

# Imitation in Action

## A Pedagogical Approach for Making Kinetic Structures

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**Abstract.** One of the problems in teaching students how to design kinetic architecture is the difficulty of helping them grasp concepts like motion, physical computing and fabrication, concepts not generally dealt with in conventional architectural projects. In this paper, we introduce a pedagogical method for better utilizing prototyping and explore the role prototyping plays in learning and conceptualizing design ideas. Our method is based on building the learner's sensory experience through iteration and focusing on the process as well as the product. Specifically, our research attempts to address the following questions: How can architecture students anticipate and feel motion while they design kinetic prototypes? How do their prototypes enable them to explore design ideas? As a case study, we applied our methodology in an 8-week workshop in a fabrication laboratory in Cairo, Egypt. The workshop was open to young architects and students who had completed at least four semesters of study at the university. We describe the pedagogical approach we developed to build the sensory experience of making motion, and demonstrate the basic setting and stages of the workshop. We show how a cyclical learning process, based on perception and action -- copying and iteration -- contributed to the students' learning experience and enabled them to create and improvise on their own.

**Keywords:** Kinetic Architecture, Digital Fabrication, Sensory Experience, Computational Making, Imitation

## 1 Approach

Inside the growing movement to go beyond static architectural tectonics and build skin configurations that include kinetic and adaptive structures, problems still arise regarding the pedagogical role in teaching such complex structures and methods to young architects. The skill sets and knowledge now required from students of architectural design have expanded to include prototyping, making and physical

computing. As stated by Frazer and Fischer (2005), architecture is being modeled as “logic states in space and time” where computers and architecture are interchangeably constructed and computed in an intelligent and interactive environment. This typically implies that architects now need extensive knowledge in the areas of human-computer interaction, programming, mathematics, computer science, robotics, electronics mechanics, and other areas.

In this interdisciplinary context, the architect/designer no longer follows a linear workflow and reductive process of simple hierarchical problem solving (Diniz 2015). He/she becomes an orchestrator integrating different concepts, viewpoints, disciplines and methodologies and technologies. As a result, architects need to understand and feel comfortable with prototyping, both for static and kinetic structures.

The significance of the role of prototyping in architectural design and making of kinetic structures have been discussed widely. While educators have explored a variety of methods to teach students to design and make kinetic architecture, most attempts have focused on the product rather than on the learning process. Some educators have focused on asking students to design certain mechanisms and then add elements such as electronics (Fox and Hu 2005). Other designers have attempted to classify motion types (Schumacher, Schaffer and Vogt 2010).

Later attempts have explored the notion of experience prototypes, prototype conceptualization, and prototypes as a vehicle for research through design and for design exploration in education (Diniz 2012). An inevitable transition occurred in architectural education as emphasis shifted from design ideas and concepts such as case-based design and representation to processes such as performance-based design, mutation and animation (Zaero-Polo and Moussavi, F. 2003; Kolarevic 2003; Aranda and Lasch 2006; Oxman 2008; Diniz 2015). This transition automatically led to a shift in mindset and the palette of skills necessary to conduct such processes as physical computing, programming, scripting, and algorithmic thinking.

In this paper, we explore a new way to teach students the skills necessary to create kinetic systems that change shape according to contextual or climatic changes. Our inquiry entails how they learn to imagine and materialize tangible elements such as structure and materiality, and intangible elements such as motion. We first adopted Fox and Hu’s approach (Fox and Hu 2005) in our pedagogical strategy. We also introduced the learning process as a holistic design activity, rather than as a discrete set of skills.

Tim Ingold argues that art and technology should be treated as one, as the ancient Greeks considered both as *practiced skills* (Ingold 2001). Imagining motion, and then designing and making it is an acquired skill gained through the action of making. With this in mind, we aimed at building students’ practical skills, which they could then apply in designing and making any kinetic structure.

To do this, we adopt  $I^3$ , a three-layered operation for making and learning that is based on *Imitation, Iteration and Improvisation* (El-Zanfaly 2015). Through  $I^3$ , students build their sensory experience and acquire the technical skills needed for design and making. We argue that  $I^3$  is particularly useful because it requires integrating computational design with additional components.  $I^3$  is a hands-on process that focuses on process rather than product.

For the purpose of this study, we designed a workshop that we called *Kinematic and Responsive Architecture and Fabrication Technology* (KRAFT). We describe below the workshop settings and its stages, outlining the approach we developed to build the necessary sensory experience. We then highlight the act of copying or imitation, and discuss how the notion of imitation-in-action affected the design and learning process of the students. Finally, we present our main findings and conclusions.

## 2 Workshop Process and Outcomes

### 2.1 Workshop Stages

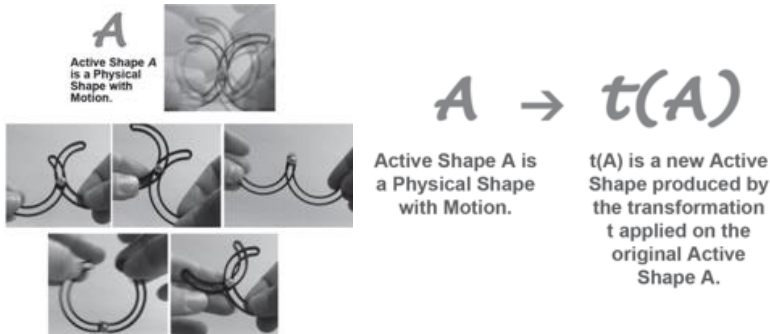
The workshop took place at the first community-based collaborative space and fabrication lab in Egypt. It was open to young architects and students who had completed at least four semesters of study at the university. We also collaborated with the Department of Architecture at Ain Shams University and with a team at an independent architectural hub. Twenty students had not been previously exposed to digital fabrication tools or elements related to responsive environments such as microcontrollers, materials and motions were participated.

Our workshop represented was the first attempt in Egypt to teach students how to design and make responsive and kinetic architecture. The workshop was conducted in 24 sessions over a period of 8 weeks. Learning by doing (Dewey 1997) was one of the main methods implemented in the workshop. We also asked the participants to present their projects' storyboards and ideas about how people might react to their projects and why. This helped the participants not only to focus on the aesthetics, materiality and motion of the structure, but also to design for user experience. We conducted the workshop in 6 different stages: (1) introducing relevant literature, (2) working with active shapes and active rules, (3) working with digital fabrication and analyzing precedents of kinetic structures, (4) imitating and copying as a creative act, (5) introducing concepts of physical computing, and (6) prototyping to design and fabricate a responsive wall system.

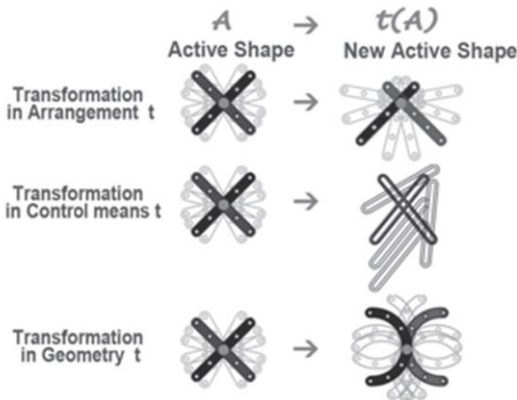
First, we introduced the students to related literature on digital fabrication, kinetic structure components and responsive environments. In order to familiarize them with KRAFT, we needed to review some basic topics within the readings, such as architectural robotics, tangible user interfaces, ubiquitous computing, digital fabrication and responsive architecture. We then introduced them to *active shapes* and *active rules* (Fig. 1), which represent guidelines for designing architectural kinetic structures, where rules based on shape grammars (Stiny 2011) are used for capturing motion and design (El-Zanfaly 2011). Active shapes and rules provide a method for the designer to describe and design novel kinetic structures through different transformations (Fig. 2).

Based on Shape Grammars, the rule  $A \rightarrow t(A)$  is introduced. (A) means an Active Shape, that is a physical shape with motion observed or created by the designer.  $t(A)$

means a new Active Shape produced by applying one or more transformations  $t$  on the original Active Shape to produce a novel motion (El-Zanfaly 2011).



**Fig. 1.** Right, Active shape. Left: Active rule, showing a transformation applied on the active shape (El-Zanfaly 2011)



**Fig. 2.** Examples of types of transformations (transformations in arrangement, control and geometry), which could be applied to the active shapes to produce novel kinetic structures (El-Zanfaly 2011)

In the third stage, the participants were introduced to digital fabrication methods and techniques, with hands-on exercises and access to a laser cutter and 3D printer. As Mine Özkar (2007) argues, digital tools and fabrication machines often overwhelm students and thus impact their design process. With this in mind, at this stage we focused on analyzing some examples of already built responsive and kinetic structures. We discussed the materials used, the assembly of the parts, and the fabrication methods used; we believed that helping students to familiarize themselves with the steps in designing responsive architecture would reduce the students' anxiety when it came time to approach their own projects.

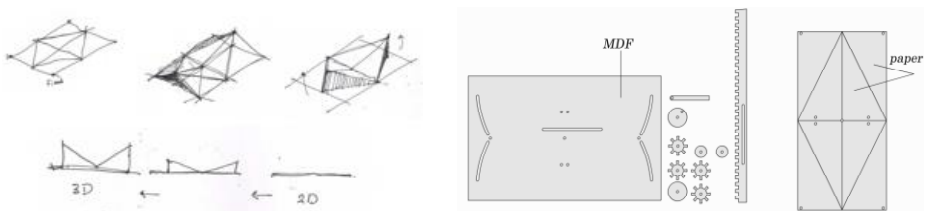
In the fourth stage, we asked the participants to imitate an existing kinetic structure and its motion by first drawing and then fabricating it. It was important here to allow the participants to select an example to replicate. We intentionally provided students

with an image of the project only; we did not provide diagrams or blue prints from the original structure. In the fifth stage, we explored the implementation of the Arduino micro-controller for the prototyping of smart and responsive skins and surfaces, with specific focus on interfacing between digital and physical worlds and programming different forms of sensors and actuators to control physical elements. Finally, the participants were asked to integrate what they learned in all stages to design and fabricate a responsive wall system. In the next two sections, we discuss the student works in stages 4 and 6, which contained most of the hands-on work and best illustrate how the participants progressed in their work and arrived at their final outcomes.

## 2.2 Imitation and Copying as Creative Act

In this specific stage (stage 4), we introduced the act of copying. We asked students to copy an already built mechanism or concept of a moving structure in any scale. Through this process, students see something new whenever they copy or imitate a part. They learn to analyze and focus on structure, material behavior and mechanisms, and how pieces come together. Copying an already built structure enables the students to learn from tangible objects and connect aspects such as materiality with intangible aspects such as motion. We asked the students to choose an example and fabricate it so as to gain hands-on technical skills through imitating and to get the “feel” of motion and materiality (Ingold 2001). The students did not have to build the whole structure; we asked them to imitate and build a structure in motion with any material.

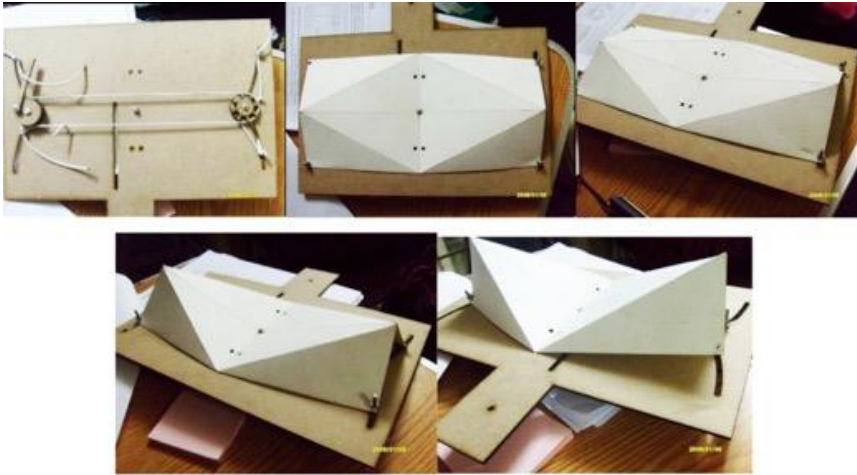
Below we describe briefly five example prototypes from the students’ work: (1) Origami Structure, (2) Walking Beast, (3) Mechanical Iris, (4) Expanding Circle, and (5) Kinetic Sine Wave. The *Origami Structure* project involved inspirations from folds and origami (Fig. 3). One student described her design of the origami structure as one that transforms from a 2D to a 3D structure. She also gave functionality to the designed structure; “...it may be a responsive curtain which can divide space, or outdoor furniture unit which can appear from nothing (2D plan to 3D unit), or it may even be a decorative wall which can interact with users.”



**Fig. 3.** Origami Structure drawings

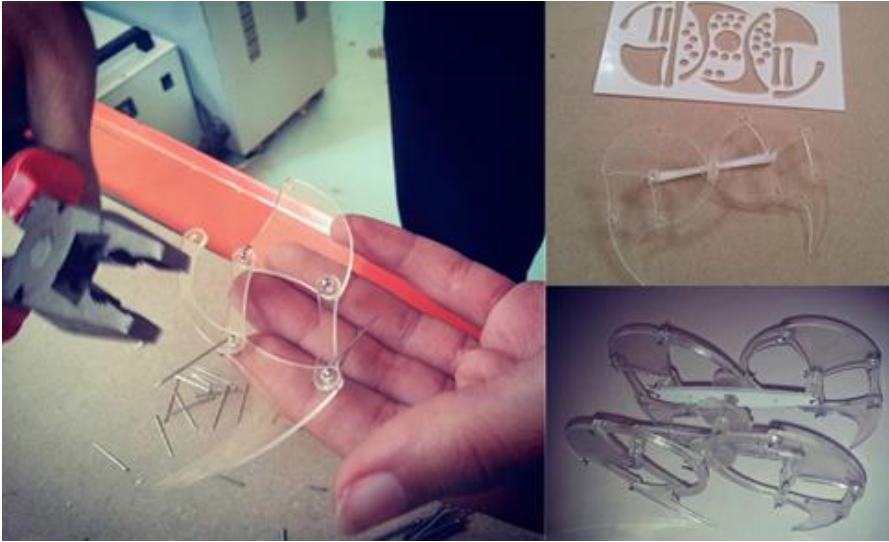
In her description of the final structure and motion (Fig. 4), she described the structure as consisting of two main parts, in which the first part is “*origami paper* –

*it's fixed from one point at the middle to the wooden plate," and the second part as "paper's edges start to move when we use the crank slider and push the two gears in the wooden plate".*



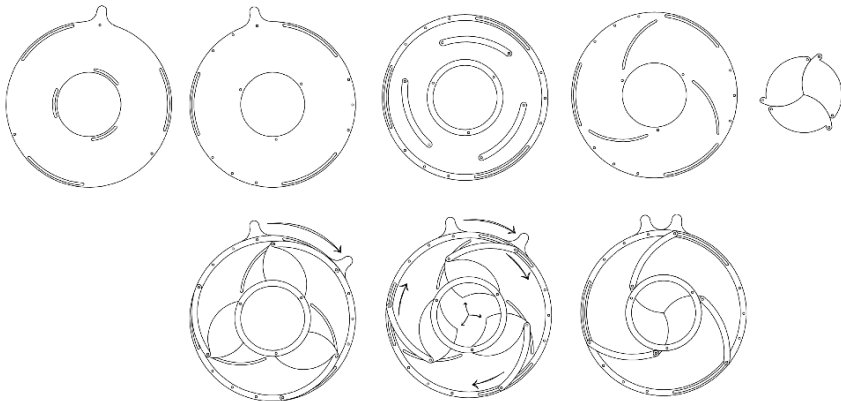
**Fig. 4.** Structure and mechanism of Origami Structure

In the *Walking Beast* project, two participants working together decided to imitate the motion of Theo Jansen's mechanism "Strandbeest" (Patnaik 2015). They designed the element and fabricated it using the laser cutter (Fig. 5). In their presentation, they explained how they studied the motion of the walking legs of some of Jansen's beasts and the motion of these kinetic sculptures. They found a new way to fabricate the continuous motion of the element using the laser cutter during their assembly of the pieces.

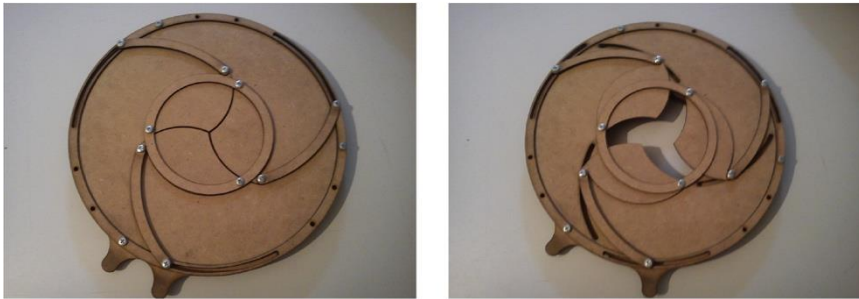


**Fig. 5.** Structure and mechanism of *Walking Beast*

In the *Mechanical Iris* project, two participants, working separately, developed a mechanical iris from scratch. The first participant designed the motion and pieces to imitate a specific type of motion captured from a video of a responsive window aperture. The structure involved a circular geometry with a double-layered guide for controlling the opening and closing of an internal aperture (Fig. 6). He made several iterations until he developed his own final geometry and motion (Fig. 7).



**Fig. 6.** *Mechanical Iris* drawings (Project A)

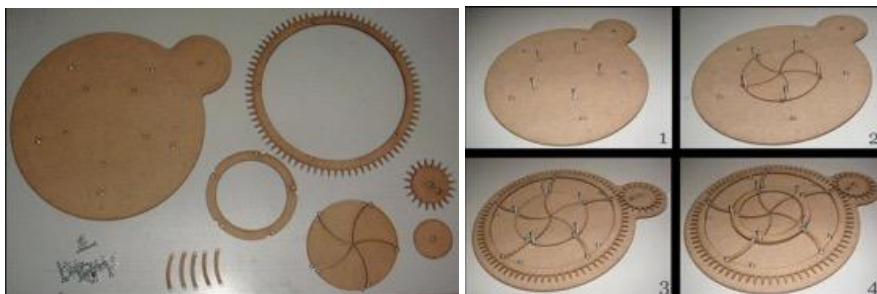


**Fig. 7.** Structure and mechanism of *Mechanical Iris* (Project A)

The second participant also worked on a mechanical iris. She was also able to replicate the motion of opening and closing with another mechanism using gears (Fig. 8). The mechanism also involved a double layer of circular geometry with motion guides and two circles that acted as gears for guiding the overall motion (Fig. 9). In both projects, the participants were able to create the same motion they attempted to imitate, but using different mechanisms and techniques.



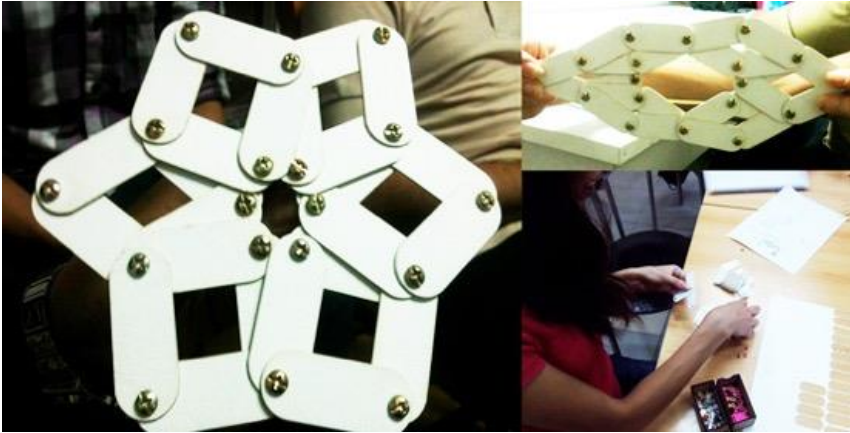
**Fig. 8.** *Mechanical Iris* mechanism, final structure and motion (Project B)



**Fig. 9.** *Mechanical Iris* detailed components and assembly (Project B)

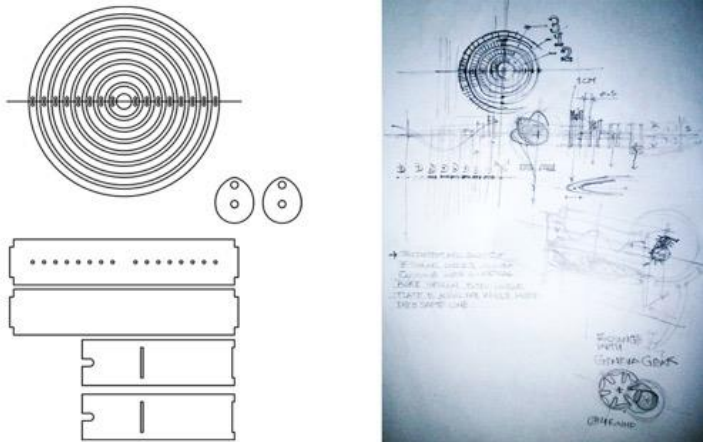
In the *Expanding Circle* project, one participant designed an expanding circle that returned to its shape once it was pulled. She used a rubber band to pull all parts together once the circle was expanded (Fig. 10).





**Fig. 10.** Structure and mechanism of *Expanding Circle*

In the *Kinetic Sine Wave* project, the participant imitated the Reuben Margolin Nebula structure. The student's sketches show that he designed the motion and parts from scratch (Fig. 11). He was able to produce his intended motion after a couple of iterations. Using pulleys and threads, he was able to pull the structure made of wooden circular rings according to several 3D sine wave motion types (Fig. 12).



**Fig. 11.** *Kinetic Sine Wave* sketches and drawings

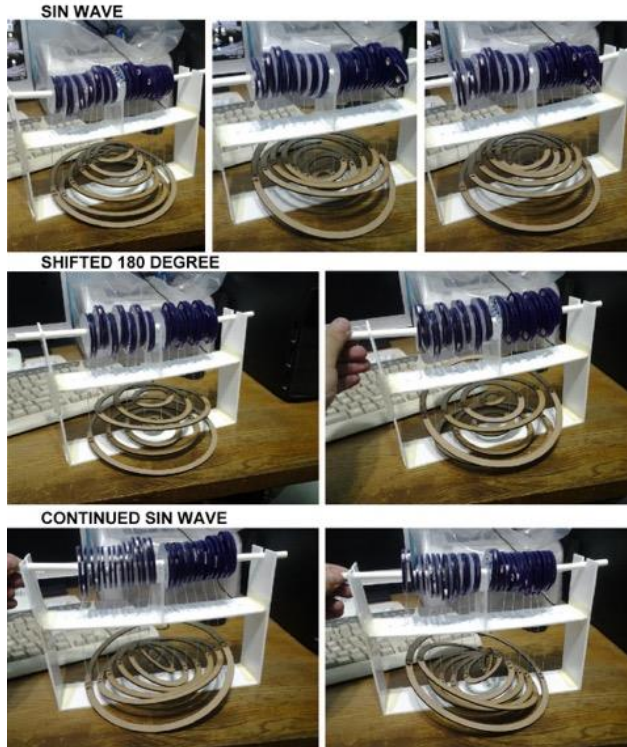


Fig. 12. Structure and mechanism of *Kinetic Sine Wave*

### 2.3 Architectural Scale: Expandable Mashrabeya

In this final stage, and after introducing the Arduino programming environment for the prototyping of smart and responsive skins and surfaces, we asked the participants to design and fabricate a wall component that represented an element of responsive architecture. The goal was to create a modular wall unit representing an exterior or interior wall that could be controlled using microcontrollers, sensor feedback systems and actuators to adapt to changing parameters. We specifically asked the participants to design scenarios for interaction, motion and reaction using this sensor network data.

The participants worked in 3-4 person groups on their projects. Each group picked a specific theme. Group projects were asked to specify and articulate their responsive architecture systems, i.e. whether they focused on responding to environmental conditions, lighting, acoustics, occupancy levels, user behavior and interaction, circulation patterns, and so on. The participants were asked for project proposals and presented them during three sessions with discussions and feedback. Each student proposed a project individually; then they formed teams based on mutual interest.

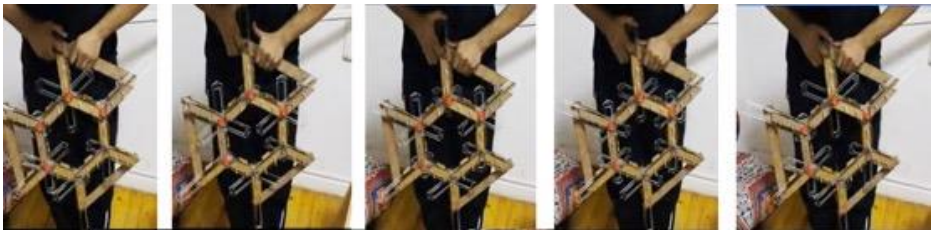
In one of the projects, the group suggested a wall system that opens and closes to control lighting and ventilation according to an ancient, well known Arabic wooden

structure called the *Mashrabeyah* -- a carved wood lattice matrix that was used in Arabic houses to allow for ventilation and sunlight, and simultaneously allowed for indoor privacy. The group first studied different geometries and patterns in existing Arabian houses. Then they studied and tried different mechanisms to produce maximum motion with the least number of motors.

The group designed a unit with five gears, which controlled linear sliders to open or close the unit and adjust the units as well (Fig. 13). This unit required only one motor. The students worked on optimizing the numbers of motors required by changing the geometry of the units and its controllers (Fig. 14).



**Fig. 13.** The basic kinetic modular unit of the *Expandable Mashrabeya*



**Fig. 14.** The modular unit requiring only one motor to make five gears work

### 3 Discussion

This paper addressed a set of questions related to teaching students how to anticipate motion *while* designing and making. It provided a pedagogical framework for helping designers to first acquire the *feel* of motion and materiality, then apply this sensory knowledge to their design ideas. The *Imitation and Copying as Creative Act* approach,  $I^3$ , was introduced to help the students make moving structures. The general results showed that students were able to create kinetic structures using this approach. The introduction of active shapes and rules helped break down the sensory experience

into explicit steps that allowed students to perceive kinetic motion and expand conventional grammar into dynamically changing possibilities. The cyclical operation of perception-imitation-action employed by students throughout the workshop changed their perspectives and produced varying levels of complexity in terms of design. Some participants adapted the original structure along more predictable lines, as in the mechanical iris and expanding circle. Others showed an adaptation of the original examples with more complexity, as in the origami structure, the walking beast, and the kinetic sine wave.

Most students used several combinations of these transformations. As their design ideas iterated cyclically, they continued to *see* their active shapes as potential new active shapes. This allowed for innovative schemes that often exceeded the initially imitated-as-is image, and consequently led to novel kinetic elements. In the final stage, the students further augmented the  $I^3$  operation. They started to include environmental, cultural and user experience considerations. The process of Imitation in this workshop was not limited to the geometrical *image* of the Mashrabeya, or even a direct translation such as in the mechanical iris.

The Mashrabeya project showed how far students could progress through the learning process. In this case, the developed mechanism featured a complex outcome based on the sensory experience learned during the workshop. This outcome combined the perception of active shapes and their expected transformations, together with an adaptation of the conceptual basis of the Mashrabeya – rather than mere geometry – and a complex kinetic optimized mechanism. The final design outcome – or *integrated system* – appeared to be more than the ‘sum of its parts.’ We conclude that the *perception-imitation-action* cyclical operation established groundwork for multiple levels of reflection, conceptualization, and learning, and led to this integration. These levels include (a) direct adoption of motion, materiality, and structure to conceptualize a prototype; (b) decomposition of the sensory experience into explicit rules of motion; (c) continuous reflection and adaptation to generate developed and complex prototypes; and (d) integration and appropriation of prototype to conceptualize and generate novel design ideas.

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