Omar Khan

Open Columns

Responsive elastomer constructions for patterning the space of inhabitation

Abstract This paper describes the use of composite urethane elastomers for constructing responsive structures at an architectural scale. It explains the underlying material research and design of an innovative molding device that assists in the fabrication of elastomer composites. These are combined to form deployable columns that are used to reconfigure and *pattern* the space of inhabitation. Further it discusses the process by which Open Columns can become an ambient technology that is more responsive to occupant and environmental needs.

Keywords composite elastomers · reconfigurable molds · responsive environments · self-organization

1 Introduction

Open Columns is a system of nonstructural columns that reside collapsed in the ceiling of an existing space. They are made from composite urethane elastomers and can be deployed in a variety of patterns to reconfigure the space beneath them. These patterns create *gradations* of enclosure, either in plan through the full deployment of columns, in section through their partial unfurling to change ceiling heights or through a combination of the two (Fig. 1). The system is a mutable architecture that can change the perception and inhabitation of the space within which it is deployed.

The genesis of this research comes out of an interest in self-organizing systems, which exhibit phenomena of nonlinearity, instability and adaptability. Ilya Prigogine describes physico-chemical "dissipative systems", like thermal convection and the Belouzsov-Zhabotinski (BZ) reaction, which exhibit complex self-organizing behaviors in far from equilibrium states [1]. These behaviors are not deterministic and can yield several responses under the same conditions. The cause for this variety lays in the system's past- some historical event that

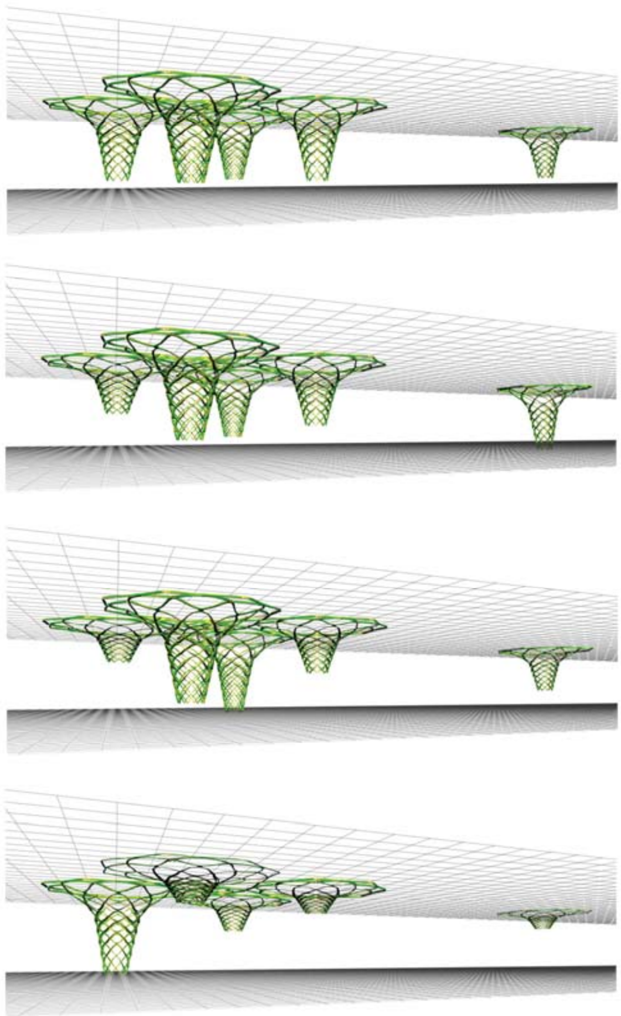

Fig 1 A study exploring the changing spatial ecology of 4 columns.

Omar Khan
Department of Architecture
School of Architecture and Planning
University at Buffalo
State University of New York
3435 Main St.
Buffalo, NY 14214
e: omarkhan@buffalo.edu
t: (716) 829-3485 x302
f: (716) 829-3256

whose effects can emerge unexpectedly at a later stage in the system's evolution. These qualities are potentially useful for an architecture that has to respond to changing needs from its occupants and environmental conditions.

Open Columns exhibits such properties both in its material composition and spatial performance. The choice of rubber as the construction material initially came out of its ability to handle the column's formal and mechanical gymnastics. However, urethane rubber's unique quality of variable hardness provided the possibility to ask more of the material. By blending different hardnesses together into more complex composites, the rubber's elasticity could be better calibrated for particular performance while also increasing variety in the overall structure. The columns' actuation (moving from collapsed to fully deployed) is controlled by networked motors. These actions can be steered by preprogrammed scenarios or through real time sensor based responses. Depending on the size of the column array and its formation the system is able to create subtle to stark variations of spaces that fulfill architect Cedric Price's dictum "never look empty, never feel full" [2]. This ambiguity of spatial composition can be beneficial for uses within hospitality, retail, exhibition and educational spaces.

2 Column Design

Traditionally rubber has taken a secondary role in architectural tectonics, relegated to assisting other materials perform their tasks: structural dampening, surface finish and weather proofing to name a few. This research looks at using rubber as the primary material for creating constructions at an architectural scale. Elastomers' polymorphous and elastic properties offer a unique opportunity for constructing kinetic and mutable structures. As a special subset of polymers their molecular chains (mers) are coiled allowing for considerable untangling before they break. This accounts for rubber's elasticity. When it is stretched its molecular chains become more regular and hence stiffer [3]. Open Columns exploits this quality by allowing gravity to act on its structure. When left to hang it stiffens and stabilizes. In addition, rubber can be molded into any shape. Its thickness and form has a direct effect on its elastic performance. To better modulate this we have developed rubber composites that can yield variable elastic qualities within the same material. At the same time, in order to build structures at an architectural scale we have looked to modularize the rubber components. This has resulted in a module type whose parameters can be altered to yield multiple offspring that can be joined to make the larger column.

2.1. Composites and Reconfigurable molds

A composite material draws on the properties of its individual parts such that their cumulative effect transcends the sum of their separate performances. However, a difficulty with composites has to do with creating robust bonds between its

Fig 2 The reconfigurable mold RCM-J, setup and pour.

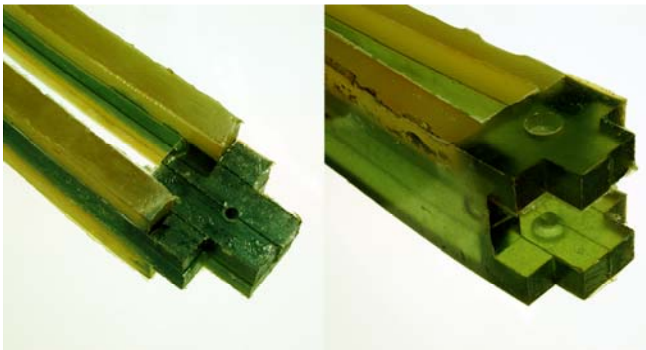

Fig 3 Male (left) and female (right) joints on each rod that provide horizontal connections

constituent materials. In this regard, urethane elastomers offer a unique affordance. As castable viscoelastic materials having both viscous (plastic) and elastic (rubber) properties, they come in a spectrum of hardnesses (measured in the Shore or IRHD scales) from as soft as chewing gum to as hard as bone. Hence a composite can be created by bonding different shore hardnesses together to create a single material with variable elastic behaviors. Our research has dealt with perfecting the bonding

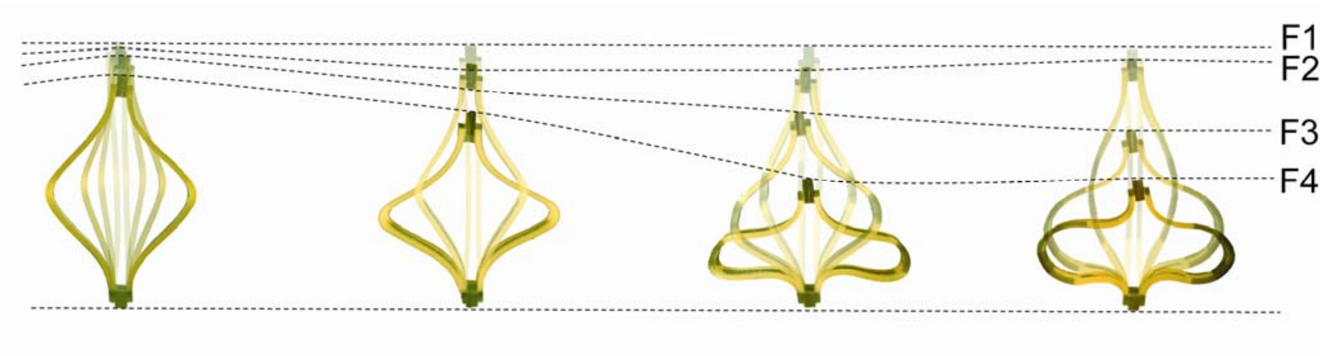

Fig 4 Pressure tests to study the elastic properties of rods of different composites.

process as well as developing a molding process that can facilitate the pouring of complicated blends. The composite elastomers created for Open Columns use two rubbers of shore hardness 45 (“soft’) and 85 (“hard”). In order to pour the individual components, called *rods*, a special reconfigurable mold (RCM-J) was built (Fig. 2). This made it possible to consecutively pour soft and hard rubbers without disturbing previous pours. In addition the RCM-J is also a calculating machine, whose 32 shifting parts are all of the same volume. Through simple arithmetic we are able to calculate the amount of rubber we need from the cavities the mold creates. The RCM-J is also able to create the standardized integrated male and female connections for each rod (Fig. 3). In this regard the RCM-J has all the possible variations of rods that we may need preprogrammed into its hardware.

2.2. Rods

The rod is the basic building module of Open Columns. It is a 2”x2” extruded square section, 18” to 54” long missing two sides. Its shape can be likened to a rubber band that can bend and twist in all 3 dimensions (Fig 4). The column’s size and form can be modulated by the number and types of rods used within it. Different force tests were done to study morphological variations based on different rubber patterns (Fig 4). The two on the left have *soft* rubber at their midsection resulting in an angular bend while the other two have *hard* resulting in a more rounded bend. The angular form was found to be preferable for the column as it supported the overall shape that interested us. Variations on this pattern became the basis for other recipes (Fig 5) parts of which we have prototyped at full scale. At present we are completely building the recipe on the far right of Fig. 5 to test its viability as a complete column at full scale.

It must also be mentioned that the complicated gymnastics that each rod performs as the column moves from collapsed to fully deployed would in any other material require sophisticated hinging. In this case all connections between parts are fixed while all the hinging and twisting is handled exclusively but the composite rubber.

2.3. Column behavior and spatial gradients

The columns attach to the ceiling through an intermediary hexagon shaped steel frame. Each hexagon holds a controllable motor in its center which releases and pulls the column up from its center based on instructions it is given. The columns themselves are 9’ in diameter at the top and 2’ at the bottom.

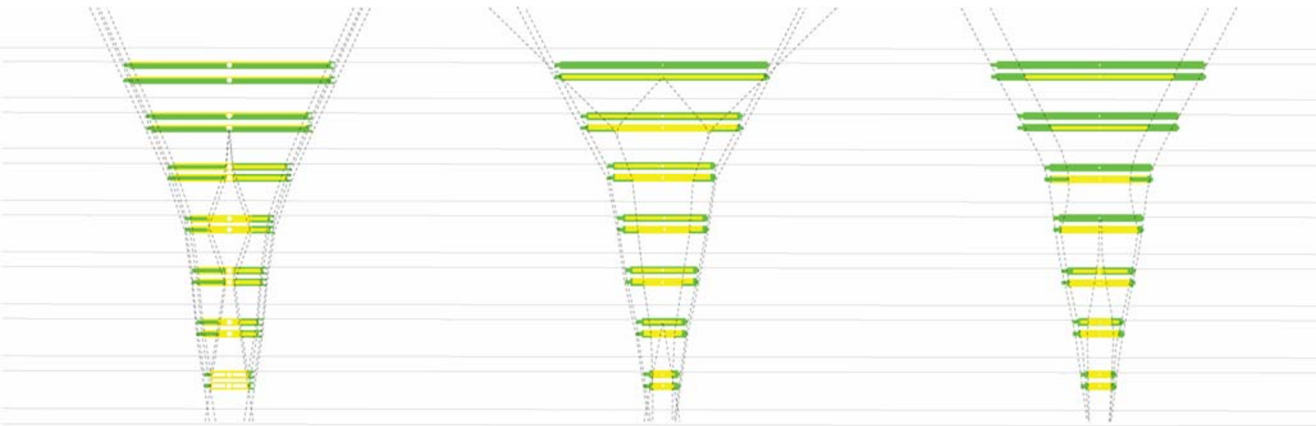

Fig 5 Studies of different recipes of hard (green of Shore 85) and soft (yellow of Shore 45) rubber combos that would provide the necessary performance. Each row shows the size and both sides of the rod. The recipe on the far right has been built as a full scale prototype.

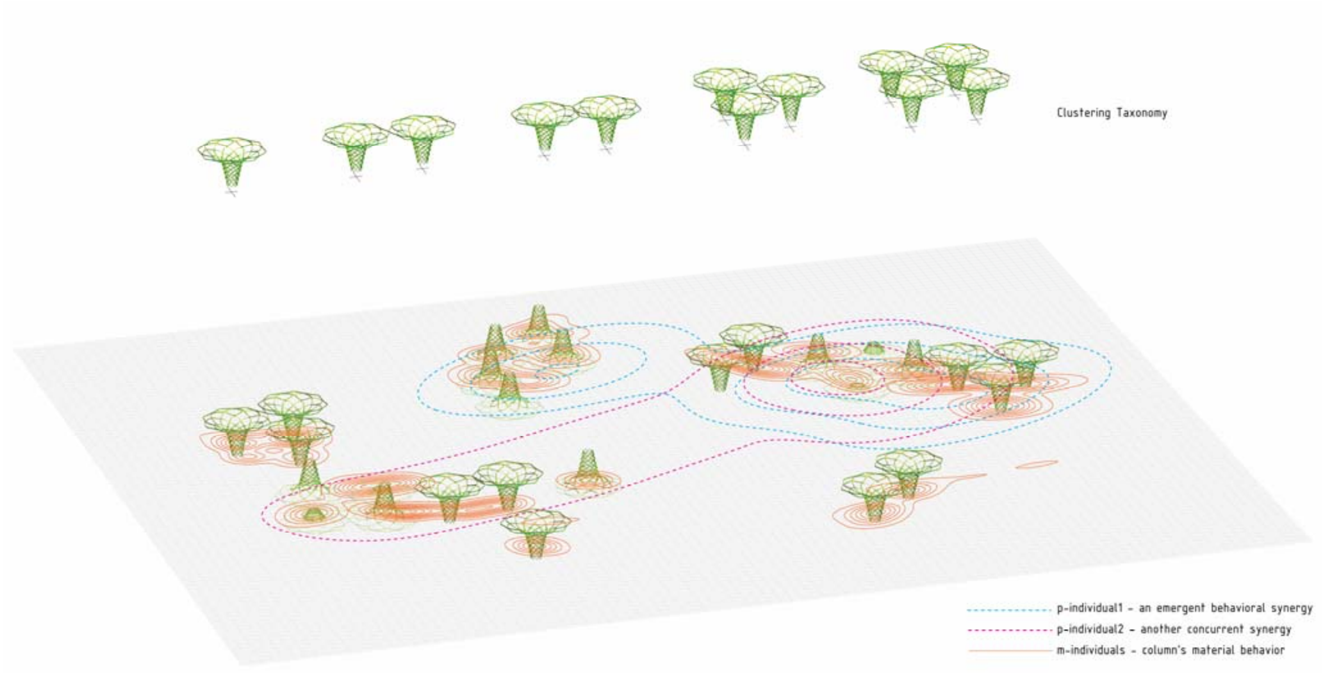

Fig 6 A diagram showing "conversations" developed through interactions. The columns create a gradient of territories for occupation. Here the system is speculated for both ceiling and floor deployment.

They can be clustered or placed isolated from one another within a space (Fig. 6) in different configurations depending upon their programmatic needs. It is at this last stage of spatial arraying or clustering that a seeming self-organization can be perceived. The rubber patterning that created gradients within the single column now scale up to create spatial gradients of habitable and inhabitable spaces. It is fundamentally in this ability to texture space that Open Columns utility as an architectural device can be understood.

3 Changing spatial ecologies

Open Columns, at its most trivial can be preprogrammed to deploy itself in prescribed configurations. In this way it can reshape a space in plan and section. This can be effective for re-proportioning a large space into smaller spaces or reorganizing the circulation of people through it. Moving up in complexity the columns can be tied to real time sensing such that they have direct reaction to inhabitant's perturbations in space. Currently we are working on such an application where CO2 sensors accessible to users will allow them to alter 2 columns' configuration through direct interactions. The next step up and tending closer to a self-organizing responsive environment involves a learning model. In this case the column's evolving behavior would be tied to real time sensing but also to its past history of responses. Here the model of Prigogine's dissipative systems [1] as well as Pask' Conversation theory [5, 6] are relevant.

The Homeostat- In order to study Open Columns' potential spatial behavior as a networked system of multiple parts we have built a performative model, *the homeostat*, through which we can observe evolving behavior over time (Fig. 7). The model is named after W. Ross Ashby legendary cybernetic machine which adapted itself to changes in its essential variables through chance operations [4]. We are using our homeostat to develop and test software that takes instructions in the form of rasters and converts them into column deployment instructions. The rasters are images of gradient fields that can be created from a variety of environmental sensors including cameras, CO2 and temperature sensors. The design of these instructions is based on Gordon Pask's Conversation Theory [5, 6], which provides axioms for thinking about interactions between things as conversations (Fig. 4). The interactions between individual columns (m-individuals) would result in emergent patterns in the array (p-individuals). An example of this would be the model of a cellular automaton where each cell would be a column. However as the environment changes through the addition of other actors; people or new environmental sensing inputs, individual columns can reformulate their response to these inputs, creating new p-individuals. What the software would search for is a growing variety of response patterns that it would put into the computer's memory which would become the basis for future evolution of the system. This offers a way to evolve spatial ecologies that are impossible to know prior to the system's actual and continued use. Such a system would learn and hence expand its repertoire of responses as it encounters new perturbations and interactions.

Fig 7 The Homeostat: a 1”=1’-0” scale model to study the behavior of multiple columns networked together. The control software is tested on this model.

4 Conclusion

The “smarting” of architectural components like facades (Jean Nouvel’s Institute Monde Arabe), roofs and walls (dECOi’s Aegis Hypo-surface) have continued to intrigue architects as a means to alter and evolve the perception and ideation of their spaces. However their reliance on hard materials, mechanical connections and large and inevitably noisy actuation technologies have perpetuated an industrial “machine” aesthetic that not only conflicts with the intended purpose of *nuanced* responsiveness but also proves difficult to maintain. Our work in rubber composites has looked to the material’s innate properties to provide some of the mechanical affordances as well as a consistent aesthetic that reads from the micro to macro scale. Rubber’s instability as a material has made it less suitable for fixed and static constructions. However, it is precisely this quality tempered through composites that makes it an ideal material for mutable and changeable constructions. Open Columns is a matured expression of a series of concurrent researches in material innovation, architectural systems and responsive technologies that we have been carrying out at the University at Buffalo. We are continuing to expand our research in reconfigurable molds as a basis for composite and sensor embedded elastomer products which will include pneumatics as an actuation technology. Additionally we are interested in how such systems can be used to make users more sensitive to the spaces they inhabit. Open Columns offers a model for a scalable system that allows increased participation by users to alter their environment.

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