SMART BUILDING PRODUCTS

Some Investigations

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Abstract. The research effort presented here is based on the view of emergent behaviors. The aim is to develop smart building products each of which is independent, self-sufficient and with very limited intelligence. Using "Basic Building Block" as a platform, three building products, interactive louvers, see-through wall panel, and sensible floor tile are developed to illustrate the emergent smart behavior. These smart building products contain intelligent technologies that can be implemented into existing buildings incrementally without having to perform major renovations.

Keywords. Building products; smart technology; emergent behavior; distributed intelligence.

1. Introduction

The nature, ant colonies, beehives, human societies, urban developments... are emergent systems where a collection of individuals interact without central control yet achieve an integral whole (Hofstadter, 1979). In a smaller scale of living organisms, they are formed by a collection of DNAs that interact with proteins to maintain the development and functioning of living organisms. *Individuals* and *interactions* between individuals are key to the evolvement of complex systems. Buildings are not unlike these complex systems. Buildings are constructed with various building products. Individual items of building products interact with one another to form a complete building. This work intends to harvest the power of individuals and interactions to create a smart building environment.

2. Background

Modern building constructions have changed from conventional on-site casting into off-site manufacturing and on-site assembly. The new construction process greatly improves the precision and quality of new buildings. This, in turn, allows better planning and integrations of new technologies into buildings. However, such approach of construction and building design is not entirely new. The curtain-wall construction of building façade is one of the first innovations that allow wall panels to be manufactured separately from the building structural framework. To date, many experimental building facades are designed to integrate digital technologies. Examples, such as the "Blinkenlights" project in Berlin, the "BIX" façade of Kunsthaus of Graz, and the "SPOT" in Berlin's Potsdamer Platz, are pioneering works (Hall, 2006).

Researchers of kinetic architecture take a step further to explore façade components that could move, change shapes, open-and-close to ensure comfortable living and achieving efficient energy use. Prototypes, such as the "Folding Egg" (Fox and Yeh, 1999) and "The Living" (Hall, 2006), as well as designs, such as the "Moderating Skylights" (Fox and Yeh, 1999), are demonstration of efforts to mimic living organisms to perform intelligent acts. These kinetic structures are composed of modular components, each of which can be treated as a small, robotic, trivial machine. Yet when these trivial machines interacting together, the whole structure can perform complex behaviors and become a non-trivial complex system (Gage, 2006).

Central to the physics of complex systems is emergence. Emergence refers to the way complex systems and patterns arise out of a multiplicity of relatively simple interactions (Hofstadter, 1979; Gage, 2006). An emergent behavior or emergent property can appear when a number of simple entities (individuals) operate in an environment, forming more complex behaviors as a collective. Such emergent behavior is usually hard to predict because the number of interactions between components of a system increases combinatorially with the number of components, thus potentially allowing for many new and subtle types of behavior to emerge. Emergent structures appear at many different levels of organization or as spontaneous order.

The research effort presented here is based on this view of emergent behaviors. The aim is to develop smart building products each of which is independent, self-sufficient and with very limited intelligence. Nevertheless, when many items of a smart product are connected, they may achieve highly intelligent behaviors.

3. Composing Smart Houses: a Systematic and Incremental Approach

In addition to the technological emphasis of developing smart building products to provide emergent intelligent behaviors, the architectural emphasis of this research is practical applications of smart technologies. Integrating smart technologies into existing houses generally requires major renovations, which maybe as time-consuming and/or costly as building a new house. Given that a building may last for decades, the needs to allow incremental integrations of smart technologies into buildings out-weight that of new smart houses.

Houses should be adaptable for dwellers' needs. To facilitate the adaptation, John Habraken (1961) advocates that housing require some form of supports providing the physical structures and access to common mechanical systems so as to enable detachable units to be installed independently from the base building. This leads to the Open Building movement worldwide (Kendall and Teicher, 2000). Two key concepts of Open Building are supports and infill. Supports contain all permanent, shared building services. An infill system is a carefully pre-packaged, integrated set of products, custom prefabricated off-site for a given dwelling and installed as a whole. These two concepts allow the separation of buildings into the distinct bundles of technology and logistics so as to address demands for effective and responsive practices of building development (Kendall and Teicher, 2000).

Open Building provides a systematic approach towards the construction of buildings. By decomposing the construction of a building into various components that can be assembled through building products, the process enables incremental modifications and improvements of existing buildings. By incrementally improving old infill elements with new smart building products, dwellers of houses may "recompose" smart houses according to their needs.

With this in mind, smart building products are considered as a class of building infill systems. The emergent intelligent behaviors, described in the previous section, are the shared characteristics of this class of infill systems. The conceptual design of the class–Basic Building Block–is proposed in the next section.

4. Basic Building Block

The "Basic Building Block" is a generic smart building product. It specifies the set of basic behaviors, i.e. core intelligence of an individual product item. Basic Building Block is designed as a responsive in-direct control system (Fox and Yeh, 1999). The system makes decisions based on inputs from sensors and neighboring systems. It makes optimized decision to perform its behavior and send messages to its neighboring systems (Figure 1).

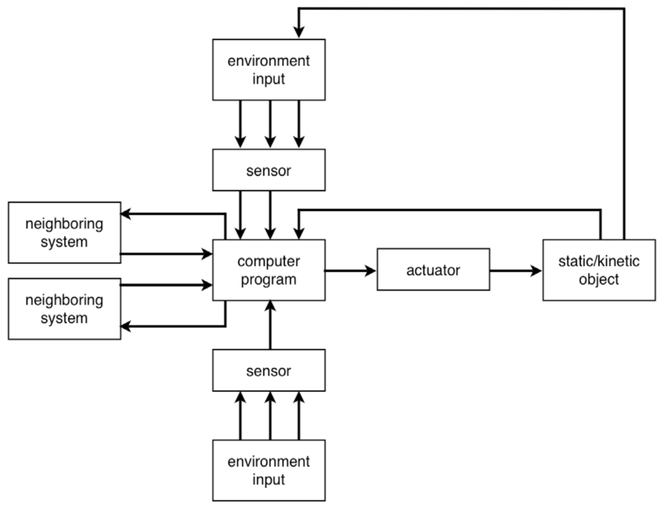

Figure 1. Responsive in-direct control (Adapted from: Fox and Yeh, 1999)

Based on the Basic Building Block, three building products, interactive louvers, see-through wall panel, and sensible floor tile are developed to investigate the emergent smart behavior among simple but interactive individuals.

5. Interactive Louvers

The "Interactive Louvers" is a building product attached to a window frame on a building façade to provide shades and control natural lighting. The "Interactive Louvers" contains a set of sensors to detect interior and exterior light conditions as well as the proximity of people in the building (Figure 2). In addition, it contains a set of actuators to adjust louvers. An embedded microprocessor is

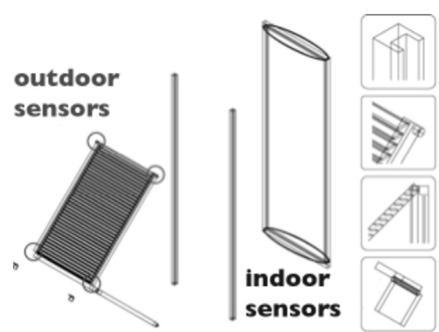

Figure 2. The schematic design of Interactive Louvers (by Chi-Kai Chiao)

used to perform the controls and interactive functions. The embedded micro-processors are programmed with two sets of rules: a set of basic rules for unit functions and a set of interactive rules for communications with connected units.

The designs of interactive louvers are explored through rapid prototyping machines and computer simulations. Detail designs of moving mechanisms are studied through iterations of rapid prototyping and redesigns. In addition, effects of the application on the building façade are studied through computer simulations as well as physical models (Figure 3).

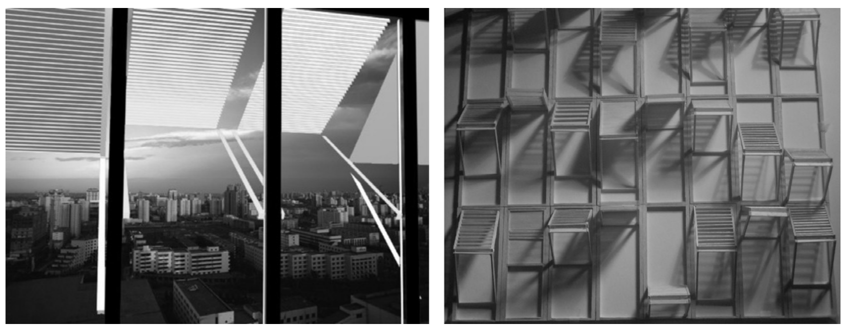

Figure 3. Simulations of Interactive Louvers in use (by Chi-Kai Chiao)

6. See-Through Wall Panel

The "See-Through Wall Panel" is a building product to be used as a partition wall. It allows people to see through it when desired. The "See-Through Wall Panel" contains a set of sensors to detect the touch of people, as well as a set of actuators to modify the translucency of the panel. When a person touches a see-through wall panel, the portion that is touched becomes transparent so that the person can see through it (Figure 4). This function is provided by an

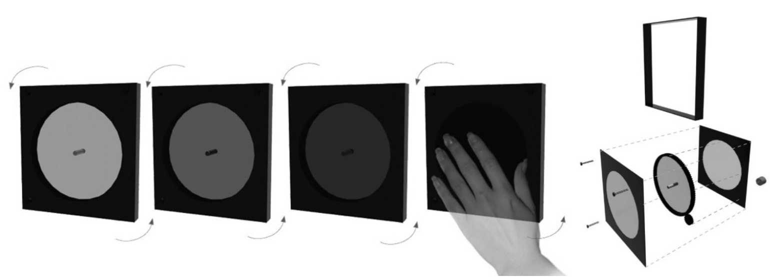

Figure 4. The schematic design and simulation of See-Through Wall Panel (prototyped by Hui-Ying Ke)

embedded microprocessor. The embedded microprocessors are programmed with two sets of rules: a set of basic rules for unit functions and a set of interactive rules for communications with connected units.

The designs of see-through wall panels are explored through physical prototypes. A prototype using switchable glazing was built to test the sensor input control. However, the material does not allow the control of translucency. Another prototype using filtering films was built to test the translucency control (Figure 4).

7. Sensible Floor Tile

The "Sensible Floor Tile" is a building product installed on the floor to sense, protect and support people (Figure 5). The sensible floor tile contains a set of sensors to detect the step of people. In addition, it contains a set of actuators to adjust colors of LED lights. An embedded microprocessor is used to perform the controls and interactive functions. The embedded microprocessors are programmed with two sets of rules: a set of basic rules for unit functions and a set of interactive rules for communications with connected units.

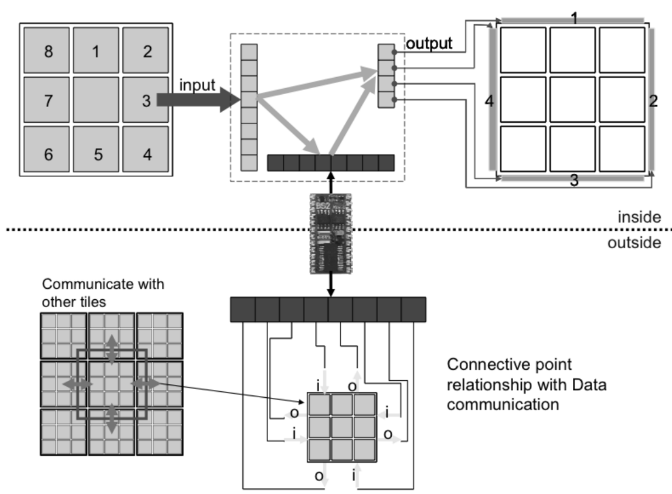

Figure 5. The schematic design of Sensible Floor Tile (by Chi-Chieh Huang)

The designs of sensible floor tile are explored through software and physical prototypes. A software simulation prototype is implemented to examine the communications between connected tiles (Huang and Chien, 2008). These communications hope to achieve predictions of the heading of a person (Figure 6).

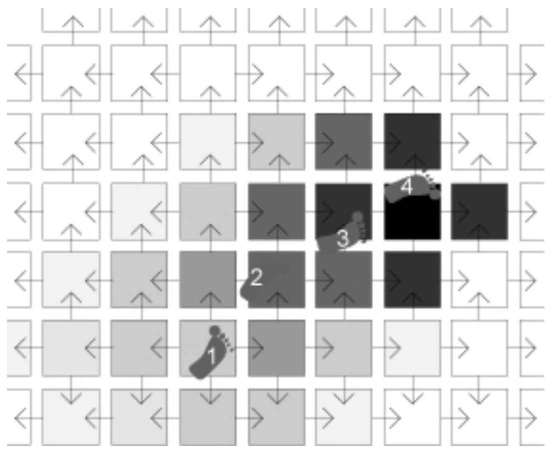

Figure 6. Movement predictions (From: Huang and Chien, 2008)

Furthermore, two physical prototypes are created to investigate programming details of embedded microprocessors. In addition, to receive inputs from pressure activated sensors, physical connections and message communications between tiles are tested (Figure 7).

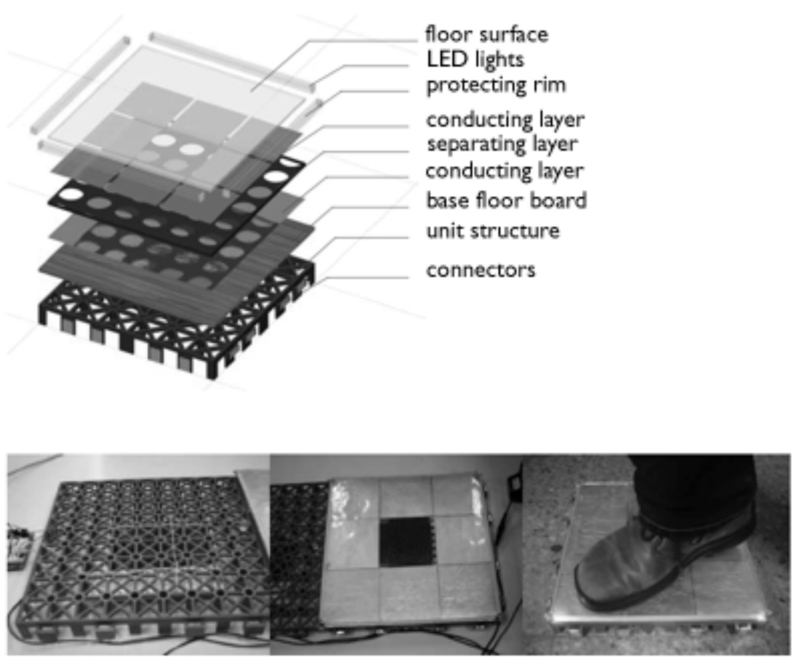

Figure 7. The detail design and prototype of Sensible Floor Tile
(first prototype by Chi-Chieh Huang)

8. Conclusion and Future Works

Several scale models and prototypes are made to examine various design details of interactive louvers, see-through wall panels, and sensible floor tiles. Research works in Robotics (e.g.: Eng et al, 2003; Jones and Mataric, 2003) and Distributed Intelligence (e.g.: Richardson et al, 2004) provide many prototypical examples and technical information that demonstrate the feasibility of systems like interactive louvers, see-through wall panels, and sensible floor tiles. This research has yet to demonstrate the emergent behavior because not enough number of the prototypes has been created.

The ongoing research effort is focusing on developing a thorough model of the Basic Building Block that includes communication protocols between blocks (initial results, see: Huang and Chien, 2009). This model is to be verified by a set of 25 Sensible Floor Tiles, which are under the manufacturing and testing process. For the practical application, a group of senior citizens has been consulted as potential users of Sensible Floor Tiles. A plan is underway to install Sensible Floor Tiles as path indicators at night in houses of senior citizens for user evaluation.

Based on the Open Building methodology and approach, by decomposing the construction of a building into various components that can be assembled through building products, the process enables incremental modifications and improvements of existing buildings. With smart building products, intelligent technologies can be implemented into existing buildings incrementally without having to perform major renovations. This allows dwellers to “recompose” smart houses incrementally and selectively according to their needs.

Acknowledgements

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