Degrees of Interaction
Towards a Classification

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Abstract. In architecture various approaches have been developed to deal with changing demands on the building. The most recent development is interactive architecture. In this paper we aim to outline what interactive architecture is. First we define the type of performance behavior that an interactive building or environment has. Following, we consider the relation between the system and the user. We derive four types of relations, characterized as “perfect butler,” “partner,” “environmental,” and “wizard.” Interactive systems are composed of sensors, controllers, actuators, and materials. Various degrees of interactivity can be achieved with such systems, ranging from passive, reactive, autonomous, to agent systems. Complete with earlier discussion of design methods this provides the range of aspects that should be considered when designing interactive architecture.

Keywords. Interactive architecture; Human-Computer interaction; design theory

THE CASE FOR INTERACTION

Buildings and urban environments have to fulfill their functions under changing demands. The functions that they are required to support change in time, the context of the building and urban environment changes, and the demands of the users and society change. Although change is a constant factor in architecture, allowing change or designing for change still poses difficulties. Various approaches to accommodate change have emerged in history. Traditionally buildings are designed to last for a very long period. Indeed, Rossi (1982) notes that specifically strong types are capable to support various functions over their life-span. They allow change through minor and major adaptations of the building. More recently increasingly flexible approaches to change have been developed however. The Open Building concept for example, by means of the notion of Support and Infill, typically assigns to the building usually a fixed core (the Support part which is designed by the architect and falls under the mandate of society) while the remainder of the building may be completed and changed at will by the user (the Infill part) - see Habraken (1998). Similar approaches in this direction acknowledge that the building is composed of various structures that each have a different change cycle, for example site, structure, skin, services, space plan, and stuff (Bijdendijk 2005). Contrary to these approaches Kronenburg (2007) argues that static and difficult to change architecture is only a fairly recent phenomenon, and that the majority of shelters in history have been mobile and light-weight structures – for example tents, mobile homes, and houseboats. Finally we
may notice that new developments in materials and control technologies (see Schumacher et al, 2010) allow buildings and urban environments to become autonomous and that they can respond to change by themselves. Many of such new developments are caught under the label “interactive architecture” (Fox and Kemp 2009). This development is the main subject of this paper.

Change is difficult to foresee and therefore also difficult to design for. Buildings or environments that do not change can only offer optimal services for a limited bandwidth of conditions. When the conditions fall outside the bandwidth, the building does not perform well. The user (or society) either tolerates such under-performance, or a decision is made to change the building or environment. Changing something usually involves (manual) labour, is costly, time demanding, and often interrupts for a long period the normal running of a building.

Figure 1 (left) shows in a schematic way that a traditional building has a bandwidth of performance which matches in a certain period with some condition (for example environment, function, activities). The running cost of a traditional building is low, and when no change has to occur, the change cost is zero. Figure 1 (right) shows how traditional change - from state (1) to state (2) - basically moves the bandwidth of performance to a different location. The running costs remains low, but the change cost is high.

Figure 2 (left) shows the typical approach taken in so-called “passive buildings.” They have a very wide bandwidth which ideally conforms to all conditions.
these conditions are mainly environmental so that the building achieves minimal energy consumption. However when a building needs to change due to dynamically changing demands then the passive building approach may not be sufficient (it may for example not be able to provide the additionally required energy to establish change). Figure 2 (right) shows the approach from an interactive building strategy: it basically curves the bandwidth of performance to make it match the outside condition. Because it is an interactive building, the capacity to change must be counted under the running costs. These are therefore high, while the change cost is zero.

Compared to traditional buildings, the trade-off for interactive buildings lies in the investment to incorporate change in the running cost rather than keeping it to incidental (manual) change. In principle it may be stated that when constant change will cost as much (or less) than traditional running cost and change cost, then it may be reasonable to invest in interactive architecture.

**Examples of interactive architecture**

We are well aware that there are not yet many examples of interactive architecture. There are many technological experiments more on the level of installations that investigate responsive structures, but these are more or less independent of the context (they could be installed anywhere) and are not an integrated part of the functioning of the building (the building does not perform better or worse with the installation). Media facades for example fall in this category. Although they dramatically change the appearance of buildings (for example the Galleria department store, Seoul, Korea by UNStudio) they do not engage in a “dialogue” with the viewer or user. The term “dialogue” means a meaningful or functional exchange of information or action between the user and the building (more on this later in this paper).

Figure 3 (right) shows the Solpix facade component, designed by Simone Giostra & Partners Architects in collaboration with Jeremy Rotsztain and Rory Nugent (2010). It is an integrated system of rotating shades with solar cells and LEDs. The LEDs effectively create a media facade, but at the same time the system functions as a shading device, as well as being self-powered because of the solar cells. Figure 3 (right) shows the N-Building shop project in Tokyo, by Teradesign Architects (2009), installation by Qosmo Inc. and Izumi Okayasu. The dynamic arrangement of black and white blocks on the facade displays a QR code which can be read for example by mobile phones. In this way the building can communicate to the outside world. Because it displays more content, we feel that this is approaching the notion of interactive architecture.

**What is interactive architecture**

The term “interactive architecture” is a bit misleading because interactive buildings as such do not exist. Buildings are composed of many parts. Some parts may be interactive and some parts are
not - very likely, most of the building parts will not be interactive. It is due to the combination of such parts that a building is interactive, but it is not the building (as a whole) itself. When can we call a system then to be interactive? Modern HVAC systems for example have complex behavior, and are hooked up with the building and the environment by means of sensors. Nevertheless we would hesitate to call them interactive. The purpose of the HVAC system is to maintain the quality and conditions of the interior of a building. Although its settings and purpose are geared towards the inhabitant, the inhabitant him- or herself does not factor in its immediate considerations. The knowledge what keeps an inhabitant comfortable is registered in the settings of the HVAC control, but as a derivate; not as the result of a direct observation or communication. Left to their own devices, most HVAC systems will continue working along their settings even when there is no one present in the building. The system will basically do the same thing for all users equally. Three different people may have three different preferences for their working environment. Nevertheless, whether there is John, Shirley, or Charles working at the moment, the common HVAC system ignores this and runs according to its general settings.

It seems to be the case therefore, that factoring in the inhabitant or user through direct engaging is the point where we would say that a system becomes interactive. What additional demands do we need to set to call one system interactive and another system not interactive? An elevator for example, takes the user into account as he or she expresses a desire (to go up or down) when pressing the button of the elevator. This gets the job done, for sure, but again it is not what we would call interaction. However, what if the elevator was connected to the building in such a way, that it could register your location, and have some sense of your daily agenda? The first is possible through RFID tags or hooking up to the surveillance system. The second is possible by connecting to your personal scheduler (PDA or intranet system). Then, when it notices that you start moving towards the elevator and knowing that you have to go for a meeting on a different floor, it may already move itself to your floor so that you do not have to wait for the elevator. If the elevator already has this possibility just for you, then we might as well extend it to all people working in a building. This would allow the elevator system to optimize its operation in a more efficient manner than by waiting passively until the next person presses a button (taking other people into account may imply that you still have to wait for the elevator, by the way). Such behavior we would surely call interactive. So, not only do we need to take the user into account, but also the system itself should be more complex than just switching on or off. Therefore, an interactive system is a dynamic system with multiple states that takes the user into account, by modifying its own behavior and states.

An interactive system takes the user into account. The user on the other hand, has two options how to relate to the system: passive or active. The user is considered to be active when he or she is directly influencing the system (pushing a button, pulling a switch, or something other). The user is considered to be passive when he or she does not directly influence the system by some action. In the last case the system works in the background. It does not mean that the user has no interest - it only means that the system is trying to figure out what the user needs and does not require additional instruction from the user to accomplish this (Table 1).
TECHNOLOGICAL BASIS FOR INTERACTIVE ARCHITECTURE

As stated above, interactive architecture is created by a combination of (interactive) systems. An interactive system consists of at least four components: sensors, controllers, actuators, and materials (see for example Schumacher et al. 2010). Sensors register the environment, controllers determine what kind of actions need to be taken, actuators make the desired change happen, and materials realize the physical part of a system. Figure 5 shows a schematic overview for an automatic sliding door. The sensors (infrared or microwave-based) detect the proximity of objects close to the door. The controller determines whether the signal from the sensor requires the door to be opened or closed. The required action is performed by the actuator (an auxiliary drive or cog wheel connected by belts or cables). The material part is formed by the door panel(s) that open or close. The system responds to a person, but the person itself is not part of the system.

CLASSIFICATION OF INTERACTIVE ARCHITECTURE

The systems that enable interaction are not all the same. There are various degrees of interaction or responsiveness available in these systems. In this paper we propose the following degrees of interaction: passive systems, reactive systems, autonomous systems, and agent systems. Each of these degrees is described in more detail below.

Passive systems

A passive system basically is any system that simply reacts to outside influences by the laws of nature (physics, chemistry, biology, and so on). Its behaviour is completely determined by these laws. There is no additional influence from the object itself that will modify its behaviour in any way.

Examples of passive systems are indirect lighting systems, fixed shades, and tourniquets. Even though the behavior of a passive system is completely deterministic, it does not mean that it displays simple behavior or acts in a predictable way. Especially when multiple passive systems react to the environment

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<td>Passive user</td>
<td>The system’s actions are partly based on user needs through observation, monitoring, measuring, or other means of detection. For the user, the system seems to act as a “perfect butler.”</td>
<td>The system runs autonomous without direct consideration of the user’s current state. For the user, the system is something running in the background without need for control. To the user the system seems completely “environmental.”</td>
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<td>Active user</td>
<td>The system and user engage in a “dialogue,” in which the system takes note of the user needs and actions, and the user actively is influencing the system. This can be characterized as the system as “partner.”</td>
<td>Most of the system’s actions are tuned to keeping some kind of state that the user requires but does not need to know or understand how it actually functions. This is typical for the control of complex systems or where the actual functioning is shielded or filtered through an interface. The system acts as a “wizard.”</td>
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Table 1 Various ways of engagement of an interactive system with the user.

Figure 5 (left) Example of sensors, controllers, actuators, and materials in case of an automatic sliding door.
(and thus indirectly to each other) things can get “out of hand” quite easily. Much of the regular systems engineering work of such systems deals with controlling exactly this behavior. A lot of effort is invested to check whether there will not be any unexpected and undesirable effects of a given system.

**Reactive systems**
A reactive system is a passive system in which a controller is added that can modify the reaction of the system. Typical modifications are amplify, decrease, delay, or speed up. In many cases the output of a reactive system is of a different character or sort than the input the reactive system receives. For example, a simple thermometer feedback cycle takes as input the temperature and may have as output lowering or increasing the amount of heating in a room. A light sensor takes as input the amount of light, and may have as output lowering or raising the shades at the window, or decreasing or increasing the light levels in a room.

Examples of reactive systems are automatic sliding doors, self-regulating shades, thermostats, and escalators with ‘stand-by mode.’ Many of the systems in architecture today are reactive systems. The controller of a reactive system can be quite complex, containing for example many tables by which it can establish which reaction is most appropriate to which input. Getting these settings right is no easy task. An ill-balanced interior lighting system for example, can lead to quite a lot of frustration or distraction of the users of the building.
Autonomous systems
A reactive system, no matter how complex, will never be able to deviate from its settings. In contrast, an autonomous system is a reactive system “with a mind of its own.” The controlling mechanism of the autonomous system consists of three parts: a state, a set of goals, and reasoning mechanisms. The state describes the current condition of the interactive system. Basically it is a snapshot of all the important settings of the system. The goals describe the targets of the system performance; in other words, what it has to achieve. The reasoning mechanisms look at the state, derive how the state differs from the goals of the system, and then determine the most proper system reaction to reach the goals. The autonomous system then produces some action in the outside world which should bring it closer to its intended state.

Examples of autonomous systems are robot production lines and contemporary HVAC systems. Having a state in other words, therefore, enables the autonomous system to step aside as it were, and to deliberate what it should do. Contrary to a reactive system, which is completely dependent on its internal settings, an autonomous system can adjust its settings. An autonomous system is thus more independent than a reactive system.

Agent systems
Autonomous systems by definition are always responsive in the sense that they first need some input from the environment, and then they act according

Kind of engagement
- Perfect butler
- Partner
- Environmental
- Wizard

Technological components
- Sensors
- Controllers
- Actuators
- Materials

Passive systems
- Reactive systems
- Autonomous systems
- Agent systems

Kind of technology

Analysis
- Concept generation
- Simulation
- Assessment

Design methods
to their goals, reasoning mechanisms, and allowed means to influence the environment. In some cases however, systems need to be able to do two additional things: (a) communicate directly with other systems, and (b) anticipate required changes by acting before an input from the environment is received. Such systems are called agent systems.

Examples of agent systems are adaptive spam filters and multi-site query systems such as for airline tickets. The agent system is continuously checking its state against its goals, and may initiate an output to the outside world even when not prompted by the environment. Additionally, it can communicate with other agent systems – either by directly addressing them, or by sending out a message to the outside world waiting for other agent systems to be picked up. Similarly, it can receive messages from other agents directly, or by waiting for signals sent out by other agents.

DESIGN OF INTERACTIVE SYSTEMS

In our view, autonomous systems and agent systems are the only systems that can establish interactivity. Passive and reactive systems can only achieve this when combined together (thus effectively creating an autonomous or agent system). An interactive system design therefore has to determine two major aspects: (a) which kind of engagement (as stated in Table 1), and (b) what kind of technology to be used (as stated in the previous section). Having stated these goals is not enough to create interactive architecture. In previous work we have outlined a number of design methods that assist in the design of interactive architecture. These methods deal with analysis, concept generation, simulation, and assessment (Achten and Kopřiva 2010). Finally, interactive architecture can only be established when the architect has a thorough knowledge of the required technological components: sensors, controllers, actuators, and materials (see Figure 10).

For the design of interactive architecture it is necessary to take each aspect into consideration. However, which aspect is taken first, or which aspect plays the most dominant role in the design depends on the architect (team) and context of the project.

CONCLUSION

In this paper we have aimed to outline a theoretical framework to establish what interactive architecture is. Interactive architecture consists of systems, which can be characterized as passive, reactive, autonomous, and agent systems. A key characteristic of an interactive system is that it takes the user into account. Systems can behave as perfect butler, partner, environment, or wizard.

REFERENCES


