REDESIGNING THE BRICK

Creating a New Vocabulary of Basic Architectural Building Blocks with Autonomous Reconfigurable Robotics

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Abstract. This research examines the value of "redesigning the brick," in creating a new vocabulary of basic architectural building blocks with autonomous reconfigurable robotics. The paper highlights several built examples by the author of robotic architectural environments and the work of architecture students whereby individual modules were created within the context of a design studio and applied to scenarios of space making at various scales. Several strategies for decentralized control were explored dictating how individual parts of a system should behave and how local interactions between individual modules can lead to the emergence of global behaviour. The students schematically designed self-replicating models which would allow for each object to be able to attach, detach, and reconfigure according to predetermined computational logic. The projects successfully demonstrate various strategies for mechanical design, locomotion and control.

Keywords. Interactive Architecture: Modular Robotics; Robotics; Kinetics; Biomimetics.

1. Introduction

Smart and networked architectural devices and appliances surround us, yet they are not considered from an architectural point of view in terms how and when they are used, and how they work together. Interactive architecture in general is built on the convergence of embedded computation (intelligence) and a physical counterpart (kinetics) that satisfies adaptation within the contextual framework of human and environmental interaction. The combination of these two areas will allow an environment to have the ability to reconfigure itself and automate physical change to respond, react, adapt, and be interactive. The inherent sensing, processing and output are now beginning to be taken out of the computer and are instead, embedded in the objects of everyday life themselves. The individual devices therefore have a remarkable ability to communicate with each other even while being specifically task oriented. Decentralization is a powerful control strategy for such systems of individually networked devices (in this case) whereby there is no central control system, and consequentially, the more the system relies on lateral relationships, the less it can rely on overall commands. An emergent behaviour can occur when a number of simple systems operate in an environment that forms more complex behaviours as a collective.

We will use the example of a smart home with an “intelligent” mechanical counter top which can raise and lower itself when needed and a smart cabinet above which can assist you in retrieving food items as desired. Both the countertop and the cabinet understand the actions of each other and while only one may deduce a response based on environmental sensing, the other may operate accordingly based on the actions of the other device. For example, as the countertop senses the height of an individual it may lower itself to accommodate a specific food preparation need, and the cabinet will use the information of the countertops’ action and lower itself and organize the food items accordingly to a learned pattern of behaviour of what the person typically eats at a specific time of day. The above scenario, while perhaps not commonplace, is very realistic and achievable by today’s technological means. Now imagine both the countertop and the cabinetry are not mechanically driven “devices” but are composed of thousands of smaller mechanical modules (the size of dice) which make up the devices themselves. The distributed sensing and control would now happen not at the level of the countertop and the cabinetry but at the level of each of the tiny modules. The geometrical flexibility, sensing capabilities and robustness of each of the larger “devices” would then be greatly enhanced.

The manufacturing technologies available for the design of such modules discussed in the scenario above compounded with recent advancements in software (computational intelligence) allow them to be increasingly smaller and smarter. Current advancements in metamorphic, evolutionary, and self-assembling robots, specifically dealing with the scale of the building block and the amount of intelligent responsiveness that can be embedded in these modules, are setting new standards for the construction of robotics. As physical robotic parts scale down, it will become increasingly possible to build using nanotechnological and bionanotechnological means.

Let us then extend the example above whereby the countertop and the cabinet are not composed of small modules but are composed of bionanotechnological materials which can morph their shapes to adapt at a very high degree of resolution. The materials are not veneers to traditional devices but are the fabric of the devices themselves with sensing and control operating biomimetically at a very small scale. At this level the countertop and cabinet can control additional attributes such as temperature, texture, colour, opacity, etc., These new interactive assembly systems will bring new unprecedented levels of customization and reconfigurability to the architectural palette. Such an extrapolation of advancements in both robotics and new materials demonstrates an architectural future whereby adaptation becomes much more holistic and operates on a very small internal scale.

2. Architectural Value of Redesigning the Brick

As architects and designers familiarize themselves with autonomous robotic systems, they are beginning to understand ways to apply them to dynamic situational activities and build them into systems that make up space. The future of interactive architecture will most certainly involve reexamining and adjusting the scale of interactive materials. Most architectural applications are neither self-organizing nor have higher-level intelligence functions of heuristic and symbolic decision-making abilities. Most applications or "devices" in architecture however exhibit a behaviour based on low-level intelligence functions of automatic response and communication.

When a large architectural space is responding to a single element then a centralized system can be effective in executing a command to a single agent but when there are many unknown stimuli such as groups of individuals behaving in unknown ways and an exterior environment which is constantly changing, then decentralized intelligence can be a very effective way to handle the sensing and response (perception and action) The beauty of this when applied to a large system is the emergent behaviour. Although there may be no centralized control structure dictating how individual parts of a system should behave, local interactions between individual modules can lead to the emergence of global behaviour. There are many biological reasons for swarm behaviour related to efficiency in foraging, hydrodynamics and aerodynamics, protection and reproduction, among others. An emergent behaviour can occur when a number of simple systems operate in an environment that forms more complex behaviours as a collective. The rules of response can be very simple and the rules for interaction between each system can be very simple but the combination can produce interactions that become emergent and very difficult to predict. The more decentralized a system is, the more it relies on lateral relationships, and the less it can rely on overall commands.

Since it will be possible to build space out of parts that have the ability to reconfigure themselves, it will be up to architects and designers to design how these pieces will come together and how these configurations will respond to the constant flow of information between inhabitant and space. As architects and designers begin to adopt the technology of modular reconfigurable robotic systems, they will begin to re-envision the creation of dynamic space. Architects in the future may design an architectural environment composed of a palate of autonomous reconfigurable parts. These materials come together to create a layering of responsiveness and an overall intelligence that is embedded in the structure itself; the material and texture of the space is the intelligence of the space.

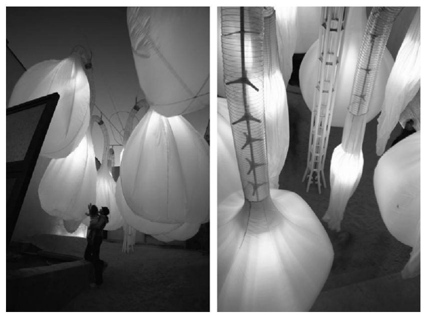

Figure 1. A full-scale interactive architectural space by the author, emergent behaviour can occur when numerous simple systems form more complex behaviours as a collective

In the near future, modular reconfigurable space will hugely impact the way people live in space, and the relationships between users and the space itself. Our furniture and entire spaces might someday be comprised of a multitude of interconnected assemblies of robotic modules that can reconfigure themselves for a variety of needs or desires. How such systems in our everyday buildings affect our behaviours and change our behaviours are the issues that architects will be forced to confront in the near future. Only when architects confront these scenarios of interaction and construct actual environments will they truly take an active role in the larger dialogue of where the technology is going and what it will mean to everyone.

3. Lessons Architecture Can Learn from Small-Scale Robotics

Designing interactive architecture is not inventing, but appreciating and marshalling the technology that exists, and extrapolating it to suit an architectural vision. There are many important lessons to be learned in both distributed computation and small-scale robotics that can feed into a future paradigm of architectural space-making. Future designers will need to simultaneously consider the methods of movement, connection, geometry, and embedded intelligence of such small-scale robotic modules.

In addressing the performance parameters of modular robotic design, concepts focus on several key strategies: 1) geometry 2) movement 3) connection 4) scale 5) materiality, and 5) embedded intelligence. The final objective of the approach is to create an innovative design that is minimally functional with the capability for evolving additional multi-functionality. An additional primary consideration is how modules can connect to each other with sufficient mechanical strength and then disconnect easily again without using too much energy.

In addition to the tectonic objectives of the robotics listed above there are several architectural objectives that this research explores 1) It will serve as a vehicle for developing strategies for decentralized control dictating how individual parts of a collective system should behave and how local interactions between individual modules work in terms of forming structures and figuring out how to move them around. 2) It will serve to demonstrate the possibilities of architectural space-making with unprecedented levels of customization and adaptability.

A few of the modular robotic precedents that are valuable to architectural designers include The Biologically Inspired Robotics Group (BIRG) at the Swiss Federal Institute of Technology which is developing Roombots (http://birg.epfl.ch/page65721.html: Nov. 2008), which are to be used as building blocks for furniture that moves, self-assembles, self-reconfigures, and self-repairs. Modular reconfigurable robotics at the scale of furniture is also being explored at the Self-organizing System Research Group at Harvard University. Also, researchers at Caltech are developing robots made up of modular parts that work as a system to interpret and act upon information (Chen and J. Burdick, 1995). Hod Lipson and other scientists at the Cornell Computational Synthesis Lab have begun developing multiple types of modular reconfigurable robots and evolutionary robots. These self-replicating prototypes were designed to allow for each object to be able to attach, detach, and reattach to different self-similar faces based on predetermined computational logic. These modular objects are able to connect to each other through electromagnetic connections, and the entire system has the ability to change its physical shape based on how it is programmed, (Lipson, 2007).

In the near future, such modular robotics will have the capacity to form reconfigurable space that can greatly impact the way people live in space, and the relationships between users and the space itself. Our furniture might someday be comprised of a multitude of interconnected assemblies of robotic modules that can reconfigure themselves for a variety of needs or desires. Miles Kemp has designed an architectural environment composed of a palate of autonomous reconfigurable parts. These materials come together to create a layering of responsiveness and an overall intelligence that is embedded in the structure itself; the material and texture of the space is the intelligence of the space. Users would be able to buy kits of parts—basic building blocks—and could reprogram the parts to accomplish their desires. Rather than having predetermined goals, the relationships between users and space would be able to grow over time, (Kemp, 2004).

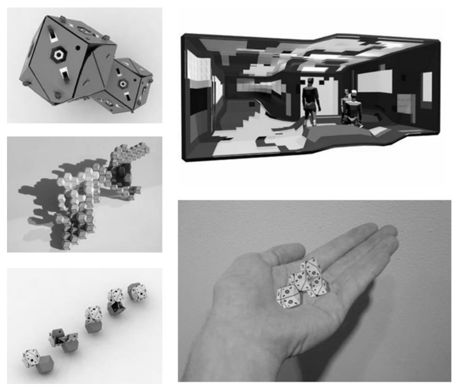

Figure 2. Miles Kemp's architecture, a palette of autonomous reconfigurable parts.

4. Design strategies for space-making with modular robotics

The intent of architectural explorations in modular robotics is to design and evaluate the system as a strategic design aimed at understanding ways to facilitate dynamic situational activities and explicitly understand the potential to build them into systems that make up architectural space.

In the examples below, we highlight the work of architecture students whereby individual modules were created within the context of a design studio and applied to scenarios of space making at various scales. Several strategies for decentralized control were explored dictating how individual parts of a system should behave and how local interactions between individual modules can lead to the emergence of global behaviour. The students designed self-replicating models which would allow for each object to be able to attach, detach, and reconfigure according to predetermined computational logic. The projects successfully demonstrate various strategies for mechanical design, locomotion and control. This advanced architectural design studio was based on the design project of Establishing a Large Scale Colony on the Moon. The studio had contributions from numerous experts in the areas of robotics and lunar exploration and modular robotics was found to be a very appropriate design strategy. In light of the difficulties with trajectory issues (getting materials to the moon), the primary considerations focused on Chemical Processing (how to make materials on the moon) and Space Manufacturing (how to fabricate and assemble/construct things on the moon). The environment on the moon was also seriously considered including: gravity, pressure, radiation, and the mass balance of resources and waste required for sustaining human life at such a scale.

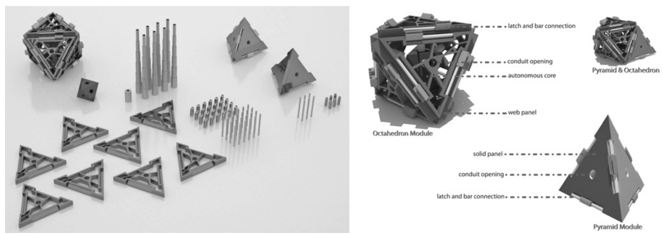

Figure 3. Architectural students' scaled prototypes of module designs.

Students worked in teams of two to produce complete colony designs including the detailed development and a construction/ fabrication concept for one of the buildings. Students developed scaled prototypes of the system that successfully demonstrated the robotic aspects of the project. Physical models demonstrated actual robotics, structure and materials. Initially a matrix of various geometries was explored as precedent to satisfy the objectives of movement, connection and scale.

The geometries explored were based upon this survey of successful similar strategies in modular reconfigurable robotics. Primarily the geometric explorations focused on how the modules can connect to each other with sufficient mechanical strength and then disconnect easily again without using too much energy. Electro-mechanical connections were also explored as a means of supplementing strictly mechanical connections. The scale of the prototypes varied from project to project but justified the implications of scale from an

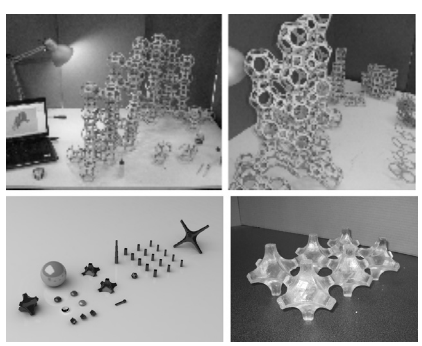

Figure 4. Architectural students' scaled prototypes of module designs.

architectural perspective. Typically the scale was based on the size of the microchip, battery, and mechanical parts that had to fit within each module. The materials were limited to in-situ lunar materials, which will not be fully described here but are quite abundant. The students' robotic explorations were limited by the current possibilities of manufacturing and of the inherent physical mechanics. In other words designs were limited to practical extrapolations of existing technologies.

The design process was implemented from an architectural (as opposed to engineering) standpoint. The final module assemblies were extrapolated to simulate various architectural applications of space-making. This aspect is unique from engineering approaches to modular robotics in speculating how such an approach to adaptive space-making can be applied in realistic situations. The design process that was carried out consisted of iterations through which module variations were generated and evaluated, refining them until they were ready for implementation.

Among the educational objectives were to: 1) demonstrate architectural applications and potentials of modular reconfigurable robotics as a means to designing adaptive space, and 2) apply future student's discipline-specific modelling and simulation skills to an interdisciplinary problem that integrates computer engineering consultancy.

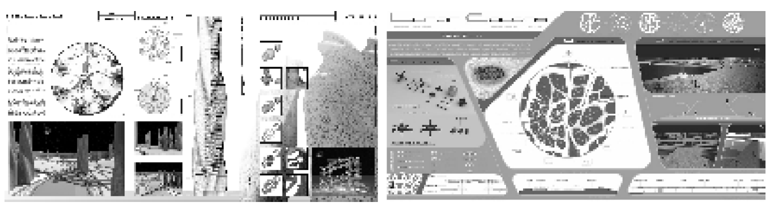

Figure 5. Architectural applications of space-making with modular robotics

5. Modular Robotics: A Step Towards Interactive Architecture.

In conclusion, we argue that the area of "redesigning the brick," or creating a new vocabulary of basic architectural building blocks, appears to be somewhat of a transitional step, however, in the evolution of robotics. In architectural terms, the issue of scale will be heavily influenced by developments in material science and biomimetics. The future of interactive architecture will most certainly involve re-examining and adjusting the scale of interactive materials. As physical robotic parts scale down, it will become increasingly possible for future systems to be built out of nanotechnological, and bionanotechnological means. These new interactive assembly systems will bring new unprecedented levels of customization and reconfigurability. The Liquid Metal Jet Printing

(LMJP) laboratory, for example, is developing a manufacturing process that builds combinatorial mechanical parts and electronic interconnects together in additive manner (Priest et al., 2008). It is likely that the gap in scale between mechanical manufacturing and nanotechnological manufacturing will become increasingly smaller.

Today we have a compressed technology transfer of production modes and design methodologies tied to form-making that bring innovations in materials to architectural reality faster than ever. Furthermore, there are numerous advancements in both robotics and new materials whereby the adaptation becomes much more holistic, and operates on a very small internal scale. The paradigm is being spurred on by the wealth of explorations in biomimetics, which refers to the architectural application (as opposed to the acquisition) of developments in robotics and materials.

Animals, plants, and microbes are the consummate engineers. Nature has found what works, what lasts, what is necessary and not necessary, and, consequently, what is appropriate for this planet. Bar-Cohen puts it well in that, "Adapting mechanisms and capabilities from nature and using scientific approaches led to effective materials, structures, tools, mechanisms, processes, algorithms, methods, systems and many other benefits" (Bar-Cohen, 2005). Specifically in terms of the development of robots, he states, "...the multidisciplinary issues involved include actuators, sensors, structures, functionality, control, intelligence, and autonomy" (Bar-Cohen, 2003). Architects need to formulate the basis for a physically dynamic architecture that arises out of human needs, and which is supported by an improved understanding of biological systems.

Evolutionary systems describe the processes of such biologically inspired architecture that operates like an organism, directly analogous with the underlying design process of nature. The important thing here is that evolutionary systems reposition the role of the designer. As Pask (2000) states in his foreword to the book, An Evolutionary Architecture: "The role of the architect here, I think, is not so much to design a building or city as to catalyze them: to act that they may evolve." Architects should be informed of these developments to understand what is possible to extrapolate from these ideas and technologies in the creation of a vision to direct the future of their profession.

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