our research conceives kinetic facades as occupying a hybrid role: performing environmentally as a shade and glare modulator; while enabling the façade to also operate as a low resolution 'media screen' that can be used for generative art. A physical prototype has been developed that explores the optimal configuration and geometry of the kinetic panels to enable the granularity determined through animation studies. Experiments with a range of configurations demonstrated a hexagonal grid provided the best combination of edge detection and contrast between shaded areas (the two factors that affect human perception of movement). However when shifting from animation to a physical prototype, it became clear that the hexagonal grid was too visually dominant. Our design development shifted to refining the geometry of the individual part, where the depth and shape of the edge provides a subtle deformation of the hexagonal grid when rotated.

The final prototype consists of 54 rotating panels algorithmically controlled via the Unity game engine linked to wireless microcontrollers. The panels incorporate a 3D printed gear mechanism to enable fine grained motion control. The physical panels are superimposed within a video projection of the 400+ components envisioned for the full implementation. The calibration of the animations to the physical prototype, demonstrates the viability of a hybrid façade screen that performs environmentally, and enables experimentation with an aesthetic of movement based on algorithmically generated compositions.

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Key words: kinetic facades; aesthetics; generative composition.

Main References:

Gabo, N., & Pevsner, A. (1920). The Realistic Manifesto. In J. Bowlt (Ed.), *Russian Art of the Avant Garde: Theory and Criticism, 1902-1934* (pp. 208–214). New York: Thames and Hudson.

Moloney, J. (2011). *Designing kinetics for architectural facades: State change*. *Designing Kinetics for Architectural Facades: State Change*. Abingdon and New York: Routledge.

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Abstract

This paper situates previous work on the morphology of movement for kinetic facades in relation to generative art and architecture. The morphology was based on identifying the variables that determine kinetics, using a framework adapted from the input-control-output model of cybernetics. These variables were used to algorithmically generate thousands of animations of movement patterns, and their analysis led to 'State Change', a theory of movement for kinetic architectural facades. In this presentation I summarize this previous work and discuss parallel thinking in generative art and architecture.

A distinction is made between use of generative computing as a creative process from which frozen moments are realized as designs, with the context of kinetic facades that by contrast, are the realization of 'process itself'. This insight opens up questions concerning issues of authorship, aesthetics and audience that have been posed within generative arts discourse. In conclusion the translation of State Change to the pragmatics of architecture is considered. Our research conceives kinetic facades as occupying a hybrid role: performing environmentally as a shade and glare modulator; while enabling the façade to also operate as a low resolution 'media screen'; thus realizing a generative aesthetics of movement for architecture.

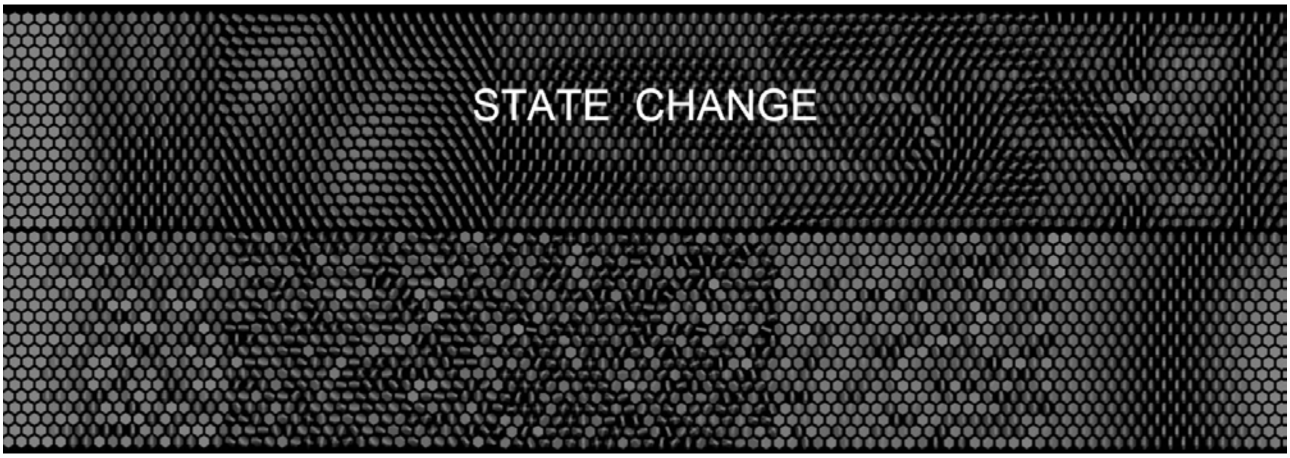

Figure 1: State Change, J. Moloney, 2011

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Key words: kinetic facades; aesthetics of movement; generative composition.

Main References:

McCormack, J. et al., 2014. Ten Questions Concerning Generative Computer Art. *Leonardo*, 47(2), pp.135–141.

Moloney, J., 2011. *Designing kinetics for architectural facades : state change*, Routledge.

Rickey, G.W., 1963. The morphology of movement. *Arts Journal*, 22(4), pp.pp. 220–231.

Introduction

Kinetic facades provide one clear opportunity to realize an aesthetic aligned with the trajectory of generative arts. In particular, kinetics allows an alternate form of architectural composition based on 'movement itself'. This phrase first appears in the 1920 constructivist manifesto as a reference to the depiction of movement in Italian futurism (Gabo & Pevsner 1920). Rather than represent movement through superimposition of frames as in the painting of Giacoma Balla, or capturing frozen form in motion as in the plastic dynamism of Umberto Boccinoni, the manifesto proposed that the aesthetics of actual movement be the focus. As will be explored in this paper there is a parallel with the typical use of generative process in architecture and design: we can perhaps, distinguish between generative techniques as a creative process but where ultimately the outcome is an instance of a series; and what might be referred to as 'process itself', where the outcome is form-in-motion.

What are the design variables, when composition shifts from stasis to a state of flux? And given this liquidity, what are the contours of this new architectural aesthetic? These questions drove an examination of precedent within kinetic arts and cybernetics, which was developed into a theoretical framework for the design of kinetic architectural facades. The theory is based on the simulation of a wide range of algorithmically generated kinetic patterns, where the variables that determine kinetics were identified and used to generate 1200+ animations. Analysis of these led to the theory of State Change, which provides a model for describing the morphology of kinetic pattern (Moloney 2011). In this presentation I summarize this previous work and discuss parallel thinking in the generative arts. In conclusion, I outline current work on hybrid kinetic sun screens, which perform environmentally to reduce thermal gain and provide the mechanism for realizing a generative art of movement at the scale of large architectural facades.

Decision planes: locating the design variables for kinetic facades

The approach taken to determine the morphology of movement for facades was to explore precedent from the kinetic arts and cybernetics, in order to locate the range of variables at play. A survey of kinetic art revealed some interesting source material, but also enabled a distinction to be made for architectural facades. This context is quite different from typical kinetic sculpture, which as exemplified by the seminal work of George Rickey, typically consist of a small numbers of parts engineered to produce 'free form' movement. As well as producing sublime art, Rickey's "Morphology of Movement" is one of the few theoretical discussions on kinetics available (Rickey 1963). This essay locates a vocabulary and syntax for his practice and became an important reference for the facades research. For Rickey the classic movements of a ship at sea (pitch, roll, fall, rise, yaw, shear) locate a concise set of movement types for his art, while the forces of nature (air pressure, gravity, weather) provide non-linear forces that, in combination with the subtle mechanics he deploys, enable non-repeating movement sequence. Rickey's morphology references his freestanding sculpture, typically consisting of several forms in motion, whereas architectural façades involve patterns of movement between multiple parts. This contrast between singular motion or small numbers of movement parts, with the large number of parts possible and the typically planar orientation of a facade, suggests a way to define the specificity of 'movement itself' for architecture. It is proposed that the distinguishing aspect of kinetic façades lies in patterns of motion, which arise from the relative movement of multiple parts. These parts have an individual vocabulary - translation, rotation, scaling and their combinations - which is analogous to Rickey's morphology. But it is the manner in which movement is synchronized or offset in time, the part-to-part clustering or dispersal of multiple parts as patterns of movement that became the focus of the research.

What then determines kinetic pattern? The way I approached this question was to develop a framework that builds on the input-control-output (ICO) legacy of cybernetics and adapt this to the context of patterns of movement at the scale of a large building. The ICO precedent was re-worked as three planes of interaction, as illustrated in Figures 2,3 and 4. Each plane enables the mapping of two variables, that were conceived as continuum in the x and y axis.

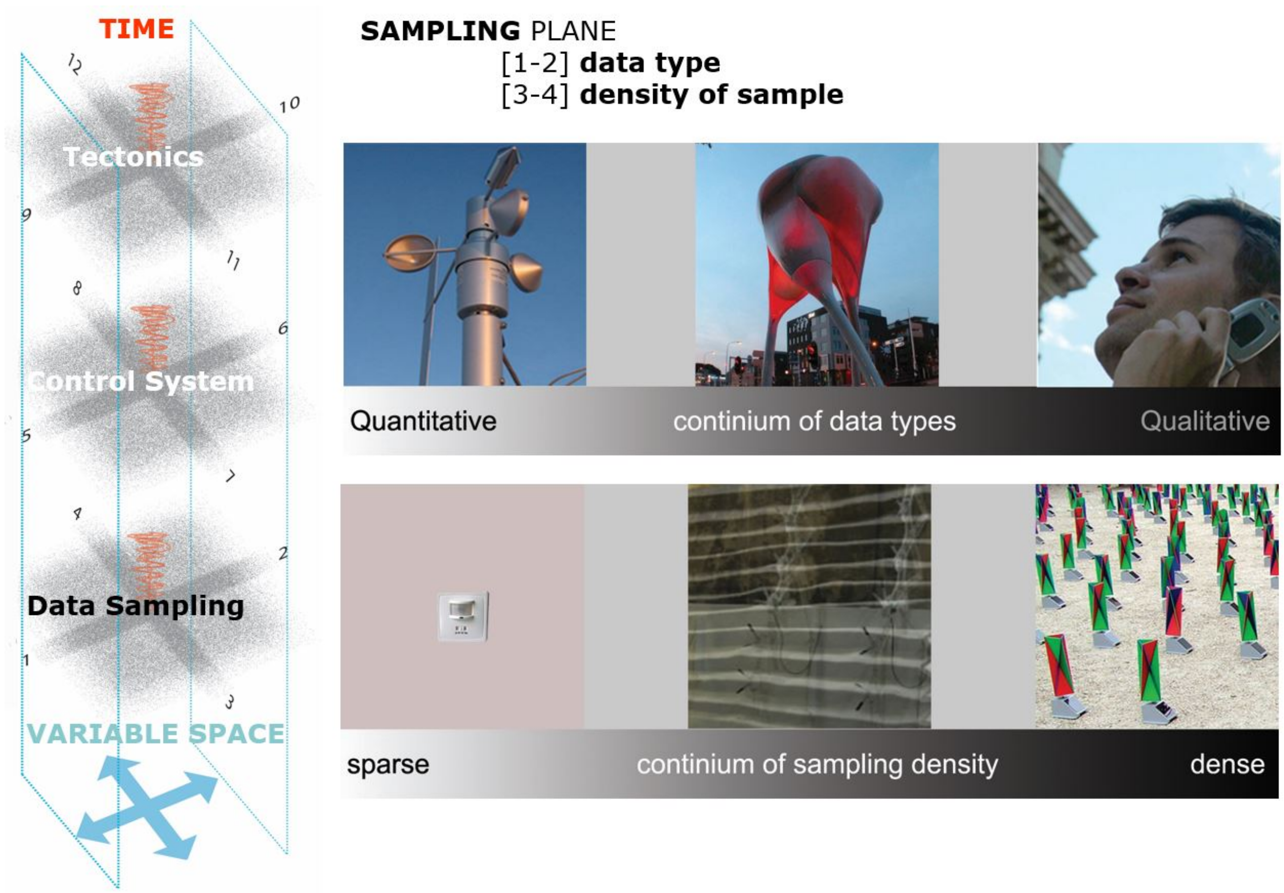

Figure 2: Variables that determine kinetics: sampling plane, J. Moloney.

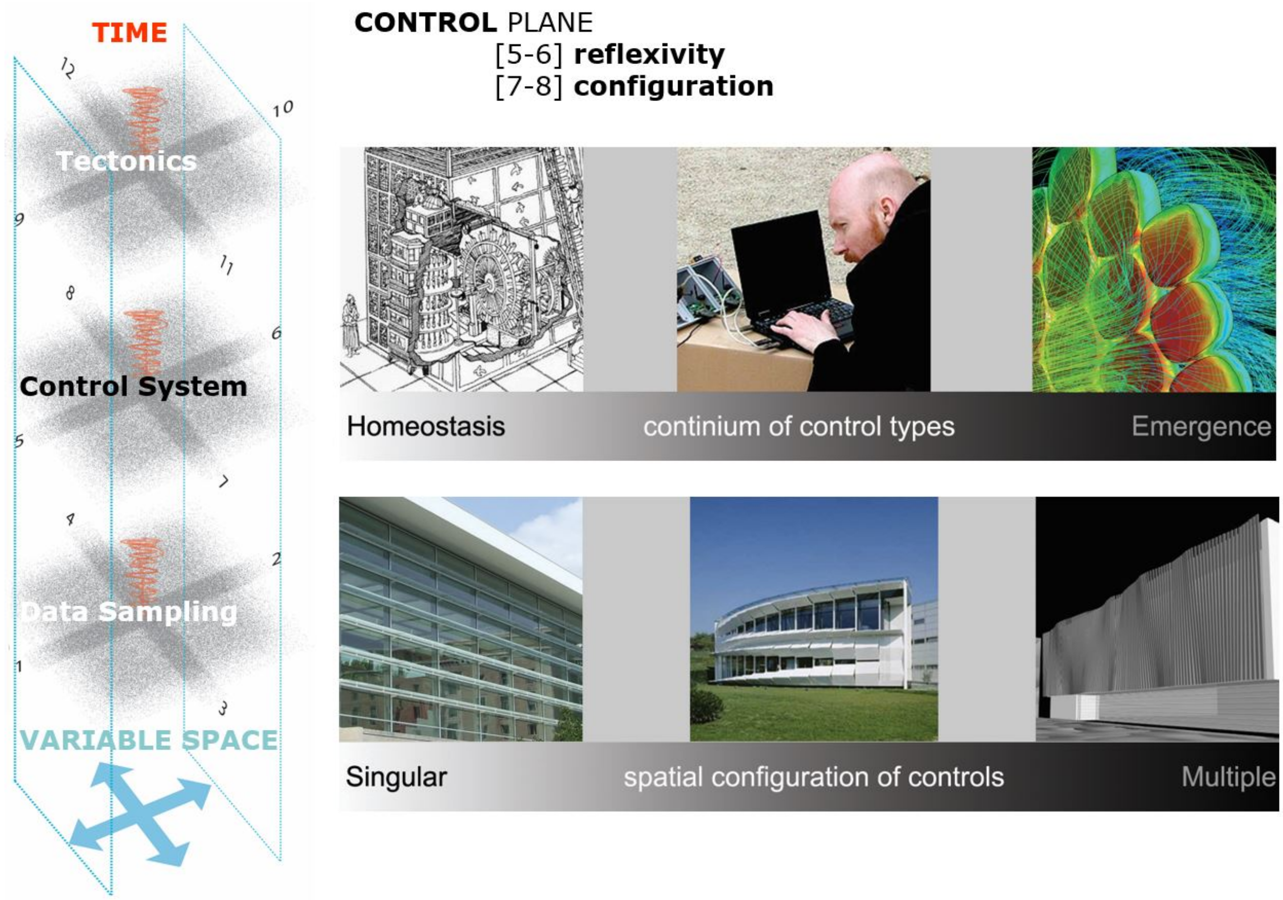

Figure 3: Variables that determine kinetics: control plane, J. Moloney.

Rather than input, the term sampling is used, borrowed from electronic music and refers to the practice of using small loops of music to generate a composition. Its adaptation here makes explicit that input specification is a design variable that can be robustly described through considering two continuum: sampling source, with a continuum between quantitative and qualitative sources; and sampling density, with a range between a sparse and a dense number of sampling devices.
The precedent of cybernetics as articulated by Catherine Hayles was used to articulate the first set of variables for the control plane (Hayles 1999). She argues that both first order cybernetics (homeostasis) and second order cybernetics (the introduction of recursion), despite allowing high degrees of reflexivity, are still ultimately directed towards maintaining a steady state. She contrasts this legacy with what she terms a third wave, which extends the cybernetic principle of reflexivity to contemporary research on self-organizing systems that generate novel outcomes. There is a shift away from the legacy of homeostasis, which Hayles maintains is still explicit in second-order cybernetics, to emergent outcomes that result from self-organizing systems (such as cellular automata and flocking algorithms). This differentiation is used to articulate a continuum of control reflexivity where there is a range between homeostasis (steady state) and emergence (self-organizing systems that produce novel outcomes). The second set of variables for the control plane relates to the spatial context of facades and Ashby's Law of Requisite Variety, which is conceived here in terms of requisite grain, or density of controls across a surface that range between single and multiple configurations (Ashby 1991). The third plane is conceived as a specific form of output, captured by the architectural term tectonic, which captures both the mechanism by which movement is realized and the aesthetics of architectural construction. The two continuum for the tectonic plane are type and granularity. Kinetic types ranges from simple transformations (rotation, translation, scaling) and their compound movements through to the fine grained multi-directional kinetics enabled by material deformation. Granularity, sets the continuum between a sparse number of moving parts and a finer granularity. The vertical axis through all three planes represents the temporal variables of periodic structure as articulated by Alan Dorin (pulse, stream, acceleration, and complex) and temporal scale (speed of movement) (Dorin 1999).

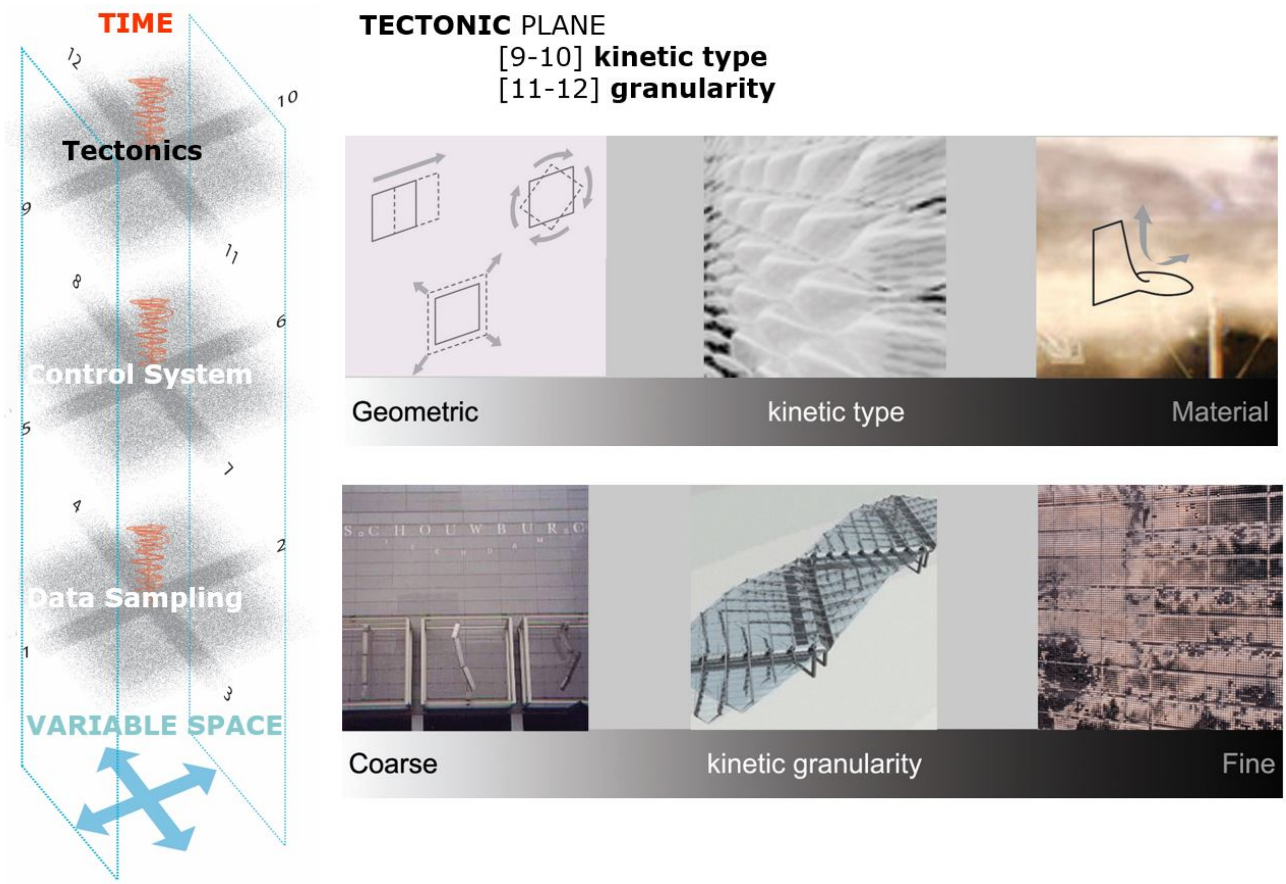

Figure 4: Variables that determine kinetics: tectonic plane, J. Moloney.

The tri-planar model allows the conceptual mapping of design variables that have a direct influence on kinetic pattern. Each decision plane impacts on the overall variable space which determines multiplicity - the range of pattern that occurs over time. This model provides a general framework that positions design variables that determine kinetic pattern. An instance of these variables was developed algorithmically to structure a series of animation experiments. The aim was to generate a series of sectional slices through the tri-planar model as a way to provide insight on the theoretical range of kinetic pattern.

State Change: The Morphology of Kinetic pattern

The ephemeral nature of kinetics provided a challenge to visualization for the animation experiments. The approach taken was to build on the tradition of façade study drawings. Typically drawings delineate significant proportional relationships, indicate window fenestration, and sectional profiles, with quick shading techniques been employed to suggest three-dimensional relief. They are not intended to represent the experience of the built façade but operate as abstractions, diagrams of relationships between parts, profiles and surface effects. In a similar vein to such drawings, the proposed animations that result from these experiments are diagrammatic, as compared to a more instrumental approach to digital visualization.

The animation experiments were undertaken in multiple stages. Given that the movement patterns will be the result of multiple moving parts, the geometry and the number of parts was informed by research on the visual mechanisms of human perception. While there is still debate on how human vision processes motion, the consensus is that the primary factor is feature recognition as determined by edge detection and relative shading (Derrington et al. 2004). The hexagon shape gave a good combination of edge detection and contrast between shaded areas with trials showed that increasing the number of edges beyond six proved counterproductive, as edge differentiation became harder. Moreover, the hexagon provided a relatively neutral orientation when a large number were combined in an offset, closely packed configuration. There was no horizontal or vertical emphasis, and lateral movements were more easily recognized, as compared to the orthogonal grid that is the outcome of multiple rectilinear shapes. In summary, the trials demonstrated a hexagon provided the best combination of edge detection, relative shading contrast and can be closely packed, without privileging rectilinear pattern formation. Stage two involved the identification of the most distinctive compound kinetics that result from pairing the base kinetic transformations of translation, rotation and scaling. These produced many similar compound types, of which four were selected - twist, roll, yaw and spring- as being the most distinctive. Twist, roll and yaw are well known and precise types of compound transformations used in flight dynamics. 'Spring' is a term introduced here to capture the distinctive quality of a compound translation that results from translation in the Y axis combined with negative scaling in the x axis.

The next stage involved the methodical generation of animations indexing the three base and four compound kinetic types against a range of control types. As illustrated in Figure 5, the continuum between homeostasis and emergence was used to identify nineteen algorithms: from simple synchronous movement; differentiating amplitude and / or period through mathematical progressions; experimentation with different types of noise algorithms; to the extreme of the reflexivity continuum, where the kinetic is generated by cellular automata and flocking algorithms. What became apparent from this set of experiments was that there were consistent types of patterns being generated by the algorithms, which were independent of the kinetic type. For example the use of a sine function generated a wave pattern, regardless of whether the base movement was translation, rotation, or scaling. With this insight a final series of animations involved more intuitive experimentation with one representative kinetic type (rotation) and combinations of algorithms. These progress from simple strategies of overlapping geometric progressions to more complex experimentation with noise and CA control variables. Over a thousand animations were evaluated and from these the most distinctive were documented.

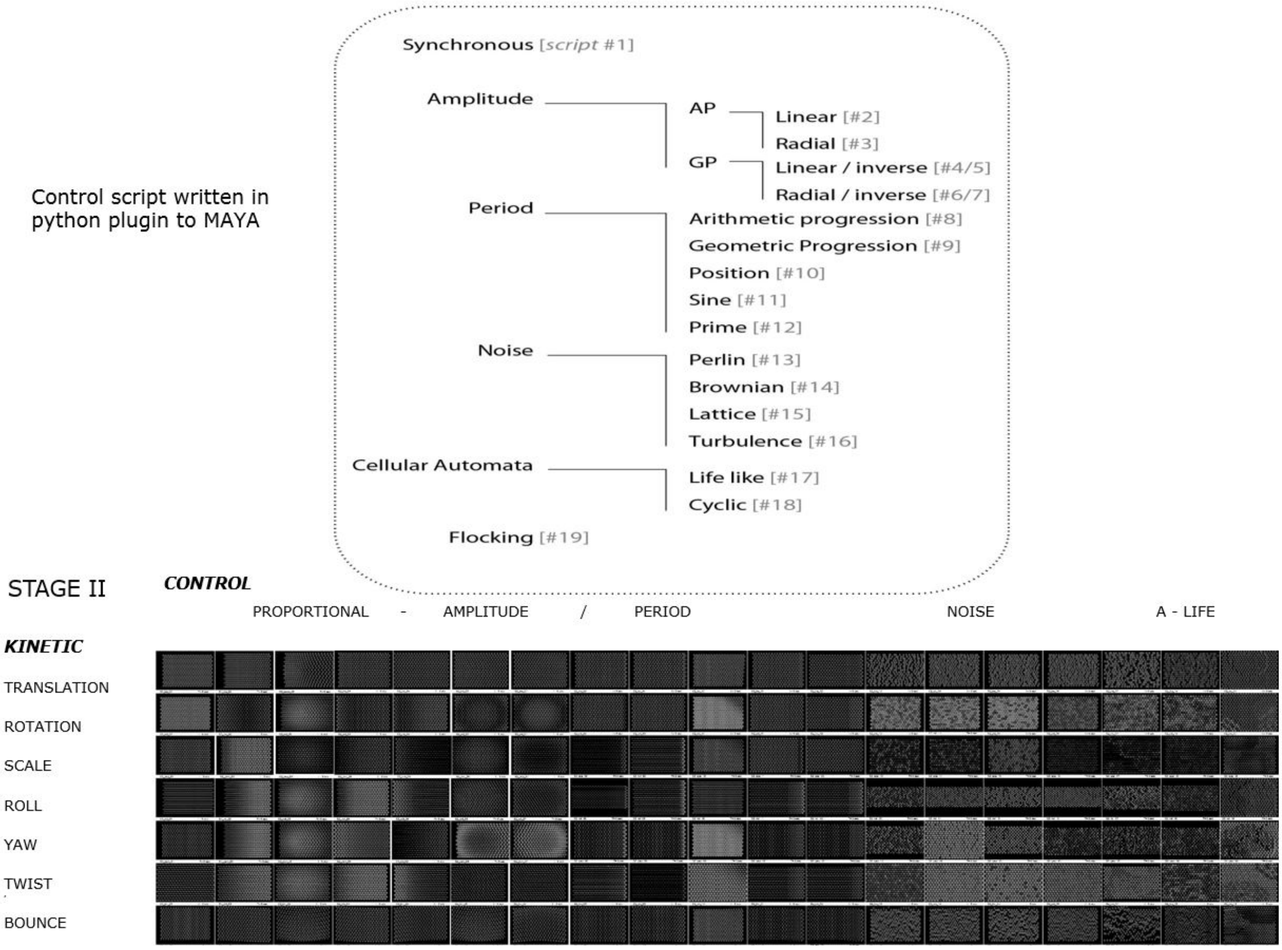

Figure 5: Matrix of kinetic type and control script for generating animations, J. Moloney,2011.

With thousands of animations generated, the challenge was to find a way to understand the range of animations produced. This required an ordering mechanism, a taxonomy of some kind, which provides a basis for comparison in terms of difference by degree and kind. The inspiration for the approach I eventually settled on was the unique solution to describing the ephemera of cloud formations, a problem which preoccupied some of the 19th century's most esteemed scientists. The breakthrough achieved by Luke Howard was an emphasis on modification: forms were under constant change but their modification could be described in relation to three basic forms (Hamblyn 2001). Moreover, Howard recognized that not only was there variation within the three modifications but that there were a number of characteristic transitional states between them. I adapted this approach to develop a theory that kinetic pattern could in a similar way to clouds, be described in relation to three basic states.

As illustrated in Figure 5, it is proposed that kinetic pattern can be distinguished by a characteristic spatial form or shape, and also in terms of temporal behaviour or dynamic. Kinetic shape and dynamic enable the identification of three states that can be used, in a similar manner to Howard's three cloud types, to describe the full range of kinetic pattern. In terms of a nomenclature, wave clearly describes a significant number of easily identifiable animations, while fold describes a particular state of re-forming or, to use Howard's term, modification, clearly distinguishable from a wave. The third state name is field, which appropriately describes a set of animations that present as a continuous aggregate of non-uniform movement. 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, produces 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 develop in a slow interweaving pattern. The last of the intermediate state changes, from fold to field, involves the disintegration 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.

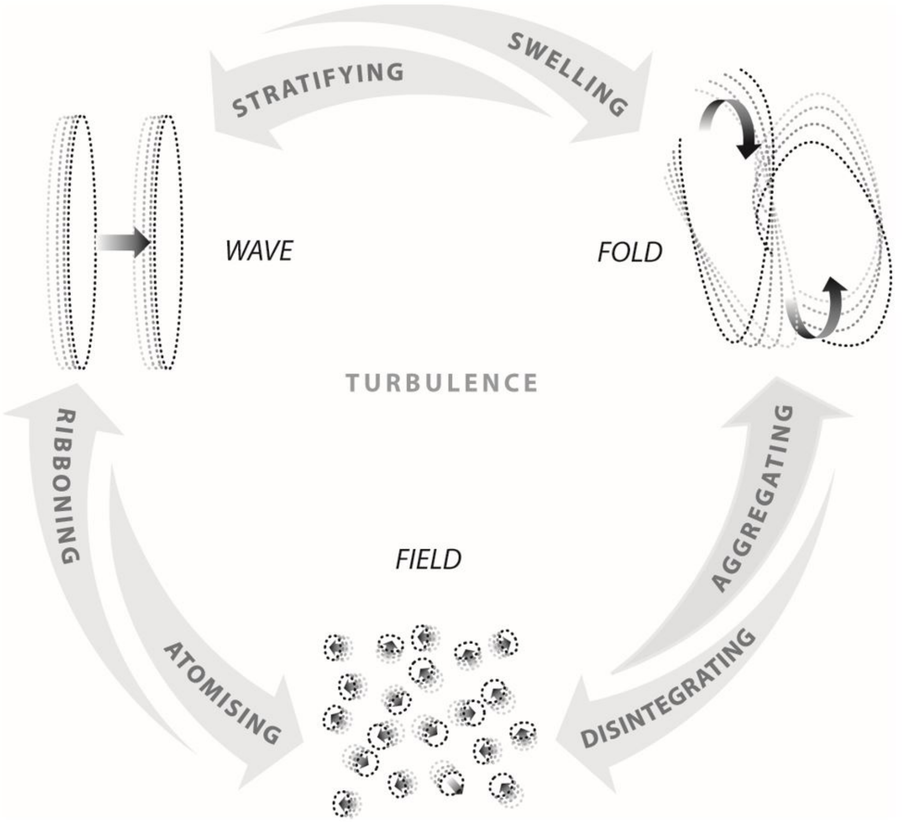

Figure 6: State Change, J. Moloney, 2011.

Discussion: process, aesthetics, audience.

State Change provides a theoretical model to understand the design variables and range of possibility for an architectural aesthetic afforded by kinetic facades. While the focus has been on the specific context of architectural facades, there are some parallels with generative concepts and techniques used in architecture and the arts. The first point of discussion concerns the adaptation of the input-control-output model from cybernetics, which places a focus on understanding the variables at play when conceiving generative art works. The tri-planer approach documented above, is a holistic conceptual mapping of design variables that have a direct influence on kinetic pattern. By setting combinations of variables, characteristic movement patterns form and reform in an infinite series. In this sense, there is a correspondence with the shift from the design of the singular artefact to Meta-design, or as articulated by Celestino Soddu the “design of a species” (Soddu 2007). The sampling-control-tectonic framework provides a way to conceive different species of kinetic pattern, shifting activity from the realization of discrete artefacts to the design of a process, from which multiples forms can emerge.

However while there are clear parallels with generative techniques in architecture and design, I propose there is a point of difference for kinetic facades in terms of what materializes from generative systems. Typically generative techniques are used in design and architecture as a way to extend creativity, through the algorithmic generation of multiple variants - in effect generating instances of a design species. Ultimately however, an individual from the population is selected and realized as a specific building, car, lamp etc. These instances of the species may be produced as a series – each lamp unique for example – but they are in effect, frozen moments of the process. By contrast, while a kinetic façade is manifest as a finite number of moving parts, what is realized is the generative process. Rather than a frozen moment, the outcome is the process from which multiple kinetic designs can be realized. Thus kinetic facades allow a radical shift in architectural composition: the potential is for the realization of indeterminate states; where parts coalesce, forming clusters and sublime patterns that resonate over time. The range of possibility will be within the sampling, control and tectonic variable space used by the designers to conceive and construct the façade system. It is hoped that the tri-planner framework for locating these variables will be useful to those interested in exploring this new aesthetic for architecture.

The observation that kinetic facades are a realization of ‘process as process’ suggests more alignment with interactive generative art, rather than architecture and design. Recently a group of leading artists and theorists articulated “Ten Questions Concerning Generative Computer Art”, two of which I will discuss in relation to the above research (McCormack et al. 2014). These concern the problematic issue of aesthetics and qualitative assessment for generative art works. The authors are critical of Kantian aesthetic theory and the associated problems of beauty, taste and subjectivity as related to a “pleasing surface aesthetic”. Rather than surface aesthetics, they propose that: “Implicitly, any generative artwork “encodes” human aesthetic judgments within its choice of rules and realization.” That is, the aesthetic for generative art resides in the design of the code and the way this is manifest to the audience. Despite the automation of the process the “aesthetic responsibility” according to this position, remains that of the artist. The authors also pose a related question: “What characterizes good generative art?” This question is posed in response to a proliferation of generative art works that appropriate available code, leading to the critique of algorithmic genericism. The authors who pose this question suggest that if the ontology of generative art lies in the process, than the subtlety and sophistication of the coding is the critical area where value lies. This as they acknowledge has some issues, given evaluation requires a level of knowledge of generative techniques beyond that of the typical audience. It also suggests algorithmic connoisseurship, begging the question of who the audience is for generative art works.

The above questions posed by McCormack et al concern issues of authorship, aesthetics and audience. While “despite the automation of the system” the artist is responsible for embedding an aesthetic, I am wary of too much focus being placed on the novelty or technical sophistication of the coding. The tri-planner framework developed for kinetic facades articulates 12 variable continuums and the important meta-variables of periodic structure and temporal scales. Most of the significant coding will be found within the reflexivity continuum; from simple geometric progressions to self-organizing cellular automata and flocking algorithms; and the capacity to sample images in terms of greyscale value, which potentially enable a figurative dimension. The algorithms for my experiments were coded by a professional programmer with a complex set of variables being exposed via an open ended input script, such that various algorithms could be layered spatially and in overlapping time sequences. My experience revealed a growing ‘intuitive’ understanding of how algorithms can interact to generate degrees of novel and unforeseen outcomes. In effect, I became a sophisticated specifier of input scripts to existing algorithms, experimenting with pattern sequences and gradually developing a personal aesthetic. I would argue that this was where the potential authorship and aesthetic sensibility lies, rather than at the level of code development.

Given the context of kinetic facades, there is also potential for mixed authorship between audience and designer of the system. Facades are experienced as a large scale artwork from outside the building and internally by the occupant at a different scale. The audience is both the general public and the building occupant while the temporal scale of an installed kinetic system is such that it could be modulated to different times of the day and in response to seasonal variation. The inputs into the control system could range from passers-by to individual occupants to web based social media sources that would interact with the sampling of dynamic environmental data. This mixed audience, multiple forms of input and the temporal scale of kinetic facades complicate issues of authorship and audience beyond that of a generative artwork on display over a relatively limited time span. In summary, it can be posited that kinetic facades provide the opportunity for a unique form of generative art where process is realized as an aesthetics of movement. One where architectural scale and urban context, hybrid role as environmental modulator over time and the potential for public interaction blur the lines between generative art work, architectural prosthesis and audience.

Towards a hybrid kinetic façade prototype

The translation of the tri-planer framework and the state change morphology to the pragmatics of hardware and tectonics is challenging. In terms of existing kinetic façade systems, the Aegis Hyposurface provides a seminal reference, but after more than 10 years of development it would appear that application outside the lab is not imminent (dECOi 2000). The 'Flare' façade prototype also indicated promise, but like the Hyposurface it is conceived as an impermeable layer, rather than as an environmental screen that mediates between exterior, glass and an interior (www.flare-façade.com). Our research conceives kinetic facades as performing a hybrid role: performing environmentally as a shade and glare modulator; while enabling the façade to also operate as a low resolution media screen that can reproduce the state change morphology, thus enabling the sun-screens to also operate as the platform for generative kinetic art. We propose that this hybrid function could alleviate the high cost of adaptive shading systems, which has constrained their uptake. We could also add further value by using the fine granularity of individually controlled panels to enable occupants to create microclimates throughout a building to suit changing needs.

A physical prototype has been developed that explores the optimal configuration and geometry of the kinetic panels to enable the granularity required to realize the state change patterns. The animation experiments demonstrated a hexagonal grid provided the optimal combination of edge detection and contrast between shaded areas (the two factors that affect human perception of movement). The animations were generated using an orthogonal camera, however, when shifting from animation to a physical prototype, non- perpendicular viewing positions and the impact of perspective reveal diagonal lines across the hexagonal grid. To address this dominance of diagonal lines within the grid, our focus shifted to refining the geometry of the individual part, experimenting with ways to breakdown this diagonal reading of the hexagonal grid. The breakthrough in the panel design iterations was the realization that the depth and shape of the edge, provided deformation of the hexagonal grid when rotated. This had to be balanced against the need to allow light in and views out, which resulted in an asymmetric section.

To evaluate the feasibility of hybrid environmental-media facades, we are fabricating a prototype of 15 panels to calibrate physical performance to the real time visualization (Figure 7). We are using the Unity game engine as the visualization and control software, with developments to date including: parametric panel and geometric array functions; a version of the animation control algorithms used for the state change experiments; and an accurate sun tracking system. The software simulation is networked to an Arduino microcontroller that wirelessly communicates to 5 servo controllers we have designed and fabricated, each of which drives up to 9 servos for the purposes of the prototype development. Initial experiments with output from the unity-Arduino set up to a servo directly connected to a panel, proved unsatisfactory in terms of smooth rotational movement. To improve the level of control we have designed a 3:1 gear system that has been 3D printed and designed to be mounted within the panel. Our initial task is to calibrate the real movement of the physical prototype with the unity simulation projected onto the wall surface of our lab (Figure 8). The scale of the calibration is based on our HD projector which produces an image size of 4.55 m long by 2.85 m high. With panels of 250 mm the mock-up will involve 200 virtual projected panels of which 15 are superimposed to align with the physical prototypes. By the time of GA16 we anticipate having results of the calibration to present.

Figure 7: Physical prototype fabrication.

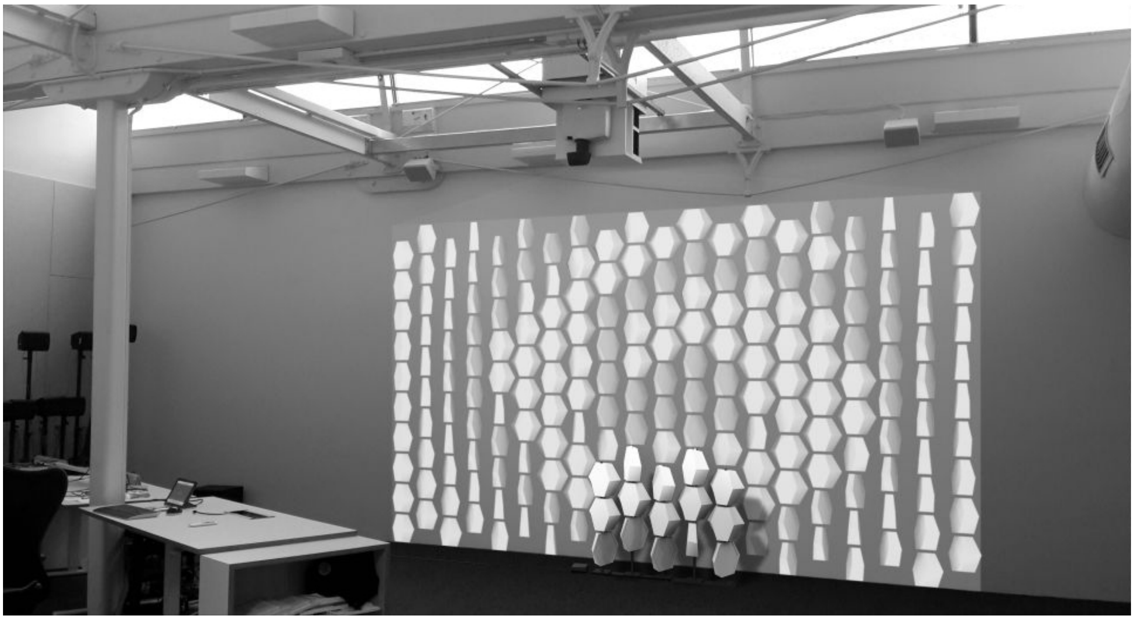

Figure 8: Calibration of projected animation and physical prototypes.

Further work

We anticipate there will be a number of panel and control iterations designed and developed using the virtual-to-physical calibration tests. The intent is to demonstrate that what we simulate is achievable, and from this evidence, produce simulations at a larger scale where we will be able to explore and evaluate their use as media facades and art installations for a range of urban contexts. A second stream of research will involve environmental simulation to quantify performance of the sun screening system in terms of thermal performance, daylighting and glare mitigation. This will involve developing sophisticated controls that track sun paths, sense direct sunlight, measure daylighting levels, and sense occupancy levels. These inputs will determine when and how often the systems can switch from environmental to generative art mode, although we anticipate being able to embed a sophisticated movement aesthetic into the day-to-day environmental operation as well. Part of the control development will include smartphone applications that will enable individual users to adjust their sun and day-lighting levels, with these individual requests interacting with the global control system to meet overall environmental performance targets. In a similar way smart phone applications can be used by the general public to interface with generative art. Clearly there is much to be done to realize generative kinetic art at this urban scale, and in the meantime we intend producing scale prototypes to enable installations and exhibition outcomes that further explore this new aesthetics of movement for architecture.

References

Ashby, W.R., 1991. Requisite Variety and Its Implications for the Control of Complex Systems. In *Facets of Systems Science*. Boston, MA: Springer US, pp. 405–417. Available at: http://link.springer.com/10.1007/978-1-4899-0718-9_28 [Accessed November 12, 2016].

dECOi, 2000. Technological Latency: from autoplastic to alloplastic. *Digital Creativity*, 11(3), pp.131–143.

Derrington, A., Allen, H. & Delicato, L., 2004. Visual mechanisms of Motion Analysis and Motion Perception. *Annual Review of Phycology*, 55, pp.181–205.

Dorin, A., 1999. Classification of physical process for virtual-kinetic art. In *Proceeding of First Iteration*. Melbourne, pp. pp. 68–79.

Gabo, N. & Pevsner, A., 1920. The Realistic Manifesto. In J. Bowlt, ed. *Russian Art of the Avant Garde: Theory and Criticism, 1902-1934*. New York: Thames and Hudson, pp. 208–214.

Hamblyn, R., 2001. *The invention of clouds*, New York: Farrar, Straus & Giroux.

Hayles, K., 1999. *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature and Informatics*, Chicago: University of Chicago Press.

McCormack, J. et al., 2014. Ten Questions Concerning Generative Computer Art. *Leonardo*, 47(2), pp.135–141. Available at: http://www.mitpressjournals.org/doi/abs/10.1162/LEON_a_00533 [Accessed November 12, 2016].

Moloney, J., 2011. *Designing kinetics for architectural facades : state change*, Routledge.

Rickey, G.W., 1963. The morphology of movement. *Arts Journal*, 22(4), pp.pp. 220–231.

Soddu, C., 2007. Endless interpretations, infinite in the mirror. In *10th generative Art Conference GA2007*.