Architectural Robotics: A New Paradigm for the Built Environment

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Abstract

The development of robotic building systems that are capable of reconfiguring their form on demand will soon enable new dynamic typologies at the scale of both individual buildings and entire neighborhoods. The ability to rapidly change a building's layout will obviate the model of a building as a large collection of rooms, each of which is only intermittently occupied, and instead focus on using all available resources to provide for the immediate needs of the occupants. In a similar manner entire neighborhoods will grow and recede in response to economic demands and other cultural factors. Technologies capable of supporting these dynamic structural systems are being developed. The remaining challenges are the creation of interfaces to allow the occupants of these dynamic spaces to direct their behavior, and a reconceptualization of the city capable of guiding this new form of development.

Keywords: architectural robotics, modular robotics, dynamic spaces, dynamic urban form

0 Introduction

Le Corbusier declared that "a house is a machine for living in" (1927). While machines have seen many technological advances since then, they have largely been applied to the artifacts within our houses rather than the houses themselves. And Le Corbusier's legacy has been a generation of poorly conceived facsimiles of his huge apartment blocks that have only served to highlight the failings of the current paradigm of the built environment: our buildings are so expensive and time consuming to construct that we cannot afford to provide their occupants with adequate spaces and even when plans for a building or a neighborhood go awry it takes decades before they can be reconsidered.

Architectural robotics is concerned with the development of a new kind of machine for living, a mechanical structural system that will allow the spaces of a building to be reconfigured in minutes, and entire neighborhoods to grow and recede in days. While there are precedents for such dynamic spaces, and dynamic urban forms have been proposed before, modular robotics technology promises to provide a new kind of building material that will support a higher order of flexibility in our built environment: robotic bricks capable of stacking themselves. Advances in computer science will give us the tools to manage the complexity of structures composed of colonies of these independent robotic modules, and advances in interface design will allow us to guide them to realize a variety of architectural forms as the need arises.

1 House as Fortress

There have been a variety of projects intent on applying advances in information technology and robotics to the built environment. MIT's House_n (http:// architecture.mit.edu/house_n/index.html), Georgia Tech's Aware Home (http://www-static.cc.gatech.edu/fce/ahri/) and Duke's SmartHouse (http://delta.pratt.duke.edu/) seek to improve the existing housing paradigm by providing more efficient building technologies and automating various household tasks. Carnegie Mellon's Intelligent Workplace (http:// www.arc.cmu.edu/cbpd/iw/) attempts to reduce the environmental impact of office spaces and increase the health and productivity of office workers.

These projects do not address the larger problems of the existing paradigm, which can best be understood as the home as fortress. The primary goals of the home as fortress are to provide a series of secure, environmentally controlled spaces dedicated to supporting a variety of activities such as cooking and sleeping, and the storage of valuable artifacts, and to establish a claim to a plot of land. The static nature of this model leads to inefficiencies on the scale of individual buildings and more serious land usage and political issues on the scale of neighborhoods and cities.

Architectural robotics promises a new paradigm of dynamic living spaces and urban forms that will afford their inhabitants the flexibility to adapt to changing demands at both architectural and urban scales. In contrast to the house as fortress, architectural robotics seeks to provide spaces for human activities as they are required, and to provide inhabitants with the power to arrange their communities and communal spaces to best serve their needs.

2 Dynamic Spaces

One of the greatest limitations of current architectural technology is that buildings are so expensive and time consuming to erect that all spaces that might be desired for decades to come must be accommodated at the same time. To compound the problem, large scale architectural features such as furniture and kitchens must all have a dedicated space to house them, even though a buildings inhabitants generally only occupy a few or even one of these spaces at any given time.

There are precedents for architectural spaces that can be reconfigured throughout the day to accommodate a variety of uses. Shigeru Ban's 9 Square Grids House (Figure 1) is a modern interpretation of the traditional Japanese home with sliding screens to provide privacy at night and large cabinets to store mattresses and blankets during the day (Ban 1998). Gerrit Rietveld also used sliding partitions to allow spaces to be adapted to different uses in his Schroeder House (Butler and den Oudsten 1989).

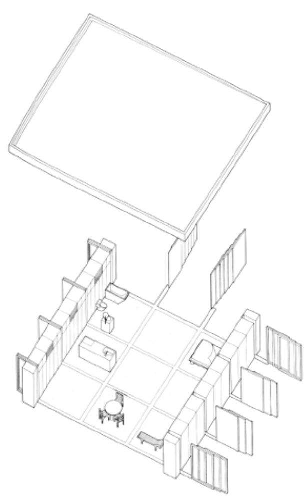

Figure 1: 9 Square Grids House (Ban 1998).

However there are several drawbacks to these systems that have hampered their adoption. Generally there are only a few possible configurations, and while the partitions are generally as lightweight as possible to allow inhabitants to move them, making them poor sound and thermal insulators, the process of reconfiguring a space is fairly labor intensive. Architectural robotics promises to provide a robust structural system that can be reconfigured into almost any configuration and requires no manual labor, possibly even anticipating the need to reconfigure a space and performing the change automatically. In the morning when the inhabitants of an architectural robotic home get out of bed, the space could quickly shift to provide a shower and sink, and then afterwards bring out the refrigerator and provide seating and a dining surface for breakfast, all in the same space.

3 Dynamic Urban Forms

While the limitations of current architectural technology lead to inefficiencies on the scale of individual buildings, they cause even larger problems on an urban scale. As modern technology has increased the speed at which businesses and governments are able to change to accommodate economic demands, entire city blocks have been abandoned as jobs shift to other areas of the globe. And short-sighted urban development has resulted in entire neighborhoods that, like bedrooms, are only occupied for part of the day.

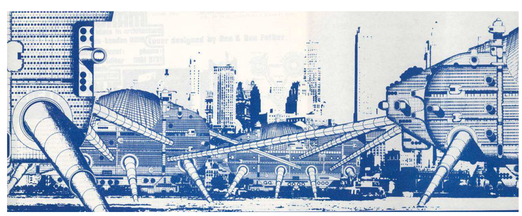

Figure 2: Archigram's Walking City (Herron and Harvey 1964).

There are few precedents for dynamic urban forms. In Seattle a group of itinerants organized the TentCity, a nomadic neighborhood of tents and a few support structures that moved between parking lots and city parks (Brown and Bamford 1999). While neighborhoods composed of tents like the TentCity are flexible, they have several shortcomings as an urban form. Tents lack adequate services and provide very little security.

A more robust model for nomadic urban neighborhoods was proposed by Archigram. Their walking city (Figure 2) is composed of huge apartment blocks each containing an entire neighborhood including shops and services that could walk around on legs. They suggested that this dynamic urban form would be better suited to the lifestyle of urban residents that were frequently forced to change jobs and find new apartments due to the fluctuations of the modern economy. (Herron and Harvey 1964)

Architectural robotics provides a similar function to the walking city with a much finer granularity. Instead of the entire neighborhood having to agree on a new location, individual residents can decide to relocate their homes and businesses. And if an entire neighborhood does decide to move, an entire swarm of buildings could crawl from one area of the city to another to quickly take advantage of economic opportunities.

4 Architectural Robotics

The field of robotics in general is concerned with creating mechanisms capable of sensing, planning and acting to accomplish some goal. Or as the eminent roboticist Rodney Brooks said "we should build complete intelligent systems that we let loose in the real world with real sensing and real action" (1991). As many of the most successful applications of robotics technology to date have involved either executing tasks in dangerous or unpleasant environments or automating repetitive processes these systems have had little interaction with people, and the most common human interaction that existing robots are designed for is simply not running into anyone in the course of accomplishing some menial task. In contrast the primary goal of architectural robotics is to provide for human needs and in order to develop these systems more sophisticated methods of human interaction will need to be developed.

An architectural robotic system is distinguished by its ability to support both dynamic spaces and dynamic urban forms. Dynamic spaces capable of generating spaces and furniture in minutes would allow much more efficient use of valuable resources such as land and structural materials. Architectural robotics promises to provide more spacious, comfortable and appropriate accommodations for human activity on a smaller footprint, using less resources by only implementing the spaces and furnishings that are being used at any given time. Buildings that could be quickly disassembled and redeployed could alleviate problems of underused urban spaces and urban blight. Displaced workers could load their homes into a rental truck and take them with them. Flexible infill development could provide housing for office temps in the urban core, or holiday package wrappers at the mall, or commercial services and daycares in suburban residential areas. Due to the reconfigurability of these structures they could even support small food vendors in the urban core during the day and then provide housing for those same vendors at night (Figure 3). These dynamic urban forms could help create neighborhoods that are inhabited and safe 24 hours a day, and help prevent the cycle of urban blight by leaving abandoned neighborhoods as empty fields rather than full of dilapidated and dangerous structures.

Figure 3: A live/work espresso stand composed of robotic building blocks (Weller 2003).

Architectural robotics should not be confused with other building technologies that merely provide a new coat of a sort of robotic paint. These other systems outfit existing inflexible architectural systems with a variety of technologies to provide for the needs of the occupants, such as automatic kitchen cabinet doors and intelligent window shades. While making the inhabitants of a space more comfortable is a worthy goal that is also shared by architectural robotic systems, and these sorts of projects provide excellent opportunities to explore user interface issues, it is important that these smaller scale projects are developed within a framework that is compatible with the larger vision of fully dynamic spaces. These other robotic systems merely serve to make buildings more expensive and time consuming to build and only exacerbate the problems caused by the inflexibility of our current architectural systems.

5 Realization

It may seem fanciful to suggest that robotic buildings could reconfigure from one shape to another in a matter of minutes, but the emerging field of modular robotics promises to supply a material with exactly these characteristics. Several current projects including the Crystalline atom shown in Figure 4 (Rus and Vona 2001) and Claytronics (Goldstein, Campbell and Mowry 2005; Karagozler, Kirby, Lee, Marinelli, Ng, Weller and Goldstein 2006) have the explicit goal of developing a material composed of an ensemble of homogeneous robotic modules that can quickly reconfigure itself into any arbitrary form. While a great deal of progress is being made in the development of modular robotics researchers in the field have been having problems finding applications for this new material. There are currently two problems: ensembles of modules can change their shape, but not their material properties; the granularity of current modules is not fine enough to generate shapes at a very high resolution. Architectural robotics is an ideal application for this new material as while many artifacts such as espresso machines and car engines and kitchen knives are highly dependent on the material properties of their components, while the most important property of most architectural artifacts such as walls and countertops and chairs is their form. It is not that the material properties of architectural artifacts are not important, but they do not need to vary so much: a tough translucent polymer with a little give and led backlighting to control the color could be suitable for a wide variety of surfaces and fixtures. And while current robotic modules are not nearly small enough to make a kitchen knife, it might actually be desirable to scale them up to the size of a brick or concrete block for architectural applications.

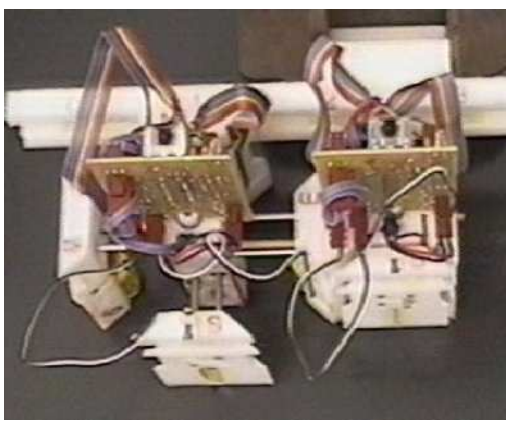

Figure 4: Two Crystalline atoms: atom on left is expanded, atom on right is contracted (Rus and Vona 2001).

There are several issues that need to be resolved before dynamic structures composed of robotic modules can be deployed. Some kind of physics model would have to be built into the control system to assure that a structure would not collapse on its inhabitants, either as some kind of explicit finite analysis agent that watched the entire system from the central planner, or as an implicit set of rules that could be demonstrated to prevent any possibility of structural failure. The individual modules of the system would also have to have some means of sensing impending collisions with inhabitants or their possessions and readjust to avoid smashing people or their things during reconfiguration of a space. And to keep the inhabitants of these dynamic structures dry and warm the modules would have to be designed to be capable of creating an air and water tight surface.

While this research could provide a new type of robotic building blocks that can stack themselves into dynamic structures, a variety of specialized modules would also be needed to support these blocks and provide for the comfort of the inhabitants. The blocks would have to be able to route power between themselves, but they would still need a power source. Structures of blocks could be plugged into the city grid, or fuel cell or solar cell modules could be purchased to provide power for the system, and excess power capacity could be sold to neighboring block structures. There could also be a central planning module that would accept input from the inhabitants and send appropriate commands to the ensemble of robotic blocks, as well as negotiate the sale of excess power capacity to neighbors and network with other block structures to provide a blocknet communication layer that could be accessed wirelessly from a laptop or used to provide free phone service to any other block structure. To provide for the inhabitants there could be a module for fresh water storage, and a composting toilet module that would be stored on the roof when not in use, as well as a heat pump module to provide hot and cold water and cooling in the summer and heat in the winter.

There would also need to be a security mechanism for block structures, as the mobility of architectural robotics would raise the possibility that someone could drive up with a truck while the inhabitants were away and order the house to load itself into the truck and then drive away. Or a neighbor could appropriate a few blocks when no one was looking. To avoid these situations PGP encryption could be used to identify the block's owner. All of the blocks in a structure could be imprinted with their owner’s public key, and the owner could also provide the public keys of family members and friends to give them varying levels of control capabilities. Each person could carry around their private key on a cell phone or similar device that they could use to identify themselves. As an additional security member all blocks could have a unique address, and all sales would be recorded to a central registry. As all blocks would be networked through the blocknet, lost modules could quickly be identified and recovered.

6 Interface

A more significant challenge for the deployment of architectural robotics than engineering the robotic modules and software control system is developing an interface that will allow anyone to direct such a complex system to behave in the way they would like. For example, to control a live/work espresso stand (Figure 3), a reference implementation of architectural robotics technology proposed in (Weller 2003), the occupants would need some mechanism to control the transformation of the entire structure from an espresso stand to a bedroom at night. At this time all of the specialized items in the space not composed of robotic blocks, such as the espresso machine and coffee grinders, would be carried away by the blocks and stored, and a mattress would be brought out by the system and placed on top of a bed frame composed of blocks. While these sorts of large-scale transitions are reasonably straightforward, there would also need to be a way to control smaller scale transformations. There would need to be a way to have the toilet module brought down from the roof as needed, and perhaps if the owner was alone at night no partition wall would be created but the medicine cabinet and toothbrush would also be brought out, while during the day if a customer wanted to use the restroom a separate compartment would certainly have to be created, but the proprietor of the stand would not want to make her medicine cabinet and toothbrush available for customers. At other times behaviors rather than configurations would need to be specified, for example an awning over the coffee counter could be set to adjust itself throughout the day to shade customers from the summer sun. And inhabitants would also need to be able to control things that are simple with our current architectural technology but could be more involved, such as opening doors and retrieving things from a closet.

A solution that could allow people to interface with such a complex system is to leverage an interface that we are all familiar with already, the interface that is presented by other people. This idea draws on Daniel Dennett's distinction between the physical stance, the design stance and the intentional stance (1991). Dennett suggests that we have a variety of methods for considering things around us, and as we move from viewing a system from the physical stance to the intentional stance, we lose sight of many of the fine grained details and increase the probability of making errors of judgment, but gain the ability to more quickly assess complex properties of the entire system. For example, when we are driving a car we generally adopt the design stance toward the steering wheel and merely presume that turning the wheel will affect the behavior of the entire car in a predictable way. We do not generally have time to consider, while driving, the motion of the rack and pinion and consider how their mechanical properties will affect our ability to make it around a corner, in fact many drivers are completely unaware that their car contains a rack and pinion. But when something in the steering system fails, and when the steering wheel is turned to the left the entire car shakes and makes a screeching noise, the design stance fails us. Those of us less familiar with a car’s mechanical systems may even briefly ascend to the intentional stance to make the assessment that the car is unhappy or sick, and seek the aid of a mechanic. The mechanic would then descend to the physical stance to assess how the physical or electrical connections between the different parts of the system were failing. Dennett suggests that we have developed the ability to adopt the intentional stance as a way to be able to understand and manipulate highly complex systems such as other people, and ourselves. I propose that by designing artifacts that can be usefully understood to be intentional systems, we can allow people to control more complex systems with little training by leveraging this innate skill.

While robotics is concerned with developing intelligent systems with sensing and actuation capable of being let loose in the world, this new field of intentional artifacts is concerned with leveraging our innate skills as "folk psychologists" (Dennett 1991) to allow us to operate complex systems. The important distinction between intelligent artifacts like robots and intentional artifacts is that intentional artifacts do not necessarily have to be very smart, they just have to behave in ways that we are able to interpret, while robots can be extremely smart yet exhibit behavior that is quite mysterious to us. Thus the interaction model proposed for architectural robotics is similar to the way people interact with a dog. Dog owners are capable of training a dog to respond to a variety of commands such as fetching things or defending against intruders, and dog owners are capable of making fairly sophisticated assessments of a dogs needs, whether it is hungry or tired or sick. And while people generally think of their dogs as having feelings and desires, they do not necessarily expect their dogs to be particularly smart, a viewpoint that if transferred to a dynamic structure such as a live/work espresso stand would not impose unreasonable expectations for the performance of the system and would tend to encourage patience and bonding.

7 Conclusion

Our current architectural technologies are inefficient on the scale of individual buildings and frequently fail catastrophically on the scale of neighborhoods and cities. Research into the new field of architectural robotics could alleviate many of these problems by providing a more flexible and reusable building technology that would allow structures to be rapidly erected and disassembled as needed, as well as reconfigured throughout the day. The field of modular robotics promises to provide the basic material for this enterprise, the robotic building block, a small robot on the scale of a brick or concrete block that is able to collaborate with its neighbors to stack themselves into different configurations. While technical advances must be made before these robotic building blocks can actually deployed, the larger research challenge is to develop interfaces that allow the average person to control such a complex system with little training.

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