Kinetic Architecture Matrix

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ABSTRACT

As we look at the potential of *Kinetic Architecture* to improve the performance of conventional buildings, on quantitative and qualitative level, we set up our mission to make kinetic building design more approachable. This research explores and re-visits kinetic architecture and establishes the "kinetic architecture matrix" that summarizes and categorizes a selective scan of contemporary kinetic design, putting a new focus on the classification of kinetic systems and their underlying technology.

By using means of mechanical engineering, we become aware of the enabling technology and functional possibilities of kinetic architecture. This research continues and re-examines the line of research that was done by Michael Fox and the "Kinetic Design Group" at MIT in the late 1990's [1], as well as it explores the motivation for designing kinetic buildings.

The "kinetic architecture matrix" is established as a database of kinetic architecture projects, providing classification methods through the implementation of our dynamic matrix tool. The matrix' unique interface allows for sorting the precedents according to different categories, interests or viewpoints, as well as visualizing interdependencies that cannot be observed in a traditional database.

Key Words: kinetic, kinetic architecture, performance, matrix, dynamic architecture

1. RESEARCH GOAL

The goal of this research is to reveal the full potential of kinetic architecture by analyzing the underlying technology of the movement mechanism and organizing it in a coherent way. We believe that with an extended knowledge and awareness of the kinetic systems it is possible to improve the performance of conventional buildings much further, on quantitative and qualitative level. We look into the mechanisms of kinetic design and at the same time explore the motivation and advantages of kinetic buildings, the way Moloney puts it: "What range of kinetic composition do the kinetic types afford? How have designers exploited this potential?" [2].

We outline "kinetic architecture" as defined by Fox and Moloney. We focus on what we believe to be the *essence* of kinetic architecture, its movement. Our contribution concentrates on the analysis of the actual moving mechanism and establishes novel categories based on the kinetic system of a project. The "kinetic architecture matrix" is a database that summarizes and categorizes a selective scan through contemporary kinetic design, focusing on projects at the scale of a full size building, with sedentary location and a steady program, which have moving parts that make them adaptive. In this research, the selected projects are analyzed by concepts borrowed from the field of Mechanical Engineering. We hope to explain fundamental concepts of movement involved with kinetic building design, and make it more approachable for architects and designers.

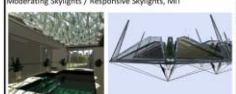
Type:	Title, Location, Year	Architect /Engineer/Reference and links	Type of Movement Mechanism	Reason/Aim of Movement	Discrete or Repetitive	DOF TYPE (DOF - Degree of freedom)	Number of DOF (DOF - Degree of	Senosr, Actuator and Control
structure								
	Kuwait Pavilion, world Expo, Kuwait, 1992 	Santiago Calatrava http://thegrillogazette.blogspot.co.il/2011/05/architecture-of-santiago-calatrava.html#!/2011/05/architecture-of-santiago-calatrava.html	a finger-like structure can be opened and closed	creating different shapes and lighting effects	Repetitve	Revolute	1 dof	Hydraulic piston and controller
	City of Arts and Sciences/L'Hemisfèric, Valencia, Spain, 1998 	Santiago Calatrava and Félix Candela http://www.calatrava.com/#/Selected%20works/Architecture?mode=english	structure shell rotation	opens to reveal the dome	Discrete	Revolute	1 dof	Hydraulic motor and controller (estimated
	Kinetic pergola, Thesis project, Cranbrook Acad. of Art, 2012 	Brian Lee http://www.architizer.com/en_us/projects/view/kinetic-pergola/38931/?sr=1#.UWR8g6NhiSN https://sites.google.com/site/unknowarch/kinetic-pergola-sequence-1	Kinetic Pergola composed of strips made of 4 linked segments and manipulated by the act of sitting.	to create benches for sitting	Repetitve	Revolute	Multiple, linked segments	manual
Operable roof								
	Montreal Olympic Stadium, Montreal, Canada, 1976 	Roger Taillibert http://en.wikipedia.org/wiki/Olympic_Stadium_(Montreal)	Retractable roof made of cevlar, hanged and manipulated by steel cables, supported by pulleys	weather protection	Repetitve	Prismatic	1 dof	DC motor and controller
	Bengt Sjostorm Starlight Theater, Rockford, Illinois, 2003 	Studio Gang Architects http://inhabitat.com/incredible-origami-shaped-starlight-theater-opens-and-closes-like-flower-petals/starlight-theater-studio-gang-6/?extend=1 http://www.archdaily.com/28649/bengt-sjostrom-starlight-theatre-studio-gang-architects/starlight_credit_sga_2/ http://www.studiogang.net/work/1998/starlighttheatre	Retractable roof, divided to a triangle shape segments, being operated and rotated to reveal the sky. Discrete approach of a mechanism that is designed and controlled as a single unit	rain protection for performances; can be opened to create an outdoor athmosphere	Discrete	Revolute	Multiple, linked triangles	DC motor and controller
	Moderating Skylights / Responsive Skylights, MIT 	Kinetic Design Group MIT / Michael Fox http://responsiveenvironments.es/post/1155320844/title-responsive-skylights-category http://www.robotecture.com/archive/Papers/Pdf/beyond.pdf	Retractable roof, divided to a triangle shape segments, being operated and rotated to reveal the sky.	optimize thermal and day lighting conditions; to utilize natural daylight and to optimally take advantage of natural ventilation	Repetitve	Revolute	Multiple, linked triangles	DC motor and controller
Moveable floor								
	"The View" revolving restaurant Marriott Marquis NY, 1985 	John Portman http://en.wikipedia.org/wiki/New_York_Marriott_Marquis	Rotated floor mechanism	panoramic views	Discrete	Revolute	1 dof	Hydraulic motor and controller
	Maison Lemoine, Bordeaux, France, 1998 	Rem Koolhaas http://james-w-coates.suite101.com/lastral-revolving-restaurant-review-a121796 http://oma.eu/projects/1998/maison-%C3%A0-bordeaux	Lift floor structure.	platform for handicapped person; the movement of the elevator continuously changes the achitecture of the house	Discrete	Prismatic	1 dof	Hydraulic piston and controller
	Sperone Westwater Gallery, New York, USA , 2008-2010 	Foster + Partner http://inhabitat.com/moving-room-transforms-the-new-sperone-westwater-gallery/ http://www.mymodernmet.com/profiles/blogs/new-yorks-vertical-art-gallery	Moving room that connects the five floors	to allow visitors to move gradually between levels; extension of exhibition space as required	Discrete	Prismatic	1 dof	DC motor and controller
Moveable partition								
	Emergent Surface/Strata™, NY, 2008 	Adaptive Building Initiative http://hoberman.com/portfolio/emergentsurface.php?rev=0&onEnterFrame=%5Btype+Function%5D&myNum=3&category=&projectname=Emergent+Surface http://www.adaptivebuildings.com/systems.html	Square elements rotated along an axis and composed of rod mechanism to create a dynamic ruled surface	shading device	Repetitve	Revolute	2 dof. Linked rods	DC motor and controller
	RE-SET. Dutch Pavilion, Venice, Italy 2013 	Petra Blaisse http://www.metalocus.es/content/en/blog/re-set-dutch-pavilion-petra-blaisse http://www.dezeen.com/2012/08/29/dutch-pavilion-at-venice-architecture-biennale-2012/	Movable partition along a slider	to reconfigure the space inside the Pavilion	Discrete	Prismatic	1 dof	DC motor and controller
	In-Out Curtain, San Francisco, 2005 	IwamotoScott, 2005 www.iwamotoscott.com/	Operable screen being opened and closed by moving the elements corners	operable screen, focusing in particular in creating a user-responsive system	Repetitve	Revolute	Multiple	manual
Dynamic Apertures and Facades								
	L'Institute du Monde Arab ,Paris, France ,1987 	Jean Nouvel http://www.jeannouvel.com/english/preloader.html http://www.galinsky.com/buildings/im a/	Camera aperture mechanism, rotated planer segments to reveal the view	control daylight	Repetitve	Revolute	Multiple	DC motor and controller
	Tessellate™ by ABI & Zahner 	Adaptive Building Initiative http://www.adaptivebuildings.com/tessellate-surface.html	Sliding window with printed pattern shapes	regulates light and solar gain, ventilation and airflow, privacy, and views	Repetitve	Prismatic	1 dof	DC motor and controller
	Media-ICT building, Barcelona, Spain, 2011 	cloud9/ Enric Ruiz-Geli http://www.designbuild-network.com/projects/media-tic/ http://www.ruiz-geli.com/	digitally controlled feature wall of ETFE surfaces; three layers of the plastic are fixed an d inflated like a pillow; 'lenticular' solution: two layers of the plastic are inflated and filled with nitrogen	Pneumatic volumes that inflate and deflate with fog, absorbing sunlight to save energy, filtering UV light and self-cleaning the non-stick surface	Repetitve	Material deformation	Material deformation	pneumatic volumes that inflate and defla with fog

Figure 1: kinetic architecture - the database: a sample of the catalog of all precedents, sorted by typology of the kinetic system (Ron, Weissenböck, Harari, 2013)

2. DEFINITIONS

The term “kinetic” originates from the Greek word kinesis, indicating motion, movement or the act of moving. “Kinetic architecture” implies the integration of a particular degree of motion within the design of buildings [3]. In recent history, the term “kinetic architecture” has been used to classify a diverse range of concepts and projects. All of those concepts incorporate adaptability and change of the architectural form, but most of them do not entail actual physical movement.

In history, an early concept that can be related to kinetic architecture is the concept of **“flexible building systems”**, which can be traced back to “tent” structures from primordial nomadic civilizations. These simple temporary shelters demonstrate concepts of portability, flexibility and movement, which still have an important role in the field of kinetic architecture today [4].

The term **“mobile architecture”** was presented by the visionary architect Yona Friedman as early as 1956. Friedman set out principles of architecture which is capable of understanding the constant changes that characterize modern society for the first time or as he puts it: the "social mobility." Friedman's **“mobile architecture”** is a bottom-up decentralized approach to urban planning, searching for spatial organization that is adaptable over time. Nevertheless, it is based on fixed mega-structures supporting changeable partitions and enclosure definitions [5]. Along with Yona Friedman's proposals, many other modular design strategies were developed during the same period of the 1960's. All these modular architectural elements were reconfigurable, but basically static, i.e. there was flexibility in the design and change over a time period of years, but once a building's partitions and envelope were placed, its space becomes sedentary (in a day to day time range).

“Portable, Deployable and **Demountable buildings”** can be defined as structures that can be shipped to a location, sometimes as a whole, other times in parts dismantled and rebuilt. Once installed, these buildings do not have a significant dynamic element and are sedentary until their next shipment. “Mobile homes”, also called ‘trailers,’ may be included in this category. Contemporary examples of this type are Jennifer Siegal's Show House [6] and Shigeru Ban’s Nomadic Museum, both assembled from used shipping containers and travelling around the world as exhibition pavilions.

2.2 Definition of “kinetic architecture*”* in this research

As mentioned before, from our point of view the essence of kinetic architecture is its movement. This research focuses explicitly on architecture that embeds actual physical movement and the technology of its underlying kinetic system. It continues and re-examines the line of research that was done by Michael Fox and the “Kinetic Design Group” at MIT in the late 1990's. “Kinetic architecture” is explored as defined by Fox: "where physical movement is an integral part of the primary functional and formal nature of the building component" [7], and, as added by Moloney, architecture that cannot be reduced to a single moment in time, but is changing by geometric translation, rotation, scaling and material deformation [8].

Some kinetic components in architecture have become ubiquitous parts of our built environment. Elements like passenger elevators, automatic doors and escalators are part of conventional architecture and are not be discussed in this survey.

In this research, we created a database of kinetic architecture. We limited our list to contemporary architectural projects at a single building scale (not the scale of an art installation, neither at urban scale). The collected precedents are built or have a built working prototype, whose movement is part of its everyday operation (i.e. not trailer homes or tensegrity structures that rarely move).
In this research, we selected precedents following these principles:

- modern and contemporary projects
- in the scale of a full size building
- which are built or have a working prototype
- with sedentary location
- with a steady program
- which have moving parts that make it adaptive

3. CLASSIFICATION OF KINETIC ARCHITECTURE

This novel approach explores the functional possibilities and examines the technologies that enable the kinetic systems, using “dynamic analysis” from the field of Mechanical Engineering. As a starting point, we looked at categories used in several previous research papers and books.

3.1 Previous classifications

In the early book “Kinetic Architecture”, Zuk and Clark [9] categorized kinetic projects by their architectural application, breaking them into the following categories: kinetically controlled static structures, self-erecting structures, kinetic components, reversible architecture, incremental architecture, deformable architecture, mobile architecture and disposable architecture. Zuk and Clark established a broad holistic view of kinetic architecture, as systems and sub-components, as modular adaptive systems and as adaptation over the course of time (disposable).

Fox's early research “Beyond Kinetic” [10] proposes two sets of classifications: the first set lays out the foundation for the general categories, including “embedded kinetic structures”, “deployable kinetic structures” and “dynamic kinetic structures”. The second set of classification is established in Fox's “kinetic design matrix”, sorting precedents by the “mechanism of movement”, like hinge, spherical joint or rope and pulleys. The matrix was groundbreaking and made a very significant step into understanding kinetic systems. However, we claim that the mechanical classification of kinetic architecture is worth to be re-examined and specified in more detail. In later publications, Fox contributes many more valuable sets of categories, expanding across multiple aspects of kinetic design, but due to the limitation of this paper, we will not cover them all.

Kronenburg [11] categorized the first half of the surveyed projects in his book “……..” by scale and program: residential homes, public buildings (entitled “community”) and buildings within urban context (entitled “architecture”). The second half of the book is sorted by flexible design strategies:

adapt / transform / move / interact. While the classification according to program and scale is relatively straight forward, the second set of grouping criteria is less intuitive. We can interpret the term “adaptable” in this context similar to the term “universal” in late Modernism, where space is relatively non-specific and generic to accommodate changing future needs. The term “transformable” describes flexible design that physically changes shape, volume of appearance and features. “Moveable” architecture means that a building can move from one place to another, like trailers and inflatable structures. The term “interactive” architecture includes the embedding of computation devices to create the potential to respond to the environment and interact with inhabitants. The categories established by Kronenburg are very useful, broad and inclusive. In this research we try to narrow down the criteria into very distinct groups.

In his book "Transformable and Kinetic Architectural Structures" Asefi examines kinetic architecture in terms of transformable structures, from history to present, classifying them according to structural principles and transformation mechanism [12].

3.2 Novel classification in this research

For better understanding and implementation of dynamic architecture, we want to analyze kinetic systems in detail. Therefore our contribution focuses on the effort to examine the actual movement mechanism, specifically according to the links and joints of the mechanism, by adding Mechanical Engineering terms to the analysis process.

In the field of Mechanical Engineering "rigid mechanics" movement is described by the ***type*** and ***number*** of "Degree of Freedom" [DOF] for each joint. The Degree of Freedom [DOF] is based on "rigid body" dynamics, assuming that an object has neglected deformation and stays intact through its movement in space. DOF can be defined as the *number* and *type* of independent ways in which a rigid mechanism can move in a system [13]. The position of a rigid body in space is defined by three components of translation and three components of rotation, which means that it has six degrees of freedom. In other words, DOF is the number of independent parameters that are necessary to define the configuration of a mechanical system, for example, the position and orientation of a robotic arm in 3D space. The two most basic DOF are: a rotary hinge called "revolute" and a linear slider, called "prismatic" joint [14]. In our matrix, each project is analyzed by the DOF for each joint, and the whole system is classified whether it has a unique singular mechanism – "discrete" or whether is it made of "repetitive" parts.

Some of the most recent precedents in the matrix use advanced material deformation as a mean for kinetic design, for example "ShapeShift"- a thesis prototype from the ETH by E.a Augustynowicz, S. Georgakopoulou, D. Rossi and S. Six [15], or the "Moving Homeostatic" façade prototype by Decker Yeadon [16]. Moloney proposes 'translation', 'rotation' and 'scaling' taken from graphic transformation in space, and 'material deformation' to describe kinetic movement [17] [FIGURE 3]. The advancement in material technologies is discussed in more details by Fox. Smart materials bring dynamic adaptation capability to the molecular level, and may replace mechanical movement with the changing of material properties (such as stiffness, opacity, or solar gain). In these cases, the mechanics of Rigid Body is not applicable. In order to change their form, these materials go through phase-change or deformation of the material due to mechanical loads, electrical loads or other external conditions, and cannot be classified with DOF. This information adds to our initial matrix categories, so we looked into 'Solid Mechanics' and used 'deformation models'. In this initial state of our matrix we used a single term "material deformation" to describe this kinetic category. We would like to further develop classification methodology for these examples. The new categories are yet to be defined and require deeper understanding of material science. Our starting point may be classifying by the type of chemical reaction, by the trigger for the change, such as heat, light level, or electrical current, or we may categorize it by linear, planar and volumetric transformation.

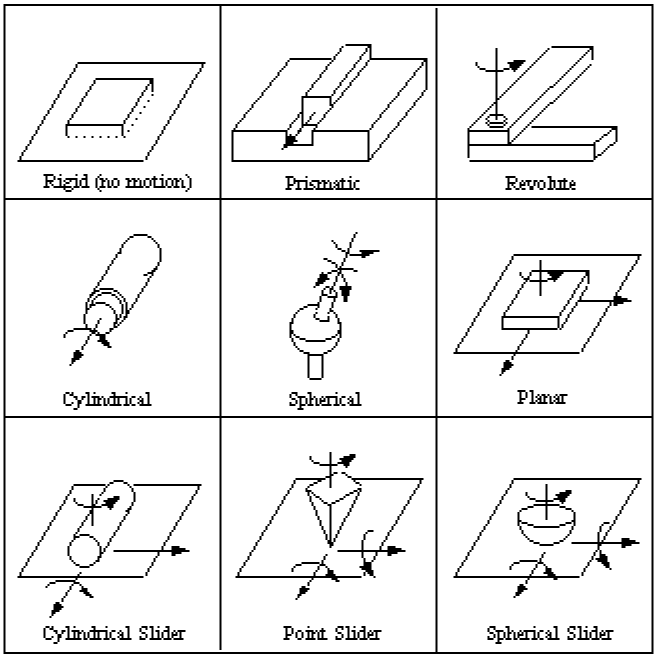


Figure 2: 3-D kinematic joints and their degrees of freedom

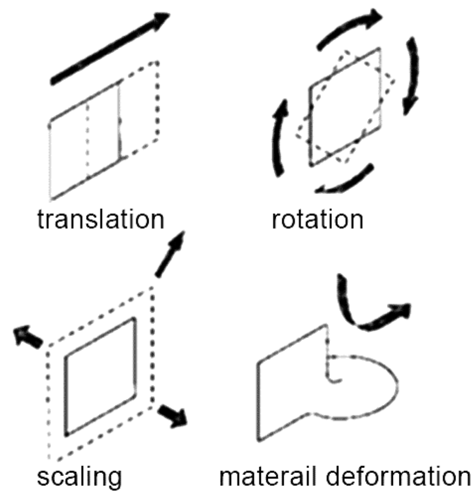


Figure 3: Kinetic Transformation

When we entered the data for each selected project, we established a series of useful and innovative categories to sort our matrix [FIGURE 1]:

- **typology of the kinetic system:** building element that embeds movement: kinetic structure, operable roof, moveable building floor, kinetic apertures and building facades, and flexible interior partitions
- **motivation for the kinetic design**
- **reason/ aim of movement and its advantages**
- **mechanical analysis of the kinetic mechanism:**
  a) degree of freedom (DOF) *type*: [FIGURE 2], DOF relates to the joints and the kinematic connection between the mechanism links
  b) *number* of degrees of freedom (DOF): one DOF, two DOF or multiple DOF system for linked (chained) elements mechanism

c) Mechanism implementation: *discrete* mechanism for a single operation, or *repetitive* mechanism for systems that contain a pattern of basic elements creating a dynamic surface or group effect

- **sensors, actuator and control: relates to the input, mechanism of operation, technology and control**

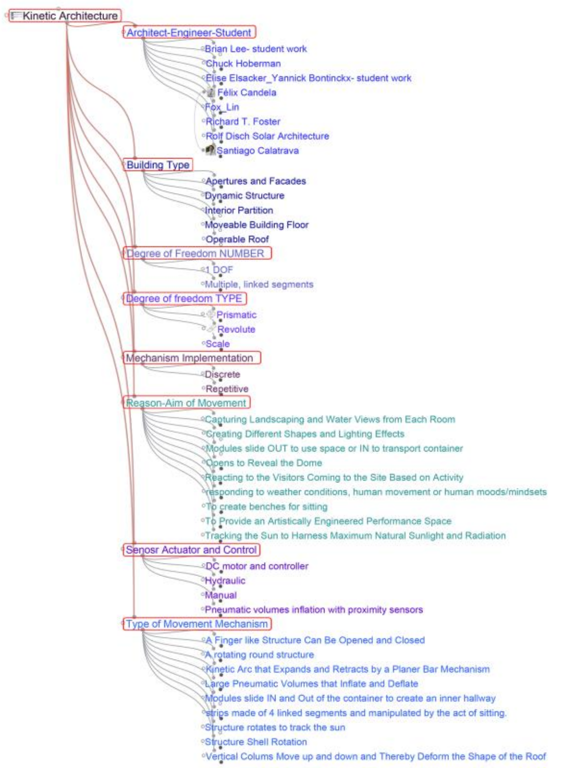


Figure 4: kinetic architecture matrix: view of the dynamic interface with the main categories expanded (Ron, Weissenböck, 2013)

4. BROWSING THE MATRIX

The goal in creating the “kinetic architecture matrix” is to make a valuable contribution to the discourse of kinetic architecture in reference to current technology, with the hope of helping architects to better understand the moving mechanism systems, technologies, potentials, types and implementation of the selected precedents. As discussed in previous chapters, we selected modern and contemporary projects that are adequate with our specific definition of kinetic architecture, and analyzed them according to our set of categories.

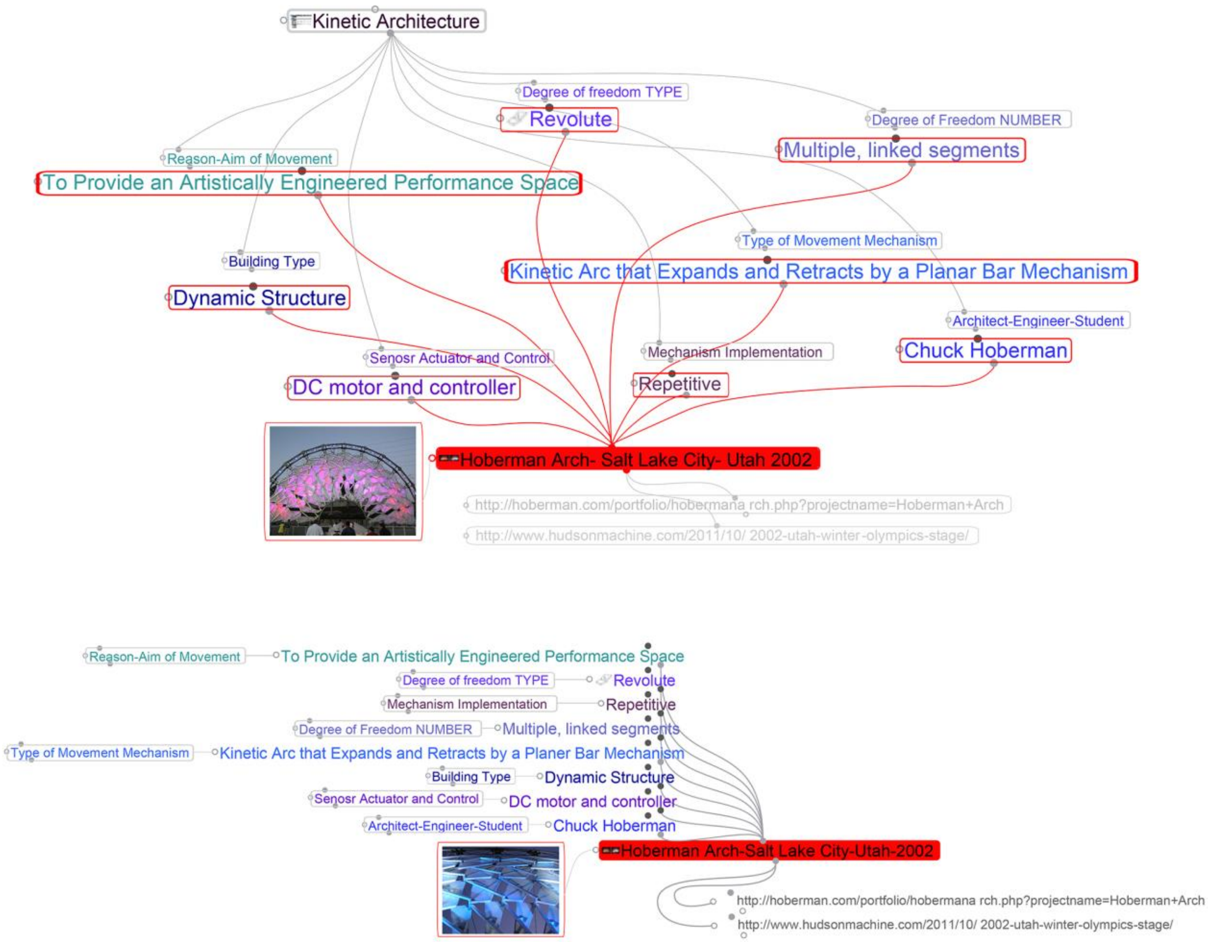


Figure 5: browsing the dynamic matrix – here: focusing on one precedent and its relations – showing two different view options of the interface (Ron, Weissenböck, 2013)

In order to allow the organization of the precedents according to different categories, interest or viewpoints, as well as visualizing interdependencies that cannot be observed in a traditional database, we explored the “kinetic architecture matrix” as a unique interface system.

Users can browse the matrix according to their interest and get a better understanding of the complex database by visualizing similarities, differences and cross-references [FIGURE 4 & 5].

It allows for multiple sorting options, for example: to click on a *project name* to see all it categories [FIGURE 5] or to click on a *category* to see all the projects it contains [FIGURE 6]. We made a working prototype to test the interaction, and would like to extend this interface in the future.

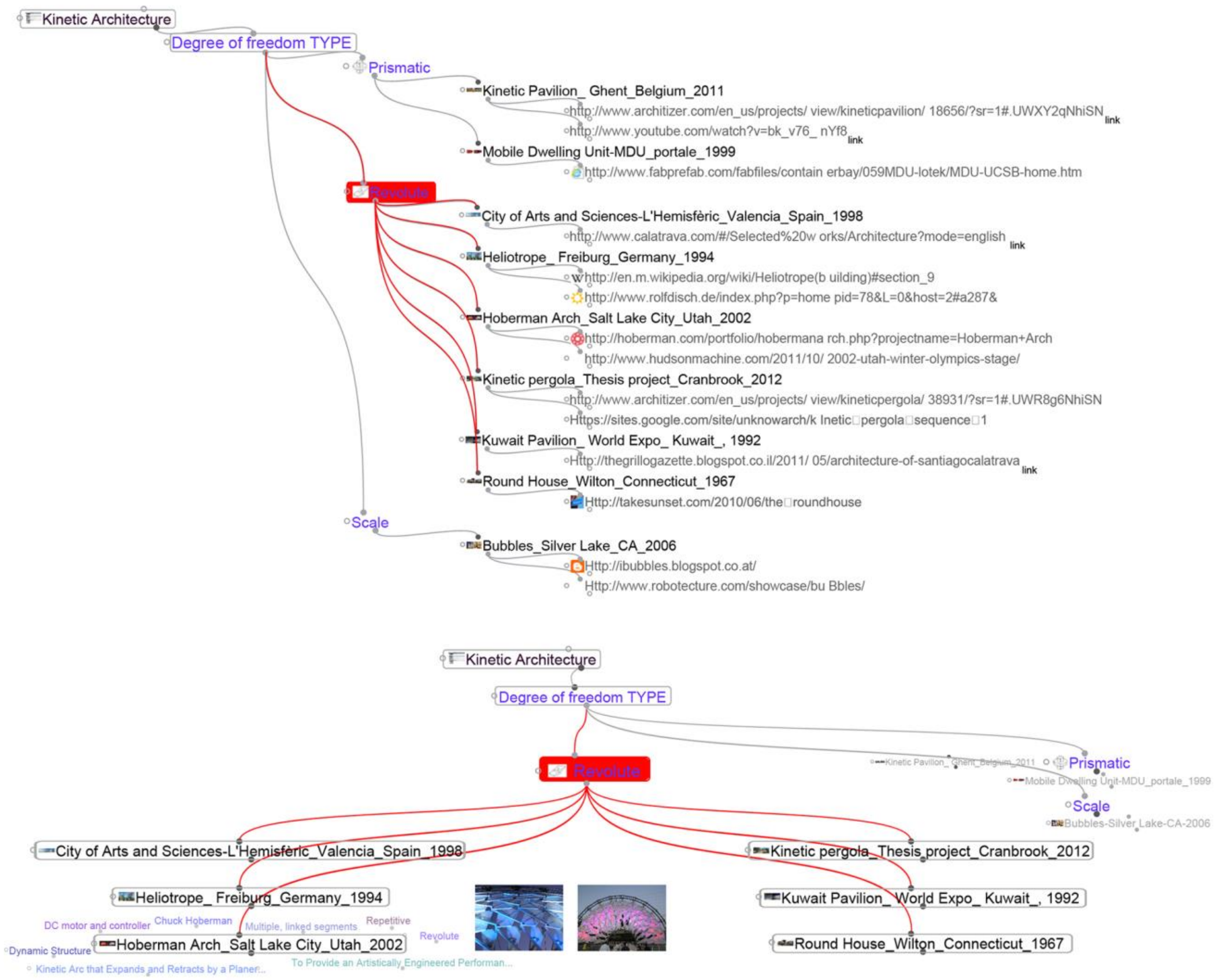


Figure 6: browsing the dynamic matrix – here: focusing on the degree of freedom type, visualizing all interdependencies of the classification sets (Ron, Weissenböck, 2013)

The “kinetic architecture matrix” is intended to be periodically updated, and could also be developed as an online tool to share the knowledge. Users can browse the matrix according to their interest and get a better understanding of the complex database by visualizing similarities, differences and cross-references.

5. SUMMARY AND CONCLUSION

"We must evolve an architecture which will adapt to continuous and accelerating change – a kinetic architecture" [18].

In this research project, we developed the "kinetic architecture matrix" as a useful tool for the following reasons:

- It helps to understand the mechanism and complexity of kinetic architecture
- It visualizes the range of kinetic projects that have been built, highlighting multiple approaches and applications.
- It displays the aspects of the kinetic mechanism of each project.
- It allows finding similarities and making comparisons of kinetic buildings.

With the help of this data-base, each dynamic project is no longer a stand-alone unique building. The classification of the surveyed projects into groups is useful for architects who are interested to create dynamic buildings.

We trust that the outcome of this research will widen the range of knowledge in the field of kinetic architecture and will contribute to forthcoming well-designed kinetic architecture projects.

IMAGE CREDITS

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Figure 2: http://adcats.et.byu.edu/Publication/94-2/paper2_10_18_97.html

Figure 3: Moloney, J 2011, Designing Kinetics for Architectural Facades: State Change, Routledge.

Figure 4: Ron, Ruth, Weissenböck, Renate (2013)

Figure 5: Ron, Ruth, Weissenböck, Renate (2013) **

Figure 6: Ron, Ruth, Weissenböck, Renate (2013) **

**Image of “Hoberman Arch” from: http://en.wikipedia.org/wiki/File:HobermanArchLit.JPG

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