Urban Infrastructure & Architectronics

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Abstract. The future of urban infrastructure is no doubt a future of control systems. An architecture that engages infrastructure can engage control systems to not only improve efficiency and mediate contested urban space but also to modifying spaces for different uses, buffer environmental factors and respond to occupation or use. The use of mechatronics in architecture requires interdisciplinary collaboration and an understanding of control systems, sensors and actuators. Through a theoretical project, research and a design studio, this paper discusses the future of mechatronics in architecture and shows the huge potential for reimagining our infrastructure. The application to the infrastructural realm pushes the design out of the scope of conventional architecture both in the use of mechatronics and its application to the larger realm of the city.

Keywords. Mechatronics; infrastructure; architecture; control systems; robotics.

Introduction

The word Architectronics embedded in the title was coined from the combination of architecture and mechatronics as it defines the emerging field of research, practice and design education. Mechatronics in turn is accepted as the combination of mechanical engineering, control system engineering, electrical engineering, and computer engineering. Architectronics was introduced and illustrated by authors at the recent CAADRIA conference in Hong Kong (Meyboom et al. 2010).

Infrastructures and Control Systems

There is an increasing recognition in architectural discourse that design of infrastructure is critical to architecture, both in its form as well as its function. The infrastructure of the city is its framework, from which the city grows organically and incrementally – our cities currently are based on streets which form a lattice with infrastructure being the street itself as well as the grid above, below it. This infrastructure is due to its intrinsic connectivity to the city fabric. Urban infrastructures today are increasingly reliant on control systems and more and more so as time passes: we have public transit rail systems running on control systems with no drivers, we have traffic monitoring and control systems which work on control systems of many types and forms, we have monitoring of buses and riders on control systems, we have taxi dispatch systems, we have control systems for 911 dispatches which rely on detailed programming. If control systems are critical in the function of cities – from communication to transportation...
where is the future of control systems in the design of the urban environment?

The design of urban infrastructures and the city fabric today relies on an approach of multiplicity of use and adaptivity of spaces. Singularity in approach is recognized to be insufficient to address the quality of life threatened by the environmentally unsustainable urbanization of the past. Giving up land area or resources to a singular use or intention is not sustainable and is recognized to be wasteful on many levels from economic to social. Spaces must function in a multiplicity of ways, in multiple seasons and therefore environments and adapt to multiple uses. Adaptable spaces and spaces which are responsive to occupation and environment can be easily produced with mechatronics. On a control system, built form has the ability to adapt and respond, bringing a multiplicity to a single design in a way previously unknown in architecture (Kolarevic, B. 2005).

Cities are complex environments with many technical and environmental challenges, especially when designing sustainably is important. Collaborative approaches are key and interdisciplinary design collaborations are recognized as leading edge in any urban design project. To bring a responsive architecture into the built environment in today's digital world requires an understanding of control systems, sensors and actuators – another field of design (Reza J. 2001). Where engineers working on aspects of infrastructure may already have this knowledge, it is new in the field of architecture. And since infrastructures currently work with control systems in many cases, it is perhaps fitting to look first to infrastructures when looking at what can be accomplished and why it might be beneficial to use such systems.

Control systems in public infrastructure are currently used for two reasons: to increase safety and economy through use of an automated system (such as an automated light rail system) and to mediate contested public space (such as traffic signals) - usually between multiple modes of travel or multiple streams of travel. The control systems and input for these systems could clearly be improved to better communicate between different users of a system and the infrastructure – such as those suggestions which have been proposed by the Media Lab for infrastructure as it communicates with the automobile or pedestrians (Mitchell et al. 2010).

Bringing architectectronics to infrastructure suggests other possible uses for control systems relate to modifying spaces for different uses, buffering environmental factors and responding to occupation or use. These additional potentials are brought by architecture to control systems, but not necessarily by infrastructures (Figure 1).

**Architectronics**

This emerging use of mechatronics integrated into architecture is an essential part of designing responsive envelopes, environment and landscapes and calls for the redefinition of architectural education and furthermore the discipline itself. Architecture schools lead in research of design of the built environment and lead speculation in what architecture will become in the future: it is appropriate that the academy ask the question of where and how control systems can and should be applied to the built environment, whether in buildings, landscapes or infrastructures.

Mechatronics is an engineering field and is similar in its relationship to architecture to other
engineering fields such as structural, mechanical or electrical engineering for buildings. As such, the architect must similarly understand and be able to work with the technology, in order that the end product express and behave as the architect intended in his/her conceptual design. The decisions to make with mechatronics involve what should be sensed, what should be actuated and what combinations of inputs or feedback will invoke what kind of actions. Design in this sense involves the choice, not of material so much, but of programming itself. A different algorithm can change the design expression, configuration and behaviour. Research which engages the questions raised by attempts to apply mechatronics to architecture is valuable to both identify potentials and limitations but also to identify what the possibilities are for the emerging field.

**ROBObridge**

The first theoretical project undertaken by one of the authors involving applications of architectronics in infrastructure is a response to the contested water crossing: a robotic bridge. In many cases, governments do not like moveable bridges because they need to be manned. This solution uses integrated intelligence within the bridge to operate itself. The bridge identifies the demand for marine and pedestrian/bicyclist traffic in real time with LIDAR and multiple motion sensors. The bridge control system checks speeds of approaching marine traffic to determine at what distance from the ship that the bridge needs to open, what amount it needs to open and it tracks the ship in real time to determine when it has passed and can then close. The bridge has multiple fingers which open in a curling motion by use of hydraulics to produce a sculpture while it is in the open form (Figure 2). It has non-deterministic programming which means that every time it opens, it produces a different opening pattern and configuration. The regular observer of the bridge will encounter a different bridge behaviour every opening. This solution mediates contested public space similar to a complex traffic light and it also improves efficiency and economy of the system in that it doesn’t require manning. In these two ways it is similar to other applications of control systems in infrastructure but it also provides a responsive environment on a very large scale and creates sculpture from infrastructure, activating public space and bringing architecture to the infrastructure.

**ROBOstudio**

To further explore this exciting field of research, a studio was framed with the mandate to investigate the application of mechatronics in architecture in the realm of infrastructure. Given a specific site of
In a dense and contested urban space, the students were left free to speculate on applications with the help of engineering. It is through collaborative working with mechatronics engineers that this becomes possible and buildable – with the grounding of in-depth technical know how working with a design intent.

ROBOstudio was a project-based course offered by University of British Columbia School of Architecture in collaboration with the departments of Mechanical Engineering, Electrical Engineering and Engineering Physics. The initial goal was to bring together students of architecture and applied science to explore the possible application of robotics, mechatronics and kinematic structures in architectural projects. In order to introduce students to the new environment, a period of research began the studio; this introduced the architecture students to the technology of mechatronics and introduced the engineering students to the culture of design. Case studies involving kinetic art, kinetic architecture, mechatronic applications in design and industrial applications of mechatronics were researched. As well, basic theories of control systems were introduced and a database of sensors and actuators was compiled.

The programming involved in the exercises was simplified by the use of TINAH boards (Figure 3). TINAH is the microcontroller-based board designed and built for an engineering robotics course. Many of the design considerations for the board were inspired by the HandyBoard, a Motorola 68hc11-based controller system designed by Fred Martin at MIT in the mid-1990’s. The built-in functions, include: up to 4 DC motors, buffered digital and analog inputs, 2 switches and 2 knobs for on-board control, 16×2 backlit LCD screen, access to the enable/direction pins for external motor control.

Students produced responsive physical models, animations of 3D models, and plans, sections and still renders of their proposed designs. All work proposed was resolved to a level where the project was buildable using current technology and techniques. There is an additional complexity in explaining moving and responsive architecture: the movement as well as the responsiveness must be demonstrated and shown to contribute to the design. In our work so far, this has entailed the use of 3D modeling software including rhino with grasshopper, Solidworks and Inventor. The last two software packages are mechanical engineering software with built in restraints for degrees of freedom. There is no special difficulty with architects using the engineering software for modeling if the restraints are explained and understood.

Two problem sets were framed for this studio: the first was framed very tightly in order to limit the
design considerations and allow a fluency to develop with the new technology. The second was framed more loosely in order that students could apply their newly found knowledge to a range of applications. As well, the projects were framed architecturally such that investigations with the first problem set addressed the issue of essential need, and the second one of electronically-assisted transfigurations and the revisitation of collective memory. The projects’ work ranged from concrete problem-solving to investigations highly speculative in nature, and the students could pursue any combination of digital, wired and/or kinetic models and videos to illustrate their explorations.

Projects resulting from this studio identified key areas for research, both in landscape, infrastructure and architecture (Figure 4).

ROBOstudio Projects

The virtual bridge project, for example, produced an infrastructure, both a bridge and a ferry, which mediated between demands for personally powered transportation across a water crossing with a high navigation clearance requirement (sailboats need to cross under this bridge). This project addressed the contested urban space of a water crossing – where water traffic takes priority over a bridge. The solution was to have the bridge fragmented and float back and forth on a control system. This is only possible with control systems technologies – traditional mini ferries have been working on this route. The advantage this solution has is that it is driverless and uses the energy of the walking/cycling passengers to help power itself: as the passengers bike or walk on the gym-type treadmills, the power is transferred through an electrical/mechanical system to the power system of the unit (Figure 5). The control system is set up to move the ferry faster when the occupants are producing more energy. There is a LIDAR (light detector and ranging) sensing system which senses when boats approach and it uses navigational rules in its algorithm to determine which vehicle has right of way and also determine if it should continue course, speed up or reverse direction. Further levels of safety to keep the ferry on course include a laser...
light guided pathway as well as GPS tracking of the units. These multiple layers of security are necessary for public safety, which is of major concern when dealing with public infrastructure projects. This project then deals with infrastructure by mediating contested public space as well as increasing the economy and efficiency of the current system and adding a responsive environment whereby people can contribute energy and have this registered in the movement of the unit. An infrastructure of this type shows the innovation possible with the application of an architectronic infrastructure – it produces a hybrid which responds to the dense condition of the site and essentially creates a new type of transportation infrastructure.

Another project demonstrated a responsive canopy for a seasonal restaurant patio plaza which was activated by movement under it as well as environmental conditions. In this case, the canopy could activate according to local activity under it so that if a person was occupying a table, that table could be shaded or protected from rain, while other unoccupied areas might not be protected – as one walked under the canopy, elements could open up to protect against rain. The rain and sun sensors would provide information on current conditions and the algorithm would respond according to programming related to occupation, time of day and year as well as environmental information. The response of the canopy is designed through the algorithm used: for example the behaviour of the canopy depends on the algorithm and whether or not it ‘predicts’ a person’s movement based on a current trajectory or responds only to the person’s current condition. As well, sun can be dealt with in a multitude of ways: people can be shaded or full sun can be allowed. In this project, the spatial occupation and environmental conditions inform the architecture but there is also an element of improving efficiency as the current configuration of the plaza uses umbrellas to provide shade and when the weather is rainy, the plaza is abandoned.

Another project which responded directly to environmental conditions was the transit shelter (Figure 5) whose canopy moved along a track to follow the sun. The transit shelter fragments in sunny weather when shelter for rain isn’t required and follows a track, pivoting on a point to angle itself to the sun. The site of the shelter is under an overpass, therefore at times of the day, the sun is further away from the shelter’s origin position. Under rainy or windy conditions, the shelter does not fragment but maintains its original position. For safety, sensors detect any resistance in the movement of the elements and halt any change in position when resistance is detected.

Monitoring areas for use and density of occupation can be useful in design of infrastructure. A transforming plaza project developed a piece of plaza which transformed into a bench when other benches in the plaza became occupied (Figure 6). This project was in response to a plaza who shows very dense use but frequently has a lack of seating. In the case of most of the other benches registering occupation, new benches would emerge slowly from the plaza. The student involved in this project built a pneumatic muscle to actuate his benches – a pneumatic muscle provides a smooth and safe movement through air pressure. Another advantage of a pneumatic muscle as a bench support is that there is a slight spring in the bench when someone sits on it.

Responding to occupation in a more specific manner, a responsive performance hall was designed to adapt to acoustics. The hall was conceived as an infrastructure which could provide a facility which adapted to the type of venue required – such
as a rave cover, an outdoor theatre or an indoor concert hall. Further, the arrangement of the elements of the design allowed the interior volume to be adjusted for reverb time – thus the hall itself could be ‘tuned’. At a smaller scale, interior panels were designed which acoustically could adjust to bounce or absorb sound. Thus there were two scales on which the acoustic tuning performed.

The control system demonstrated ran an algorithm similar to that which is run in the popular iPhone app Shazam (Figure 8). The algorithm analyzes sound from a simple microphone and can actuate based on the analysis.

Movement of the theatre elements was based on current stadium roof mobile roof element technology. In this project, the multiple configurations of the performance space allows an efficiency in land use and an ability to respond to different programmatic requirements in a minimal footprint thus mediating contested urban space. The further responsiveness, in this case to occupation as measured by acoustic criteria, hints at an ability to measure or process simple sensor information in a much more complex way to respond more sensitively to the environment.

Another type of responsiveness which can be used as input is a direct request by an occupant. This type of responsiveness is conventionally used at pedestrian crossing or at a traffic light when a

Figure 6
Bench emerges from plaza using pneumatic muscle actuation

Figure 7
Theatre configurations
pedestrian wants to cross, for example. In this case it was used in the design of a robotic landscape (Figure 9). The elements of the landscape moved hydraulically responding to user touch. At other times of the day, when a busker performance is scheduled for example, the landscapes configuration can be fixed into a small amphitheatre or a market – say on a Saturday morning. In other configurations, the landscape could take on the form of a beach – giving a much needed access to the water.

The elements of the landscape each had a touch sensor integrated into the top surface (Figure 10), which gave the system the signal to move the landscape block up when touched briefly and down when held for two seconds. Multiple safety features were designed in and the system was scaled to a step and seat, again to ensure safety. The motion was actuated by a hydraulic system which pumped seawater into the units, floating them. The hydraulic pumps were activated individually from a central control system. This project crosses many boundaries of disciplines and uses – it is a landscape and/or furniture, it is fully configurable by the occupants or can be used as art which reconfigures based on almost anything. It can be functional on multiple levels and configured as pathways, amphitheatre, beach or market. This is a responsive kind of environment which can be modified for different uses or respond to occupation in multiple ways. It does not promote efficiency or mediate contested space in a conventional infrastructural way.

The examples discussed in this paper demonstrate the growing range of possible application of architectronics in infrastructure. Mechatronics in the
hands of architects is a design component whose potential is just beginning to be uncovered in shaping the new XXI century city. This paper attempts to point out the potency of a control system in an architectural discussion and how very much we have to further research in this emerging field. The built form integrated with the control system has the ability to adapt and respond, bringing a multiplicity of conditions to a single design in a way previously unknown in architecture. When connected as networked to form smart urban infrastructure it will lead to a redefinition of Urban Design in decades to come.

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References
