# Microcontroller - Enhanced Physical Models for Architectural and Product Design

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*Electronic sensors, controllers, displays and actuators can significantly enhance the value of physical models as processes of use, interaction and transformation take center stage in various fields of design. These technologies allow the development of novel computer interfaces for new kinds of interaction with virtual models, and in the future they will allow new types of active building components and materials for automated construction and dynamic runtime adaptations of inhabitable environments. However, embedding programmed logic into physical objects seems to confront designers and model makers with a steep learning curve outside the domains of their traditional expertise. The variety of alternative technologies and development tools in this area has a particularly disorienting effect on novices. Some early experiences however suggest that mastery of this learning curve is easily within reach, given some basic introduction, guidance and support. It is the purpose of this paper to provide designers with a starting point for explorations into this area, to give orientation and to demonstrate some possible development approaches and results.*

***Keywords:*** *interaction, process, high-fidelity models, microcontrollers, electronics.*

## Introduction

The early years of computer-aided design saw a significant shift in research, practice and education within the architectural and design fields from the physical to the digital realm. Digital models, in the form of 3D geometry descriptions, visual renderings or, more rarely, programmed performance simulations, began to offer a number of advantages over „traditional" physical models, sometimes also allowing for distant collaboration. The above-mentioned developments in models harness benefits of general office automation, advanced computer graphics and electronic data exchange, deploying computers as „fancy drawing boards" or, in the case of performance simulations, executing algorithmic descriptions of specific operational aspects of a proposed design purely digitally. As a result of technological advances in recent years, the production of functional software models such as dynamic performance simulations has experienced increased interest, which manifests itself in various new software simulation tools and design applications. Examples in the architectural domain include structural, thermal, acoustic, lighting and use simulation. The digital simulation of use, in the form of interaction (circulation flows, play patterns, menu navigation, etc.) also plays an increasing role in the field of product design.

However, it is often charged that for all the gains made possible by digital models, many qualities of physical models are missing in their virtual counterparts. Lost advantages of physical models include tactile and material qualities as well as spatial realism and the required tectonic and construction skills that used to play much more important roles in design education until ten or fifteen years ago. Moreover, physical models are often more useful than digital ones when functional aspects need to be explained and evaluated. Human factors such as ergonomic considerations, spatial proportions, material qualities and simple mechanical functions are examples of features in architecture and product design that are best assessed using physical models. This is even more the case in areas such as toy and entertainment design, where the engagement with physical objects for its own sake is often the primary objective. Here in particular, the benefits of evaluating these products on the basis of digital prototypes alone are very limited. The challenge is that for the assessment of new designs, models should not only address issues of appearance but also issues of interaction behavior. Traditional physical models, while possessing some advantages over digital models in allowing assessment of physical interaction-related criteria, are understandably not always very useful in answering questions that address issues of process such as interaction performance and sequential logic.

Designers find themselves in a situation in which digital models are often not true-to-life enough in the physical sense while physical models are often not true-to-life enough in the performative sense. While considerable research effort is being invested into making digital models more realistic, this paper explores the complementary strategy of embedding digital technology into physical models and prototypes. This strategy has already been explored sporadically over many years (e.g. Frazer, 1995) and its development is facilitated by the availability of new and increasingly cheaper and smaller embedded systems technology. In many cases, the embedding of sensors, actuators and controllers into spaces and physical objects can allow models that unite the advantages of both digital and physical models, to provide logic functionality to simulate complex aspects of mechanical performance and realistic user interaction patterns while at the same time expressing properties of proportions, materiality, construction principles and so forth.

The range of potential application areas in design is very broad and covers not only model making in architecture and product design but also the development of mock-ups and research tools in haptic human-computer interface design (Fischer, 2001), user-centered design, participatory design as well as various more specialized fields such as toy and entertainment design, kiosk design and „smart" fashion. There is also a strong potential for embedding microcontroller technology not only into models but, at a high level of granularity, also into architectural building materials. This could lead to new kinds of „intelligent" architecture with new capabilities at all stages of a building's life cycle. For example, sensors, motors, displays and so forth could be driven by large networks of embedded microcontrollers to facilitate construction work, following approaches such as Autotectonics (Frazer, 1995 and Fischer et al. 2003) or kits-of-parts theory (Howe, 1997) or to offer new capabilities to adapt architecture to changing needs.

The key challenge in digitally-enhanced physical models lies in mastering and integrating the required electronic and microcontroller technologies. Technological advances have made these components, as well as the required development tools, available at very low cost but the required learning curve represents a major obstacle for designers.

The number of different types of available components and microcontrollers is overwhelming and requires even experts in the electronic engineering field to study data sheets and reference materials closely before making selections. The choice of programming and configuration options and tools is similarly confusing and the typically required low-level programming in languages such as Assembler or C is particularly painstaking from a design prototyping perspective. The typically tight schedules that characterize design projects and studio design education are prohibitive to most low-level circuit design and programming approaches. For these reasons, the following pages summarize some minimum knowledge and study references required to embed digital processors into physical models and give an overview of some previous experiences in this area. The objective is to encourage and facilitate designers and architects to develop prototypes and models that are physical and yet expressive with respect to process and performance. The material presented will also allow designers to enter the field of designing, modelling and prototyping novel interactive systems such as tangible computer interfaces and machine-readable models. As it is not possible to provide a full technical introduction within the scope of this paper, readers interested in further pursuing the discussed strategies can find more detailed technical information in (Iovine, 2000) and (Igoe).

## Modeling with Purpose-Centered and Universal Electronics

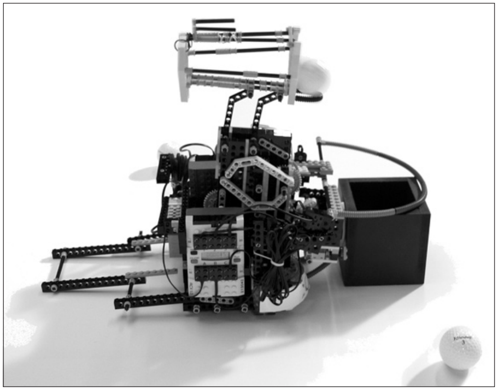
A rather simple way to develop a new interface or to enhance a model digitally is to simply search for interfaces, circuits, devices or toys whose behavioral logic resembles the process that is to be modeled and to adapt them for the best possible results. This approach has for example been used in designing the haptic interfaces discussed in (Fischer et al. 2002), which are primarily based on the electronics of USB optical mice and in the interface discussed in (Lee and Jeng, 2002, p. 162) which is based on the electronics of a joystick. This use of standard computer interface hardware has the significant advantage that driver support and development tools software are readily available where custom-built hardware such as machine-readable models or prototypes of interfaces with screen and multimedia extensions need to interact with standard computers. It is more challenging to develop digital models and interface extensions for which no cheap and easily adaptable toy or standard interface is available. In these cases, more flexible, universal and generic platforms are needed.

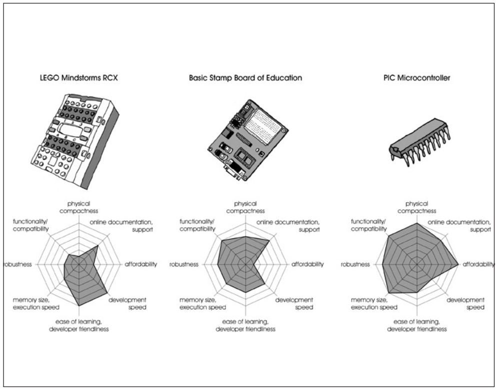
The differentiation between machines designed for specific purposes and universal machines (the most commonly known form of the latter is the digital computer) also applies at the scale of integrated circuits. While the majority of ICs are designed to support specific functions (logic gates, timers, amplifiers etc.) others are designed to carry out any user-defined functions. Representatives of this universal type of integrated circuit are referred to as microcontrollers. Electronics development using microcontrollers, which is typically found in electrical engineering contexts, involves low-level programming and requires extensive know-how. One of the first attempts at making microcontroller technology available and programmable for non-engineers is the LEGO Mindstorms series. A large LEGO brick called RCX is fitted with a microcontroller, a small LCD display, a battery compartment and input/output facilities. It allows for the digital enhancement of LEGO constructions using different types of motors and sensors. Desktop computers are used to develop programs in visual form that are uploaded into the RCX. For an example application in design education see (Russell, 2002). Figure 1 shows a student-designed golf-ball collecting mobile robot using LEGO Mindstorms.

The visual programming languages provided with LEGO Mindstorms kits are educationally very powerful and provide a highly suitable introduction to computer programming, even for young children.

*Figure 1*
*Golf ball collecting robot based on LEGO Mindstorms*

*Figure 2*
*Comparison between different microcontroller solutions available for rapid prototyping of hardware interaction designs.*






The system is however limited in terms of number of input/output channels, its large physical size and the lack of programming flexibility. The latter issue has been addressed by open-source initiatives, which have resulted in Java tools for the LEGO RCX (see Barnes, 2002).

A more advanced educational alternative to Mindstorms is the BasicStamp. The BasicStamp is considerably smaller than the LEGO RCX and programmed in a BASIC dialect, which is relatively easy to learn. It is available in different versions with 8 to 16 input/output channels. A wide range of compatible industrial components (electronics, actuators, sensors, displays) and educational material is available for BasicStamp. As educational systems, both Mindstorms and BasicStamp are more robust than adapted standard interfaces or toys but also relatively costly.

As the standard industrial solution to small-scale digital systems control, microcontrollers used to be a difficult subject for designers due to the large number of systems available and the difficulty of the programming languages involved. Recently, however, BASIC language compilers have become available for some microcontrollers such as the PIC (programmable integrated circuit) controller family, which are available in different sizes, and for which an increasing amount of educationally useful support material is available online (Igoe) and offline (Iovine, 2000). Originally, microcontroller chips were dependant on additional external circuitry, mainly for input/output interfaces and clock oscillators. Later models integrate various I/O capabilities such as analog/digital converters, serial and USB interfaces and built-in oscillators so that, depending on the application in question, the component count of a PIC circuit (and hence the respective difficulty of circuit development) can be extremely low. Some PICs can be programmed once only (OTP: „one-time programmable“) while others have re-programmable flash program memory. These forms of memory (which are also found in BasicStamp modules) make PIC microcontrollers very reliable and robust since programs and data stored in the ICs remain stored safely even when power is disconnected.

Figure 2 above gives a rough comparison of the three controller technologies discussed above. It assumes programming in the easiest languages available for each platform. In this comparison, the PIC microcontroller seems particularly strong when considering its comparatively very low cost.

Figure 3 shows a programming editor used with programming languages PicBasic or PicBasic Pro (microEngineering Labs, 2002 and 2003) on the left and the pin assignment of a very flexible and cheap member of the PIC family, the 16F628(A) microcontroller on the right. It has 18 pins, two of which are used to supply power (5V-) and 16 of which are

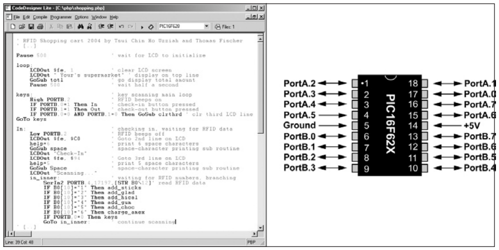



*Figure 3*
*PicBasic Pro Programming Editor and PIC16F628(A) pin assignment.*

divided into two eight-pin input/output channels. The I/O is „TTL compatible", meaning it is also 5V- based with 0V representing logic 0 and 5V representing logic 1. The chip is re-programmable and holds 2kb of program data. It contains an on-board 4MHz oscillator and costs less than US$2.00.

**Example Applications of PIC Microcontrollers**

The prototype of a kitchen spice rack shown in figure 4 is a student project designed in collaboration with the Hong Kong Blind Union. It addresses the problem that elderly visually impaired residents of Hong Kong oftentimes cannot read Chinese Braille and in many cases share kitchen facilities. The rack informs users of a container's contents and fill level using spoken language.

The model is based on a 16F84(A) microcontroller that controls an ISD25120 sound chip. It makes use of a pre-packaged soldering kit for a voice recorder circuit that was extended with a small microcontroller circuit. Speaker and audio amplifier were all part of the soldering kit.

The model shown in figure 5 is a student-designed marble track construction kit that acts as a music sequencer (Spicciolato, 2004). It is designed as a tool for young children's music education. Rolling marbles trigger signals that are sent from tube segments to a central controller located in the base using a custom-designed serial communication protocol. Transparent pipe segments passively determine the duration of notes while color-coded 12C508(A) microcontroller-enhanced segments determine pitch. The modified circuit board of a toy music keyboard is used in the base as a sound synthesizer, controlled by a 16F628(A) microcontroller. The original functionality of the toy keyboard is used to allow control of volume, instrument sound and a record-and-play function.

Figure 6 shows a student-designed working model of an RFID-enhanced shopping cart. The handle of the cart is fitted with an RFID-reading display console. For the RFID reading technology, again a pre-packaged soldering kit was used. The kit was designed to output a sensed card's ID number via a serial communication. A 16F628(A) microcontroller is used to read and parse this communication and to drive a backlit 4-line pixel LCD display. The PicBasic Pro programming language includes high-level functions to allow easy interaction with so-called

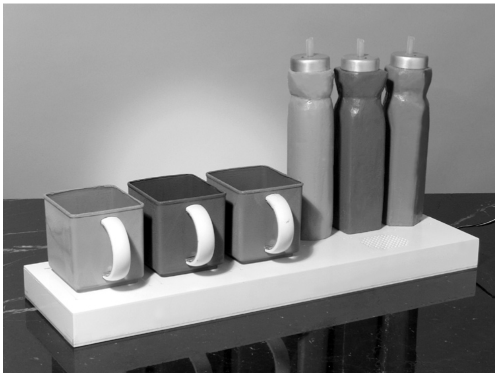


*Figure 4*
*Spice rack for the visually impaired (working prototype).*

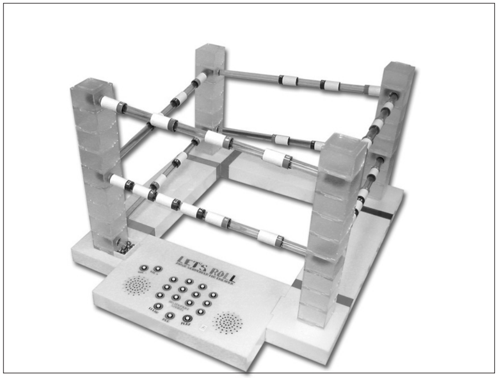


*Figure 5*
*Marble track music sequencer for children (working prototype).*

standard intelligent LCD displays (see Ilett, 1997). Using a set of RFID-tagged product packages, the model demonstrates check-in, cancellation and payment procedures.

Figure 7 shows a hardware cellular automata model that is used to simulate processes of parallel use in high-density vernacular architecture in Hong Kong. The model was designed as a research tool to reproduce „complex“ properties of architectural use patterns. Two slabs, representing buildings, carry 24 cells each and each of the cells carries a 16F628(A) microcontroller, communication facilities and twelve display LEDs. Inter-cellular communication is based on a user-determined wiring network. Individual cells can identify different façade extensions which trigger different responses. An integrated bus infrastructure allows 96-bit parallel data input and output with a desktop computer via two 8255 interface cards. A detailed discussion of the model is given in (Herr and Fischer, 2004).

## Conclusion

Of the controller technologies available to designers for digitally enhancing physical models, PIC microcontrollers are an excellent choice – especially in terms of cost and size. This chip family was long reserved for experts with engineering know-how, but the integration of a number of required external components into some of the later PICs and the growing number of easy-to learn development tools for some dialects of BASIC make this technology a very powerful option for developing high-fidelity design models that go beyond passive representations. The discussed examples were chosen to demonstrate the versatility of just one of the most basic and inexpensive PIC microcontrollers, the 16F628(A) (without remotely covering all of its possibilities and features). Fields of application in design are numerous, most importantly in architectural and industrial design modeling and prototyping. User-centered design, participatory design, interactive systems design, the design of fashion and retail spaces, Autotectonics, haptic interfaces and kit-of-parts design are only a few of the current fields in design and design research for which this strategy seems particularly suitable and useful.

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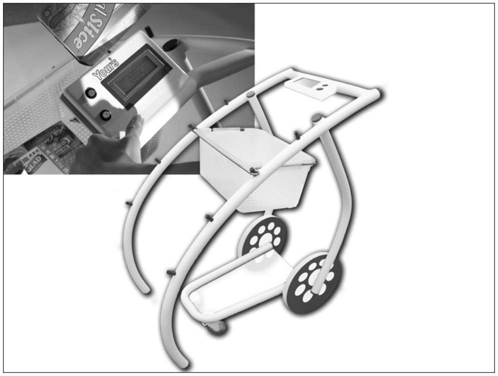

*Figure 6*
*RFID shopping cart (working prototype).*

*Figure 7*
*Hardware cellular automata to model processes of use in adaptive architecture.*

of Lau Mei-Ki Miki (spice rack in fig. 4, marble track in fig. 5) and Tsui Chin Ho Uzziah (RFID shopping cart in fig. 6). The What-If Machine shown in fig. 7 was designed, implemented and photographed by Christiane M. Herr and Thomas Fischer. The golf ball picking robot in fig. 1 was built and programmed by Chan Kin Hei Rio, Leung Wing Yan Essing, Leung Yuen Man Vivian and NG and Yuen Wa Debi and photographed by Ambrose Wong. The discussed hardware models were supported by Departmental General Research Funds of the School of Design at The Hong Kong Polytechnic University (project code A-PB84).

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