Mechanism in Design Studio: A Transformable Space Design and Construction

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Abstract. Historically, architecture has been perceived as a stationary creation and thus the study of mechanisms or kinetics was beyond its scope of curriculum-based architecture studios. This is particularly true for functional spaces that are used by occupants often needing flexibility in space use. In the last twenty years the design of small spaces for functional optimization has become an area of increasing interest. Interiors having transformable spaces through kinetic walls, moveable partitions, foldable surfaces, dynamic furniture, etc. is an area that can be a valuable studio learning for curriculum-based design education. The study of mechanisms and understanding their application in design can enhance the quality of smart spaces that are multi-functional. The use of hinges, gears, cranks, levers, coils, springs, struts, principles of weight and counterweight, principles of tension-compression to formulate design ideas to incorporate various kinetic elements is one of the objectives of this studio. It is to be noted that the scope of the studio was limited only to design and construction and not on follow-up evaluation of its use or effectiveness.

1 Mechanism and Design Studio

Mechanism refers to the functional systems that enables movement, transformation, support, and interaction. These mechanisms can be grouped by purpose and scale, from building systems to small hardware details in furniture. The basics of mechanisms revolve around moving parts called links, connected by joints, that are assembled to form a system that transforms input force and motion into a desired output motion or work. In architecture, "mechanism" refers to kinetic systems of moving parts that transform a static structure into a dynamic, deployable one, enabling it to expand, contract as needed, change shape, or adjust to fulfil functions like offering shelter or creating spaces that are multi-functional.

This design-build undergraduate studio in its first phase looks at the notion of design thinking and design principles through a series of constructed artifacts that encompasses from artwork to household objects. Then the studio focuses on the design and construction of a small-scale transformable 6’ cubic space (in groups of four students) using available mechanisms to adapt to various configurations of spaces to exhibit created artifacts.

This studio is an exploration on the human scale. It explores the commonality of visual languages between industrial design and architecture, and the relationship between

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transformable space and designed artifacts. It requires simplicity and complexity, expansion and contraction, mobility and immobility, assembly and disassembly. The studio deals with parts, connections, and their relationship to the whole.

Fig. 1. Study of basic applicable mechanical components such as hinges, springs, struts, sliding tracks, pullies to construct transformable spaces.

2 Overall Studio Objectives, Framework, and Projects

The framework of this design-build studio course is based on two primary objectives:
1. To explore the commonality of visual languages in art, product, and architecture.
2. To explore the use of mechanisms to design and construct smart transformable spaces.

This Design Build Focus Studio first looks at the motifs of applicable visual design language through design and fabrication of 4 to 5 artifacts that encompasses from artwork to household objects of everyday use. Then, using the study of applicable mechanisms the studio explores design and construction of a small-scale transformable architecture that becomes the vessel for created artifacts that align with contemporary lifestyle and space optimization. At the same time these artifacts create various types of ambiance to complement the environment of the constructed vessel. For example, the design and fabrication of dinnerware (plate, spoon, for, napkin holder, etc.) complements the vessel to create an ambiance of dining.

Considering the fact that architecture is as much a science as an art, this paper aims at linking and applying both arts and science in a full-scale construction of transformable microenvironment (functional pod) and various product design. While exploration of commonality of visual design language in art, product, and architecture directly refers to ‘Art’, the study of mechanism, and precise construction of the transformable Pod using digital tools directly refers to ‘Science’.

Design, drawing, and fabrication of Dinnerware, Time Device, Illumination, Surface Typology, and Architectural Painting are the medium to explore objective # 1, i.e. the commonality of visual design language.

3 Pedagogical Objective One: Commonality of Visual Languages in Art, Product, and Architecture

Design, fabrication, and display of various artifacts to complement the ambiance of the design-build transformable cubic space is the task of this segment. The goal is to initiate the awareness of common visual languages that are applicable to art, everyday used product, and architecture. Design and Fabrication of five short duration assignments (1 to 2-weeks) for individual students are;
- Surface Typology
- Tableware/Dinnerware
- Time Device

- Illumination
- Architectural Painting

These are the assignments intended to complement the ambiance of the proposed Pods. Strategically these are designed to be individual assignments spreading over the semester so that in case of delay or pause in the construction of main Pods the studio will be active with these smaller individual projects. Assessment of individual work will also help to have a balanced final grade averaged by these assignments and the group assignment of the Pod.

The central theme being visual grammar, each project in this segment deals with specific tangents of visual design principles. For example, Dinner Plate design project is exploration of application of visual graphics that are two-dimensional demonstrating common design principles of repetition, progression, anomaly, etc. through elements of line, image, and other graphics. The Surface project requires use of digital tools to create perforated and three-dimensional patterns requiring CNC Router, Laser Cutter, and 3D Printer. On the other hand, the Illumination project is more on the dissemination of light quality, ambiance, and overall form. Examples of such three projects are discussed below.

Dinnerware project

Gathering, adapting, and transforming two-dimensional graphic motifs from various sources around us and then applying them to dinner plate design for unique visual expression was the objective of this exercise. The technique that followed was to create a composition using manipulated photographic image that express one or more of these design principles, such as: repetition, progression, movement, gradation, radiation, rotation, anomaly, contrast, concentration, hierarchy, and focus. Highlighting the features of overlap, size variation, and figure-ground are some techniques that were encouraged for graphic composition.

The dinnerware project called for a dining table set up for 2 people with Plate, Glass/Cup, Spoon, Fork, Knife, Table Runner, Place Mat, and Napkin Holder. The graphic design motif may be divided into 3 categories, Architecture, Art, and Abstracted Nature.

Fig. 2. Visual graphic motifs applied to dinner plates and other accessories.

Time device project

This project focused on non-physical (perceptual) nature of time that requires visual images to transform its perception. Re-visualization of the time scale, its units in proper visual graphics, and movement are the objectives. The goal of this project is to initiate awareness in these areas:

- expression of time through visual graphics
- exploration of visual design/graphic vocabulary in a product design

- connection between art, product and architecture
- role of technology in creation of form, geometry, pattern, solid-void.

Illumination: Luminary Lamp project

Luminary means "a body that gives light. A light fixture or luminaire is a technical and professional term for an electrical fixture that holds a lamp, a light bulb, the light source.

This project looks for references in architecture, applied graphics, and elements and principles of visual design. Students are asked to formulate three design ideas based on 1. architectural precedents, 2. surface to volume (using techniques of fold), and 3. repetition of elements and modules to create geometry and form. The Applied graphic motifs reflecting abstract composition using point, line, etc. for light disseminating screen were encouraged. Highlights include:

- Form and geometry
- Light quality
- Construction technique & finish
- Graphic strength.

Fig. 3. Illumination quality and three-dimensional articulation through visual organizing elements.

4 Pedagogical Objective Two: Mechanism and Transformable Multipurpose Cubicles

The focus of this paper is to illustrate the exploration of mechanisms for transformable spaces in groups of 3 to 4 students and complete the full-scale construction in 12 weeks to address the primary objective of this studio, i.e. segment 2. Transformable structures in architecture have the ability to change morphology and readjust in response to varying conditions and needs that can include changing environment and climatic conditions, different functional requirements and emergency situations [1].

Design, representation, and full-scale construction of a transformable space modulated by transformable surfaces creating an implied cubic volume of 6' on all sides is the primary task of this studio. This space volume blurring the definition of interior and exterior would then become the three-dimensional canvas to hold designed objects of everyday use for modern lifestyle and optimization of space. This would be like an exhibit booth showcasing their products. Transformable walls with articulated surfaces to portray the ambiance of the cubic space is an important aspect of this phase.

Assignment

Design and full-scale Construction (using simple mechanism) of a transformable pod for multiple activities is the primary task of the studio. All 18 students are asked to generate two

ideas of proposed structure through scale-drawings, 3d renderings, and physical scale models. Out of 18 proposals, 5 are finally selected by a formal review process involving three other professors (figure 4). Then teams of 3 to 4 members were assigned to each proposal for development and full-scale construction.

Fig. 4. Five accepted proposals to be developed for construction.

While these 5 proposals are being developed by 5 groups, individual students are asked to design various artifacts that will become part of the constructed pods to support intended activities. For example, the pods with dining activity would create design and fabricate dinnerware set including plate, spoon-fork-knife set, table mat, table runner, napkin holder, salt and pepper shaker, etc.

Context: Research on Mechanism, Surface, and Transformation

Mechanism

The project started with the research on mechanism that are low-cost and available to be ordered and delivered within a week. Each student is asked to gather information on these;

- Mechanism, definition, purpose
- Different types of mechanism and their principles
- Use of mechanism in architecture
- Application of mechanism/kinetics in architecture (history, categories, examples, etc.)
- The type of mechanism to be used and their effectiveness in space space transformation.

Transformation

The Oxford Dictionary defines Transformation as “a thorough or dramatic change in form or appearance”. In architecture, transformation is the systematic alteration of form, mass, space, or geometry through specific operations such as scaling, rotation, subtraction, or deformation—while often retaining the identity of the original form.

The common type of architectural transformation includes Geometrical Transformation, Dimensional Transformation, Additive Transformation, Subtractive Transformation, Rotational Transformation, Hierarchical Transformation, and Formal Transformation.

Regarding framing the purpose of transformation to facilitate multiple functions, students are asked to clearly address these points:

- Primary objective, Activities/Program
- Documentation of two minimum options illustrating how the proposal transforms into different activities
- Ambience and elements of ambiance in context of transformation
- Method/technique/application of transformation.

Surface

Next, students are asked to individually research on definition of “Surface” in physical, visual, and sensual entities and in architecture. Investigation of materials, methods, and

techniques to create unique surfaces with texture, pattern, color, and applied graphics for cladding of structur/skeleton/frame is the goal. Students are asked to research on these:

- Define Surface in physical entities
- Surface in Architecture
- Characteristics of Surface; Physical, Visual, Sensual
- Categories of surface; Graphical, Textural/Modular, Porus/Perforated, Translucent
- Materials, Methods and Techniques of fabrication.

This assignment asks students to design, draw, fabricate, and represent various types of surfaces using principles of visual composition in a 2'x2' surface. This surface can be a single plane, or, tiled, or, modular to be applied on a 6'x6' surface. The design and construction calls for expressing one or more of these visual design principles; Progression, Movement, Gradation, Radiation, Rotation, Anomaly, Contrast, Concentration, Hierarchy, Focus.

A minimum of these four types in various combinations are to be designed; 1. Graphical, 2. Textural/Modular, 3. Porus/Perforated, and 4. Translucent.. For construction and fabrication students are asked to consult with the instructor and construct one 2'x2' full-scale surface selected from the combination of above four designed options that can be expanded to a 6'x6' surface.

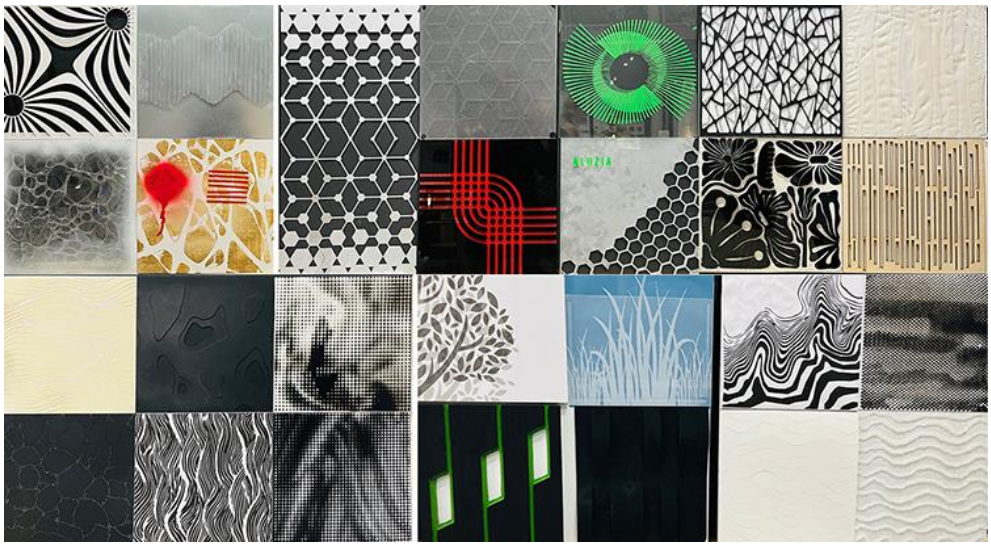

Fig. 5. Fabrication of Graphical, Textural, Porus and Transculent Surfaces in 2'x2' tiles illustrating commonalty of visual language in art and architectutral surface.

5 Mechanism and Five Design-Build Transformable Multipurpose Pods

Focusing on the use of mechanisms to design and construct smart transformable spaces for multiple functions, 5 proposals for full-scale construction are selected out of 18 individual Submissions (12 weeks assignment duration in groups of 3 or 4). Each of these five proposals accommodates a minimum of two or more activities and changes the overall form and relationship of interior and exterior relationships through the hidden use of mechanisms. The techniques of Accordion Expansion-Contraction, Surface Folding, Sliding Envelope, Modular Linear Expansion-Contraction, Shifting Walls are incorporated into these five design proposals and their iterations.

The process of design iteration and learning includes:

- Hand drawing, 3D digital model
- 1/3 scaled physical model (4" = 1'-0")
- Material study
- Mechanism, components for assembly & structure study
- Surface and cladding study
- 50% Scaled Model (6" = 1'-0")
- Electrical and light fixture study
- Full scale construction of mechanism detail for transformable features
- Full Scale Construction (12" = 1'-0")

Research through:

- Mechanism study
- Structure Study
- Material & Cost
- Timeline.

25% reduced scaled and 50% reduced scaled Model for Structure, Envelope, Material, and Assembly

To understand the primary structure, students are asked to construct a 25% reduced sized physical model to understand the stability and details. Materials of interior, accommodation of battery, wiring, and other systems are required to investigate through this model. It is noticeable that most groups initially considered heavy material use based on their Revit computer model rather than consideration of optimization. Then in the next iteration of 50% reduced scale model they are required to include every deatils as they woukd appear in the full-scale construction where most groups changed structure into thinner materials. This model is particularly important to understand the reality of construction and final assembly process to see how effectively transormative elements operate. At this point students are also asked to construct a portion in full-scale to test the workability of the transformation mechanism.

Construction Cost, Funding, and Timeline

Budget is an important consideration which can become a hindrance for design iterations and experimentation. Each group is asked to research materials and supplies in context to their specific pod design and mechanism. The initial budget is set to US $800 mainly for material and equipment. Since there is no funding available from the school or other sources each student had to contribute to all necessary purchases for their respective construction. A detailed list of itemized materials and timeline of construction schedule is a requirement for this portion of the assignment.

5.1 The Flex: Expansion and Contraction through Sliding Envelope (full-scale construction by 4-students)

Mechanism Used: Sliding Track, Rotational Hinge, Rolling Wheel
This cubic Pod uses four different types of mechanisms:

a) Hinge Mechanism - allows objects to swing open or close
b) Sliding Mechanism – saves space by providing wide openings
c) Gas Struts – provide controlled lifting, supporting, and counterbalancing of objects with

a push or pull force
d) Cam and Follower – converts rotary motion to reciprocating motion.

For the design methodology, the process began with researching various types of mechanisms that enable a vertical wall surface to be shifted and rotated manually at ease. The aim is to control the act of expansion and contraction of surface planes through strategies of extension, projection, and spatial opening that connect interior to the surrounding context.

By using spatial sequences that alternate between expansion and contraction, this studio-built design creates open areas as well as tighter focused areas of space. The material choices and the lighting strategies are planned to emphasize ambiance of space variation. Having textured surfaces such as the wood allows for the experience of the interior to feel more grounded and contained. Light becomes an important aspect of space as it modulates between the interior containment and the exterior transition. The duality of the targeted micro-environment is intended to create a unified design concept that responds to the varied programmatic needs of the project.

This studio-built project in a group of four students in Bachelor of Architecture program focuses on understanding how mechanisms can help with pulling and pushing surface planes inward and outward in a specified space-volume to create contrast between introvert and extrovert spaces that are dynamic and transformable.

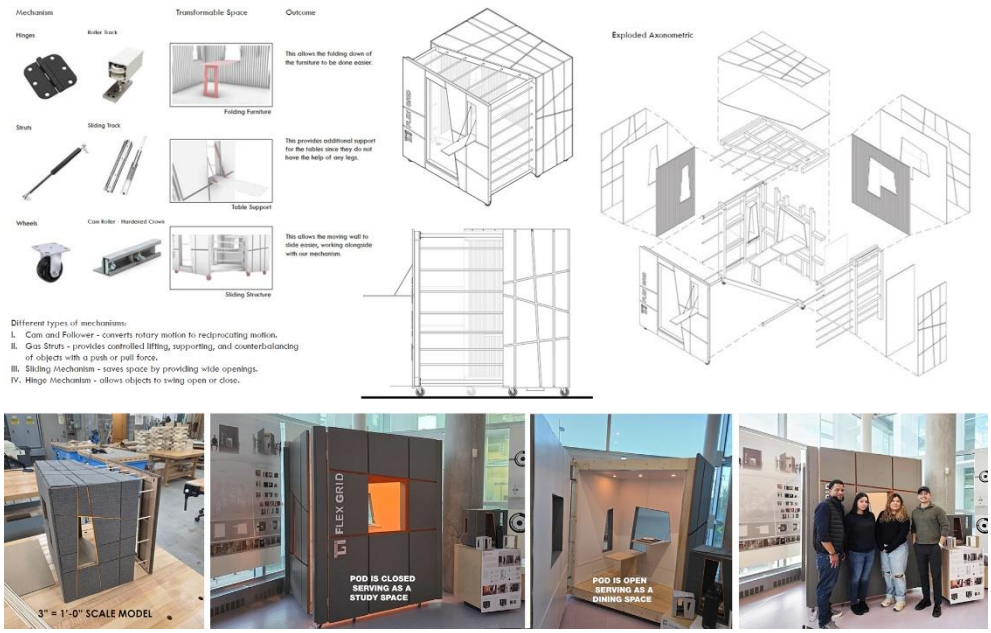

Fig. 6. Specific types of mechanism, orthographic scaled drawings, 3" = 1'-0" scale model to facilitate study of materials and details, and final full-scale construction.

5.2 The Slice: Modular Transformation of Architectural Assemblies through Rotational Mechanism System (full-scale construction by 4-students)

Mechanism Used: 270-degree Rotational Hinge, Swivel Mechanism, Rolling Wheel.
This full-scale constructed project considered four types of mechanisms:
a) Rotary motion mechanism - moves rotationally around an axis
b) Linear motion mechanism – moves in a straight line motion

c) Oscillating motion mechanism – moves across fixed range within an angle
d) Reciprocating motion mechanisms – moves across fixed range in a straight line.

The focus of this research is on the configuration potential of modular transformation in architecture through rotational mechanisms. The value of this work is based on how mechanisms enhance architectural design in construction, transportation, and experience of space with mass-produced devices. This is especially relevant within compact areas or high-density environments, in which expansion or contraction is functionally and aesthetically desirable. Key elements of the flexible and dynamic nature of kinetic forms in this project are an examination of changes to program, circulation, experience, and the overall transportable nature of the entire assembly. One of the important constraints for this research was a limited square footage for the design footprint and area of human experience. Another significant constraint for the study was the selection of basic rectilinear modules from the part-to-whole assembly scales. The methodological procedure for the analysis in this study involves precedent analysis, digital and physical model-making of prototypes, and visual matrices for comparison of different configuration options. The collection of rotational mechanism types, optimal application between various modules measured by visual and physical integration, and ideal application based on efficient transfer of weight loads underpin the assessment of mechanical systems. Quantifiable measurements include the ratio of modules to possible configurations, the ratio of possible configurations to experiential quality as measured by standard dimensions for human comfort, and the ratio of configurations to mechanical elements used. Expected production includes both a modeled example found on insights gathered, and design rules for application in small-scale architectural interventions in which a single mechanical system can create strong variation for an engaging experience of the design.

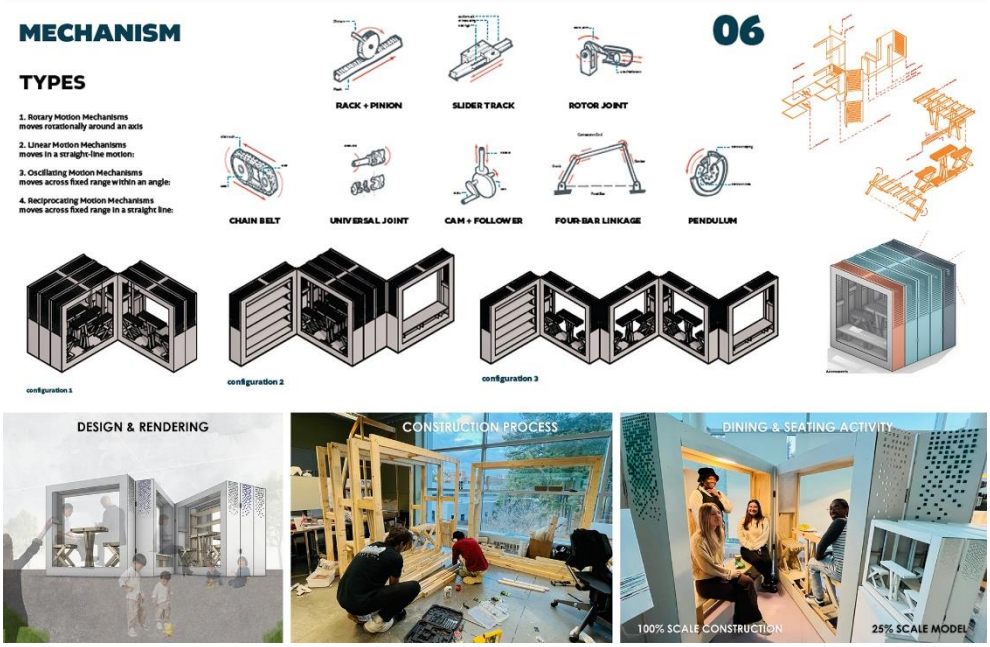

Fig. 7. Modular transformation allowing flexibility in activity and space configuration.

5.3 Oasis: Unfolding Surfaces in a Multipurpose Study-Sleep-Dine Pod (50% reduced scale by 3-students)

Mechanism Used: Struts, hinges, rollers, and tension springs
With the use of struts, hinges, rollers, and tension springs, the pod adapts to the needs of the user. The key design feature of the pod is the usage of a strut-supported sleep system where a section of the wall swings downward with the aid of hinges and struts that transform from a vertical wall to a sleeping platform. The partition on the frame is split in half so that it creates a semi-private space while the other half of it is on a pivot system that hinges down with the section of the wall to create a more private space. The exterior, sleek with metal cladding, provides perforations that allow light to transmit through the frame. To aid in use for studying, a desk hinges across from the sleep system, revealing a break in the fabric facade. The ambiance of soft lighting and textures creates a delicate cocoon to invite the weary student user for a warm embrace.

Fig. 8. Initial design proposal, segment of a full-scale construction to test hinge and tension spring system's effectiveness and final 50% scale model.

5.4 Triptych: Mechanical Walls Reconfigure Space and Sensory Experience (50% reduced scale by 3-students)

Crucial to the design are three mechanisms: hinges, which produce oscillating moments of openness and closure; track systems, which allow for smooth, linear transitions that expand or contract space; and pivot systems, which revolve around a central point to reroute movement and visual orientation. The project investigates how three walls that pivot, hinge, and slide along track systems might reinvent human interaction, spatial perception, and sensory experience in both an extroverted and an introverted manner, transforming architecture via motion.

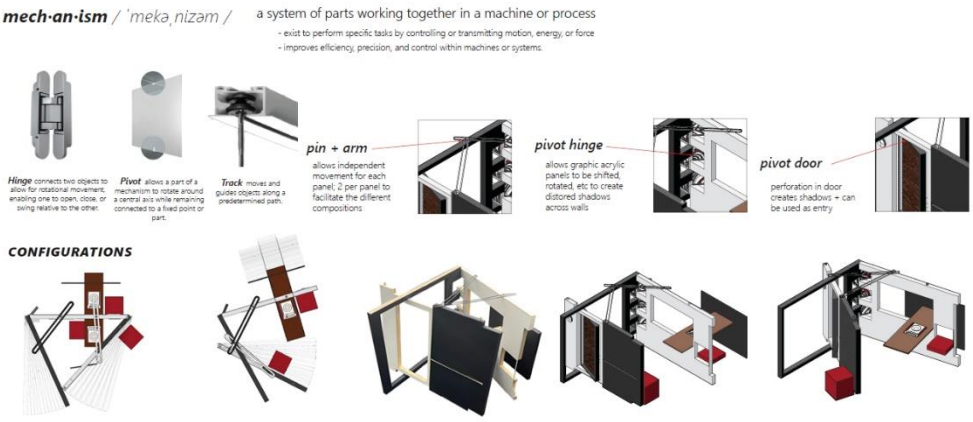

Fig. 9. Preliminary review with skeleton of a segment in full-scale construction to test structural integrity and application of mechanism systems.

The proposal, which draws inspiration from Tim Ingold's housing viewpoint [2], places mobility inside a continuous conversation between the material state, mechanism, and tenant. Tim Ingold's book titled "The Perception of the Environment" suggests that humans construct their world through direct, ongoing engagement with their environment rather than by conceptualizing it. Similarly, in the end, thsee three walls question the traditional static nature of architecture. Instead of just separating space, it suggests a flexible system in which three walls become performance components that choreograph experience.

5.5 Xtrude: Transforming Activities Using Linear Mechanisms (50% reduced scale by 4-students)

Mechanism Used: Improvised Scissor/Accordion and Guided Sliding Track.
The pod transitions between programs such as dining, studying, and relaxing. A vital precedent, The Shed in New York City, demonstrates how movement and scale can reshape perception of openness and light. Its architectural phenomenology inspires this smaller, more intimate application of similar principles. The result is a compact and adaptable environment where mechanical design and sensory awareness work together to create a responsive and human centered architecture.

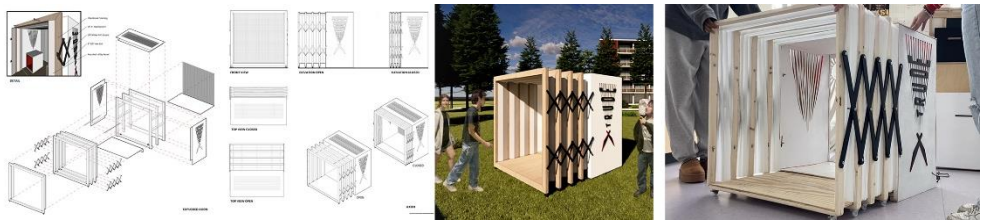

Fig. 10. Accordion and Scissor mechanism using X-bracing for expansion-contraction of building envelope.

The core mechanism is the Scissor/Accordion mechanism (X-Bracing), where vertical steel or aluminium members (pickets) are connected by diagonal, riveted, or hinged braces. This creates a flexible, expanding, and contracting structure. Panels fold neatly onto themselves, allowing them to shrink to a small fraction of their extended width. Guided track system at top and bottom with roller or casters help improve smooth movement. Motorized systems can be used to control the folding movement via sensors and remote control.

6 Conclusion

The recent trend of digital tool-dependent learning by students seems to compromise the depth and various layers of design thinking. In most instances such tool-based approaches are far from reality of full-scale physical construction. A design-build studio pedagogy in this paper is perceived as an opportunity to minimize that gap. This studio demonstrates the entirety of a design process from conception to execution using both manual and digital methods to embrace design thinking, visualization of details, graphic motif for architecture, composition of space-form-material-light, calculated budget, and methods of full-scale construction. From the pedagogical perspective this paper perceives architecture as much a science as an art and thus aims at linking and applying both arts and science in a full-scale construction of a functional pod that uses technology, alternate power, and improvised construction method through applied research.

In a positive note, it can be stated that the role of digital tools for design and representation gradually has become more integrated with full-scale fabrication. There is no reason why the education of architecture would only be limited to design and representation and not embrace construction. With the availability of digital software and hardware, in particular 3D applications in combination with CNC routers, 3D printers, laser cutters, and traditional wood shop, unlimited combinations and opportunities are available to explore 'design thinking' and 'visual design grammar' along with execution of full-scale physical construct. The concern of safety in construction, as well as duration of completion within a semester's time is now more realistic than before.

A design-build studio can be unpredictable. Many variables contribute to its success and outcome. Availability of digital fabrication tools, proximity between studio and fabrication lab, material selection, construction details, students' effort, teamwork, budget, schedule, and timeline are some of the important aspects that need to be examined beforehand for successful outcome.

Fig. 11. Curated exhibition of completed studio work to demonstrating use of art & technology in everyday used products and transformable Pods for multiple activities.

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