ROBOTIC ENVIRONMENTS

Henriette Bier*

Department of Architecture, Delft University of Technology, Delft, The Netherlands
** Corresponding author (h.h.bier@tudelft.nl)*

ABSTRACT: Technological and conceptual advances in fields such as artificial intelligence, robotics, and material science have enabled robotic architectural environments to be implemented and tested in the last decade in virtual and physical prototypes. These prototypes are incorporating sensing-actuating mechanisms that enable interaction with their users and surroundings in real-time. While these prototypes obviously point towards a paradigm shift from inanimate towards animate architecture, they do not operate at building but at building component scale and do not address socio-economical or environmental aspects that affect architecture and society at large. This paper, on the one hand, critically discusses robotic prototypes built in the last decade at Delft University of Technology, on the other hand, it proposes a framework for future research envisioning robotic environments, as resizable, able to spatially expand or contract as well as move or be moved as needed. Such reconfigurable environments aim to validate the assumption that robotics incorporated in architecture improve efficiency of use due to multiple use of built space in condensed timeframes, while at the same time they advance technology for distributed autonomous robotic systems exhibiting collective behavior as well as test their application to sustainable architecture.

Keywords*: Interactive Architecture, Mechatronics, Robotics*

1. INTRODUCTION

Robotic devices have been in the last decade increasingly incorporated into architectural environments and building components. Furthermore, robotics were also integrated into the fabrication process of building components in such a way that not only operation but also production of buildings fundamentally changes: While buildings become animate, their customized on demand production is implemented via automated, rapid fabrication.

As already presented and discussed in Digitally-driven Architecture [1], the development of such robotic environments may be traced back to the mid-20th century work on systems adapting to continuous feedback from users and environment: Archigram's vision of indeterminate architecture [2], for instance, Zuk and Clark proposals for kinetic architecture [3] and Eastman's vision on spaces and users as feedback systems [4] allowing architecture to self-adjust in order to fit the needs of users. Technological and conceptual advances that took place since then have enabled these ideas to be implemented and tested in the last decade in functioning prototypes for reconfigurable, robotic environments. These prototypes [5, 6] are incorporating mechatronic, sensing-actuating systems enabling them to interact with their users and surroundings in real-time

While acknowledging that prototypes such as Hyperbody's Muscle Projects [5] and dECOi's Aegis Hypo-Surface [6] point towards a paradigm shift from static towards dynamic, interactive architecture, it is obvious that they do not operate at building but at building component scale and do not address socio-economical or environmental aspects that affect the society at large.

The aim of future research is, therefore, to develop reconfigurable, robotic environments at building scale that address, with consideration to environmental impact, issues such as inefficient use of built space and rapid urbanization and has, therefore, an influence on architecture and society at large. The innovation of such a proposal does not lie, however, in the idea of systems that are adapting to continuous feedback from the environment and users [4] instead it lies in the application of such an idea to architecture by means of robotics. Reconfigurable, robotic architecture, as proposed in this paper, accommodates, therefore, on the one hand human needs addressing imperative requirements for sustainable functional flexibility and reconfiguration; on the other hand, it extends human needs by establishing interactive relations with the built environment.

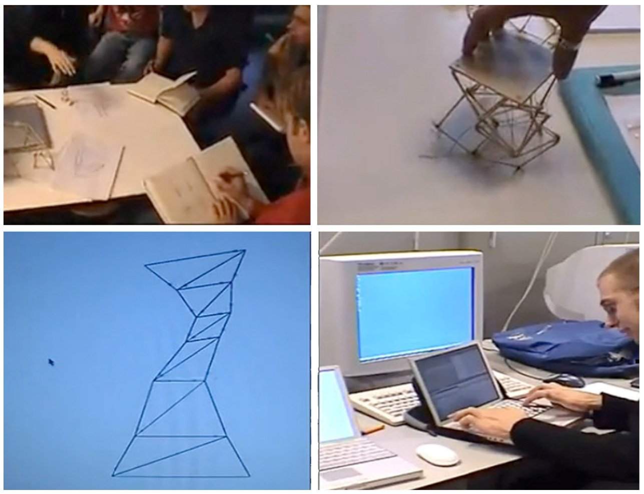

Fig. 1 Conceptual development of interactive prototype Muscle Tower II

2. DESCRIPTION

Robotic environments are, basically, distributed systems of sensor actuator devices exhibiting behaviors that allow for sensorial and physical changes in varying timeframes. Behaviors such as flexibility and dynamic change of shape and geometry may, for example, address a range of time-sensitive issues - from local issues such as inefficient use of built space originating from mono-functioning neighborhoods to global issues such as increased built space demands due to overpopulation and rapid urbanization. Solutions for these problems may be found in reconfigurable structures that permit multiple, in short timeframes changing uses [1], whereas robotics applied to architecture may become test bed for development of new building operation technologies.

Future research in reconfigurable, robotic architecture aims to develop and apply autonomous robotic systems to architecture in order to not only advance robotic technology but also offer solutions for inefficient use of built space and overpopulation. The outcomes of such research are interdisciplinary robotic solutions for reconfigurable architecture employing pneumatic, electric, servo-pneumatic, or electro-mechanical systems aimed at meeting the following objectives:

2.1 Intelligent control and regulation allowing for downtime, which is time when the system, in this case the building, is nonoperational, to be reduced through physical reconfiguration enabling efficient 24/7 use of built space. Efficiency aspects relating to management and multiple use of built space in reduced timeframes are addressed by substantially increasing 24/7 use of buildings from 30% to 60-100%. This estimated increase is based on the consideration that mono-functioning neighborhoods such as offices and residential areas, respectively, are from 24 hours per day only 8-16 hours used, while multiple, changing use may allow for 16-24 hours use.

2.2 By transferring the principle of collective behavior implemented through intelligent sensor actuator technologies, several autonomous architectural sub-systems are envisioned to operate in cooperation in order to accomplish major reconfiguration tasks.

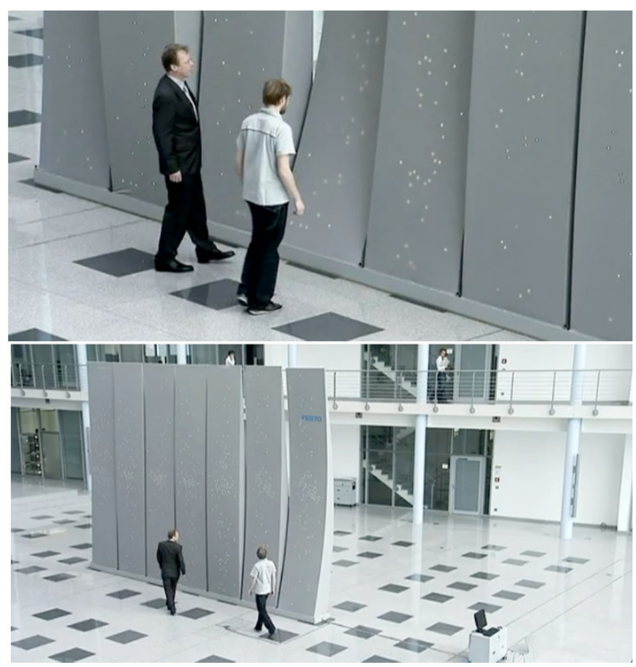

Fig. 2 InteractiveWall in operation at the Hanover Fair (2009)

Autonomously reconfigurable environments built at Hyperbody such as MuscleTower II, and InteractiveWall (Fig. 1&2) show how collective behavior can be implemented by means of intelligent sensor-actuator technologies [7] pointing out opportunities offered through combination of intelligent and adaptive mechanics with interacting and anticipatory architecture and software.

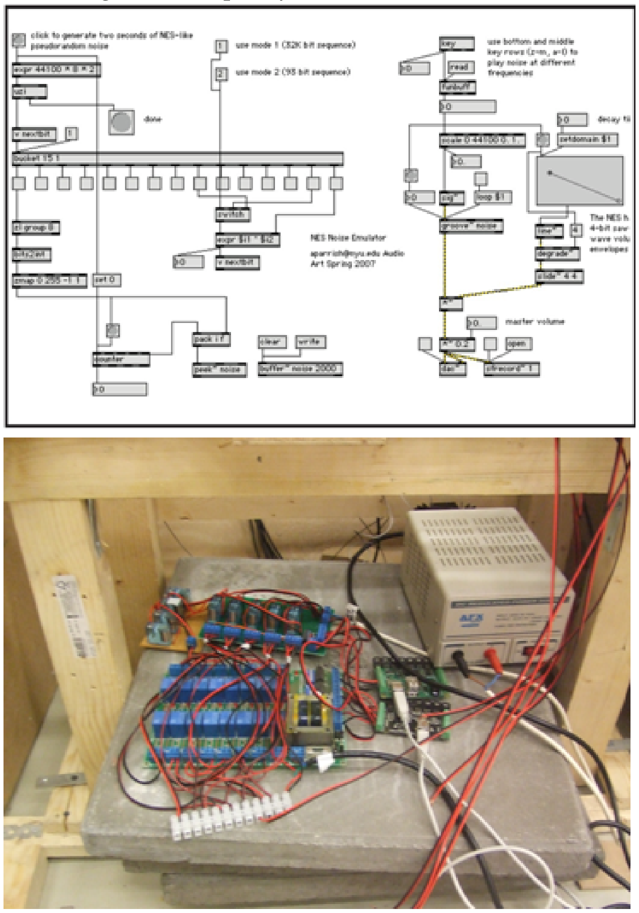

Fig. 3 Max MSP interface and sensor-actuator system for InteractivePortals,

In this context, application of robotics to architecture advances research in distributed autonomous mechatronic systems becoming test bed for development of new robotic building systems that aim to be energy efficiently resizable and spatially expandable or contractible as well as kinetically moveable or moving. They, furthermore, aim to generate and use energy gained from solar and wind power [8], which implies that their ecological footprint is minimized and their economical efficiency increases significantly due to the maximized 24/7 multiple use of built space as well as sustainable operability. Robotic architecture, therefore, applies and advances technologies for distributed, autonomous systems that are developed in disciplines such as automation and robotics, implying not only transfer of intelligent mechatronic strategies to architecture but also development of new concepts and ideas for kinetic, reconfigurable architecture based on principles of intelligent distributed systems, where reconfiguration is accomplished collectively by smaller sub-systems such as building components that are operating in cooperation.

3. IMPLEMENTATION

Research in robotic environments incorporates mechatronics (mechanics and sensor-actuator systems), real-time perception (sensory inputs), embedded systems and software architecture, as well as intelligent control and human-machine interfacing (interaction) and requires a multi-technology platform for the development of architecture, mechanics, electronics and software:

3.1 Development of reconfiguration principles with respect to geometry and use by allowing multiple, changing functions in condensed time frames. Development of spatial patterns based on additive-subtractive and folding (bending) principles [8] as well as design of inhabitable units at individual and urban scale.

3.2 Software and hardware development for interactive functional change and form reconfiguration (Fig. 3, 4), which implies development for modular additive/subtractive and folding/bending systems.

3.3 Advancement from individual to collective behavior based on the idea that autonomous, self-organizing systems are seen as the answer to future spatial reconfiguration scenarios.

3.4 Materials research with respect to inflatable, flexible materials, and programmable matter as well as integration of regenerative energy systems and sustainable power generation.

With respect to 3.1, 3.2 and 3.3 there has been considerable research implemented at Hyperbody in the last decade: Software development (3.2&3.3), for instance, has been dealing with Swarm Intelligence as employed in multi-agent systems, which are in Computer Science distributed

Artificial Intelligence systems consisting of several agents capable of reaching collectively goals. Within Hyperbody multi-agent systems have been employed in the development of Virtools-based software prototypes such as Campesato's (Fig. 4) consisting of agents interacting locally with one another and with their environment similarly to the way fish interact in a swarm and birds in a flock. In the absence of top-down control dictating, how individual agents should behave, local interactions between agents lead to the bottom-up emergence of global behavior. According to Campesato the following development steps were considered: Urban analysis and definition of site parameters implied survey of the area, definition of the physical-geographical constraints as well as mapping of social structure within the area. Toolkit development and parameters definition implied that the script employed set of parameters defined in the first step. Furthermore, architectural and structural design prototyping required selection of one prototype from a series of design prototypes for further architectural development and detailing. In this process, Campesato observed that this computational design tool does not substitute the designer but instead offers a broad variety of solutions, all structurally and formally justified from which the designer may choose.

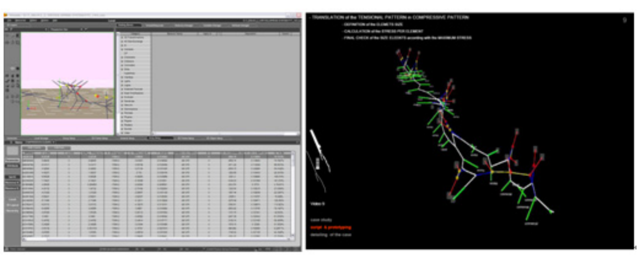

Fig. 4 Software prototype for architectural and structural design

Another relevant software prototype is Piacentino's Java-based particle spring system (Fig. 5) developed for spatial allocation simulations. This prototype addresses on some level principle of self-organization: While the architect might find it difficult to have an overview on all functions and their attributed volume and preferential location, functional units can easily self-organize towards achieving local optimal configurations.

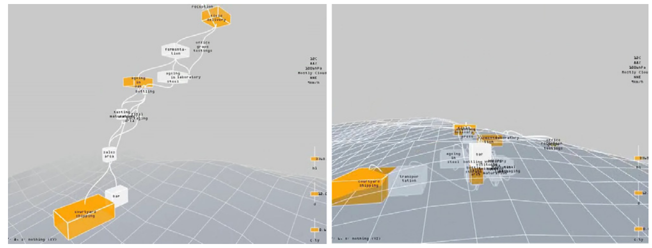

Fig. 5 Software prototype for programmatic design developed within Hyperbody

Interaction has been investigated in representative projects such as SpaceCustomizer (Fig. 6) in which the interaction between the human body in movement and geometry is addressed at the level where each movement is translated into a corresponding spatial displacement and geometrical deformation, hence reconfiguration [8].

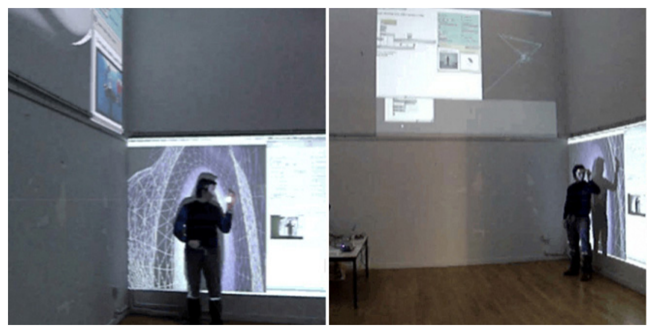

Fig. 6 Max MSP interface and sensor-actuator system for SpaceCustomizer - Interactive

Spatial reconfiguration (3.1&3.2) has been explored not only in MuscleTower II, and InteractiveWall but also in InteractiveCurtain (Fig. 7), which is a portal materialized as a *wall* that senses when it is approached by a person and automatically creates an opening in order to allow passage. The wall consists of a series of strings that bend in order to create openings and acts as a transition and gateway between two different spaces while exchanging data with other portals. With reference to interactivity, the idea of game was implemented at the level where the portal would allow or refuse certain users trespassing based on specific user traits or on data being supplied by other portals within the system.

Fig. 7 Interactive prototype built with students at Hyperbody (Interactive Curtain)

4. DEVELOPMENT

Software and hardware prototypes built in the last decade allow for taking the next step in development implying that reconfigurable, robotic environments as proposed in this paper may offer new technical solutions for dealing with contemporary reduced use of built space and future socio-economical problems such as rapid urbanization while taking into consideration ecological footprint and environmental impact.

Such systems are envisioned as operating at unit (part) and group (whole) level as autonomous distributed systems. A unit is, therefore, envisioned as a distributed sub-system of a larger distributed system, which is a group or colony of units (swarm). Characteristics of units are as follows:

4.1 Units are specialized: Leisure, living and office units have other spatial, material and technical requirements then energy production (solar and wind) and water-pumping units [9].

4.2 Units are reconfigurable: All units are able to change spatially and connect to existing urban structures implying that they either plug into the existing water and electricity supply systems or use their own, as needed [9].

4.3 Units operate individually and collectively forming groups and colonies, as needed.

The proposed robotic architecture implies an extension of the existing products range towards incorporating dynamic (interactive) architectural components and at the same time contributes to the reduction of economical inefficiency and environmental damage, since sustainable multiple use of built space in condensed timeframes renders an increased 24/7 use and ecologically sensitive operability. Such architecture aims to have a reduced impact on ground (landscape or urban fabric), it has a level of mobility and/or is easily transportable, docks onto the existing infrastructure with respect to (waste and fresh) water and electricity system, but has also own solar and wind energy generators that can be used if needed.

5. CONCLUSION

Embedded robotic systems prove that architecture is no longer static but dynamic, responding interactively to users' and environmental needs. This implies that a socio-technological paradigm shift from inanimate towards animate architecture is being implemented in such a way that use of built space is significantly improved.

Therefore, application of robotics in architecture represents a step forward in technology and science because it implies development and testing of new approaches to control and regulate autonomous systems in architecture, whereas the outcomes are interdisciplinary robotic solutions for space reconfiguration. The urgency of implementing such research deals with, on the one hand, recent developments in mechatronics and intelligent control allowing for taking the next bigger step in the advancement of reconfigurable architecture, on the other hand, availability of interdisciplinary expertise within Delft University of Technology.

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