Composite Elastomers—Patterns of Performance

OMAR KHAN
University at Buffalo, SUNY
LAURA GAROFALO
University at Buffalo, SUNY

This research looks at the principles of self-organizing systems and their application for the design of responsive materials. Self-organization is the phenomena wherein independent assemblies (natural or artificial) join together to form a system whose holistic behavior cannot be deduced from its individual parts.[1] Self-organizing systems are "performative" since interaction between components must be maintained in order for the system to remain stable. Responsive materials are an emerging breed of materials designed to fulfill particular performative criteria. They are usually hybrid composites whose combinatorial patterning allows for specific material behaviors to occur. This work looks at how self-organizing concepts can apply to not only the design but also the production of large-scale structures made from composite elastomers.

The modeling of self-organizing systems in screen based computational environments is quite common. However their application to the design of material objects has been more "imagistic" than behavioral. This has not been helped by rapid prototyping devices like 3D printers or CNC machines which maintain the material and tectonic neutrality of the computer model. Neither the heated nozzle nor the cutting bit is responsive to specific material attributes- in fact they are designed to shun them. To imbue material performance to the work this research designed its own fabrication tools, reconfigurable molds (RCMs), that provide not only the means to build the pieces but also alternative models for rethinking computer assisted manufacturing tools.

Traditionally rubber has taken a secondary role in architectural tectonics, relegated to assisting other materials perform their tasks: structural dampening, surface finish, weatherproofing. This is because elastomers exhibit widely variable behaviors: soft as chewing gum to hard as plastic. To this end their chemistry is quite interesting. As a special subset of polymers their molecular chains (*mers*) are coiled allowing for considerable untangling before they break. When rubber is stretched its molecular chains become more regular and hence stiffer. Their chemistry has a latent structural performance in it: when stressed the material stabilizes otherwise it is variable. Both these material properties, "hardness" gradient and elastic stability, can be exploited to create composites that exhibit radically different behaviors under different stimuli. These performances can be designed and conditioned to respond to specific environmental conditions.

The two projects described below are made from composite urethane elastomers of different shore hardness. They engage a method of design that is loosely based on the strategy of object-oriented computer programming (OOP) where object classes are dynamically instantiated within an evolving program. This method was adopted because of its correlation with designing self-organizing systems. A basic class with parametric variations behaves as a cell in the overall construction. These cells combine to create larger structures which further cluster to create even larger constructions. Here the environment is understood as the evolving

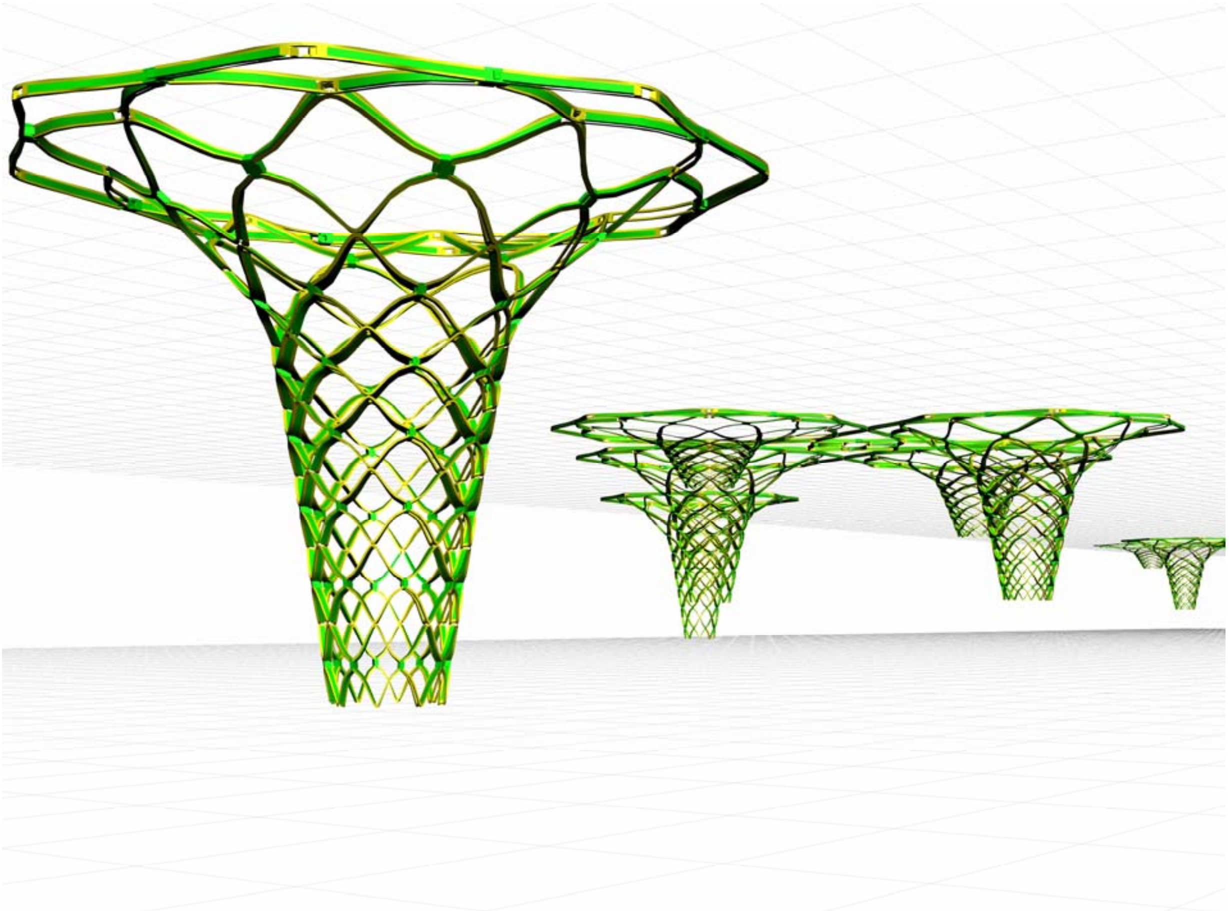

Fig. 1 Open Column Clusters

program and not the final material instantiation. This is paramount to understanding the possibilities of a self-organizing architecture whose whole is the dynamic result of its performative parts.

cara(s)pace 1: open column

Open Column is a collapsible enclosure that resides as a skin layer on the ceiling and/or floor of a space. It is activated to drop or rise creating freestanding constructions that span the space's vertical expanse. As a responsive architecture its deployment will be tied to real time interaction with users (sensing) or to an evolving code of behavior contingent on the space's compounded use (history). Open Column is an artificial self-organizing ecology. It is assembled from repetitive 2"x2"x24" rods built from two elastomers of different shore hardness. The form of each rod is the same but variation is built into it through parametric relations between its two rubber constituents. Its mechanical performance solely relies on these material calibrations to allow all its parts to function as a seamless whole. Open Column is an adaptive structure whose simple behavior of moving from flat to stretched can achieve considerable complexity when the structure is repeated. In larger organizations (Fig. 1), achieved through different strategies of clustering, new behaviors emerge. Critical to this thinking has been Pask's Conversation Theory (CT)[2] which provides axioms for thinking about evolving relationships in informationally open yet organizationally closed systems. As clusters each columns performs in "conversation" with one another adjusting its position relative to the others.

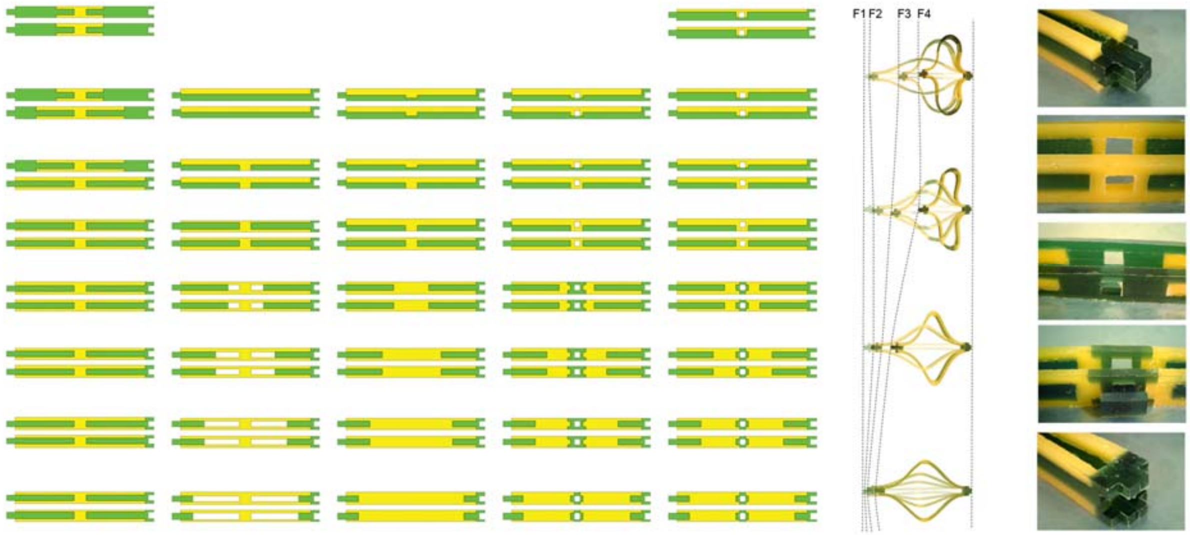

Fig. 2 RCM- J

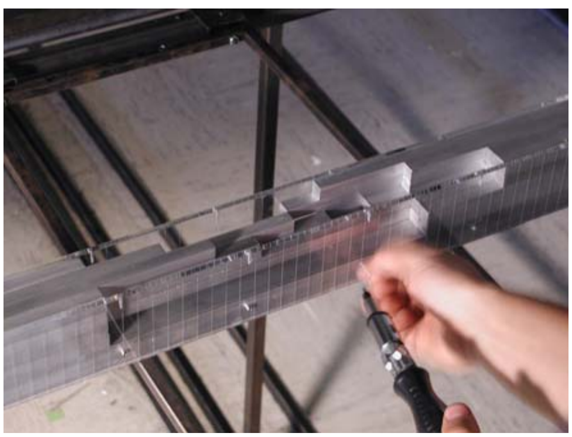

Fig. 3 Rod taxonomy, performance tests and connection details

Object Class: Rod

The basic building block of Open Column is a rod: a square section 24” long missing two sides. As an object class it is a parent that can generate a variety of offspring with different combinations of hard and soft rubber. These patterns depend on the offspring’s location in the column. To construct an instance of a rod requires continuous but alternating pours of hard (85 shore hardness) and soft (45 shore hardness) rubbers for which conventional mold making is too static. Since both repeatability and hybridity is required in the pour the only way to achieve this is through a re-configurable mold (RCM). A RCM allows consecutive rubber pours to take place without disturbing previous ones. he RCM-J (Fig. 2), designed specifically for Open Column, uses 32 shifting parts to create the cavities for each pour. All possible variations of the Rod class are embedded in the RCM-J’s design. This fact is quite important because while the mould offers considerable variations on the type it also provides a constraint, which is necessary to achieve material and tectonic clarity in the individual parts. The RCM-J also constructs the details necessary for the rod-type to connect to others like it in both x and y directions.

Instances: Columns

To generate instances of rods a set of performance guidelines were set. First there is a structural criterion that requires different performances from each part depending on their location in the whole. Secondly there is an aesthetic criterion of color patterning that reinforces the tectonic reading. To properly communicate the self-organizing tectonics of the column the pattern allows observers to read the parts without undermining the understanding of the whole. This gestalt results from serial repetition of individual rods as well as the simple indexing of hard (green) vs. soft (yellow) rubber. Like Warhol’s portrait series an individual component is slightly altered relative to its closest neighbor allowing for local variation while maintaining systematic wholeness. Each of these rods is then structurally evaluated along a scale from "resistant" to "flexible" by subjecting them to the same forces. In the final taxonomy both criteria, aesthetic and structural, are taken into consideration when matching a component's performance with its physical location in the column. One other aspect of the rod production is that its connectors are also made from rubber. This allows combination of the parts to become materially and performatively seamless maintaining elastic properties throughout the whole construction.

Environment: Clusters

In the final iteration the single column is multiplied and clustered to create spaces. The configuration of these spaces is in response to their occupation by people and their own communication amongst one another. Responsiveness is a characteristic of "smart" systems. Open Column, however is not a sophisticated artificial intelligence whose behavior is controlled by a central computer but is the result of distributed intelligence across its many parts. Each part has a small set of behaviors (stretching and collapsing), which can be sequenced so that they respond to internal and external instigations. Pask's conversation theory[4] provides helpful axioms to understand how this might take place. In his conversation theory there are two types of individuals: mechanical and psychological. Mechanical individuals are objects in an environment while p-individuals are the conversations that objects carry on amongst themselves. In our case through interactions of m-individuals (the individual rods, the columns and the people in the space) p-individuals (conversations) emerge. P-individuals can be maintained so long as the m-individuals persist in those particular interactions. However as new actors (people and columns) are added to the environment, new p-individuals can emerge. This results in evolving collective behaviors many of which we can't imagine based solely on the simple behaviors of the parts. On another level this deliberative system can also act as a heuristic for determining the material design of each part. By studying varying clustering possibilities individual column taxonomies can be re-evaluated and each rod's material code recalibrated to allow for richer variations in the collective performance. In other words collective behavior can be reflected back to the molecules that make up each individual piece. For lack of a better word this can be understood as an evolving material intelligence.

cara(s)pace 2: gravity screen

Gravity Screen is a deep surface whose morphology results from gravity's effect on its material patterning. It is composed from two elastomers of different shore hardness that take an organized form when the screen is hung. Rubber's elasticity and high weight to volume ratio make it particularly problematic as a self-supporting material. However, the compounded effect of excessive weight on a stretchable material results in it stiffening. By crisscrossing hard and soft rubbers Gravity Screen uses this property to create a controlled stretch. The hard rubber acts as a cross brace to the soft, creating a changing surface weave that has structural properties. Generally screens use modular parts to maintain pattern continuity such that each piece is micro-version of the whole. Gravity Screen's modules are more nuanced. Their individual behaviors affect not only the look of the entire screen but its structural and formal performance. Composed from multiple 6"x24" pieces, they can't predict the collective. In contrast, Gravity Screen is a "network" structure whose final look and behavior can not be deduced from the behavior of individual parts.

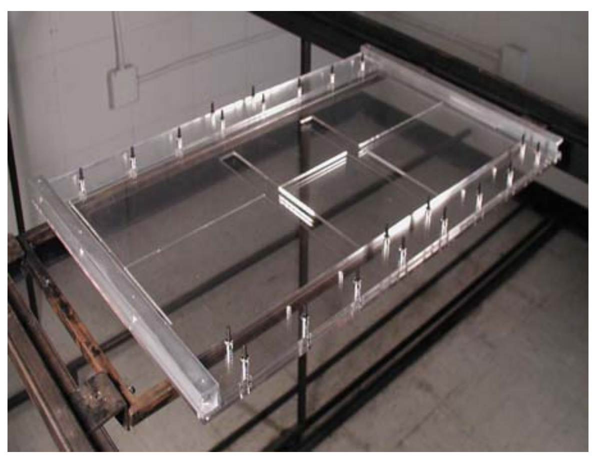

Fig 4. RCM-D

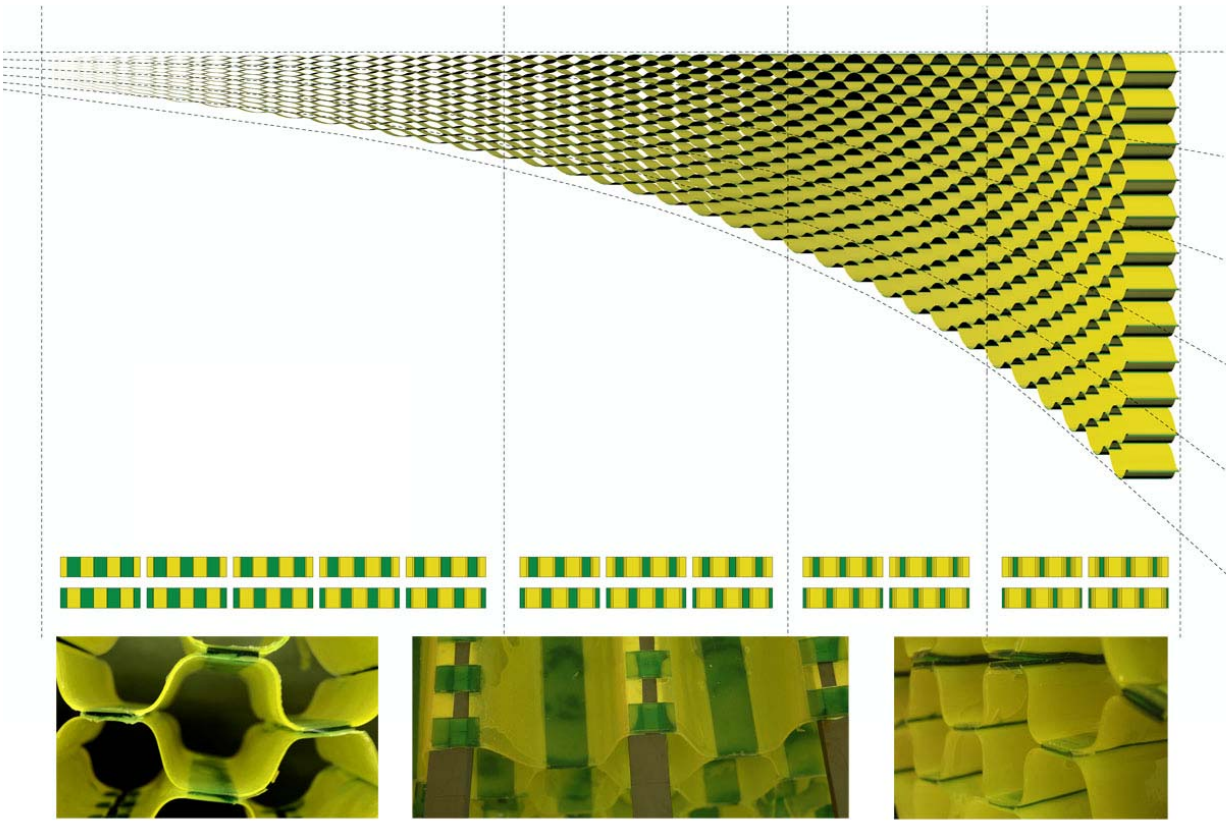

Fig. 5 Screen recipe taxonomy and resulting prototypes

Object Class: BarCode

The Screen is the result of a novel reconfigurable mold, RCM-D (Fig. 4) that uses laser cut templates as formwork. These templates are added onto the mold to orchestrate sequences of hard and soft rubber pours. While the soft rubber fills the mold's entire area the hard rubber is administered in parallel bar patterns (Fig. 5) on top of it. By modulating the width of the bars the mold yields a weave that moves between loose to tight. The wider the pour, the tighter the weave. This allows one to create different gravitational resistance across the screen's surface. The modules are poured in 12”x24” molds with different depths depending on the desired number of layers and then cut in half. By changing layer metrics the combinations are not limited to the repetition of the same sized pieces. In addition, each module can have a unique performance irrespective of its size solely determined by its recipe. Seaming the individual modules to one another is done by creating a friction joint, laying one piece on top of another and weaving a thin band of rubber through both.

Instances: Taxonomy

The screen's half arch design is only one version of many that could result from this type of building system. This design is allows one to see how individual modules subjected to subtle variations create a monolithic network structure. Divided into columns each module has the same depth (numbers of rubber layers) with different barcode pattern pours (Fig. 5). These pours iteratively go from thin to wide along the structure's surface to create the semi-arch form. The resulting tight
and loose hexagonal patterns on the module faces negotiate material tensions and ease into their final shape with the assistance of gravity. Screens as a system for spatial differentiation are inherently flexible. Their ingenuity lies in the fact that they are deployable; there when needed removed when not. But what if disappearance was the last resort? What if the screen could adapt itself to a variety of configurations facilitating new spatial interact-

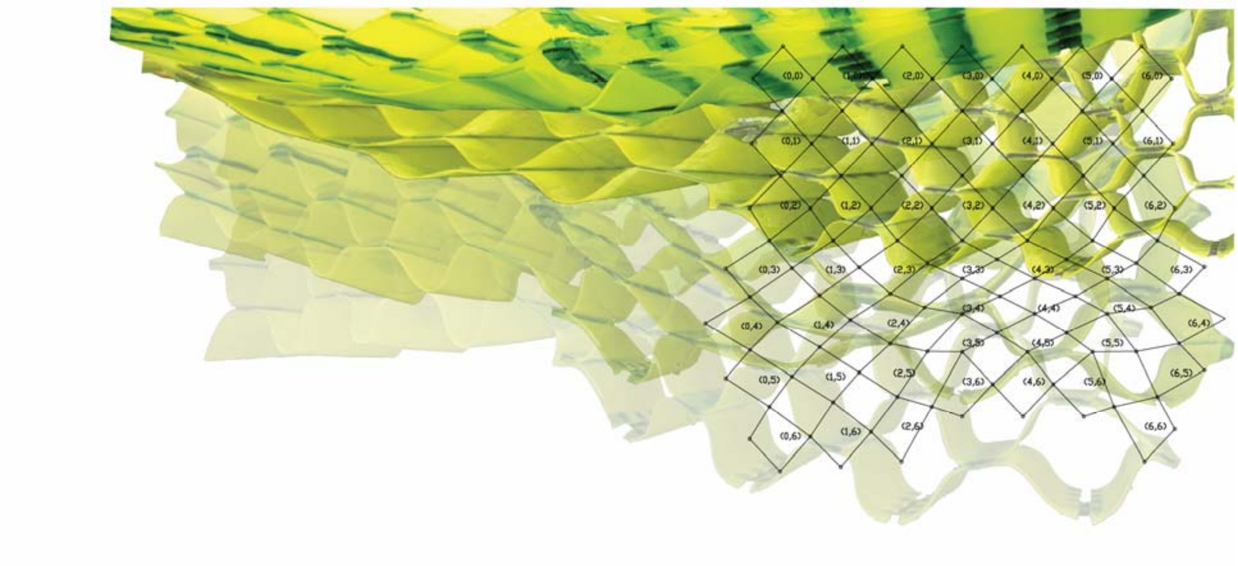

Fig. 6 Screen prototype

ions? Such a system is easily plausible for Gravity Screen whose material makeup can accommodate a variety of shapes. To study these possibilities we designed a special tool that would allow us to dynamically affect a hypothetical screen surface. A VBA script running in AutoCAD allows a designer to create as large a screen as he wishes and then iteratively alter nodes such that the entire screen is reconfigured (Fig. 6). The computation was empirically derived from tests done on the actual material prototypes. These hypothetical screens can be deconstructed to yield barcode recipes that can be used to construct the actual screen.

Environment: Partitions

Gravity Screen is a responsive structure in that its properties, formal and performative, are a direct result of a relationship between materials, tectonics and gravitational forces. It is responsive in that it doesn't take these relationships to be static and universal but evolving and hence alterable. Like Open Column its intelligence lies in its material makeup but its alterability is more specific to environmental forces than self generated. As an elastomer it has the capability to collapse vertically (into a wall) and horizontally (into the ceiling). But it is more likely to remain an active participant in the actions of a space. Its adaptable form can be understood as an information system that registers the changing needs of a space. Or it can become an interface to provide new interactions between environmental actors. As such its conversations with other actors can have beginnings and ends. As a wall-type boundary it can go from opaque to permeable or opened to closed. These possibilities provide a variety of useful behaviors that can be used to formulate domestic, commercial and institutional spaces. As an autogenetic architecture the space's potential use can also be understood as an emergent property of the system.

Conclusion

Composite elastomers provide a unique vehicle to think about materiality in a post digital age. Materials have become "performative" not simply registers of human agency but active participants in the evolving creation of social spaces. Real time "responsiveness" is one measure of this agency both to internal and external stimuli. In the case of rubber composites the responses are both precise and variable. This is because they can yield multiple and often contradictory behaviors. In addition, rethinking modular patterning along the lines of self-organization rather than economies of scale can confound material relationships between parts and wholes. The individual part's behavior does not predict the structural or formal performance of the collective. Finally the tools for design and production of such systems, the reconfigurable molds, themselves embody these qualities.

While they provide considerable freedom to construct alternatives of a type they also yield the necessary constraints for tectonic consistency. These factors contribute to our aesthetic reading of the wholes as relational systems and not indeterminate blobs.

Endnotes

[1] Ashby, W. Ross. “Principles of the Self-Organizing System” in Von Foerster, Principles of Self Organization. Pergamon Press. 1962.

[2] Holland, John H.. *Emergence: From Chaos to Order,* Perseus Books Group, 1999.

[3] Pask, Gordon. *An Approach to Cybernetics*, Hutchinson & Co LTD. 1961.

[4] Pask, Gordon. “Developments in Conversation Theory- Part 1” in Int. Journal of Man-Machine Studies 13 (1980). p. 357-411.